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第十二屆週年研討會

Boilers & Pressure Vessels Safety
and Technical Development
鍋爐壓力容器安全
及技術發展

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The Hongkong Electric Co. Ltd.
香港電燈有限公司
Hong Kong Boiler and Pressure Vessel Inspectors Association
香港鋼爐及壓力容器
檢驗師協會
Hong Kong Oxygen & Acetylene Co. Ltd.
香港氧氣有限公司
Hong Kong Institution of Engineers
(Mechanical, Marine & Chemical Division)
香港工程師學會
(機械輪機及化工分部)
The American Society of Mechanical Engineers Int’l
(Hong Kong Chapter)
美國機械工程師學會國際會
(香港分會)
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Miss Jacqueline Willis, JP, Commissioner for Labour
at the 12th Annual Seminar (1996)
Boilers and Pressure Vessels Safety & Technical Development

Director Ma, Mr. Tanner, Distinguished Guests, Ladies and Gentlemen;

Welcome to the 12th Annual Seminar on "Boilers and Pressure Vessels Safety and Technical Development". This year's seminar is again jointly organised by the Labour Department, the Occupational Safety & Health Council and supported by six other organisations from the industry. Our aim is to facilitate the exchange of safety and technical experience among boilers and pressure vessels professionals. I am glad to see a growing support from owner organisations of pressure equipment as reflected in the increase in participation rate over the years.

This year we are celebrating the 50th Anniversary of the Labour Department. We launched the Occupational Safety Charter in September and introduced a new Occupational Safety and Health Bill into the Legislative Council yesterday. All of these are milestone events. The seminar today shows our commitment, as well as your commitment, to promote a better safety culture through involvement and
participation of all those who have a duty of care.

Boilers and pressure vessels are potentially hazardous equipment. Through the concerted efforts of equipment makers, engineering contractors and professionals, competent persons, owners and the Labour Department, we will continue to aim for zero fatality and minimal accidents in our workplaces. The Labour Department on its part will play an enforcement and facilitator role in ensuring high standards of installation and maintenance consistent with the best international practice. We will organise events for the exchange of ideas to promulgate the concept of self-regulation and for the protection of workers safety and the public against any potential hazards.

This year, we are honoured to have the largest number of overseas and local speakers. Many of them are international experts or authorities in their own right from the United States, the United Kingdom, the People's Republic of China and Japan. I am sure you will all benefit from the talks and social contacts during this seminar.
Finally I would like to thank the organisers and co-organisers, particularly the staff of the Boilers and Pressure Vessels Division for all the hard work which has gone into the preparations for this seminar.

With these words, I now declare the seminar open.
Boiler and Pressure Vessel Safety Requirements
The U.S. Experience

by

Mr. Richard L. Allison
Assistant Executive Director
National Board of Boiler & Pressure Vessel Inspectors

Boilers & Pressure Vessels Division, Labour Department, Hong Kong
About the speaker... Richard L. Allison

R. L. Allison has been the National Board’s Assistant Executive Director, Administrative since May 1995. In this capacity, he is responsible for all nontechnical functions and staff. Mr. Allison graduated from Ohio State University with a degree in welding engineering. He began his 28-year career with Babcock & Wilcox as a welding engineer. He subsequently served in various positions including quality assurance manager, and manager of quality and technology for the construction division.

Mr. Allison's extensive association with the National Board Inspection Code Committee began in 1974, and he was elected the NBIC chair in 1993. He also served as a member of the National Board's Advisory Committee from 1985 through 1995, and served on the National Board Commissions & Examination Committee.
Boiler and Pressure Vessel Safety Requirements

The U.S. Experience

Abstract

This paper traces boiler and pressure vessel safety requirements from the early 1900's to present. It reviews the key elements in the success in implementing boiler and pressure vessel safety requirements in the U.S.

One such element is the uniform acceptance of a construction standard (the ASME BPV Code) and the uniform enforcement of its requirements.

The cooperative standards development process which combines the experience of owner/users, manufacturers and enforcement authorities is another key element.

Finally, the role of the National Board in shaping the past and the future will be presented.
In the next few minutes, I want to give you an overview of the U.S. experience with boiler and pressure vessel safety requirements. Generally, requirements grow from a need for change. To understand that need for change, we need to go back to the mid-nineteenth century.

It was during this time that boiler explosions occurred at a rate of one every four days, killing some 50,000 Americans each year.

These catastrophes took place everywhere: on farms and in cities, in factories and houses, in railroad locomotives and aboard ships on the open seas.

The public rarely took much interest in boiler accidents back then. They were accepted much as most of us glance at a newspaper article describing an automobile accident.

Back then, there was no such thing as National Standards for construction. Each State and Municipality was essentially on its own. The consequences were devastating.

The worst steam explosion ever took place after the end of the civil war. It occurred aboard the Mississippi steamship Sultana and involved the deaths of 1200 soldiers.

For much of this early part of our history, boilers confounded Mechanical Engineers. Engineers looked for the more plausible mechanical explanations such as faulty workmanship, inferior construction materials, operator error, large gaps in scientific understanding, and inconsistent inspection standards and practices.

In 1880, a conservative, business oriented group of mechanical engineers was formed called the American Society of Mechanical Engineers, or ASME.

Although ASME distrusted centralized government authority, many of its members insisted that the engineer be a good citizen involved in Municipal, State and National engineering problems. However, few engineering problems rivaled boiler explosions for the danger they posed to life, property and productivity.

It was in 1911 when ASME appointed a committee to write a boiler construction code. The problem, however, involved getting this well-written code legally adopted for enforcement by a jurisdictions.

The publication of the ASME boiler code in 1915 was the beginning of a solution. Called a model voluntary standard, the code was a good reflection on the private sector and its ability to generate standards that served the public interest. But many wondered out loud what value there was to having a comprehensive code if there were no competent, well-trained inspectors to enforce it?

Not only was the uniform code adopted in 1915, that same year a man by the name of Carl Myers became an inspector with the Ohio Boiler Inspection Division. Ohio was progressive in this area of industrial safety. It was also one of only a handful of States that had an
organized Boiler Inspection program and Laws governing boiler construction, installation, and operation.

Mr. Myers was enthusiastic about the ASME Uniform Boiler Code as a remedy to the confusing boiler scene. This was a time of different boiler laws in different states. Sometimes it involved laws that varied from city to city.

Carl Myers not only appreciated a uniform approach to boiler laws, he envisioned the need for uniform qualification and commissioning of Boiler Inspectors throughout the United States.

On December 2, 1919, in New York City, Myers and several other inspectors had an informal meeting at which Myers suggested the idea of a national organization of inspectors. His companions liked the idea, and the National Board of Boiler and Pressure Vessel Inspectors was born.

Mr. Myers’ insight proved to be the basis for the success of boiler and pressure vessel safety requirements in the U.S. He believed that there should be one construction code. Today, 47/50 of the states of the U.S. and all the Canadian provinces have adopted the ASME Code.

He believed there should be uniform qualification and commissioning of boiler inspectors. Today, there are over 3,000 National Board Commissioned Inspectors, worldwide.

The significance of construction to a uniform code and inspection by uniformly commissioned inspectors is that a Boiler or Pressure Vessel built in one state or province could be easily accepted by any other state or province accepting the same rules. Also, by placing controls on the design, materials and fabrication methods improvements in the quality of the final product are achieved.

Through the standardization and rationalization that the ASME Code and the National Board brought to all phases of the industry, boiler explosions greatly declined during the 1920’s and 1930’s.

Today, the number of accidents recorded by the National Board are modest by comparison, but nonetheless significant.

Since the beginning of this decade, there have been more than 13,000 accidents involving boilers and pressure vessels in the United States. The difference between accidents now, and the time of the industrial revolution is that these accidents-statistically speaking- are less likely to kill. But boiler and pressure vessel accidents continue to injure and do significant damage to property.

To put it all in perspective, let me give you a brief overview of last year’s Incident Report covering 1995.

During that year, there were a total of 13 deaths, 76 injuries, and 2612 accidents. Compared to 1994, these figures represent a 63 percent increase in the number of deaths and a 69 percent increase in injuries. Total accidents inched forward a modest 5 percent. What was particularly disturbing about these statistics was the dramatic increase in the
injury per accident ratio: 1 injury for every 33 accidents in 1995, compared with 1 injury for every 55 accidents in 1994.

Granted, our data may not generate the same dramatic curiosity reserved for those industries with substantially higher accident numbers. But our numbers are perhaps more significant because boilers can potentially kill any time, any place, any one.

What our statistics do not show are the serious accidents that did not occur because inspectors were able to affect correction of potential problems through an early identification and inspection process.

We have established that the principle of uniformity was a key factor in the development of boiler and pressure vessel standards. Another principle is that of self-governance. By that I mean the reliance on the stakeholders in the standards development process. That is, those who have a vested interest in the safety of the product. The ASME Code, and for that matter, the National Board Inspection Code are developed by a consensus method which involves a leadership effort from owner/users, manufacturers and enforcement authorities. The standards are based upon the collective experience from those who operate boilers and pressure vessels, those who design and fabricate them and some extensive R&D efforts. This process is culminated with a public review period which allows any interested party to provide comments.

Earlier, we mentioned the role of the National Board in the standards development process. The National Board is headquartered in Columbus, Ohio. Our purpose, quite simply, is to promote greater safety through uniformity in the construction, installation, inspection and repair of boilers and pressure vessels. We are comprised of 56 Chief Boiler and Pressure Inspectors, representing U.S. and Canadian government agencies empowered to assure adherence to code construction and repair of boilers and pressure vessels.

As some of you may know, the National Board is the authority in developing inspection, repair, and alteration standards. Our National Board Inspection Code is an American National Standard.

We answer more than 15,000 inquiries per year concerning boilers and pressure vessels. Additionally, we are involved in the training and commissioning of boiler and pressure vessel inspectors all over the world.

The National Board registers well in excess of a million boilers and pressure vessels each year to assure access to critical information required for safe equipment operation, maintenance and repair. We also annual conduct more then 800 tests of safety relief valves at our test laboratory in Columbus.

There are external forces causing national board members to review some of their rules and regulations.

The world today somewhat mirrors the U.S. situation in the early-1900's. There are a number of boiler and pressure vessel standards. Some countries have adopted the ASME Code, others have their own code and standard. A non-ASME Code item poses a problem for many of our members to accept.
The Membership has directed the National Board to reconsider some of our policies and procedures in light of treaties entered into by our government. For example: we are all aware of the drive to remove trade barriers that may have been erected to restrict trade. National Board members are considering the impact of the treaties on a requirement of only one standard for construction. The current thinking is that there is a need for recognition of additional standards.

The primary focus will be on safety. The National Board Membership will develop the criteria a standard must address in order to produce a safe product. Once the criteria is developed, the National Board will review standards against the criteria. The International Standards Organization (ISO) has a similar initiative underway.

If a standard is found to comply with the criteria, authorization to register will be considered. National Board Members would then be in a position to recognize the standard and product constructed to the standard. The end result will be a decision based on protection of public safety rather than a comparison to other standards.

The National Board Membership is looking to their organization and - in reality - to themselves to determine the requirements they need to ensure safety. They are recognizing that they can no longer rely on other organizations to provide the assurances that individual companies are in compliance with the requirements of the jurisdictions. As standards move away from the national flavor, the jurisdictions are losing a degree of input and control they have traditionally exercised.

The sense is that the responsibility entrusted to our members to ensure safety will be retained, if not directly through the standard, then through the members' requirements. In short, nothing has occurred which alters the essential function of a jurisdiction: that is, the protection of public safety as it relates to pressure-retaining equipment.

Changes will also occur in related areas. Inspectors will need training in any additional standards recognized by the jurisdictions. This training will be in the areas of construction, in-service inspection, repairs, and alterations. The National Board recognizes that specific training will be necessary for those inspectors who will perform inspections during construction.

Additionally, there may be standard specifics which affect repairs and alterations. Inspectors will need training to be aware of these requirements.

Finally, revisions to the National Board Inspection Code will need to be considered as additional standards are recognized. The 1995 N-B-I-C recognizes that many jurisdictions are responsible for the repair and alteration requirements for pressure-retaining equipment constructed to various standards, including A-S-M-E.

The N-B-I-C will allow use of the "R" Stamp on repairs made to pressure-retaining equipment constructed to any code. This is a fundamental change to the repair program, and one that many National Board Members feel is long overdue.
In summary, I have tried to show the U.S. experience in boiler and pressure vessel safety requirements by tracing their development from the mid-19th century. Some keys to the standards development process have been discussed. The role of the National Board in this process has been presented, where we started, where we presently stand and where we are headed.
Developments in the Accreditation of Inspection Bodies in the United Kingdom Following the Introduction of EN45004

by

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AUTHOR BRIEF - MR D EVANS

Mr D Evans is an Assessment Manager with the United Kingdom Accreditation Service. Until August of 1996 he was Director of Quality Services at the United Kingdom Institution of Mechanical Engineers where he had worked since 1987 on the assessment of inspection bodies. Prior to this he was Quality Assurance Manager with a major supplier of engineering components.
DEVELOPMENTS IN THE ACCREDITATION OF INSPECTION BODIES IN THE UNITED KINGDOM FOLLOWING THE INTRODUCTION OF EN45004

BY D EVANS CEng, FIMechE, FIQA

Synopsis

ISO 9001 OR 9002 and its predecessors has been used, suitably supplemented and interpreted as the basis for the assessment of pressure equipment and other inspection bodies in the United Kingdom for over 15 years.

As a result of the publication of EN45004 a new inspection specific quality system standard is now available. This is being bought into use in the UK by United Kingdom Accreditation Service.

This paper outlines the progress in making the change.

INTRODUCTION

In presenting this paper I make no attempt to address the technical aspects of pressure equipment inspection. The paper deals with the way the United Kingdom has in the past and intends in the future to manage its inspection body assessment and approval activities.

Working from the historical background my paper discusses the recent approval arrangements, the development of EN45004 - a management systems standard for inspection activities, and the events leading up to the transfer of the UK inspection assessment activities to the United Kingdom Accreditation Service (UKAS). The paper considers how UKAS intends to develop these activities and reviews the implications for inspection bodies intending to seek accreditation and the implications for interested parties, who may wish to depend on the UK accreditation process.

HISTORICAL BACKGROUND

The origins of the United Kingdom plant inspection industry can be traced back to the early days of the industrial revolution where the safety of pressure plant became linked to insurance considerations where industrial users of steam and related equipment quickly realised that insurance against loss of manufacturing output and machinery damage made good sense. The insurers, in turn, insisted that in order to reduce the risk to sensible proportions certain minimum standards of plant design, manufacture, maintenance and operation must be imposed, with regular examinations of condition to be carried out by persons of their choice and nomination.

In parallel with the insurance led approach various legislative measure were introduced compelling owners to comply with simple rules relating to the adequate design, construction and initial inspection of pressure plant by an independent third party and to the operation of the equipment.

These simple but effective rules stood the test of time until the mid 20th century and an industry developed to service these needs within the United Kingdom which employs some 3 000 people, and turns over some £150 m per annum and probably performs some 7 million plant inspections per annum.

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The Health and Safety Executive’s experience within the UK has led to the development of non-prescriptive legislation in the plant and equipment safety field. Current legislation does not specify technical detail of industrial plant items or plant groups or detailed procedures for inspection. It does, however, specify the responsibilities of individuals and organisations. It specifies the responsibility of plant owners to ensure that their plant is safe and requires inspection of plant items to be performed by “competent persons”. Where this is shown by result of regulatory surveillance or of incidents not to have been achieved individuals and organisations may be prosecuted under the very general provisions in the Health & Safety at Work Act.

Notwithstanding the availability of these legal sanctions the regulators felt that additional surveillance of the inspection industry was appropriate. The non-prescriptive nature of UK legislation in this field presented an early opportunity to use a management systems approach to inspection body assessment and acceptance and the first steps in using what was then BS5750 were taken in the early 1980’s by the United Kingdom Institution of Mechanical Engineers (IMechE) acting very much with the encouragement of the Health and Safety Executive. Inspection body assessment using this management systems or “quality” management systems approach was developed throughout the 1980’s and 1990’s by the IMechE using BS5750 and then the 1987 and 1994 Editions of ISO 9001 and 2 as these were themselves developed. By 1996 The IMechE’s inspection body assessments covered voluntary approvals in the new construction inspection and in-service inspection areas in the technical fields of pressure systems, gas cylinders, power presses, lifting plant and ventilation equipment. The UK government also made use of IMechE expertise by way of Institution recommendations as a basis for statutory appointment of inspection bodies required for the verification of gas cylinders and for the European Union Directive associated with simple pressure vessels such as air receivers.

DEVELOPMENTS IN MANAGEMENT SYSTEMS STANDARDS FOR INSPECTION BODIES

The ISO 9000 series of standards has developed since the late seventies, from even earlier roots, into sophisticatedly worded and very effective standards. From an inspection view-point ISO 9001 and 9002 have always suffered from their origins as systems standards for the manufacture of products rather than for the provision of services. For this reason great care in interpretation and use by inspection bodies and assessors has always been necessary. This has not always been convenient.

During the 1980’s and 1990’s developing European integration has led to the need for the development of a range of European Standards dealing with dedicated conformity assessment issues in areas such as laboratories, management systems certification, mass production product certification and certification of personnel. The need for a dedicated standard for inspection bodies in this series was enthusiastically endorsed by the UK inspection industry who were seeking, for the future, a clear route for appointment as notified bodies under relevant EU directives.

EN45004 published in August 1995 is the result of some 5 years of European standards development activity.

The responsibility for determining the policy in the UK for the application of the EN45000 series of standards falls on the UK Government’s Department of Trade and Industry. After a suitable
consultation process it was considered that assessment against EN45004 of inspection bodies seeking UK recognition should be carried out by the United Kingdom Accreditation Service.

The United Kingdom Accreditation Service -UKAS was formed on 1 August 1995 from the organisations who had been previously responsible for providing management systems certification body and laboratory accreditation services. In making it's decision DTI added the provision that the IMechE's expertise in the inspection body assessment field should be recognised and integrated into the new arrangements.

The DTI views happily coincided with those of the IMechE who felt that, as a professional institution with it's major interests in the development of its members, it had fulfilled its obligations to government, industry and the public at large in respect to it's inspection body assessment work.

As a result the IMechE's inspection body assessment activities transferred to the United Kingdom Accreditation Service on 16th August 1996 operating very much on a 'business as usual' basis with UKAS offering transitional accreditation to previously suitably approved bodies pending full compliance with all EN45004 requirements before the end of an, at maximum, two year transition period.

At the time of the transfer the IMechE's approved or recommended Inspection bodies lists covered 60 different inspection organisation with individual approvals compromising

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<tr>
<td>Simple Pressure vessels directive Recommendations (to DTI)</td>
<td>12</td>
</tr>
<tr>
<td>Transportable Gas containers Recommendations to (HSE)</td>
<td>23</td>
</tr>
<tr>
<td>In-Service Inspection approvals</td>
<td>37</td>
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A significant proportion of the latter category being in-house inspection bodies approved for the in-service inspection of pressure plant owned by their process operating parent organisations.

EN45004

EN45004 specifies general criteria for the competence of impartial bodies performing inspection irrespective of the sector involved. It incorporates relevant requirements of the ISO 9000 series of standards and many features of ISO/IEC Guide 39 (General Requirements for the Acceptance of Inspection bodies). It is intended for the use of inspection bodies and their accreditation bodies as well as other bodies concerned with recognising the competence of inspection bodies.

Two novel features introduced in EN45004 are a new definition of "inspection" which supersedes previous definitions in EN45020 and ISO/IEC Guide 39, and innovative independence criteria.

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Definition of Inspection

Inspection is defined as - examination of a product design, product, service, process or plant, and determination of their conformity with specific requirements or on the basis of professional judgement, general requirements. This broad definition is a gentle reminder of the wide variety of inspection activities that exist. Conformity assessment by inspection is not limited to product and plant, but is equally relevant in other areas such as services and processes.

The reference to professional judgement in the definition is a recognition of the breadth of knowledge certain inspections, such as examination of equipment in service, demand from inspectors and inspection bodies.

Independence

The new standard implies that demonstrable independence of an Inspection Body may strengthen the confidence of its customers in the Inspection Body's ability to perform its duties with impartiality.

In the United Kingdom the conventional descriptions of an inspection body's independence has been that of first, second and third party. These descriptions, particularly the first and second party vary with the circumstances in which the inspection is performed, making it difficult to apply these definitions consistently to describe the independence status of an inspection body.

The new concept introduced in EN45004 is based on the characteristics of an Inspection Body rather than the role in which it operates. Three type, Type A, Type B and Type C, are designated depending on the Inspection bodies' relationship to the parties involved, its organisation structure, responsibilities and ownership. Basically, Type A bodies are third party, Type B bodies are separate and identifiable entities, and can only undertake inspection either as a user or as part of the manufacturing organisation. Type C bodies are identifiable entities, but not a separate part of the organisation. Type C can supply inspection services to parties other than the parent organisation. It will be UKAS's task to assess the competence and to establish the type of independence for each applicant for accreditation.

Technical Competence

EN45004 anticipates the need for interpretation documents for specific industry sectors or areas of inspection activity. UKAS, through its representative technical committees, will be developing such documents to meet the needs of specific sectors that wish to apply EN45004 in a consistent manner.

In the field of in-service inspection the UK already has an established model in the form of a national certification scheme, which focuses on assessment of plant and equipment safety at work and the technical competence of those involved -that is those that are making the professional judgements. Arrangements are in place to incorporate the principles of this scheme's technical competence criteria into UKAS' requirements for in-service inspection of safety sensitive plant.

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THE UNITED KINGDOM ACCREDITATION SERVICE

UKAS is an independent non-profit distributing organisation which operates under a Memorandum of Understanding from the UK Department of Trade and Industry. Its shareholders include representatives from the DTI itself and others with interests in the accreditation process.

As a young organisation UKAS is ‘doing a lot of listening’ at the present and while this seminar presents an opportunity to reach a wider audience it also presents an opportunity to gain feedback from a wider audience. I hope that such feedback will be forthcoming from some of you who have experience of past and present UK approved inspection bodies.

The Memorandum of Understanding with its associated license agreement to use and licence the use of the royal crown records the joint commitment of UKAS and the Secretary of State “to maintaining and developing a strong and unified national accreditation service in the UK as a means of promoting quality and the competitiveness of the UK industry”.

In making this commitment Secretary of State recognises UKAS as the sole national body, for the duration of the memorandum, for the assessment and accreditation of, amongst others, inspection bodies. Inspection was added to the MOU in September 1996 and the Secretary of State will ensure that when inspection (or other conformity assessment activity) is required to demonstrate compliance with EU Directives or UK Regulations then the UK government will normally specify the use of bodies accredited or recommended by UKAS.

The authority given by the MOU puts UKAS in a powerful position. UKAS recognises this and as a result of its first year of operations, whilst working in its listening mode, it has identified and highlighted a number of points of future accreditation practice that it intends to adopt.

These include:

1. To operate in a flexible way to give greater service to all stakeholders.

2. To conduct its accreditation business with a light touch while policing strongly where appropriate.

3. To accredit to nationally or internationally agreed criteria which may be wider than the EN45000 series standards alone. (In many respects UKAS feels that certain of the EN45000 series are too broadly drafted for use as a basis for consistent accreditation. In the plant inspection field appropriate well developed supplements already exist within UK practice based on prior work with the inspection industry).

   It is intended that the loosening of the tight previous link with the 45000 Series standards will encourage UKAS to accredit in a more imaginative and useful way.

4. To arrange that UKAS accreditation certificates should have expiry dates that are consistent with internationally agreed intervals between assessments.

5. To record and act on customer feedback for work it carries out.

6. To set firm and realistic estimates for the cost of work to be carried out.
To seek to develop assessment individuals or teams capable of assessing to a range of appropriate standards. This is a natural consequent of the bringing together within UKAS of laboratory, inspection and certification accreditation activities and the need to efficiently handle clients performing multiple functions.

**ACTIONS FOR INSPECTION BODIES**

Following the announcement of the changes in the UK arrangements just described all the presently IMechE approved or recommended UK bodies (with one exception) have elected to transfer to UKAS EN45004 accreditation or recommendation by the end of the transfer period. Similar changes are taking place elsewhere in Europe and equivalent choices have faced or are facing other European based inspection bodies.

EN45004 is a management systems standard for inspection that incorporates the relevant requirements of the ISO 9000 series standards that are applicable to the quality systems of an inspection body. It follows, therefore, that ISO9000 series approved inspection bodies should have not great difficulty in the management of the changeover to the new standard and in satisfying the relevant accreditors.

Over the years a well established pattern has emerged in the incidence of non-conformities noted during the assessment or surveillance of inspection bodies.

Typically these are spread:

<table>
<thead>
<tr>
<th>Description</th>
<th>Approximate %</th>
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<tr>
<td>Document control (including the control of standards and regulations)</td>
<td>22</td>
</tr>
<tr>
<td>Internal audits and management review</td>
<td>18</td>
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<tr>
<td>Inspection process control</td>
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<td>Training</td>
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<td>8</td>
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<td>Organisation and Quality System</td>
<td>7</td>
</tr>
<tr>
<td>Other</td>
<td>14</td>
</tr>
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and it is felt unlikely that this pattern will shift radically in the long term due to the introduction of the new standard.

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ACTION FOR INSPECTION SERVICE USERS

Over the years a number of overseas governments and other regulatory authorities have given recognition to the UK inspection body approvals and appointments that were based on the work of the UK Institution of Mechanical Engineers. As far as can be ascertained the IMechE work has been well received, valued and its decisions have stood the test of time.

The changes that have been described in this paper are recognition of developing international and European integration and the need for removal to barriers to trade. The author hopes that those who have relied on decisions made by UK approved inspection bodies will be able to continue to do so with enhanced confidence that the new arrangements are intended to provide.

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Quality Control and Development of
Boiler and Pressure Vessel Inspection in China

by

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1. Outline

For the purpose of promoting greater safety to life and property, the quality control, as a very important factor, is a key portion of the course of industrialization. As matter of fact, the quality control is no more a simple concise, it is a special system composed of codes, standards, inspection, supervision and scientific research and technical support as well.

At the end of 1970's TQC was initially introduced to the management of enterprises and to the supervision of the governmental agencies with the policy of opening to the outside world and the fast moving changes that were taking place in China. Due to the promotion of the government, since then, TQC has been a major portion of enterprises’ management among those industries including machinery, electronic, chemistry, light industry and textile industry at mid/large size enterprises.

Prior to the issuance of ISO 9000 - 87, combining the promotion of TQC theory and experience applied in the areas of industry, also referring to the ASME CODE and NB pertinent to the rules and regulations and the experience of Chinese enterprises that have procured their qualification of the authorized manufacturers dealing with the ASME, the Ministry of Labour and Industrial Ministries concerned have stipulated a series of relevant codes and standards on the quality control of boiler and pressure vessel inspection, the effective measures thereof have been taken according to the documented requirement.

So far, taking boiler and pressure vessel for example, China has established its quality control system that approach the fifth qualification, one of the most serious and more complexed qualification, compared with those eight kinds of the qualification that have been adopted by international organization. At present, quite a lot of countries have paid more attention to these areas. Because of the influence of the promotion of ISO - 9000, the quality control of boiler and pressure vessel is developing towards the global standardization.

2. Quality control of boiler and pressure vessel inspection in China

It is well known that boilers and pressure vessels are special equipment, therefore, the quality control is an important feature in preventing them of potential explosion, hence, protecting life and property.

Based on the experience of industrialized countries, referring to the related international standards, ASME CODE and present situation on boiler and pressure vessel in China, the quality control is as following:
2.1 Legislation of boiler and pressure vessel

In 1982, the Provisional Regulation of Safety Supervision for Boiler and Pressure Vessel was issued by the State Council. In the same year, also, the Implementation Detail of Provisional Regulation on Boiler and Pressure Vessel Supervision was issued by the Ministry of Labour. Both legislations mentioned above, since then, have been playing an important role in the field of quality control of boiler and pressure vessel and also become a basic constitution to the area in all over the country. Accordingly, the inspection system is consisting of training, education, examination, qualification, accident report, technical assessment and test, etc.

Since 1979, along with economic prosperity and growth, efforts on perfecting the codes and standards of quality control of boiler and pressure vessel has become strategy of the Ministry of Labour to strengthen safety management and inspection.

In view of the requirement of inspection, regulations related to Safety technical regulation on gas cylinder, Safety technical regulation on steam boiler, Safety technical regulation on hot water boiler, Safety technical regulation on pressure vessel and Specification for qualification of welders for boiler and pressure vessel were issued by the Ministry of Labour. Up to now, there are 33 kinds of regulations have been issued, a legislation system dealing with the equipment thereof has been shaped to enable the comprehensive development of quality control of boiler and pressure vessel in China.

2.2 Inspection agency on boiler and pressure vessel

Now a comprehensive inspection system has been established in conducting inspection to both manufacturers and owners/users according to the Provisional Regulation of Safety Supervision for Boiler and Pressure Vessel in China.

Under the direction of the State Council, both the Ministry of Labour and Authorized jurisdictional authorities at provincial or municipal level have performed their inspection in their jurisdictions, respectively.

Among those the Authorized jurisdictional authorities and under the direction of them, there are professional inspection agencies that perform related inspection activities at shop and field.

According to the requirement of the Ministry of Labour, the registration and authorized inspection are necessary, that means all inspection agencies and inspectors must hold the qualified certificate issued by the Ministry or Authorized jurisdictional authority.
Totally, there are 897 inspection agencies registered and authorized by the Ministry of Labour, about 16,000 inspectors to conduct their inspections on boiler and pressure vessel in accordance with those jurisdictions. According to the statistic, take the year of 1995 for instant, the boilers that had been inspected by the inspection agencies were up to 92.7%, the stationery pressure vessels up to 80.46% and 28,000 sets of boilers and pressure vessels were in potential danger or with certain defects, resulting in repair or decrease their pressure in use.

2.3 **Major inspection on boilers and pressure vessels**

Based on the Provisional Regulation for the purpose of promoting greater safety to life and property, the design construction, installation, operation, inspection, repair and alteration of boilers and pressure vessels or their other pressure retraining items and their appurtenances must coincide with the requirements of related codes and standards.

2.3.1 **Design**

The design of boilers and pressure vessels must coincide with the requirements of related codes and standards. The design drawing must be audited and approved by the technical responsible staff of the designing agency that has procured their qualification authorized by the Ministry of Labour or Authorized jurisdictional authority. The design agency shall be responsible for their correctness and rationality of the design.

2.3.2 **Construction**

The manufacturers must procure their qualification authorized by the Ministry of Labour or Authorized jurisdictional authority.

The manufacturers shall assure that the quality of their products corresponds to the requirements of related codes and standards. Welders and NDT staff shall pass the examinations conducted by the Ministry of Labour or Authorized jurisdictional authority.

A certificate of qualification may be issued to an applicant by the Ministry of Labour or Authorized jurisdictional authority in accordance with the rules of related codes and standards and meeting the requirements contained therein. The finalized products must be attached a completed drawing and the certificate of quality control and inspection.

2.3.3 **Installation**

In accordance with the requirements, the installation in-site and the operation of welding must keep the same condition as in construction. Subsequent to the products finalized, the inspection of the products must be carried out by an inspection agency under the direction Authorized jurisdictional authority.
2.3.4 Operation

On the basis of the requirement of related codes and standards, the owners/users must have their boiler registered at the Authorized jurisdictional authority with all necessary documents in order to get their qualification of operation prior to those equipment are allowed to operation.

Owners/users shall establish their own rules or bylaws for running boilers safely and assign professional staff who are responsible for management to be in charge of the boiler operation. The engineer/operator of boiler shall pass the examination conducted by Authorized jurisdictional authority and procure their individual qualification of operation. The inspection of in-service boiler and pressure vessel must be carried out by an inspection agency under the direction of Authorized jurisdictional authority.

2.3.5 Inspection

All inspection agencies function and their purposes are specified as in section 2.2.

In term of qualification and examination of inspectors, the National committee for examination and qualification of NDT inspectors of boiler and pressure vessel was established by the Ministry of Labour in 1983. The committee is composed of a senior subcommittee, 30 mid-level subcommittees and 184 primary subcommittees.

The purpose of the committee is to conduct various kinds of training course and examination to all inspectors and applicants for procuring their individual certificate of qualification.

2.3.6 Repair and alteration

The enterprises engaged in repair and alteration of boilers and pressure vessels or other pressure retaining items and their appurtenances must hold the certificate of qualification issued by the Ministry of Labour or the Authorized jurisdictional authority. Meanwhile, the repair and alteration shall coincide with the requirements of related codes and standards.
2.3.7 Import and export inspection/safety and quality licensing system

2.3.7.1 Import and export inspection

According to the law of the P.R. China on import and export commodity inspection, China implements an import commodity safety and quality licensing system for important import commodities involving safety, hygiene and environment protection, etc. The system is a governmental legal safety certification system, no commodities subject to import safety and quality licensing system issued by the State shall be allowed to export to the P.R. China unless the foreign manufacturer or its representative agency has been granted the safety and quality licensing certificate.

2.3.7.2 Safety and quality licensing certificate

The licensing qualification for nine kinds of import commodity, which are covered in the first issued list of import commodities subject to import safety and quality licensing system, has been implemented mandatory by the State since May, 1990.

For boiler and pressure vessel safety quality licensing system, on Sept. 1995 the Ministry of Labour and the State administration of import and export commodity inspection promulgated a notification in which the products list of import and export boilers and pressure vessels subject to safety quality licensing system was issued. The list specifies the details of 4 kinds of products subject to boiler and pressure vessel safety quality licensing system which includes boilers, transportable pressure vessels, stationery pressure vessels and their appurtenances. The notification also specifies that the application of boiler and pressure vessel safety quality licensing shall be accepted formally as of Oct., 1995.

According to the requirement of the notification from 1 October 1997, no boiler and pressure vessel product which are covered in the product list of import boilers and pressure vessels subject to safety quality licensing system shall be allowed to export to China unless the foreign manufacturer or their representative agency has obtained the safety quality licensing certificate of the Ministry of Labour.
3. Development of boiler and pressure vessel inspection in China

With a quick growth of economic in China, the annual output of boilers made in China will be 70,000 sets by the year of 2000, and of pressure vessels up to 400,000 sets, and of gas cylinders high up to 15 million pieces. The production scale mentioned above may basically meet the demands of future. However, while the output is highly up to the desired level rapidly we should keep on turning the safety into better condition. There is a long way for us to go in the industry of boiler and pressure vessel in China and we must to do the job as following:

- We must scientifically plan and rationally adjust the industrial distribution of boilers and pressure vessels and try our best to make the regional industrial distributions and the series, various, sizes and grades of products be rational and energy saving. Therefore, we can solve the issues such as the dispersion and isolation of product distribution, product repetition, pollution and low efficiency.

- We must lay equal stress on both the development and import of technology, speed up the technical transformations and the replacement of equipment, raise the mechanized and automated level of boiler and pressure vessel industry in China and rapidly shorten the gap between the domestic technology and the advanced one in the world in the fields of design and construction. In the mean while we have to strengthen the absorption of technical import.

- For the purpose of assuring the reliability and efficiency of non-destructive inspection, we will popularize and adopt hi-tech measures to guarantee the accuracy and high efficiency of the quality control of the inspection.

- With the establishment of the modern enterprises management system, we must improve the level of management and quality control system of boiler and pressure vessel. At the same time, we have to improve the qualifications of all inspectors, managing staff and workers entirely.

By the year of 2000, the number of boilers in service will be up to 700,000 sets, the pressure vessels up to 1.5 million and gas cylinders up to 70 million.

Because of raising up the construction capability of boiler and pressure vessel, the quality control of the inspection will bring us a large amount of work and be more difficult in practice. In addition, there is a number of problems existing in the quality control of boiler and pressure vessel, those of equipment thereof with serious defects and hidden troubles are still in service at present. Therefore, we should do repair on the houses before it rains, and take the following measures in advance.

- According to the experience, most of accidents were caused by bad management and wrong operation, a pressing matter of the moment is to enlarge the contingent of management and inspection and to raise up its capability while improving the qualification of managers and operators as well as their safety ideology and technical knowledge.
- Continuously perfecting the related codes and standards of boiler and pressure vessel and meet the requirement of quality control and social development.

- Combining the technical import and their absorption we should establish a scientific and efficient system of quality control/assessment and the method of accident prevention in order to solve most of the problems such as serious defects, hidden troubles of boiler and pressure vessel in service.

- Speeding up the applications of modern technical measure in controlling/monitoring of boiler and pressure vessel, especially in developing the automatic control and monitor system, the analysis system of accidents and the interchanging system of related information so as to raise up the level of quality control by means of systems mentioned above.

4. Conclusion

The obvious achievements have been obtained since the issuance of the related codes and standards and the enforcement of the legislations thereof by the Ministry of Labour and Authorized jurisdictional authorities at provincial or municipal level. The safety situation of boiler and pressure vessel has already taken a favorable turn in China. The rate of explosion accident has gone down. The rate decreased from 7.6 times/10,000 sets in 1978 down to 1.4 times/10,000 sets in 1985; the pressure vessel from 3.5 times/10,000 sets in 1980 to 1.35 times/10,000 sets in 1985.

Over the years of 1986 to 1993, the rate of explosion accident has been keeping on going down, i.e. 0.85 times/10,000 sets in 1993 of boiler; and 0.72 times/10,000 sets vessel in 1993 of pressure vessel.
Research, Application and Development of Safety Assessment Techniques for Pressure Vessels in China

by

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Abstract

This paper fully described the current state of pressure vessel safety assessment techniques and presented in detail some important research achievements in China. Certain engineering applications and the future developing trends in the field of pressure vessel safety evaluation were also discussed. For both professional and management personnel engaged in pressure vessel inspection and safety assessment this paper will provide much information.

Key words: pressure vessel safety assessment technique research, application and development

Introduction

As a special kind of pressure-containing equipment and due to its potential hazard of explosion, the safe operation of pressure vessel has a great impact on both the human life and social stability. According to a statistic analysis\(^1\), there are more than 30 million liquefied natural gas containers and 1 million pressure vessels in mainland China. Among those pressure vessels about several hundred thousands of them had different kinds of severe defects or were well beyond their designed service lives. Long time ago, great concern had been taken by the government agencies and scientific researchers about the investigation and application of pressure vessel safety evaluation methodologies. Along the approach a big step had been made since an important scientific research project "The Research of Technique of Safety Assessment and Explosion Prevention for In-service Boilers and Pressure Vessels" was issued by the National Science and Technology
Committee. Many valuable research results had been got during the period of the 8th 5-year plan of national economic and social development through the project, which was organized by the Boiler and Pressure Vessel Inspection and Research Center of National Labor Ministry and participated by about 46 different units and 260 scientific researchers. With all these efforts China has been approaching the level of industrialized nations in respect to the theories and techniques of pressure vessel safety assessment. In the next 5-year plan of national economic and social development, which starts in 1996, China will focus parts of its attention on the research of safety assessment technique for in-service industrial pressure piping although certain efforts will still be put on the research jobs for pressure vessels especially for revising, improving, and utilizing the newly proposed "The Guide for Safety Assessment of In-service Pressure Vessels Containing Defects". It is evident that the research and applications of pressure vessel safety assessment techniques have entered a new stage and become one of indispensable related technique and insurance measurements for rapid, stable and thorough development of national economy in China.

Overview

Generally speaking, two periods can be separated in the developing process of pressure vessel safety assessment techniques in China. The first half corresponds to the period from the beginning of 70's to 1984. The next half started in the middle of 80's.

During the first period a lot of experimental data had been gathered and more than 400 papers had been documented. As a result of these hard work, a special code of defect assessment for pressure vessel was proposed and issued jointly by the National Institute of Pressure Vessel and the National Institute of Automation for Machinery in Chemical Industry in 1984. That code was titled "The Code of Defect Assessment for Pressure Vessels" and designated as CVDA-84. It represented the techniques of defects assessment techniques worldwide at that time, and obtained supports from most factories, industries, research institutes, and government agencies through its wide application. It had been shown that the CVDA-84 was a conservative engineering assessment method, which played an important role in the safety assessment research of pressure vessel in China and got enormous benefits in both social and economic aspects.

The procedure of CVDA-84 fracture assessment belongs to that of COD design curve method, and is similar to the procedures adopted by BSIPD6493 and WES2805. However, the COD design curve of CVDA-84 has a higher safety margin in the region around \( e/e_y = 1 \).

It can be said that the CVDA-84 is the first defect assessment code published in China which to a certain extent combined research results obtained by Chinese scientific researchers.

In the second developing period, which started in the middle of 1980's, great achievements have been obtained through many scientific researches especially those belonging to the important scientific research projects of the 8th 5-year plan. For example, a series of difficult problems were successfully solved relating to the assessment procedures, techniques, and methods of safety assessment for in-service pressure vessels, the relationships between transferring and development, learning and invention were fully settled. Being a
milestone in the developing process of pressure vessel safety assessment in China, a new code about safety assessment was proposed in 1995. This new code, entitled "The Code for Safety Assessment of In-service Pressure Vessels Containing Defects" and designated as SAPV-95[8], has adopted many advanced techniques and reached the level of related codes of industrial countries.

It should be pointed out that for the standardization of scheduled inspection of in-service pressure vessel, a requirement of evaluation for the safety state of inspected in-service pressure vessel had been suggested in first time in the "Inspection Procedure of In-service Pressure Vessels" issued by the National Labor Ministry in 1990. The requirement was set up by referencing both positive and negative practical experiences in the in-service pressure vessel industry and consulting the principle of fitness for purpose. This requirement played an important role in the scheduled inspection of in-service pressure vessels in China and continued to be used successfully. With the proposed inspection procedure, an effective relation can be established between safety assessment and scheduled inspection of pressure vessels. By means of management and technique the application of the inspection procedure has greatly improved the safety records of pressure vessels in China. Along the same approach another related research item, entitled "The Research of Safety State Level Evaluation of In-service Pressure Vessel and Development of Related Software", had been proposed by the National Science and Technology Committee during the 8th 5-year plan. That research activity resulted in an unique and advanced evaluation method, entitled "The Recommended Method of Safety State Level Evaluation for In-service Pressure Vessel", and related software[10]. The method broke through formerly used evaluation procedures which mainly based on experienced and further promoted the level of safety assessment techniques for pressure vessel in China.

Research Activities of Safety Assessment Technique for Pressure Vessels in China Before 1984

The publication of CVDA-84 marked the first milestone in the research process of safety assessment techniques for pressure vessels in China. The first period of the process corresponds to a time interval from 1970's to 1984. During this period of time, much work had been done in the following research areas. They are: Theoretical derivation and experimental evaluation of COD design curves; Characterization and K-equivalent conversion of defects; Estimation methods for welding residual stresses and peak strain values near nozzle zones; Multiprofile methods and related data analysis for the determination of COD fracture toughness; Determination of fatigue crack growth rates for cracks in both base metals and in welded nozzle zones; Fatigue assessment, etc. Most of the results had been included in the CVDA-84. The following sections briefly described those research activities.

1. COD design curves[7,11] used in China

COD design curves are the major references when performing pressure vessel safety assessment by CVDA-84 method. After making a thorough engineering derivation and comparing results obtained from wide plate tests
and pressure vessel fracture experiments with both PD6493 and JWW's COD design curves and Japanese WES2805's COD design curves, CVDA-84 proposed the following safe design curve:

\[
\begin{align*}
\phi &= \frac{\delta_c}{2\varepsilon_y\bar{a}} = \left( \frac{e}{\varepsilon_y} \right)^2, & 0 \leq \frac{e}{\varepsilon_y} \leq 1 \\
\phi &= \frac{\delta_c}{2\varepsilon_y\bar{a}} = \frac{1}{2}\left( \frac{e}{\varepsilon_y} + 1 \right), & \frac{e}{\varepsilon_y} > 1
\end{align*}
\]  

(1)

where \( \phi \) is a non-dimensional COD, \( \delta_c \) critical crack opening displacement (COD) in mm, \( \bar{a} \) the half length of K-equivalent through-wall crack for surface or submerged crack, \( e \) and \( \varepsilon_y \) are the strain and yield strain, respectively.

Compared with the COD design curve adopted in PD6493-80, the CVDA-84's design curve is about the same as PD6493-80's when \( \varepsilon/e < 0.5 \). For \( 0.5 < \varepsilon/e < 1.5 \), especially for \( \varepsilon/e = 1 \), CVDA-84's design curve has a higher safe margin than PD6493-80's design curve. When \( \varepsilon/e > 1.6 \), PD6493-80's design curve is more conservative, as shown in figure 1.

Fig. 1  Comparison of CVDA-84's COD design curve with other design curves

It has been shown that the CVDA-84's design curve is suitable for pressure vessel safety assessment in China.


Because the existing analytical solutions of COD are only valid for through-wall cracks in wide plate with narrow yield strip, certain conversions for surface and submerged crack sizes must be made in order to use the COD design curve for safety assessment.

For surface crack,
For K-equivalent through-wall crack

\[ K_t = \sigma \frac{F \sqrt{a}}{\Phi} \]

The K-equivalent formulation becomes

\[ \hat{a} = \frac{\sigma}{t} \left( \frac{F}{\Phi} \right) \left( \frac{a}{t} \right) \]

where \( a \) is the depth of surface crack, \( \hat{a} \) the half length of K-equivalent through-wall crack, \( t \) the thickness of plate, \( \Phi \) the second kind complete ellipse integral, \( F \) the coefficient of free surface effect for surface crack.

After analyzing existing foreign formulas of stress intensity factor for surface crack, such as Maddox's method\[13\], Newman-Raju's method\[14\], and Schmitt-Keim's method, and referencing the tensile fracture test data of 40Mn2A steel plate with surface cracks, it was shown that there were no significant difference among the three methods. Maddox's and Newman-Raju's methods, however, in some cases predicted lower \( \sigma \) values than tested ones. While for Schmitt-Keim's method, conservative \( \sigma \)'s can always be got when compared with actual \( \sigma \) values. So, Schmitt-Keim's formula was adopted for K-equivalent conversion. It was also found that when \( a/t \leq 0.1 \) and \( a/c = 0 \) the \( F \) value calculated according to the above three methods were greater than related \( F \) values of two-dimensional edge crack in tension. This phenomenon was not ideal. So, it was suggested that when \( a/t \leq 0.5 \) and \( a/c = 0 \) the analytical solution for edge crack was adopted in order to make a good connection with two-dimensional edge crack formulation (see Fig. 2).

![Fig 2 Comparison of free surface effect coefficient \( F \) with the correction coefficient \( f \) of two-dimensional edge crack](image)

It should be pointed out that the equivalent crack size is affected by both material's properties and applied stress level. The K-equivalent conversion method is only valid in circumstance where only small scale yielding presented before fracture. For fracture problem with large scale yielding, the K-equivalent conversion method is
not only not suitable but not conservative. Although some researches were carried out for J-equivalent conversion techniques, the related findings were not included in CVDA-84 due to the lack of strict evaluations.

3. Estimation Methods for Welding Residual Stresses and Peak Strain Values Near Nozzle Zones

The effect of welding residual stresses on fracture behavior of metal depends on service temperature. The influence of residual stress can be neglected if the service temperature is high enough to cause fully ductile fracture where the residual stresses have been totally relaxed.

There are many different calculating methods for welding residual stresses among existing codes of defects assessment. For example, in WES2805, 0.6\(\sigma_y\) is added to external applied stresses to compensate the effect of welding residual stress for cracks oriented perpendicular to welds. Thus, the corresponding design curve became:

\[
\phi = 0.557 \left( \frac{\varepsilon_{\text{appl}}}{\varepsilon_y} + 0.6 \right)
\]

where \(\varepsilon_{\text{appl}}\) is the strain resulted from applied external stress.

While in PD6493-80, the magnitude of welding residual stress is set to \(\sigma_y\) for all cracks near welds. Therefore, for \(\varepsilon/\varepsilon_y > 0.5\) the corresponding design curve became:

\[
\phi = \frac{\varepsilon_{\text{appl}}}{\varepsilon_y} = 0.75, \quad \frac{\varepsilon}{\varepsilon_y} > 0.5
\]

If let \(\sigma_y = 0.6\sigma_y\), then

\[
\phi = \frac{\varepsilon_{\text{appl}}}{\varepsilon_y} + 0.35, \quad \frac{\varepsilon}{\varepsilon_y} > 0.5
\]

Figure 3 showed the relations presented by equations 3, 4, and 5, respectively.

![Fig. 3 The effects of welding residual stresses on the safe design curves](image)

- Through-wall cracks
- Surface cracks
Experimental tests performed by Harrison had shown that all test points possessing welding residual stresses were under the line corresponding to equation 4 in Fig. 3. Except for only one point, all other ones also located underneath the line of equation 5. It is clear that the PD6493-80's treatment for welding residual stress is over conservative. So, in CVDA-84 a more reasonable level of welding residual stress had been selected where \( \sigma_r = 0.6\sigma_y \), which is the same as WES2805's method. Many experimental tests had been set forth to investigate the effects of welding residual stress on the brittle fracture behavior of cylindrical pressure vessels in China\(^{18} \). These experimental results indicated that welding residual stresses generally not exceed the value of 0.2\( \sigma_y \) when they are evaluated according to their influences on the burst pressures or cracking pressures. From above researches and tests it is evident that in CVDA-84 choosing 0.2–0.6 as the equivalent coefficient of welding residual stress is conservative.

Acting as a geometrical discontinuity, the nozzle zone of pressure vessel usually presents severe stress concentration. Various types of welding imperfections can appear in the region. As a result engineering communities all over the world have taken great attention to scientific researches relating to the integrity, estimation of acceptable defect size, and plastic fatigue behavior in nozzle zone. And many related research projects were proposed.

The following conclusions had been reached after a series of experimental tests, elastic finite element analysis, and mathematical derivation for stress and strain in nozzle zones\(^{19} \).

1). The maximum strain appeared at the corner of inner wall of nozzle. For thin wall pressure vessels (\( R_o/R_i = 1.02 \)) the maximum strain value could reach \( 6\varepsilon_y \) when applied stress level approached 0.87\( \sigma_y \).

2). There are steep gradient of strains. The extent of strain concentration become less for points having distances larger than half diameters of nozzle from the corner. That is to say the property of strain concentration resembles that of notches in an infinite plate.

3). The peak strain corresponds to a state of unidirectional stress. The elastic-plastic peak strain of notch can be expressed as

\[
\frac{\varepsilon}{\varepsilon_y} = \frac{1}{\alpha} \left( \frac{\sigma_1}{\sigma_y} \right)^2
\]

where \( \sigma_1 \) is the elastically calculated nominal stress in the notch region, \( \sigma_y \) the flow stress, \( \alpha \) the material's hardening coefficient (\( \alpha = \sigma_0/\sigma_y \)), \( \varepsilon \) the actual strain in the notch area, \( \sigma_y \) and \( \varepsilon_y \) the yield strength and yield strain, respectively.

The above expression is derived from Neuber relation.

For perfect plastic material where \( \sigma_0 = \sigma_y \) and \( \alpha = 1 \), equation 6 became

\[
\frac{\varepsilon}{\varepsilon_y} = \left( \frac{\sigma_1}{\sigma_y} \right)^2
\]

If knowing \( P_{xy} \) as the initial yielding load in the notch area, then
Theoretical analysis and experimental tests showed that the strain in nozzle zone can be estimated by using equations 6, 7, or 8, as indicated in figure 4.

Fig. 4 Comparison of estimated and tested strains in nozzle zone.

Those estimation equations had been adopted in CVDA-84.

If the accepted crack size $\tilde{a}_m$ is expressed as

$$\tilde{a}_m = k \left( \frac{\delta_c}{e_y} \right)$$

(9)

Then, the relations between $k$ and $e/e_y$ can be depicted in figure 5 for different assessment codes.

Fig. 5 Relationship between $k$ and $e/e_y$ for different assessment codes when $\tilde{a}_m = k (\delta_c / e_y)$
It is obvious that the k value for CVDA-84 is just between those of PD6493-80 and WES2805. This means that the allowable crack size in CVDA-84 is more conservative than that in PD6493-80.

It should be noted that for so many factors affecting the actual strain in nozzle zone the aforementioned estimation methods still need certain improvements in order to give more accurate assessment results.

4. Multiprofile Methods and Related Data Analysis for the Determination of COD Fracture Toughness

In defect evaluation for pressure vessel one of the critical steps is to determine the COD fracture toughness of weld. For that purpose, many different methods can be used, such as electric potential method, acoustic emission method, ultrasonic method, etc. However, all of these have some limitations. Due to the large variations of microstructures and properties in weld regions, the commonly used multisample resistance curve method is also not suitable here.

The multiprofile method, also called metallographic section method, is suitable in this case, especially for ductile materials. In this method the average value of stretch zone width (2xSZD), which is measured by means of bench microscopes in several sections perpendicular to the front line of crack, is obtained. The saturated initial COD $\delta_a$ is

$$\delta_a = 2 \times SZD = \frac{PQ - O_1O_2}{2}$$

(10)

as shown in figure 6[20].

Fig. 6 Schematic diagram for the principle of multiprofile method

Practical uses indicated that the multiprofile method is simple and time-effective. It is also included in CVDA-84.

In order to obtain the information about initial cracking COD ($\delta_0$) and maximum COD ($\delta_m$) of base metals, weld, fusion interface, and heat affected zone for steels 16Mn, 15MnVN, and 15MnVNR, which are commonly used materials for spherical pressure vessels in China, 26 groups of test data had been analyzed according to Weibull distribution[20]. By using the maximum likelihood estimation method all of those Weibull parameters and related mathematically expected values and relative variation values were computed, as shown in table 1.

It is evident from the table that in respect to regions near the fusion interface besides a low value of mean fracture toughness exists, this area also has a large scatter for tested data. This fact should be taken into account in safety assessment.
### Table 1  Initial cracking COD (5) and maximum COD (5m) of base metals, weld, fusion interface, and heat affected zone for common steels

<table>
<thead>
<tr>
<th>Type</th>
<th>Samples</th>
<th>( \alpha )</th>
<th>( \beta )</th>
<th>( \bar{\delta}_{(\text{mm})} )</th>
<th>s.d./( \bar{\delta} )</th>
<th>K-S test (0.05)</th>
<th>Quantity</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>15MnVN-base</td>
<td></td>
<td>2.48</td>
<td>0.138</td>
<td>0.43</td>
<td>0.12</td>
<td>0.179&lt;0.181</td>
<td>43</td>
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<tr>
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</tr>
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<td>0.18</td>
<td>0.191&lt;0.207</td>
<td>13</td>
<td>20 °C</td>
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</tbody>
</table>

Research Activities of Safety Assessment Technique for Pressure Vessels in China After 1984

Since the publication of CVDA-84 in 1984, much useful information have been gained by using the assessment code and much research work about the theories and techniques of safety assessment been continued. During the 8th 5-year plan (1990–1995), a lot of scientific researchers and experts in the field of safety assessment in China have taken part in related research projects. As a result a new code for safety assessment was proposed in
1995, entitled "The Code of Safety Assessment for In-service Pressure Vessels Containing Defects" and designated as SAPV-95.

In the following sections some major important achievements in SAPV-95 will be presented.

1. Fracture assessment for planar defects can be performed at three different levels which have coherent interrelations. The failure assessment diagram techniques have been adopted.

Three categories for assessment of planar defects were set up. They are the first level (screening assessment), the second level (normal assessment), and the third level (advanced assessment), respectively. Table 2 listed their assessment purpose, procedures, and necessary fracture data.

<table>
<thead>
<tr>
<th>Category</th>
<th>Purpose</th>
<th>Procedure</th>
<th>Fracture Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screening assessment (the first level)</td>
<td>Determine if cracking and/or plastic collapse of structure takes place for the assessed defects</td>
<td>Failure assessment diagram based on COD design curve</td>
<td>( \delta_i ) or ( \delta_e )</td>
</tr>
<tr>
<td>Normal assessment (the second level)</td>
<td>Determine if cracking and/or plastic collapse of structure takes place for the assessed defects</td>
<td>General purpose failure assessment diagram</td>
<td>( J_{le} ) of ( J_e )</td>
</tr>
<tr>
<td>Advanced assessment (the third level)</td>
<td>Determine whether a tearing process happens in the progress of structural fractures</td>
<td>Modified EPRI method</td>
<td>( J_R (\Delta a) ) curves</td>
</tr>
</tbody>
</table>

Table 3 showed the commonly used steps in the SAPV-95 assessment.

Although similar with PD6493-91, CEGB R6-Rev.3, IIW/IIS Code, and SST-1157091\(^{[21,22]}\) in respect of assessment procedures, the SAPV-95 does have some unique features.

The screening assessment fully inherited the best parts of CVDA-84 and still permitted the use of allowable equivalent crack size \( \sigma_m \). The difference is that the assessment is performed with the help of failure assessment diagram.

In the normal assessment R6's general failure assessment diagram and partial safety factor method were used. It has been further approved that except a few special cases most failure assessment diagrams derived in J style are located outside the R6's general FAD\(^{[23]}\). For comparison about 800 FAD's curves in J style have been established which considered the effects of base metal, structural geometry and service condition. Figure 7 depicted the general distribution of those established FAD's.
### Table 3: Steps of the SAPV-95 Fracture Assessment for Planar Defect

<table>
<thead>
<tr>
<th></th>
<th>The First Level</th>
<th>The Second Level</th>
<th>The Third Level</th>
</tr>
</thead>
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<tr>
<td>R6-Rev.3</td>
<td>The option 1 FAD</td>
<td>The option 2 FAD</td>
<td>The option 3 FAD</td>
</tr>
<tr>
<td></td>
<td>$K_r = (1-0.211L_r^{13})[0.1+0.9 \exp(1-1.72L_r^{0.4})]$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$K_r = 0, L_r &gt; L_r^{crit}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$L_r = 0.8, L_r &lt; L_r^{crit}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PD6495-91</td>
<td>The COD design curve</td>
<td>The general FAD based on the D-M model</td>
<td>The R6's option 2 FAD</td>
</tr>
<tr>
<td></td>
<td>$\sqrt{\delta_r} = 0.7, S_r = 0.8$</td>
<td>$\sqrt{\sigma} = 0.7, L_r = 0.8$</td>
<td>$\sqrt{\sigma} = 0.7, L_r = L_r^{crit}$</td>
</tr>
<tr>
<td>SAPV-95</td>
<td>The screening FAD based on COD design curve</td>
<td>R6's option 1 FAD</td>
<td>Engineering optimized EPRI method</td>
</tr>
<tr>
<td></td>
<td>$\sqrt{\delta_r} = 0.7, L_r = 0.8$</td>
<td>$\sqrt{\sigma} = 0.7, L_r = L_r^{crit}$</td>
<td>$\sigma(\sigma, \alpha) = \sigma_R(\Delta \alpha)$</td>
</tr>
</tbody>
</table>

**Fig. 7** Scattering band and the lower bound curve for FAD's of steels with long yield platforms.

The lower bound for those curves can be expressed as

\[ K_r = (1-0.211L_r^{13})[0.1+0.9 \exp(1-1.72L_r^{0.4})] \]  

It is clear that the difference between the lower bound curve and the R6's general FAD is less than 10%. This fact gave a strong support for SAPV-95's decision of adopting the R6's general FAD.

For advanced assessments the optimized EPRI method is used, which can fully describe the fracture behavior of defective structures including finite tearing and tearing collapse.
In the optimized EPRI method, the compatible stresses $\alpha_v's$, which satisfy the equilibrium condition $I(\sigma, \alpha_v) = J_0 (\Delta \alpha)$ for a given $\Delta \alpha$, are sought first. The maximum value of $\alpha_v's$, then, corresponds to the required collapse stress. This collapse stress can be easily computed by using the proposed SAPV software. This optimized method represented one of the achievements in SAPV-95.

For effectively using the screening assessment method, SAPV-95 sets the allowable $\delta_c$ as measured fracture toughness $\delta_c$ divided by 1.2, and requires both screening and normal assessments to be performed for critical structures. If different conclusions about safety are reached, the result of normal assessment should be adopted. Because different cutoff lines are set for the two assessment methods, i.e. $L_{\text{max}} = 0.8$ for the first level assessment and $L_{\text{max}} = \sigma / \sigma_y \geq 1$ for the second level assessment, the screening method is usually more conservative than the normal method. The abnormal situations, where a structure assessed as safe with the normal method is evaluated as unsafe one with the screening method, are very uncommon. This conclusion is verified by about 1000 assessment examples.

In order to make a smooth transition between the normal and advanced assessments, a combined safety factor of 1.5-2.2 is chosen in the advanced method. The exact value of safety factor is determined by referencing to the cumulative effect of partial safety factors used in the normal assessment for important and critical parameters and the condition of fracture toughness for small scale yieldings. The combined safety factor have been successfully applied in many practical structural assessments.

From previous discussion it is evident that the three level assessment procedure adopted in SAPV-95, which effectively utilizes the failure assessment diagram and has a smooth transition between various assessment levels, can make a thorough, multilevel, and multimode safety assessment for planar defects.

2. The Newly Invented Plastic Limit Load Analysis Method of Dented Area Is Adopted in SAPV-95 for the Assessment of Volumetric Defects

Dented areas are common volumetric defects in pressure vessels. They may be present as results of corrosion, mechanical damage, or grinding to remove surface or subsurface defects. The severity of dented area is generally less than that of cracks. If a suitable assessment method is supplied for dented area it will be possible to eliminate some unnecessary welding repairs of dented area and reduce the risk of cracking resulted from the welding process.

The failure of pressure vessels with dented area can be exhibited in either global plastic or local plastic collapses. After performing a series calculation and experiments about plastic limit load and stability load for plates, spherical and cylindrical vessels, the close relations between the plastic limit load for a certain dented area and related parameters are established. For example, the following formula shows the relations for spherical vessels

$$\left( \frac{P_{\text{pl}}}{P_{\text{lo}}} \right)_{\text{lower \_limit}} = \frac{1 - 0.6 \left( \frac{C}{T} \sqrt{\frac{A}{RT}} \right)}{1 - 0.6G_o}$$

where $A$ is the half length of dented area, $C$ the depth of the dented area, $T$ the thickness of the vessel, $P_{\text{lo}}$ the plastic limit load for vessel without dented area.

For cylindrical pressure vessels, it has
The maximum allowable working pressure, \( P_{\text{max}} \), for pressure vessels with dented area is set to \( P_{\text{L}}/2 \), i.e.,

\[
\left( \frac{P_{\text{L}}}{P_{\text{L}}/2} \right)_{\text{lower-limit}} = 1 - 0.3\sqrt{G_o}
\]

When \( G_o < 0.2 \) the corresponding \( P_{\text{L}}/P_{\text{L}} \) is always larger than 0.94. That is to say the negative effect of dented area on the plastic limit load is less than 6%. With this sense in mind the SAPV-95 will accept those dented areas whose \( G_o \)'s are less than 0.1, i.e., no safety assessment is needed in this case, as shown in figure 8.

![Test data of the limit load and corresponding regressive curve for spherical pressure vessel with dented areas](image)

Compared with those similar codes of foreign countries the allowable sizes of dented area in SAPV-95 are a little larger. In this way a certain part of existing dented defects can pass safety assessment. This engineering judgment is safe enough if no planar defects coexist. To prevent abuse, SAPV-95 put some mandatory requirements on application of the method.


Welding residual stresses and thermal stresses are always present in welded pressure vessels. Their effects on the fracture behavior of structure vary with many factors. These self-balanced and self-limited stresses will plastically relax or redistribute upon the action of external applied loads. Because of the lack of conservativity for Rice \( J \) integral, it is difficult to perform an analytical treatment on these secondary stresses. One of the acceptable treatments about secondary stress is the \( p \)-factor method, which was proposed by R.A.Ainsworth. However, as the authors of the CEGB R6-Rev.3 admitted in related paper, the \( p \)-factor method is unsafe for small cracks acted with large residual tensile stresses and is over conservative otherwise. Figure 9 indicated this effect.
Having carried out theoretical analysis and experimental tests, the research personnel of related project of the 8th 5-year plan proposed a modified $J$ integral being conservative in the presence of secondary stresses. Computer software also developed in order to facilitate the calculation of $J$ integral. The newly derived $p$-factors are more reasonable than the original R6's $p$-factors\cite{ref7}. This result was fully accepted in SAPV-95.

Theoretical analysis and related calculations approve that the secondary stress related coefficient $\alpha$, which is used in the screening assessment, is not only inconstant but also more changeable. For reasons of consistency and safety certain adjustments were made toward the $\alpha$ values.

In actual engineering structures defects are hardly present in single. In order to take the interaction among defects into consideration, the following treatment is usually used in codes of different countries. In this treatment two adjacent smaller cracks are equivalent to one larger crack if they resulted in increase of stress intensity factor to a certain extent. Researchers of related project found that the elastic-plastic interference effect ($J_{\text{double}}/J_{\text{single}}$)\textsuperscript{1/2} among cracks were much greater than the elastic interference effect ($K_{\text{double}}/K_{\text{single}}$), and related to both the constitutive laws of material and the applied external load. According to original assessment codes, the interaction of two cracks can be neglected if they are separated more than one half of the sum of the original crack lengths. However, as shown in figure 10, the elastic-plastic interference effect of those cracks can reach 1.4 when $L > 1$ for A533B steel, for 16MnR steel that value will be 2.1.
Obviously, it is dangerous to neglect the interference effect in these cases. For practically performing a fracture assessment which could take account of the effect of elastic-plastic interference, an elastic-plastic interference factor, \( G \), is multiplied to the stress intensity factor of single crack. In this way an assessment can be carried out by using the R6' general FAD as usual. A tabular form of \( G \) values corresponding to different materials was provided\(^{28,29}\). The SAPV-95 has decided to apply the research results in the normal assessments.

4. The Reliability of Fatigue Assessment Has Been Raised Due to the Use of Actual Fatigue Data, Which Are Measured with Commonly Used Steels for Pressure Vessels in China and Analyzed in Respect to Data's Reliability and Survivability.

1). SAPV-95 recommended the following processing method of fatigue crack growth data for pressure vessel steels made in China. In the method a factor of not less than 4 is multiplied to a Paris formula which derived from the average data (50% survivability) of fatigue test. The newly resulted Paris formula is applied to fatigue assessment. The factor of 4 is selected by considering probability distribution of test data and related treatment of item 15.3.2 in PD6493-91. Statistical analysis showed that the finally resulted Paris formula corresponds to a survivability of 99.98889% ~ 99.99997% in TPB and CT tests for 16MnR, 20g, and CF62 steels made in China\(^{30}\).

2). In cases of lacking actual test data, currently wide used Paris formulas are recommended by SAPV-95. For example, the following Paris formula is used for ferrous steels with yield strength less than 600 MPa.

\[
\frac{da}{dN} = 3 \times 10^{-13} (\Delta K)^3
\]

That relation was approved reasonable by actual fatigue crack growth rate test of surface cracks on butt welds for 16MnR and Q235-R steels under one- and two-dimensional loading conditions.

3). In order to increase the accuracy of calculated fatigue crack growth size, several estimation methods were compared during the 8th 5-year plan by referencing to fatigue test data of through-wall and surface cracks obtained under various loading conditions for base metals and welds in pressure vessels.

These methods include stepwise cyclic counting method, Kawahara method of WES2805-83, and multilevel S-N curve method of PD6493. After comparison SAPV-95 strongly recommended the stepwise cyclic counting method, which uses Paris formula and Newman-Ran's solution of stress intensity factor for the estimation of fatigue crack growth size and can be easily performed by using microcomputers\(^{32,33}\). Compared with the cyclic counting method, both Kawahara and S-N curve methods have poor accuracy. As an alternative method the approximate integration can be used for the same purpose. In this method the total increment of fatigue crack, \( \Delta a \), is first separated into many smaller intervals where the parameters like \( \Delta K \), \( a \), \( c \), and the geometry of crack could be regarded as constant. This will greatly reduce the amount of mathematical calculation and make manual computation possible.

4). Biaxial fatigue loading tests were performed in order to investigate the effect of lateral loading on the fatigue crack growth rate. The research indicated that there were no significant influence of transverse loads for biaxial loading ratios \((A = P_x/P_y)\) of 1 or 0.5. In this case only the uniaxial fatigue test data are needed. However, for surface cracks the stress intensity factors decreases with the increase of loading ratio \( A \). At the same time fatigue crack growth rates are also affected. The stress intensity factor for biaxial loads can be...
expressed as the stress intensity factor for uniaxial loads multiplied by a modification factor $f$, where the modification factor is set to $f = 0.9203$ for $\Delta = 0.5$ and $f = 0.8836$ for $\Delta = 1.0$, respectively.

In summary, the newly proposed code of safety assessment for pressure vessels (SAPV-95) took modern advanced knowledge in fields such as fracture mechanics, plastic mechanics, metallic fatigue, etc. as its foundation; fully accepted the current scientific research results worldwide; focused on the main trends of development in assessment codes; maintained the best parts of CVDA-84; combined practical engineering experiences of safety assessment and national scientific research results obtained after 1984. It is one of the most important achievements among scientific projects during the 8th 5-year plan. Generally speaking, SAPV-95 has reached a high level in the field of safety assessment for pressure vessels all over the world. With development in both scientific and engineering perspectives, SAPV-95 will catch up the pace of development and become a complete assessment code.

Applications of the Safety Assessment Technology for Pressure Vessels in China

The application of safety assessment techniques started in 1980 in China. Due to a severe explosion of a spherical pressure vessel in 1979, a thorough investigation for about 2,000 large spherical pressure vessels was carried out nationwide. During that investigation a large number of defects, such as cracks, voids, lack of penetration, lack of fusion, etc., were found in those vessels. Since then, extensive scientific researches and applications were performed in the field of defect assessment by using fracture mechanics. About 100 million yuan had been invested for that researches. More than 10,000 people took part in various activities related to inspections, maintenance, and management jobs for pressure vessels. Large number of useful data and great experiences were also gathered.

With the publication of CVDA-84 and the development of advanced nondestructive inspection methods, such as acoustic emission technique, the application of safety assessment techniques was also extended to other pressure-containing equipment, for example, high pressure vessels, very large spherical pressure vessels and other critical pressure vessels. More than 100 practical uses showed that those assessments were successful.

About 1.1 million pressure vessels had been evaluated according to "the code of categorizing safety states for pressure vessels" from 1988 to 1993. During that time, many jobs were performed, such as, pressure vessel inspection, defect evaluation, and in-service pressure vessel registration.

With the help of newly proposed safety assessment code SAPV-95 and the research of end-diffraction ultrasonic inspection for defect height, safety assessment techniques have been applied to hydrogen reaction pressure vessels and ultrahigh-pressure vessels. The application range of safety assessment techniques are extended markedly.
For future development of safety assessment techniques, the following areas will be focused on.

1. Further apply, modify, and complete the existing SAPV-95; Make the code a industrial standard and national standard.

2. Expand the application range. During the period of 9th 5-year plan, safety assessment code of pressure piping and related safety states categorizing method will be proposed. Combining with the existing SAPV-95 will result in a complete safety assessment system for pressure vessels and piping.

3. Increase the assessment ability. Make the whole assessment system involve not only safety assessment but also prediction of residual service life.

4. Research in depth governing parameters for various failure modes and related conditions for mode transition. Complete the multimode and multilevel safety assessment systems.

The following researches will be taken place in this area.

1). Research of the multiparameter controlled elastic-plastic fracture affected by three-dimensional constraint state in vicinity of crack tip;

2). Researches of the engineering method of fracture analysis for non-matched welds and safety assessment for statically loading fracture where the propagation of crack is controlled by non-J integral parameter;

3). Elastic-plastic analysis, limit load analysis, stability analysis, and experimental verification of various volumetric defects in complex pressure vessels; Establishing complete volumetric defects safety assessment techniques and methods;

4). Researches of the resultant loads from the interaction of pressure vessels and associated piping; Fatigue crack growth rates under large strain, creep, creep-fatigue, stress-corrosion, corrosion-fatigue conditions, etc.; Completing the related safety assessment techniques for those special circumstances;

5). From the methodology point of view, the existing deterministic method will gradually approach to probabilistic assessment, fuzzy assessment, and intelligent assessment. Combined with modern techniques, such as transducer technique, fault and defect in-line inspection techniques, and computer techniques, an advanced safety assessment system will be formed.

It is obvious that the safety assessment techniques and methods will progress with social developments. With respect to the critical job of quality inspection and safety assessment for pressure vessels we heartily wish that strong relationship and cooperation be established among professional personnel engaged in the field all over the world for maintaining a high safe record in the pressure vessel industry.
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Safety Administration and Development of Boilers & Pressure Vessels in China

by

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SAFETY ADMINISTRATION AND DEVELOPMENT OF BOILERS AND PRESSURE VESSELS IN CHINA

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By the end of 1995, there are 504,000 sets of in-service boilers and 1.16 million sets of in-service pressure vessels in P. R. China, the periodical inspection rate of them were more than 95 percent and 85 percent respectively; the numbers of in-service truck transport tank units and railway transport tank units were 120,000 and 12,000 respectively, both of them keeping a periodical inspection rate of 100 percent; the periodical inspection rate for more than 47 million various gas cylinders was more than 80 percent.

The most serious period of boiler and pressure vessel explosion accidents is in the 1970s. There were 324 explosion accidents with 284 deaths and 1443 injuries in the most serious year. All these accidents caused a lot of economic loss. For example, on September 7,1979, a liquefied chlorine cylinder explosion accident happened in Wenzhou, Zhejiang Province. More than 10 ton liquefied chlorine poured out in the air which spread to an area of 7.35 square kilometers. There were 59 deaths and 779 injuries in the accident because of the chlorine poisoning. On December 18,1979, another LPG spherical tank explosion accident happened in Ji Lin Coal Gas Company. The fire caused by the explosion kept burning for about 19 hours. This accident damaged 6 spherical tanks with a volume of 400 cubic meters for each tank, 4 horizontal tanks with a volume of 50 cubic meters for each tank, and more than 5000 LPG cylinders. This accident caused 33 people died and 56 wounded.

Through these years’ effort and strengthening the boiler & pressure vessel safety administration and safely supervision by the government, large and serious explosion accidents disappear and general accident rate is steadily decreased. There are about 100 boiler & pressure vessel explosion accidents with approximately 100 deaths and less than 500 injuries per year in the recent years. However, the accident situation is still more serious than that of the advanced countries. The main reason is that the responsible personnel of the enterprises still pay much attention to profit and neglect safety during the transitional period from planning system to market system. Although the pressure-retaining components of boiler & pressure vessel have the better manufacturing quality and higher safety performance in general, the safety accessories, as well as the operational & control equipment & instruments are lower in quality and are in relatively low and backward technique level, etc..

The main characteristics of boiler & pressure vessel safety administration in China are as follows:

1. The state safety administration policy and its system

The state carries out the policy of putting safety first and uses prevention as the basic method. The State actively takes legal, economical and administrative measures to decrease the accidents and ensure the safety operation of the equipment.
The administrative system is that the enterprises carried out the responsibility for safety, the industrial sectors carry out the responsibility for administration, the state performs the supervision, and the workers strictly follow the safety rules and regulations.

2. Supervision organizations of boiler and pressure vessel safety and their functions

The safety supervision organizations of boiler and pressure vessel of P.R.C. was initially established in June, 1955. The safety supervision organization of boiler and pressure vessel directly under the Ministry of Labour, State Council of the People's Republic of China, takes charge of the nationwide safety supervision of boilers and pressure vessels; the subordinative safety supervision departments and sections of boiler and pressure vessel under the labour bureaus of all provinces, autonomous regions and municipalities directly under the Center Government, and prefectures and cities centralized with industries respectively are in charge of safety supervision of boiler and pressure vessel under their jurisdiction areas. By the end of 1995, there were more than 2200 supervisors engaged in supervision of boilers and pressure vessels in the above-mentioned executive departments of the governments at various levels. The lower level safety supervision organizations under the leadership of their local labour bureaus (or department) shall accept the professional guidance of their higher level authorities of boiler and pressure vessel.

The supervisors of boiler and pressure vessel employed in the supervision organizations were selected from senior engineers, engineers, or assistant engineers in boiler and pressure vessel fields.

The main functions of safety supervision organization of boiler and pressure vessel are as follows:

* Making publicity of the principles and policies for safe production, and the safety-technique codes and regulations for boiler and pressure vessel;

* Formulating the safety-technique codes, regulations and standards for boilers and pressure vessels or participating the review of them;

* Conducting supervision on the units of design, installation, operation, inspection, repair and alteration of boilers and pressure vessels; being authorized to ask the units involved to correction in case the violation of codes or regulations of safety supervision for boilers and pressure vessels.

* Conducting qualification and certification of operators of boilers, boiler and pressure vessel welders, welding operators, non-destructive testing personnel and inspectors;

* Participating the investigation and handling of major accidents of boiler and pressure vessel.

In addition, the Ministry of Labour and labour bureaus of some provinces, prefectures and counties set up many boiler and pressure vessel inspection institutes, specially engaged in
inspection service for boilers and pressure vessels. These institutes should be qualified and approved by the Ministry of Labour or the responsible provincial labour bureau. By the end of 1995, there were more than 860 inspection institutes with more than 15200 inspectors in our country.

3. The scope and contents of supervision

Scope of Supervision

Based on the Regulations of (The Provisional Act on Safety Supervision of Boiler and Pressure Vessel) promulgated by the Central Government in 1982, all units engaged in the design, manufacture, installation, operation, inspection, repair and alteration of all pressure-retaining boilers and various pressure vessels whose working pressure is higher than 0.1 Mpa, must accept safety supervision by the boiler and pressure vessel safety supervision organizations under the labour bureaus of government at different levels.

Contents of Supervision

*Supervision of design

The design of boilers and pressures vessels shall comply with the relevant safety supervision statutes and technical standards. The institute of design should be responsible for the safety-technique performance of the boilers and pressure vessels designed by them.

The draft of boilers and gas cylinders must be examined and approved by the safety supervision organizations of boiler and pressure vessel of the Ministry of Labour or the local provincial Labour Bureaus.

The design institute of pressure vessel must be approved by its competent authority and reported to the safety supervision organization of boiler and pressure vessel under the Ministry of Labour at the same level for placing on file.

*Supervision of Manufacture

The manufacture plants of boiler and pressure vessel must be examined and approved by the Ministry of Labour or responsible provincial labour bureau for getting manufacturing licenses.

The welder, welding operator and non-destructive testing personnel of the manufacture plant should be qualified and certified by the labour organizations.

All boiler and pressure vessel products manufactured should be inspected by the boiler and pressure vessel inspection institutes authorized by the responsible provincial labour organizations.
*Supervision of installation

The installation units of boiler and pressure vessel must be examined and approved by the boiler and pressure vessel safety supervision organizations of the responsible provincial labour bureaus. The installation quality should be supervised and inspected by the safety supervision organizations or authorized inspection institutes.

*Supervision of Operation

All boilers and pressure vessels must be registered at the local safety supervision organizations for getting operation certificate before putting into use. No operators shall be allowed to work independently unless they have successfully passed qualification and certification through training and examination.

In-service boilers and pressure vessels must be inspected periodically in accordance with the relevant provisions. The boiler and pressure vessel inspectors should be qualified and approved by the safety supervision organizations of the Ministry of Labour or provincial labour bureau and got the certificate of qualification.

*Supervision of Repair and Alteration

Repair and alteration units for boilers and pressure vessels shall be examined and approved by the local safety supervision organizations of boiler and pressure vessel.

The schemes of major repair and alteration of boilers and pressure vessels must be examined and approved by the local safety supervision organizations of boiler and pressure vessel.

*Supervision of import and export boilers and pressure vessels

The (Implementing Regulations of Import Boiler and Pressure Vessel Safety Quality Licensing System) was promulgated in 1990 in China. According to the requirements of the Regulation”, import licensing system is executed on boiler and pressure vessel products in our country. No boiler and pressure vessel products shall be allowed to exported to China unless the foreign manufacturers have obtained the safety quality licensing certificate issued by the Ministry of Labour of the People’s Republic of China from October 1, 1997.

In accordance with the (Provisions of Supervision and Administration for Import and Export Boilers and Pressure Vessels of the People’s Republic of China) issued in 1985, the safety performance of imported boiler and pressure vessel products shall be inspected at the trading port and approved by the inspection institute authorized by the responsible provincial labour organization. Otherwise, they would not be allowed to pass the customhouse.

4. Laws, regulations, codes and standards, and mass organizations

The laws concerned with the safety of boiler, pressure vessel and cylinder are mainly Labour Law, Product Quality Law, and Standardization Law, etc. as well as the Labour Safety
and Health Law which is under draft. The main regulation concerned is the Provisional Regulation on Supervision of Safety Performance of Boilers & Pressure Vessels issued by the State Council on February, 6, 1982. There are more than 34 administrative rules and regulations concerned with the safety of boiler & pressure vessel issued by the Ministry of Labour which are based on the aforementioned laws and regulation. All these laws, rules and regulations are mandatory implemented nationwide. Besides the laws, rules and regulations, there are still more than 100 national technical standards. All these technical standards have absorbed the safety principles and requirements as well as the other advantages used in the industrialized & advanced countries and conform to relevant international (ISO) standards. Most of the technical standards are mandatory. All these laws, rules and regulations, and technical standards form the safety regulation and technical-code system of boiler & pressure vessel in China.

There are many mass organizations dealt with boiler & pressure vessel in China, mainly including: Boiler Standardization Technical Committee, Pressure Vessel Standardization Technical Committee, Cylinder Standardization Technical Committee, Pressure Vessel Committee, Chemical Engineering Equipment Association, Water Treatment Association, Inspection Association, Qualification and Examination Committee for NDE Personnel, etc. The members of all these mass organizations are come from the related enterprises, trading companies, universities, research & design institutes, etc. Since the founding of these mass organizations, they have performed a very positive role in the aspects of standard drafting, consultation, training, examination, and propaganda, etc. They are the intermediary organizations in the market economy and also the important link between government and enterprises.

5. Future development

As the development of social reform and opening to the outside world of China, the development and establishment of socialist economy, and the rising of people's living standards, to guarantee the safety operation of special equipment including boiler, pressure vessel and cylinder etc. and to raise the safety technique level will become a more and more important research subject in the future.

The anticipated future development will be as follows:

i) In the aspects of safety administration, safety supervision, and safety technique etc., the laws and regulations will be further strengthened, perfected and systematized to suit the needs of market economy and international practice.

ii) Further strengthen the safety supervision and enhance the consciousness and sense of responsibility for the relevant organizations and personnel to strictly observe the laws, regulations, and standards and pay much attention to occupational morality. Further measures will be taken to standard the government activity. For the action which violate the laws and regulations, administrative sanction and economic penalization will be used. For the accidents which cause the serious consequences and involve violating the criminal laws, the criminal responsibility will be investigated.
iii) Improve the quality and techniques of boiler & pressure vessel safety accessory and control system; Further increase the safety of boiler & pressure vessel body.

iv) Intensity scientific research and popularize the practical and effective achievements in scientific research. Emphasis shall be given to accident prevention technique, inspection & test technique, defect evaluation and equipment prolongation technique etc..

v) Intensity periodical inspection and speed up the elimination and replacement of old equipment and the in-service equipment which has the large potential risk.

vi) Carry out the extensive investigation for boilers and pressure vessels. Investigating and determining the large and dangerous source for boiler & pressure accident. Take effective measures to prevent and put an end to the serious accidents.
Boilers & Pressure Vessels
Safety and Technical Development
- Hong Kong Experience

by

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Synopsis

This is a follow up paper of my seminar paper proposal given at the 9th Seminar in October 1993 proposing some organisational changes and development areas for the Boilers & Pressure Vessels Division (BPVD). In my last paper, I highlighted the need on some organisational changes and development areas for BPVD to pursue. Those who are interested to have a copy of that paper could approach me later.

Over the past few years, contacts and exchanges were made with many local and overseas experts or authorities such as from China, Japan, U.S.A., Germany, U.K. and Australia, in the field of boilers and pressure vessels. Ideas and proposals raised in our annual seminar events in previous years had also given us great deal of input to the ongoing development of BPVD. I take this opportunity to report here the progress on the boilers and pressure vessels safety and technical development areas of Hong Kong experience over past few years.

1.0 Introduction

1.1 The safety of the industrial equipment and machineries are subject to random inspections by the relevant enforcing authorities. Despite of this, mishaps sometimes happened. Serious industrial accidents often wreck lives and cause family tragic, for example, the passenger hoist accident caused 12 lives, the hydrogen pressure vessel explosion accident caused 2 lives and the Rumber Bridge accident caused 6 lives etc. All these have urged for lessons to be learnt. Also, they have prompted greater concern and attention for more stringent standards and control.

1.2 The few serious steam receivers explosion cases happened in the period between 1988/90 deprived for 6 lives. These have served a strong signal for the Boilers and Pressure Vessels Division on the need to review and streamline its organisation structure, functions and procedures so as to enhance its technical support in upholding adequate safety standards in the control of pressure equipment.

1.3 From the review exercise in 1993, it was considered more important and desirable to have a pro-active organisation structure with comprehensive procedures which would help the Division to cope with demands resulted from currently more open and accountable government administration and public awareness on safety. Nevertheless, one must realise that the monitoring of occupational safety is a risk management exercise in optimising and prioritising the limited of manpower available for many key functions.
1.4 This paper will re-examine BPVD's progress on safety control and development issues over past few years with a view to identify further development issues for the future pursuit in order to catch up with international development.

2.0 Functional Roles of the Division

2.1 The main task of the Division is responsible in providing an efficient and professional service to the industry relating to control and safety standards in the design, manufacturing, inspection, testing and operation of pressure equipment in Hong Kong and to ensure an acceptable level and standard are maintained.

2.2 The functional roles of the Division in collective terms would be on safety control, law enforcement, safety promotion and development relating to safety of pressure equipment. Hence, its main functional roles under Boilers and Pressure Vessels Ordinance are summarised as follows:

(a) Managing Registration of pressure equipment by assessing technical document and allocating the registration number to each pressure equipment;

(b) Controlling Safety of Pressure Equipment by:
   - maintaining an effective monitoring of the safety condition and operation of pressure equipment through conducting regular spot checks.
   - issuing warnings, closure orders or prosecutions on offenders of the ordinance.
   - granting exemptions to individual or types of pressure equipment from any provision of the Ordinance for the issue of exemption certificates or exemption orders;
   - inquiring into accidents relating to boilers and pressure vessels;

(c) Managing Appointed Examiners System by appointing private engineers as Appointed Examiners and monitoring their performance. The Division is ensuring availability of inspection service of pressure equipment by maintaining the supply of qualified inspectors and operators. Currently, there are total of 38 Appointed Examiners, about half of them are Boilers Inspectors, the remaining are Air Receiver Inspectors.

(d) Managing Competent Persons System by conducting examinations for the issue of the Certificates of Competency to equipment attendants/ supervisors to become Competent Persons, i.e. qualified personnel to supervise the operation of boilers or steam receivers.
Recognising Engineering Standards and Inspection Bodies for the purpose of assessing of design and performing inspection of new pressure equipment required under the Ordinance, the requirement of recognition is currently being reviewed;

Managing a Mini-Computer System in providing an efficient information record system for the purposes mentioned in above;

Promoting Safety through seminar, training courses, workshop and publication;

Handling Development Areas, consultation, and maintaining local and international contacts.

2.3 Another role of the Division is the technical support and advice to Fire Services Department on the pressure vessels, i.e. gas containers/ cylinders, and pressurised systems containing gases relating to dangerous goods under Dangerous Goods Ordinance.

2.4 Appointed Examiners are the qualified engineers in the private sector, being appointed as Boiler Inspectors or Air Receiver Inspectors by the Authority, i.e. Commissioner for Labour, to carry out various duties such as the assessment of technical document of pressure equipment for the Division's registration approval and to conduct their initial/periodic inspections. Their performance and inspection standards are monitored and supervised by BPVD.

2.5 Competent persons are the qualified operation personnel or supervisors or engineers, holding certificate of competency, employed by factory owners to provide direct supervision to the boilers and steam receivers during operation to ensure these equipment are in safe working condition. The Division is coordinating training courses and conduct examinations for the issue of Certificates of Competency for competent persons. Safety training courses are run regularly in Making Wong Technical Institute and Occupational Safety & Health Council.

2.6 A non-statutory Pressure Equipment Advisory Committee was set up in 1990 in advising the Authority on a range of policy matters and held discussion meeting as necessary. The Division organises technical seminar annually for up-dating technical development for its staff, the Appointed Examiners and professional in the industry.

3.0 Performance and Safety Records

3.1 The above overall responsibilities and duties are currently undertaken by an existing team of total 24 public officers. The Division has changed its name from former name "Pressure Equipment Division" in May this year to get in line with international terminology of boilers and pressure vessels. The existing organisation chart of Boilers and Pressure Vessels Division as indicated in Annex 1. The Labour Department's organisation has also
been re-structured in the middle of this year forming two 'Branches' distinction roles and the Labour Department's organisation chart is at Annex 1A.

3.2 With its small work force, it supervises and monitors annually around 38 Appointed Examiners, 12,500 competent persons, around 52,000 active registered pressure equipment, approves of around 2,800 boilers and pressure vessels for registration, spot-checks around 6,000 factories, conducts around 600 examinations for the issue of certificates of competency and approves of 30,000 gas cylinders and pressure systems under the Dangerous Goods Ordinance.

3.3 Performance pledge of the Division was commenced on 16 August 1993. The Division has undertaken the pledge in completing a registration of pressure equipment within three weeks from time of application subject to adequate document submission. Over many years, the commitment of this aspect under the Ordinance requirement is four weeks. The undertaking of three weeks in this aspect without extra resources has prompted some adjustment made in the operation procedure and staff commitment in order to achieve this target. Other pledges are the undertaking of examination arrangement for certificates of competency and their issuance within four weeks. The performance pledges of the Division was able to meet pledged targets for around 99% of cases handled.

3.4 Accident statistics relating to boilers and pressure vessels in recent years (3 cases in 1991, 1 cases in 1992, 3 cases in 1993, 1 case in 1994 and 2 cases in 1995) is regarded as minimal comparing with its total number of equipment in active use. There was zero fatal case since 1991. In fact, great deal of effort has been spent in coping with growing workload to maintain acceptable safety standards despite the limited resources.

4.0 Review of Safety Structure and Proposals in 1993

4.1 From the functional roles and performance of BPVD described above, it helps to form the basis for of a set of its operative goals and objectives. In order to continually meeting its intended role in an efficient manner, an overall review study was made in 1993 on the operation of BPVD. It was considered necessary to review BPVD's operation with a view to update its development in coping with its public demand and engineering development in meeting international standard.

4.2 In the analysis of the organisation of BPVD, a set of Organisation Task Environment Components of BPVD is evaluated as indicated in Annex 2. It is categorised into internal and external environment components involved and encountered by the Division. The internal components are the staff resources of the Division which forms the layout framework of the Division, with its task activities, functions and objectives whilst the external components are those dealing with customers and related organisations or parties in the private sector, social and technological bodies etc. This produces a clearer picture with relevant activities and functions for streamlining and planning its future operational strategy.
4.3 From the findings in last review of the Divisions, a list of improvement areas were identified for consideration and attention. The proposals in 1993 include the following improvement areas:

(a) review the requirements and assessment methods for the appointment of Appointed Examiners;
(b) formulate requirements and procedures on the monitoring of A.E.s' performance to ensure quality of inspection services including periodic monitoring;
(c) formulate criteria on the disciplinary action of suspension and revocation of Appointed Examiners. A de-merit point system for this purpose may be necessary.
(d) review the requirements and structure on the setting up of Recognition of Inspection Bodies (RIB), the assessment and monitoring requirements;
(e) formulate the requirements and structure for the setting up of Registration of Pressure Equipment Contractors, the assessment and monitoring requirements; and
(f) Other Relevant Changes:
   (i) amendment of Ordinance.
   (ii) review of PEAC structure and functional support.
   (iii) enhancing the internal and external contacts and safety promotion.

5.0 Progress on Safety Development Areas and Yearly Action Plan

5.1 In the revision of the organisation structure, much emphasis was placed on the communication and integration aspects with internal and external elements. A more closed network including all relevant activities will provide more information feed-back to the Division so as to reduce uncertainties, hence, it will facilitate decision making. The above recommended measures and changes are particularly aimed for the purpose of streamlining existing operation so as to enhance its operation effectiveness.

5.2 Integration and co-ordination with the society and major institutions are also considered essential areas of task for the longer term success of the Division in enhancing its easier access to the available expertise and facilities in these local/overseas bodies and institutions. Effort in this aspect had been progressed
over past few years in the form of seminars, training workshops, attachment visits etc.

5.3 For the proposed development issues made in 1993, I am glad serious consideration was given by the Labour Department and supports were given to bulk of the proposals give therein. Majority of the proposed improvement areas were completed and some of them are underway for implementation when the agreed manpower resources are materialised. Additional manpower of one surveyor, one inspector and one clerical will be created for 1996/97 for undertaking some of the improvement and new services identified.

5.4 The Division had initially concentrated its work scope in 1994 to improve its safety structure by streamlining its existing operation, internal structure, effectiveness committee structure, adequacy procedures and policies before it moved on other re-structuring work. Some progress was made on the structure of Appointed Examiner's and recognition of inspection bodies, amendments of ordinance and codes of practice.

5.5 Streamlining the Appointed Examiner's and inspection bodies organisation structure were the initial improvement task which forms the backbone for the safety control of pressure equipment. A survey was attempted to obtain information from a number of overseas organisations operated in the developed countries in the control of similar areas concerning their operation structure set-up and controlling concepts and methods as summarised in Annex 3. This information would be useful for the analysis and evaluation of organisation structure of the Division. The survey information reveals:

(a) that many overseas developed countries carry out law enforcement by Government department whilst the duties of technical inspections and the setting engineering standards are entrusted to private bodies/organisations and professional institutions. The monitoring and auditing efforts appear to come from both parties serving checks and balances situation.

(b) that there are usually examination arrangement and grading of inspectors who are qualified to carry out inspections of pressure equipment.

(c) that there are requirements and criteria laid down for the recognition of inspection bodies and monitoring conditions.

5.6 Based on the above findings, the revised "Requirement for the Appointment of Appointed Examiners" was issued in 1994. This coupled with a number of training courses and training workshops for Appointed Examiner (AE) candidates. The number of AEs was increased from 28 to 38 as now stands. Currently, there are 5 to 6 AE candidates in the pipeline pending for appointment assessment.
5.7 Reference information was made on the recognised inspection bodies or authorised agencies from the U.K. and U.S.A. Authorities. This information would be useful in reviewing Hong Kong's structure in this respect. Since 1993, the number of recognised inspection bodies has increased from 4 to 7 till recently. Majority of them meet the requirements of ISO 39 on "Requirement for Inspection Bodies" and ISO 9001 or 9002 for quality management system.

5.8 Amendment work on the BPV Ordinance has been another major action areas. It is necessary to update the ordinance and regulations in order to improve the operation effectiveness and some anticipated changes areas were identified. The Division has been critically reviewed the existing operation and recommended necessary amendments in five stages over last three years for consultation with PEAC and industry. Next consultation meeting with PEAC will be on 10 December 1996 regarding regrading of AEs and inclusion of hot water boilers for control under the BPV Ordinance etc. It is expected that these amendments would be ready for legislative amendment in 1997.

5.9 There were four sets of bilingual codes of practice issued at the end of 1994 which help to improve safety control of equipment in the industry.

5.10 Along with the proposed improvement areas in 1993, various new suggestions from industry through seminar and consultation for purpose of enhancing effectiveness in the control and upholding of safety standards for future development of the Division were inserted.

5.11 A Yearly Action Plan (corporate plan) of the Division including the above-mentioned components was produced each year since 1993 in line with department's program areas management. This helps the Division to focus more readily on those key activities and targets involved in each year. A copy of the Yearly Action Plan of BPVD is at Annex 4 for reference.

6.0 Technical Development Areas

Most of those described above are related to safety control areas such as organisational and procedural changes and amendment work of BPV Ordinance. However, there are also some technical and technology development areas being undertaken by the Division such as the development and updating of a computer information system on pressure equipment (PEIS), usage of Internet and PC based software package on the strength assessment of pressure vessels.

6.1 Development of Pressure Equipment Information System (PEIS)

(a) As society development has advanced so rapidly, ability to manage and analyse large volume of information to meaningful result or presentation is important for effective operation. The Division was able to utilise a mini-computer system for this purpose in 1987.
(b) The old system, named as Management Information System (MIS), was a mini-computer system from DATA GENERAL with one hard disk of 160 Mb x 2 and coupled up five work stations for data entry. It was used for registering competent persons, certificates of competency and for equipment enquiries purpose. The old system was replaced with a newer computer system of a mid-range type of the latest computer technology in 1994.

(c) The project development of PEIS took about 12 months in 1993/94, including technical & funding approval, final completion of Documentation. There was an estimated extra manpower resources equivalent to about 3 man-years required from BPVD staff to assist in the project exercise which was absorbed by existing staff effort.

(d) The new system is aimed for a higher storage capacity of 1.3 Gb x 3 and higher processing speed system. Its eventual performance should be able to integrate with all the Division's operation and function so as to achieve operational efficiency and accuracy. A brief descriptive information of the PEIS is in Annex 5.

6.2 Major Enhancements for PEIS Development in 1996/97

(a) The new PEIS was completed and put on line in October 1994. It had been running smoothly since then. Thanks to the devoted effort of the officers concerned from the Division and staff from Information and Technology Services Department (ITSD).

(b) From today's technological point of view, the new system with the major enhancement works should be capable of meeting the requirements of the operations of BPVD in the next five to ten years.

(c) As the new PEIS system is capable for expansion, a preliminary list of enhancement features had been prepared by the Division for discussion with the project team in January 1995. A paper on this aspect was presented in our 11th Seminar last year. There were proposals of practical and effective application features. It was agreed that would be implemented in two stages of enhancement, i.e. minor enhancement and a major enhancement including the following areas subject to fund availability :-

- Appointed Examiners may be able to access the computer data relating to certificates of fitness issued by them through the use of a PC with modem. This will provide more updated pressure equipment particulars of the pressure equipment for AE's reference prior to his periodic inspection for the renewal of certificates. The proposed arrangement is equivalent to the provision of a data base system
available to all Appointed examiners. This will greatly improve reliability of pressure equipment data and accuracy.

- PEIS would be able to register candidates for applications for examination of certificates of competency, issuing letters to candidates on examination result and printout of certificates of competency.

- PEIS would be able to retain more certificates of fitness data records for reference.

- Appointed Examiners may be able to access the computer data on certificates of fitness issued by them through the use of a PC with modem. They would be able to type in their daily inspection results and produce certificates of fitness directly from the system data.

- The system would be able to effect better control on the registered pressure equipment. The new system would be able to printout a standard certificate of registered pressure equipment.

- Pressure Equipment Owners may be able to be a subscribed user of the PEIS at a nominal charge so that they will be able to access the certification status of the pressure equipment own by them through the use of a PC with modem. Alternatively, subscribed user may seek a quarterly printout service at less cost.

- a computerised Examination System for the issue of Certificates of Competency for competent persons. This will include the print out of demand notes, notification of examination results and the printing out of the Certificates of Competency like that of a vehicle driving licence.

- The PEIS coupled with the implementation of PC based application software would be able to produce extra presentable executive reports and information, such as company profile etc.

- Integration of Chinese character support software, it would support input of some pressure equipment data such as Chinese company names and their addresses; Chinese name for competent persons and Appointed Examiners and their addresses.

- Information listing such as listing of approved equipment types, listing of Appointed Examiners and recognised inspection bodies etc.
(d) After the enhancement project of the above areas which is scheduled to commenced in April 1997 if approval if the feasibility study is approved, then, the PEIS will enable to achieve nearly all the Division's operational service areas by the use of computer efficiently.

(e) The upgraded PEIS system after the enhancement project would allow public access by appointed examiners, and equipment owners as indicated in Chart 1 of Annex 5. The host computer will be accessible through modems during office hours and extended hour till 8.00 p.m. PEIS may be left on 24 hours operation if there is demand from the industry provided that resources is adequate to cover such expansion.

(f) The PC work stations of PEIS give BPVD extra flexibility in future in the used of commercial standard software packages in providing further service to the industry such as :-

- creating database of all pressure equipment related organisations (mailing labels),
- BPVD library books cataloguing,
- producing periodic BPVD's Newsletters, codes of practice etc.
- permitting the use of pressure equipment assessment software package to perform checking of registration approval document on complicated cases.

6.3 Use of Labour Department’s LAN, Internet and Homepage

As pointed out earlier, communication is an important aspect to update our information, building up client’s relationship, hence, minimising organisation uncertainties. Apart from the annual seminar and the occasional participation in various seminars and workshops, the Division would benefit through strengthening its contacts :-

(a) Through Labour Departmental LAN Link

The newly established LAN of labour Department is another important information system for improving BPVD's services and outreach. This LAN allows emails, fax on demand, data exchanges etc. It would certainly facilitates exchange of information more easily.

(b) Through Internet Link

(i) The electronic superhighway, the Internet, has opened up a wider perspective for the efficient distribution of essential information to the public. Early this year, the Division has already marked its presence by listing of concise information in the APEC's ILO gopher site (see
example in Chart 2) along with the Factory Inspectorate's information. The Internet access through an ISP extends our vision more so allow us to find important information, such as Material data sheets from academic institutions elsewhere in the world, in much less time than by the conventional method of looking up manuals in libraries remote from our office. Foreign legal requirements on boilers and pressure vessels registration and inspections are obtainable from various web sites for reference. Other useful features are email and subscription to discussion group such as "Steam List".

(ii) All the above Internet feature may be added advantage at present. I feel that it will become a routine or daily chore soon for a responsive organisation to be prepared for.

(c) Developing Homepage

We strive to achieve our role as a competent controller, adviser and facilitator on safety practice, management and control of risks in workplaces relating to boilers and pressure vessels through communication links. Perhaps a "homepage" with full accessibility to safety message and service offered by BPVD will be the next priority for promoting BPV safety standard and safety culture in the local and international community.

7.0 Safety & Technical Development of Gas Cylinders & Systems related to Dangerous Goods Ordinance

7.1 The safety and control of the related pressure vessels and associated pressurized systems are of prime importance because of the potential risk and danger in connection with the storage in a relatively high pressure of gases, which may have flammable, toxic and poisonous natures. To assist the Fire Services Department in implementing the control of these equipment, BPVD is providing the following technical services:

(a) technical advice on equipment approval, which includes gas cylinders, bulk containers, VIE and cryogenic containers, road tankers and pressurized systems etc. for Category 2 DG;

(b) site inspections of plants and systems under DG licensing control as requested by the Fire Services Department;

(c) investigation of accidents related to pressure equipment as requested by the Fire Services Department.
other technical assistance will also be provided by BPVD to FSD on request.

7.2 The Present Situation on the Safety Control

Pressure Vessels under provision of the DGO are mainly related to the Cat. 2 Compressed Gases due to such category of gases has to be stored and used under pressure. The Director of Fire Services (DFS) is currently "the Authority" for all dangerous goods categories except category 1 on land. Presently, the Boilers & Pressure Vessels Division (BPVD) of Labour Department (LD) is providing technical support to the Fire Services Department (FSD) on matters related to the pressure vessels and systems under the DGO, including assessment work on gas cylinder approval, and pressurized systems for DG license purpose. A summary of current practice is indicated in Annex 6.

7.3 Changing Needs

(a) The rapid market development of the gas supply industry and the increase complexity of pressurized system brought in relevant engineering standards from various foreign countries, which may require alignment of such standards with recognized international standards that are adopted widely and accepted in the world-wide.

(b) In the present mode of gas supply in Hong Kong, some of the gases (i.e. electronic gases) are produced and filled in foreign countries, which have a very quick turn-over at the present moment allowing very limited time for cylinder approval, there is a current need to streamline existing approval process.

(c) As the Government become more and more opened, information are provided for the access of the general public or industry. Useful statistics regarding to gas cylinders have to be kept by computerization rather than by manual searching of records to facilitate quick access and retrieval.

7.4 Future Development of Safety Control of Gas Cylinders

To achieve a common goal on safety control, both FSD & BPVD are trying to provide better and more efficient services to the general public as well as the gas supply industry. Details on such recent and future improvement initiatives as proposed in relevant working group, subject to resources availability, are as follow:

(a) to enhance in the dissemination of information, such as giving clear general guidance on matters related to the approval and licensing of pressure vessels & systems under the DGO. The proposed draft on the revision of the "Guidance for Approval of Gas Cylinders (revised Nov.1996)" is attached in Attachment 1 of Annex 6;
(b) to expedite gas cylinder approval process by reducing the processing time to around 20 working days, provided that all required documents are provided by the applicant;

(c) to expedite the approval process, BPVD would exchange directly with the applicant (i.e. gas supply companies) on technical matters related to gas cylinders approval to replace the previous practice by giving advice directly to FSD.

(d) to keep readily available statistics on gas cylinder information that may be of interest to the general public or industries by computerization of data related to approved cylinders/types which would be worked out between FSD/LD/Gas Industry.

(e) to enhance the liaison with various interest parties (i.e. gas supply companies, hospital authority, government departments etc.) on matters related to the safety control of pressure vessels & systems related to DGG which will promote better cooperation on the safety control.

8.0 Staff Professional Development

8.1 An effective organisation relies on its own devoted and competent staff to conduct fruitful business. In order to maintain a competent team of technical and professional staff for coping with all the functional roles on the safety control of boilers and pressure vessels described above, and keeping up with its development areas. It requires a support system for staff development.

8.2 The Division is, in fact, supported by the Occupational Safety & Health Branch (OSHB) on its staff development and supplemented by those from the Marine Department. There are 12 core competencies recently developed by the OSHB for officers within the OSH Branch to go through some training program to help them gear up with such skill of competencies. These include communication & influence, external relationship, professional competency, concern for safety management, client focus, management orientation, leadership, problem solving & decision making etc.. Through a set of defined competency system, it is expected that our officers would be more readily to fulfill more challenging and demanding role in their occupational safety career.

8.3 In addition, there are other job related training, workshops, attachment visits etc. for our officers to enhance their skill and knowledge. Resources in these aspects has been improved over the years to meet our planned programs. Also, the Department had been giving continuous training support to clerical officers in language and customer service training which could help our staff in improving
their service at work. Action is stronger than words, Division's achievement is very much relied on team work and commitment.

9.0 Conclusion
9.1 Occupational safety charter launched recently is a clear commitment from the Labour Department towards greater effort in minimising risk at workplace coupled with a series of development programs including human resources and organisation development.

9.2 As an organisation must continually interact with its environment to meet its increasing demand and improving its service standard, corrective measures derived from periodic review as an appropriate course of adjustment is necessary. Such review at interval of five years would be most appropriate. This paper would be useful as an interim report for the next review.

9.3 The rapid advancement of technology and demanding management from most organisations in the private sector would moving towards wider utilisation of computer information inside and outside the civil service. The new PEIS would permit the Division developing towards the destiny of an overall integrated computer management system such as link up with departmental LAN or OSH LAN in the Labour Department which is an essential move to meet future needs.

9.4 The "Yearly Action-plans of BFVD over last few years has assisted it in achieving a responsive, efficient and responsible organisation. Many improvement are under way for implementation. However, these areas should be continually being reviewed as necessary and it is equally important to see necessary resources are forthcoming to meet its expectation in providing an efficient and high quality standard service to the industry.

9.5 To achieve implementation on proposals mentioned earlier for gas cylinder safety control, it would require additional resources to acquire such improvement of service. It requires greater commitment and effort from the government and the industry for the adequate assurance of gas safety and control in the industry, and in maintaining safety practice meeting international standard.

9.6 So far, all the proposed changes has received good support by the staff of the Division, Labour Department and the industry, particularly our Appointed Examiners for the purpose of enhancing the Division's function role on safety control of pressure equipment. It is hoped by going through a process in reviewing current systems and practices, a high quality of professional service will be in place. Hence, safety standard in pressure equipment would continue to be maintained and upheld.

9.7 In fact, many challenging tasks are still lying ahead for the Division to uphold safety standards along keeping with the pace of engineering advancement and development. Despite the current standard of safety relating to pressure equipment is maintained and
accident rate is at its minimal, there is still room for improvement. Strategic planning and adaptive changes to achieve better pro-active organisational structure and setting balanced policies would be highly important in sustaining its on-going efficient operation.
ORGANIZATION CHART OF
BOILERS AND PRESSURE VESSELS DIVISION

Commissioner for Labour
(Boilers and Pressure Vessels Authority)

Deputy Commissioner for Labour
(Labour Administration)

Deputy Commissioner for Labour
(Occupational Safety & Health Branch)

Assistant Commissioner for Labour
(Occupational Safety)

Occupational Health Division

Occupational Safety Division

Boilers and Pressure Vessels Division

Principal Surveyor

Boilers and Pressure Vessels
Registry Unit

1 Surveyor
(Boilers and Pressure Vessels) - Operation

1 Senior Inspector
(Boilers and Pressure Vessels/ Operation)

8 Registry Clerks
(Boilers and Pressure Vessels)

Remarks:
1. A & B are responsible for enforcing the Boilers and Pressure Vessels Ordinance
2. C is responsible for giving technical advice to the Director of Fire Services on matters relating to Dangerous Goods Ordinance and other technical support to other government departments.
3. In addition to routine work, Inspectors are assigned follows:
   - Two Inspectors (BPV) look after P.E. Information & Equipment
   - Two Inspectors (BPV) look after Statistics & Computing
   - Two Inspectors (BPV) look after Publication & Code of Practice
   - Two Inspectors (BPV) look after Code & Standards (library)
This Organization Chart shows the senior establishment position of Labour Department at 18 May 1996. This Chart is for general reference use only.
Organisation Task Environment Components of BPVD

Internal

(a) Organisational Personnel Component
- Administrative/ clerical staff (EO & clerical)
- technical staff (Inspectors)
- professional (Surveyors/P.E. Officers)
- specialist (System Manager)

(b) Organisational Functional Units Component
- carry out assessment/approval of registration document of pressure equipment and their registration
- conduct examinations for the issue of certificates of competency & co-ordinate training for operators
- process prosecution matter
- perform spot check/factory inspections
- perform follow-up inspections
- management information system (MIS)
- manage the appointed examiners, competent persons, and recognised inspection bodies
- update legal machineries: ordinance, regulations, engineering standard/codes, instructions, advices and notices
- manage manpower and funding resources
- liaise with customers, professional institutions and public.

(c) Organisation Target Component
- objectives and goals:
  - control & monitoring safety standards for pressure equipment
  - integrative/contributing to attaining goals
  - nature of services:
    Government services on the safety control and law enforcement

External

(a) Customer Component
- pressure equipment Owners
- pressure equipment makers
(b) Quasi-Customer Components
- appointed examiners
- competent persons
- recognised inspection bodies (being developed)
- registered pressure equipment contractors (yet to be developed)

(c) Social & Political Components
- local government departments
- foreign governments
- professional bodies
- relationship with union and association
- public attitude towards the Boilers and Pressure Vessels Division and Labour Department

(d) Technological Component
- meeting new technology requirement of industry & related services
- improving & developing new services by implementing new technological advance such as computerisation, technical collaboration with other government, updating of law etc.
### Summary of Information on Overseas/Local Authorities

**Relating to the Structure of Appointed Inspectors and Inspection Bodies**

<table>
<thead>
<tr>
<th>Countries</th>
<th>Regulatory Bodies</th>
<th>Appointed Examiners/Inspector</th>
<th>Inspection bodies/agencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.A.</td>
<td>Government Yes Yes Yes</td>
<td>Yes, AI-N-(B) AI-N-(A) AI(B) AI(A) AI</td>
<td>by authorising many inspection agencies</td>
</tr>
<tr>
<td></td>
<td>&amp; professional institution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.K.</td>
<td>Government Yes Yes No, but CEng, IEng, etc.</td>
<td>Yes, B(2) B(1) P(2) P(1)</td>
<td>by approving many inspection bodies</td>
</tr>
<tr>
<td></td>
<td>&amp; professional institution</td>
<td></td>
<td>membership grading</td>
</tr>
<tr>
<td>China</td>
<td>Government Yes Yes Yes Yes</td>
<td>Yes, B(2) B(1) P(2) P(1)</td>
<td>by authorising, inspection organisation in China under</td>
</tr>
<tr>
<td></td>
<td>&amp; professional institution</td>
<td></td>
<td>Ministry of Labour</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>Government Yes Yes No, but boiler/air receiver interview inspector</td>
<td></td>
<td>by recognition, (in preparation)</td>
</tr>
</tbody>
</table>

**Note:**

(1) Inspectors' grading in U.S.A.
- AI-N-(B) = Authorised Inspector/nuclear (supervisor)
- AI-N-(A) = Authorised Inspector/nuclear
- AI-B = Authorised Inspector (supervisor)
- AI(A) = Authorised Inspector (new construction)
- AI = Authorised Inspector (In-service)

(2) Inspectors' grading in China
- B(2) = Senior Boiler Engineer (being examined by central body)
- B(1) = Boiler Engineer (being examined by provincial body)
- P(2) = Pressure Vessel Engineer (being examined by central body)
- P(1) = Pressure Vessel Engineer (being examined by provincial body)
Annex 4-(rev.27/9/96)

Boilers & Pressure Vessels Division (BPVD)

Organisation Functions and Yearly Action Plans

(a) Mission & Vision of Occupational Safety & Health Branch of Labour Department

Vision: Low occupational accidents, zero fatality & minimum health hazards for all employees at work.

Mission: To ensure that risks to people's Health & Safety from work activities are properly controlled, through law enforcement, education & training, publicity & promotion, taking the role as facilitator and adviser on safety.

(b) Objectives of BPVD

To ensure the safe operation of boilers & pressure vessels (BPV or pressure equipment) used in industry through publicity, effective service and training, monitoring and enforcement of the relevant legislations. Hence, our ongoing roles would be controller, adviser and facilitator (promotioner) on safe practice, management and control in workplace relating to BPV.

(c) Divisional Functional/ Operative Goals

- carrying out assessment/approval of registration document of pressure equipment and their registration; granting exemption to pressure equipment where necessary
- performing spot check/ factory inspections, and follow-up inspections
- conducting examinations for the issue of certificates of competency & coordinate training for operators
- initiating warnings and prosecutions on offences
- inquiring into accidents relating to boilers and pressure vessels
- managing and monitoring the appointed examiners, competent persons, and recognised inspection bodies, and registered of pressure equipment contractors
- recognising engineering standards/codes
- providing expertise to Fire Services Department on the safety control of pressure equipment containing dangerous goods
- managing and maintaining Pressure Equipment Information System (PEIS)
- updating safety and legal machineries: ordinance, regulations, engineering standard/codes, codes of practice, instructions, advices and notices
- liaising with customers, advisory committee and professional institutions and authorities local and overseas
- issuing codes of practice, notices and other publication for promotion of safe working environment
- enhancing the communication between the Authority and the pressure equipment related parties or organisations
- managing manpower and funding resources; handling development operational reviews and forward planning

(d) Matters Required Special Attention & Completed in 1993/94 (Action Plan):-

- replacing of existing Pressure Equipment Information System by an up-to-date computer system by preparing justification for funding.
- completing the preparation/translation of four sets of bilingual codes of practice for issue in 1994
reviewing and streamlining the operation of the Appointed Examiners system, i.e. revising the instructions to AEs, preparing guideline on AEs' performance monitoring point system
- consolidating work reports, forms and statistical returns.
- commencing the review of operational procedures and policies (to be continued)
- preparing the amendments to BPV Ordinance and consultation (to be continued)
- preparing a BPVD operation manual

(e) Matters Required Special Attention & Completed in 1994/95 (Action Plan):-

- coordinating and assisting in the mini-computer replacement project of Pressure Equipment Information System (PEIS)
- exploring the enhancement features to be integrated to the new Pressure Equipment Information System (PEIS)
- consulting, issuing and gazetting 4 bilingual sets of Codes of Practice
- promoting safety awareness on the safe use and operation of pressure equipment, i.e. issuing codes of practice by holding or co-organising few technical seminars for the industry (Dec 94 and Mar 95)
- streamlining the procedures in the appointment and monitoring of Appointed Examiners, i.e. devising AE's reporting of daily inspections and guidelines for the appointments as AE.
- enhancing training courses availability to the industry by coordinating with technical institute and Occupational Safety and Health Council
- reviewing Certificate of Competency structure and examination syllabus
- participating regional or international seminar or conference on boilers and pressure vessels safety (APEC seminar Oct 94 in Taiwan with OSHC)
- drafting draft of instructions for the amendments to Boilers and Pressure Vessels Ordinance (to be continued)
- continuing the review of operations procedures and effectiveness (to be continued)
- formulating technical staff training strategy and policy to ensure continuity in the effective technical support by BPVD (to be continued)


- 1) implementing the minor enhancement work on PEIS, i.e.
   # computerising the work reports, forms and statistical returns
   # computerising the issue of standard letters PEL-8 and PEL-19
- 2) preparing justification for the major enhancement features to be integrated to the Pressure Equipment Information System (PEIS)
- 3) consulting the revised Certificate of Competency structure and examination syllabus
- 4) revising the Guidelines for Appointment as Appointed Examiner and preparing bilingual publication
- 5) coordinating with training institutes for more UPDATED training courses for training of competent persons and appointed examiners (one specialised training course or workshop)
- 6) consolidating the computer applications with PCs:-
   # working out work statistics formats and graphic reporting using EXCEL
- 7) promoting safety awareness on the safe use and operation of pressure equipment by holding seminars or training courses to promote the compliance of the four sets of bilingual codes of practice issued in 1994 (Sept 95 through seminar of OSHC and Dec 95 in Science Museum)
- 8) participating regional or international seminar or conference on boilers and pressure vessels safety (seminar June 95 in Shenzhen PRC)
- 9) revising the Prosecution Orders (01) & (02) of BPVD for the purpose of enhancing law enforcement effort by reducing the number of warnings for each violations found.

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Matters Required Special Attention in 1996/97: (Action Plan):

1) conducting feasibility study with ITSD on the requested major enhancement/upgrading work (est. cost is $1.9 mil) on the Pressure Equipment Information System (PEIS), including:
   # enhancement work on computerising examination application, appointment and issue of the certificates of competency;
   # direct access of PEIS by Appointed Examiners for the enquiries and the issue of certificates of fitness (similar to Singapore's BPV system & practice)
   # direct access of PEIS by equipment owners for the enquiries & record keeping.
   # provision of Chinese character input function (for bilingual purpose)

2) consolidating the computer applications with PCs:
   # computerise BPVD technical library using FOXPRO,
   # wider usage of computer software programs in assisting the strength calculation assessment of pressure equipment,

3) seek support and resource to enhance the expertise, functional role and better representation of BPVD for coping with local and international requirements on the safety and control of BPV.

4) revising the BPVOrd gazetted forms 1, 2, 3 and 4;

5) preparing PEAC papers and arrange consultation meeting for Nov 1996.

6) continuing the drafting draft of instructions for the amendments to Boilers and Pressure Vessels Ordinance; preparing further amendments to BPV Ordinance and consultation

7) revising and amending the 4 sets of bilingual Code of Practice, particularly the Chinese terms to be in line with BPVO.

8) continuing the streamlining the operation of the Appointed Examiners system, i.e.
   standardising registration inspection procedures, consolidating disciplinary procedures,

9) publishing the revised bilingual Guidelines for Appointment as Appointed Examiner.

10) revising the Code of Practice for Appointed Examiners and preparing bilingual publication,

11) preparing the draft on Code of Practice for Electric Boilers and for Competent Persons,

12) revising the requirements, procedures and wider implementing the recognising of inspection bodies under BPV Ordinance,

13) continuing the wider implementation in the recognition of inspection bodies, conducting periodic auditing and monitoring,

14) studying the safety and operation conditions of pressurised fuel containers in use in Hong Kong and reporting on the need of law enforcement under BPVO requirements.

15) further revising the Prosecution Orders(01) & (02) for the purpose of further stepping up law enforcement action and deterrent effect on violators.

16) analysing the past accident cases with a view to publish fuller statistics and lessons learnt from these mishaps for the reference of the industry.

17) preparing draft on the formulation of pressure equipment contractor requirements and monitoring procedures and its implementation.

18) formulating technical staff training strategy and planning to ensure continuity in the effective technical and expertise support in BPVD,

19) establishing formal communication through regular meeting (4 or 6-monthly) with FSD to discuss the progress of technical support services rendered by BPVD

20) participating regional or international seminar or conference on boilers and pressure vessels safety, (June 96 organised by HKO & HKUST on D.G. Gas safety)

21) promoting safety awareness on the safe use and operation of pressure equipment by holding seminars, setting up and monitoring safety training courses, (i.e. 3 seminars in June, Dec, Mar97, 2 specialised courses in Jan97, Mar97 and 24 BPV safety training courses.)

22) Implementing the Enhancement Project of the Pressure Equipment Information System after the approval of the Feasibility Study Report.
The Pressure Equipment Information System (PEIS)  
(1994 Computer Project of BFVD)

(1) System Project Objectives

- Pressure Equipment Information System (PEIS) is a re-development application system using UNIX/ORACLE system set up to mainly replace all the functions handled by the out-dated DATA GENERAL mini-computer system which has been used for over 7 years. The PEIS is integrated with some improvement features;

- PEIS is able to store all relevant data information relating to pressure equipment to facilitate the efficient law enforcement purpose under the Boilers and Pressure Vessels Ordinance, Cap 56;

- PEIS has been catered for capacity expansion in future for Pressure Equipment Division of Labour Department.

(2) System Configuration

- The new system is using a Unix Master Server Main station to hook up six work stations. The main server run on UNISYS/ORACLE system set up with 1.3 Gb x 3 hard disks and 150 Mb tape drive data storage capacity. The work stations are 80486PC based terminals.

- The new system configuration is presented in Chart 1, excluding public connection. The system is also supported by an un-interrupted power unit which would minimise the possibility of data loss when power supply is interrupted. It is also provided with a modem link to ITSD for continuous technical support by Government computer specialists.

(3) Business Areas Served:

The PEIS system will maintain master data of:

- Factories (Equipment Owners), equipment, equipment histories, inspections and Certificates of Fitness status and prosecution matters;

- Exemption Certificates & Factories, their equipment and inspection status;

- Appointed Examiners,

- Certificates of Competency and competent persons.
Pressure Vessels (gas cylinders) & Systems related to the Dangerous Goods Ordinance (DGO)

The Present Practice on Safety Control

1.0 Background

1.1 There are different legislation in Hong Kong controlling the safety of different types of pressure vessels, namely the Boilers and Pressure Vessels Ordinance, the Dangerous Goods Ordinance, the Gas Safety Ordinance and its subsidiary Gasholders Examination Regulation. Pressure Vessels under provision of the DGO are mainly related to the Cat. 2 Compressed Gases due to such category of gases has to be stored and used under pressure.

1.2 The Director of Fire Services (DFS) is currently "the Authority" for all dangerous goods categories except category 1 on land. Presently, the Boilers & Pressure Vessels Division (BPVD) of Labour Department (LD) is providing technical support to the Fire Services Department (FSD) on matters related to the pressure vessels and systems under the DGO, including assessment work on gas cylinder approval, and pressurized systems for DG license purpose.

1.3 According to the Dangerous Goods (General) Regulations, Compressed gases are grouped into 3 classes:

<table>
<thead>
<tr>
<th>Class</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Permanent Gases</td>
</tr>
<tr>
<td>2</td>
<td>Liquefied Gases</td>
</tr>
<tr>
<td>3</td>
<td>Dissolved Gases</td>
</tr>
</tbody>
</table>

2.0 Control on Gas Cylinders

2.1 Gas Cylinder Approval

Regulation 64 of the Dangerous Goods (General) Regulations requires all cylinders and containers for the storage of gases to be approved for use by "the Authority". The following information are normally required for such purpose:

(a) fully dimensioned drawing and details of construction of the pressure equipment;
(b) design specification and calculations;
(c) manufacturer's certificates;
(d) reports of physical tests and chemical analysis of the material for pressure equipment construction;
(e) report on tests carried out in accordance with the standard/code used;
(f) detail of any heat treatment;
(g) inspection report issued by an independent inspection authority;
(h) detail of valve, fitting and safety devices to be provided.

Hong Kong is a free port and does not have its own pressure vessel standard & code. Many relevant national standards that have been experienced are accepted by "the Authority". Because of the variations in design philosophy between different national engineering standards, it is important that the pressure vessels design should fully comply with a single engineering standard. Mixing of
standards is normally not acceptable. Pressure vessels designed and manufactured in accordance with
the following recognized engineering standards have previously been granted approval for use in
Hong Kong by "the Authority":-

American Standards  (DOT)
Australian Standards  (AS)
British Standard     (BS)
Canadian Standards  (CTC)
Chinese Standards   (GB)
Japanese Standards  (JIS) (JHPGCL)

Apart from a sound design, the quality assurance of the finish product is most important to
ensure only good quality gas containers are allowed to be used for containment of gases. The
inspection and certification should therefore be completed by inspection agencies recognized by the
"Regulatory Authority" in their country of origin and acceptable by the "Authority". Such
certification would be more significant for imported gas containers, which very often is the only piece
of document confirming that the gas container is in compliance with a design standard.

2.2 Identification of Gas Cylinders

Cylinders containing category 2 gases other than those for medical purpose shall be painted in
accordance with the colour recommended by the British Standard Specification 349 and for cylinders
containing medical gases in accordance with BS 1319, or the heads of the cylinders shall be painted
conspicuously as required by the regulations:

(a) red, if the gas contained is inflammable;
(b) yellow, if the gas contained is poisonous;
(c) one half red and the other half yellow, if the gas contained is both inflammable and
    poisonous.

Cylinders shall be provided with labels as required by Dangerous Goods Ordinance, the
Factories & Industrial Undertakings (Dangerous Substances) Regulations or in accordance with the
International Maritime Dangerous Goods (IMDG) Code, showing unique symbol and description on
the contained gas and its properties & associated risks and safety precautions etc..

2.3 Periodic Examination of Gas Cylinders:

(a) Cylinders for permanent and liquefied gases shall be tested and examined according to
    regulation 66 within the preceding 5 years by competent person approved by the
    "Authority".

(b) Cylinders for dissolved gases shall be examined both internally and externally in
    accordance with regulation 67 within the preceding 12 months by competent person
    approved by the "Authority".

3.0 License of Cat. 2 DG Storage & Manufacturing (Pressurized System)

Under Section 6 of the Dangerous Goods Ordinance, license is required for the manufacturing,
storage, conveyance or use of any dangerous goods exceeding the exempted quantities stipulated in
the Dangerous Goods (General) Regulations. For category 2 DG, the exempted quantities of
different gases vary from none to the maximum of 2 cylinders (5 cylinders in aggregate), with the exception of \( \text{CO}_2 \) cylinders intended for use as fire extinguisher, in which case the exempted quantities will be unlimited. The following information are normally required for licensing.

A plan drawn to scale of the store with the following particulars:

(a) the siting of the store;
(b) the material of which it is or is to be constructed;
(c) the means of ventilation;
(d) the routing and method of fixing any pipelines which is to be installed for the gas distribution associate with the storage, and the material of which it is to be constructed;
(e) any particulars, if any as the Authority may required.

The plan shall be accompanied by:

(a) a statement in writing declaring the nature of the gas or gases to stored and the maximum quantities thereof in respect of which the license is required;
(b) the design and specification of the distribution pipelines and ancillary equipment to be constructed (e.g. BS, AS, GB, ASME, ANSI, CODAP, AD-M etc.).
1. **Introduction**

1.1 Pursuant to Regulation 64 of the Dangerous Goods (General) Regulation, Chapter 295, Laws of Hong Kong, no person shall use, cause or permit to be used, for the storage of any gas in any cylinder or other container except of a type appropriate for the storage of such gas and approved by the Director of Fire Services (DFS) i.e. "the Authority".

1.2 In Hong Kong, many national standards are recognized and adopted, it is the responsibility of the owner or importer of the gas cylinders to keep records of the approved design documents and certificates/reports of those cylinders as long as they are remained in use in Hong Kong. Such practice is one of the effective control means adopted by many developed countries.

2.0 **Application and Approval Procedure**

2.1 All applications for approval of gas cylinders shall be submitted to the Investigation and Research Division of the Fire Protection Bureau of this Department for processing and evaluation.

2.2 Every application shall be accompanied by the following supporting documents (in triplicate) indicating that the gas cylinders submitted for approval has been assessed/tested to a standard/specification accepted by "the Authority".

2.2.1 gas container/cylinder of a design first time introduced for use in Hong Kong:

(a) fully dimensioned drawing and details of construction of the cylinder/container;

(b) design specifications and calculations, in accordance with the relevant standard;

(c) specifications of valves to be used with the cylinders;

(d) manufacturer's certificate;

(e) inspection report by independent inspection authority;

(f) report of physical tests and chemical analysis of material used in construction;

(g) report on tests carried out in accordance with the standard/code used;

(h) details of any heat treatment;

(i) gas(s) to be contained in the cylinder/container.

2.2.2 for gas container/cylinder of a type previously approved by "the Authority", only document of 2.2.1 (d) to (i) will be sufficient for assessment provided that such type/model and DFS approval reference can be identified.

2.3 Two sets of the above document shall be submitted to Investigation and Research Division of Fire Protection Bureau of Fire Services Department. One similar set shall be submitted directly to Boilers and Pressure Vessels Division of Labour Department for technical assessment.

2.4 The inspection report as mentioned above should be issued by an Independent Inspection Bodies authorised by the relevant standard or local regulatory authority. Authorization/approval document should be provided when consider necessary as follow:

- **British Standard (BS)** —
  - to be approved by the UK Health & Safety Executive
US Department of Transportation (DOT) --
to be approved by the US Department of Transportation (Director of Hazardous Material Regulations)

Canadian Transport Commission (CTC) --
to be approved by the Canadian Transport Commission.

Australian Standard (AS) --
to be approved by the Standards Australia as required in AS 2337

Chinese National Standard (GB) --
to be specially approved by the Bureau of Boilers & Pressure Vessels Safety Supervision for cylinder importation to Hong Kong

Japanese Industrial Standard (JIS) --
to be approved under the Japanese High Pressure Control Law by the Japanese Ministry of International Trade & Industry (MITI) or by the High Pressure Gas Safety Institute of Japan (KHK)

3.0 Standards/Specifications

3.1 Currently, the following standards/specifications in association with relevant national standards on material, welder qualification, testing standard & specification are acceptable to "the Authority".

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<th>American Standards</th>
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<td>DOT 3A</td>
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<td>JIS B8241</td>
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<td>AS 2470</td>
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Japanese Standard

Japanese Standard

Japanese Standard

Japanese Standard
3.2 Engineering Standard other than those listed above may also be considered to be acceptable. Applicant would be requested for evaluation report of the concerned standard when necessary. Additional time may be needed on top of the time normally required for cylinder approval.

4. Processing of Application

4.1 Applications are generally dealt with on first come first serve basis, the time required for processing an application is normally 20 working days (4 weeks).

4.2 For any technical irregularities related to the submitted document, the Boilers & Pressure Vessels Authority of Labour Department would contact directly with the applicant for clarification, all such correspondence would be c.c. to Fire Services Department for record and reference. When such irregularities have been rectified, the Boilers & Pressure Vessels Authority would issue a letter to the applicant stating that no objection in principle on the technical acceptance of the application, a copy would also be circulated to Fire Services Department for consideration.

4.3 A letter of approval together with a set of duly endorsed supporting documents will be issued to the applicant by the Director of Fire Services if he thinks fit and all conditions for approval are met.

5.0 Enquiry

5.1 For further information and advice regarding to:
(a) the approval of gas cylinders containers, please contact Fire Protection Bureau, (Investigation & Research Division), Fire Services Department 1, Hong Chong Road, 5/F., Tsimshatsui East, Kowloon. Tel. No.: 2733 7596 Fax: 2723 2197; or

(b) on technical requirements and assessment, applicants may contact:- Boilers and Pressure Vessels Division Labour Department 17/F., Harbour Building 38 Pier Road, Central Hong Kong Tel. No.: 2852 4189 Fax: 2850 5191
The diagram above indicates some potential new services areas, but the actual implementation of these services will depend on the availability of fund, acceptance by public and other criteria.
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- The Factory Inspectors Division
- Occupational Health Division, Labor Department
- Boilers & Pressure Vessels Division in Occupational Safety & Health
ISO 9000
Implementation and Training
- A Consultant’s Perspective

by

Mr. Roger Johnson
Director of Quality Assurance Services,
P-E Handley-Walker (HK) Ltd.

Boilers & Pressure Vessels Division, Labour Department, Hong Kong
Roger Johnson is Director of Quality Assurance Services for P-E Handley-Walker (HK) Ltd, a division of management consultants P-E International. He is responsible for their quality related consultancy and training business in this region. Prior to being transferred to Hong Kong in 1992 he worked in USA, India, Hong Kong, UK, Eire and other European countries. He has considerable experience in continuous process industries, particularly in the petrochemical sector and in the service sector. Prior to becoming a consultant and trainer he led his previous employer through a number of quality system certifications.
ISO 9000 Implementation and Training - A Consultant's Perspective

This afternoon I would like to review some of the issues which we have found when assisting organisations to achieve certification to an ISO 9000 standard. Our world-wide experience includes more than 2000 ISO 9000 consultancy assistance projects and the provision of public, in-house and customised training, seminars and workshops.

The issues which affect an implementation are varied and influenced by many factors. I would like to consider some of these:

Motivation

- External
- Internal

Implementation issues

- Fears and myths
- Documents
- Records
- People

Training

Role of the consultant
Motivation

The creation and implementation of an ISO 9000 based quality management system is costly. Whether an organisation chooses to use external assistance or its own resources, the process requires commitment and involvement from people at all levels in the organisation if the investment is to result in benefits. The process of implementing an ISO 9000 based system is not easy, so we should consider the reasons why organisations decide to follow the ISO 9000 process.

- The most common motivation is that customers, or potential customers, require their suppliers to obtain certification. Often customers will only invite quotations or tenders from certified suppliers and may set deadlines for achievement of certification on existing, no matter how long-standing, suppliers.

It is the case, all too often, that when the only motivation is that of meeting a customer requirement the ISO project becomes a necessary but unwanted intrusion. The certificate becomes the objective and this must be bought at the minimum cost, in the minimum time with the minimum disruption. In the extreme cases, there is no understanding or desire to understand the concepts and potential benefits. Such projects are characterised by delegation to the consultant and designated staff. While adequate systems can be put in place and certification can be achieved, the system continues to be a cost centre. No benefits accrue, and the ISO 9000 system gets a bad name.

Managements which are more discerning do question why customers require the system and seek to understand how benefits can be obtained. The consultant has a role to interpret the standard to explain and suggest how this can be achieved. Such leaders still have to work within cost and time restraints but are likely to ensure that they and their senior management teams are sufficiently knowledgeable, visibly involved and playing an active role in the implementation. It is far more likely that consultants will be able to use their experience to assist in the improvement of the operations at the same time as achieving certification. It is also more likely that more people in the organisation will be both motivated and involved resulting in a system which is more effective.

- We find amongst the fast developing economies in Asia that achievement of certification is perceived as providing an additional or necessary competitive edge to businesses seeking to export to the more developed economies of, for example, America, Europe and Australasia.

This view is well supported by governments who subsidise and encourage ISO 9000 activity within their nations. This motivation is less specific than the requirement of a particular customer but is probably the second most common.

Whilst there are still some leaders who look for minimal systems, many more fall into the category of seeking a benefit, and the ISO 9000 consultant frequently finds that the management and staff seek much more than just ISO 9000 consultancy. Consultants, frequently subsidised, are enthusiastically drawn into improvement activity often calling on skills and experience far removed from ISO 9000.
• The third most common motivation falls well below the other two numerically and results from internal reviews of the organisation. There is a recognition that ISO 9000 can provide an important step in the process of operational improvement. Certification may not be a requirement but is used to provide a goal.

In projects where this is the motivation there is likely to be the highest level of involvement and interest and the consultant must not only work within this environment but also bear in mind possible later developments and initiatives. To this end the consultant will often be in the position of advising not only what changes might be beneficial but also what to leave alone if the benefits are likely to be greater in a later development stage.

Motivation has a major influence both on the implementation and benefits of an ISO 9001 system. At one extreme working virtually in isolation with a few designated people producing a system of minimal interest to that of playing a significant role in not only implementation but also planning for further improvement initiatives.

Implementation issues

No matter how well motivated the leaders of the organisation may or may not be the implementation of an ISO 9000 management system brings about some change. The amount of change does depend on the motivation and objectives of the project. The management of change is too broad a subject for inclusion in this presentation but I have selected a number of issues which we have found frequently. These matters need to be addressed and the role of the consultant is outlined.

• Fears and myths

The number of stories about bad experiences that one hears far outweigh the number of good ones. Perhaps that is because bad news travels further and faster than good news. We hear about a need for large numbers of procedures and detailed instructions even for minor activities. Bureaucracy and mountains of records and forms producing rigid systems which allow no creativity or discretion and require extra staff to administer feature frequently in the stories we hear. Then there are the iniquities of the auditors. Unfortunately we rarely hear more than one side and there have been examples of poorly designed, over documented and poorly implemented systems. There have also been good ones where organisations have found improvements in reliability, consistency, morale, motivation, interdepartmental cooperation, supplier performance, customer attitude and of course profit.

The consultant must anticipate that the fears and myths will be there and should take action in the early stages with top and senior management to ensure that there is a clear understanding of the objectives and requirements of the standard.

Fears arise from lack of knowledge and misunderstandings of the objectives of the standard and the clauses in it. Documents and records must be regarded as tools just like any other piece of equipment designed to enhance the production of work.
- **Documents**

The characteristic of a good documented management system is that the number of documents must be adequate - not one more nor one less. They must be written for the user.

The consultant must ensure that the level of detail and wording allow, within limits, the use of authority, qualifications and expertise. Users should contribute to their content and be involved in their testing and refinement to ensure that the documents reflect the training, experience, needs and language of those users.

- **Records**

ISO 9000 standards require records to provide evidence of compliance with requirements and to provide data for analysis to facilitate improvement programmes.

The consultant must make sure that these objectives are achieved with the minimum of forms but with necessary and useful measurement data.

- **People**

No matter how well motivated the leaders of the organisation may or may not be there will usually be some entrenched attitudes amongst the staff which should be anticipated and provided for. Typically these include the long serving employee who sees no need for documentation at all, the middle managers who feel that clearer definitions of methods and authorities undermine their roles, the professionally qualified who fear that systems will create constraint and the bureaucrat.

Such attitudes need careful handling both for the benefit of those with them and perhaps more importantly those who are positive about a system designed to improve.

All of these issues highlight the need for carefully planned and comprehensive training.

- **Training**

Consultants are most likely to be participating in the design and implementation of a complete system when there is little, if any, in-house expertise. The consultant must plan training to develop awareness and understanding at different levels and also to provide specific skills to the organisation's development team. The training must take account of the needs for development and implementation and also for the maintenance, change and improvement of the system after certification.
Such training needs to start with the top management where it is essential to provide an overview which concentrates on the principles and objectives of ISO 9000 standards. The organisation’s objectives need to be clarified and the role of top management in driving the process, anticipating problems and demonstrating commitment and involvement made clear.

Awareness, understanding and interpretation of the requirements and how they can be integrated with the organisation’s objectives and systems is the training objective for the implementation team. This is best approached by a mixture of formal classroom and workshop sessions.

Specialist skills that are required include document writing, internal auditing and when appropriate external auditing. Some approved lead auditors courses provide very useful initial training covering auditing and interpretation of the standard.

There is not much to be gained by training staff other than those directly involved in developing the system until implementation commences. Such training then should restrict the ISO 9000 content to principles and objectives and concentrate on the developing system and its content and objectives.

There is a need to ensure that staff are aware of the objectives and methods used by external auditors particularly those from certification bodies. Staff should be trained in behavioural matters relating to these activities.

- The role of the consultant

The nature of the assistance provided by consultants and trainers falls broadly into two categories. The first of these is the provision, by consultants, of specific skills and services to meet readily definable requirements. This group would include; system and document reviews, gap analysis, auditing, corrective action advice, preassessments and training activities such as formal classroom activities covering briefings, awareness, auditing training and specialised workshops on specific subjects.

The second principle activity is assistance from inception to certification and it is in this area that misconceptions are more likely to occur.

The implementation project must optimise the talent and resources of the consultant and the client. It will be the client who operates the system and achieves certification not the consultant and it follows that the project must ensure that the client staff are prepared adequately.
First the consultant must study the operation and propose the structure and content of the documented systems and suggest how the resources may be allocated to the development and implementation of the system. From this derives the training requirement, project team and plan.

The documents can be considered broadly in three groups: the top level quality manual, the system management procedures with high ISO 9000 content and operational procedures with high client technical and knowledge content. High levels of input should come from the consultant into the first two and the client should provide the input for the third group. The consultants must not do too much for the client. If they do there is the danger of lack of "ownership" and real understanding of the system or the use of standard or model procedures which while providing a viable system do not integrate with the organisation's activity. The effect of that is to provide a "bolt on" systems which has only a limited benefit.

Training is an integral part - in fact is the major contribution and it is essential to get the balance right between formal and informal on the job training. Workshops with a few people on a few restricted topics are much more effective and can be turned into plans for document production and timetabling.

Project management is another aspect of the consultant's role - an opportunity for the exercise of diplomacy and assertiveness - because the project belongs to the client however the consultant is in a good position to set standards and targets and to assess the overall progress.

The quality system that result will be more effective at producing benefits if the consultant's role is seen as a facilitator rather than as a deliverer of documents.
A User’s View of ISO 9000

by

Mr. J.H. Evans
General Manager, Optns /Engineering
Hong Kong Oxygen & Acetylene Company Limited

Boilers & Pressure Vessels Division, Labour Department, Hong Kong
HOWARD EVANS - Welsh, 50 yrs. Of Age, Married with two Sons, both at University in U. K.

Currently Operations & Engineering Manager, Hong Kong Oxygen.

Responsible for Production Facilities at Tai Po and Tseung Kwan O and a team of Engineers who design and build gas plant installations. In addition the Engineering & Operations Group provide support to HKO. Joint Venture Companies in Pearl River Delta.

Started working life as a Apprentice in Steel Industry with Steel Company of Wales and moved to BOC in 1970.

Had experience in Production, Distribution, Production Planning, Work Study and General Management. Mostly in line Management.

Prior to leaving U. K. in 1995 was Manager of a Major BOC Site in U. K. serving the Sheffield Steel Industry.
WHY HAVE ISO 9000 ACCREDITATION

BS5750 or ISO 9000 is almost a necessity nowadays in U. K. Most customers expect ISO 9000.

In early 1990s whilst managing a Major U. K. BOC Gases site a decision was taken, at Director level, to seek accreditation.

As a Plant Manager I could see the need for ISO in the Market Place but felt that I had a well motivated and managed operation and questioned the need.

As the process towards accreditation progressed I became aware that my well managed operation had flaws - some major!

IMPLEMENTATION

Implementation was initially painful. In spite of using good consultants I had to lead the process at my site and I needed training and support. This was done 'on the run' as the deadlines set were very tight.

A presentation was prepared for ALL staff. I led this but was supported by Consultants and more importantly a Director of the Group. This presentation explained what ISO 9000 was and the process of change. Regular meetings were held at Department level during the implementation stage to review progress. This was vital to demonstrate commitment and LISTEN to concerns.

Along with me many staff felt that they were well organized and resisted change initially. The analogy the consultants used was of a large group of professional musicians being uncoordinated without Music or a Conductor was a good example and removed the personal problems.

As implementation progressed staff bought into the change process as they realized it brought benefits particularly at Department interface e.g. Production and Distribution.
The Departments where staff involvement was done early and well gained benefits later as the Work Instructions developed were robust.

One of difficult issues to address was “what is Quality Critical”. A good relationship with our Consultants helped here as we could debate openly.

Successful accreditation should be celebrated as a team BUT be realistically understood to be Step 1.

**BENEFITS**

Customer confidence is increased given a separate body is doing surveillance visits. May U. K. purchasers will not deal with a non ISO Accreditation organization.

Some customers use ISO 9000 System on supplier visits to rate supplier capability - Electronics customers do this regularly.

Public Image is improved.

A great benefit is improved document control on a multi activity site, this gave much better control and visibility that the appropriate documents were being used. It also put the W. I. at the point of use NOT in the Managers office.

A much better understanding of customers contracts came out of ISO 9000 process as we had to define the requirements and create a non conformance procedure. This product non conformance made visible some outages that would have previously been ‘hidden’ or not mentioned.

W. I. created better definition of Responsibility and Authority.

Training needs are easily identified and managed.

W. I. removed the need for Operations to keep personal (and varying standard) Plant start up/optimization procedures.
Customer Complaint/Feedback System - Structured in a way to enable trends to be recognized.

I have found that moving between companies/organizations is relatively easy if the old and new organization operates an ISO system - an unforeseen benefit!

**CRITICAL SUCCESS FACTORS**

Management commitment must be obvious.

Staff involvement in building up system is vital and helps the subsequent training process.

Understanding that Accreditation is only the start. System maintenance and support are vital.

A good open relationship with Auditor.

**SUMMARISING**

Commend ISO as a management tool.

Use a Consultant to help implement.

Involve all levels of staff. Show Management Commitment.

Management and Maintenance of the system is vital.
New Maintenance Technologies for Power Boilers

by

Mr. Hiromi Nakatani
Mitsubishi Heavy Industries, Ltd.
Personal Data

Hiromi Nakatani

Acting Manager,
Power Plant Engineering Department
Utility Boiler Designing Section

Mitsubishi Heavy Industries, Ltd.
Nagasaki Shipyard & Machinery Works

Education: University of Tokyo B. Mechanical Engineering
(March, 1985)

Summary: 9 years Tokyo Head Office
Boiler Engineering Department
Boiler Mechanical Design Group
2 years Nagasaki Shipyard & Machinery Works
Power Plant Engineering Department
Utility Boiler Designing Section

Experience: Mr. Nakatani has been a boiler engineer at Mitsubishi Heavy Industries for 11 years.
He has been responsible for development of new boiler technologies and maintenance technologies for safe operation. Currently Mr. Nakatani is also in charge of failure analysis for actual boilers.

Major Projects:
- 1x1000MW Oil Fired Utility Boiler for Tokyo Electric Power Company
- 2x700MW Gas Fired USC Utility Boiler for Chube Electric Power

Papers:
- Metallurgical Damage Detection System of Boiler Pressure Parts
  EPRI 4th Incipient Failure Detection Conference
  (October, 1990 Philadelphia, USA)

- Advanced Technologies for Power Boilers
  AMIME Boiler and Pressure Vessels International Congress and Workshop
  (November, 1996 Acapulco, Mexico)
New Maintenance Technologies for Power Boilers

Hiromi Nakatani
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Nagasaki Shipyard & Machinery Works
1-1 Akunoura-machi, Nagasaki 850-91, Japan
(1) Life Evaluation Technologies
Life Evaluation Technologies

INTRODUCTION
In the year of 1950-1970, Japanese electricity had a great growth and large number of thermal power plants were erected and their unit capacities also became larger.
On the other hand, owing to the growth of nuclear power and changes in electric power demand, old thermal power plants designed for base load operation have come to be exposed to severe operations such as frequent start-and-stops and rapid load swinging, and these old plants are planned to be operated for a further long period from the viewpoint of decreasing the cost of electric power supply by effective utilization of existing facilities.

Against this background, in order to maintain the reliability and to carry out preventive maintenance for aged boiler, it is necessary to establish the overall life evaluation technology. MHI has been developing such technology practically and systematically, called MLEX (Mitsubishi Life Extension System). Fig.1 shows a flow diagram of life evaluation technology. Life evaluation technology is classified into 3 methods as follows.

(1) Evaluation by stress analysis
(2) Evaluation by destructive test
(3) Evaluation by non-destructive test
Evaluation by stress analysis and evaluation by destructive test have already been used and almost common technology. On the other hand, non-destructive tests are divided into non-destructive inspection (NDI) for detecting cracks and non-destructive evaluation (NDE) for detecting damage earlier than cracks initiation. NDI has already been used and now efforts are being made to make it more efficient by using a robot and to extend the scope of its application. We have developed our own non-destructive life evaluation method (MLAS: Mitsubishi Metallurgical Life Assessment) and it has already been applied to boilers.
1. Evaluation by Stress Analysis

This is a method to calculate life consumption ratio from stress and temperature history by using material characteristics such as creep strength and fatigue strength. Fig. 2 shows a flow diagram. In order to obtain stress, finite element method (FEM) or other computer aided analysis is commonly used, however, since a boiler is a very complex structure, an analysis method should be selected after fully understanding the structural characteristics of the evaluated part and an optimum modeling should be used. Some examples are given below.

(Example 1)

Fig. 3 shows a stress analysis model of horizontal element spacer. First, temperature distribution is given to overall analysis model which represents element tubes and hanger tubes by beam elements and tube axial force, shearing force and bending moment are obtained. After that, vicinity of saddle spacer is taken out and zooming analysis with a three-dimensional solid model is made by giving forces and moment obtained by overall analysis to obtain stress in spacer welds.

In order to make a precise evaluation of fatigue life, a fatigue curve suitable for stress obtained by analysis is required. Since most of fatigue damage or crack in boiler originates in welds, effects of stress concentration and fatigue strength at welds should be grasped exactly. For this purpose, MHI conducted fatigue tests using a full size samples simulating the actual fatigue strength and obtained fatigue curves for FEM analysis in order to evaluate accurate fatigue life.
Fig. 4 shows a simulation fatigue test of spacer. Fig. 5 shows a fatigue test of fin end. Fig. 6 shows a stress analysis model of finite element method for fin end. Thus, various fatigue tests are conducted and unified fatigue curves shown in Fig. 7 are obtained to improve accuracy of life evaluation.

(Example 2)
Regarding corrosion fatigue on tube inside surface, factors of damage are varied, so it is difficult to make a quantitative evaluation by tests at laboratory level alone. Therefore, fatigue curves are obtained by reverse analysis at crack initiation in actual boiler.

Fig. 8 shows a procedure to obtain corrosion fatigue curves. Sample tube examination is made to check for corrosion fatigue cracks, stress at initiated crack is calculated by finite element method, and fatigue curves shown in Fig. 9 are prepared by using the number of starts and stops. Fig. 10 shows distribution of stress at rod welds of furnace wall tubes as an example of stress analysis results of tube inside surface.

(Example 3)
For evaluation of ligament crack on inside surface of a header which is a thick-walled pressure part, it is necessary to calculate history of stress at each time to obtain creep fatigue life consumption. As a mechanism of thermal stress in ligament, temperature gradient around nozzle hole and temperature difference between perforated part and other part at boiler start and stop are considered. (Fig. 11)
In order to establish a life evaluation method for ligament cracks, a simulation test was conducted and ligament cracks were reproduced. Fig. 12 shows the test being conducted and Fig. 13 shows cracks reproduced. At the same time, a reverse analysis was made by the finite element method shown in Fig. 14 to confirm the behavior of temperature and stress. The results were incorporated into thick-walled pressure parts life analysis program (BSAS-ID: Boiler Strength Analysis System of 1 Dimensional Component) and life evaluation for ligament cracks was made possible. BSAS-ID calculates metal temperature distribution and thermal stress of thick wall every hour by inputting pressure temperature and flow of internal fluid to make a plastic elastic analysis and calculate life consumption. Fig. 15 shows examples of analysis.

2. Evaluation by Destructive Test
Destructive evaluation, that is, the method of estimating residual life by taking test pieces from parts actually exposed to operation and making various rupture tests have been used generally for parts where test pieces can be taken easily (typically boiler tubes). An advantages of this method is that residual life can be estimated directly even if the history of stress and temperature to which the material was exposed is not clear, but its disadvantages are that it takes time to conduct creep rupture tests or fatigue tests, its application is limited to certain parts and locations.
3. Evaluation by Non-destructive Test

Non-destructive inspections (NDI) such as penetrant test (PT), magnetic test (PT), radiographic test (RT) and ultrasonic test (UT) to detect defects on metal surface and interior have been commonly conducted. Recently, various new methods have been developed to evaluate life consumption by creep and fatigue damage quantitatively and non-destructively before defects occur. (See Fig. 16.) While the conventional non-destructive tests are aimed mainly to detect cracks or flaws, these methods are called non-destructive evaluation (NDE) because they handle evaluation of crack initiation life.

3.1 Non-destructive Evaluation (NDE)

The non-destructive evaluation is advantageous in that the parts which are critical in stress can be evaluated in a short time and it is used in combination with life evaluation by stress analysis in most cases. Methods are varied depending on mode of damage and so on, typical ones of which are described below.

3.1.1 NDE of Creep Damage

There are structural comparison method and electric resistance method in NDE of creep damage.
(a) Structural Comparison Method

NDE by structural comparison method is well proven for HAZ of Cr-Mo steel. This method makes life evaluation by making an overall comparison between standard structure and life expenditure ratio, with attention paid to changes in mechanical damage, microstructure and distribution of precipitates.

As shown in Fig. 17, each damage factor is divided into 3 or 4 stages and by their combinations, life expenditure ratio can be estimated in the range of 8 divisions.

For example, when mechanical damage, microstructure and distribution of precipitates are divided as IIₚ, IIIₘ and IIₚ, respectively, creep rupture life consumption ratio is estimated at 50 ~ 60%.

(b) Electric Resistance Method

Electric resistance method evaluates creep damage by measuring changes in electric resistance value due to changes in mode of precipitations caused by accumulation of creep damage, initiation and development of creep voids. (Fig. 18)

High accuracy monitoring is made possible by removing effects of noises, etc. by locating damaged part and non-damaged part between the same current input terminals and by using alternating current method instead of the conventional direct current method.
3.1.2 NDE of Fatigue Damage

At an initial stage of fatigue damage of boiler materials, transfer density in metal structure increases and a change in transfer structure occurs. Because of this, the thin membrane method which directly observes changes in transfer structure and the X-ray refraction method which detects disarray of crystal lattice due to changes in transfer structure are effective. (Fig. 19)

On the other hand, in and after intermediate stage of damage, changes in transfer structure are saturated and microcracks occur and grow, so MT transfer method and replica method which observe length of microcracks are suitable. Particularly in actual life evaluation, evaluation of the latter half of life is important, so the above methods which are capable of evaluating the latter half of life are effective. Fig. 20 shows an outline of MT transfer method.
Selection of part to be evaluated

Level I  
(Evaluation by stress analysis)

Level II  
(Evaluation by non-destructive test)

Level III  
(Evaluation by destructive test)

Stress analysis
An example of analysis by finite element method

Temperature measurement in boiler

General material data
Operation records
Calculation of life consumption

Evaluation of life consumption by non-destructive test
- Microstructure
- Precipitates
- Creep void
- Hardness

Heat affected zone of Cr-Mo material

Evaluation of residual life by destructive test
- General material test
- Creep rupture test
- Low cycle fatigue test

Future operation plan

Evaluation of residual life

Fig. 1 MLEX Life Evaluation Flow Diagram
Fig. 2 Life evaluation method by stress analysis
Fig. 3 Example of FEM model of horizontal element and spacer
Fig. 5  Fatigue test of fin end
FIG. 7 Fatigue curve of welds showing secondary stress

Number of cycles

Secondary stress range

FIG. 6 FEM model of joint end

σ : Standard deviation
Results of sample tube examination

Check for corrosion fatigue cracks by sample examination

Initiation of corrosion fatigue cracks

Results of stress analysis

Calculate stress at initiation of corrosion fatigue crack by stress analysis

Preparation of fatigue curve

Summation of stress amplitude (strain range) at crack and number of start and stop

<table>
<thead>
<tr>
<th>Stress range $\sigma_i$ (strain range $\Delta \varepsilon_i$)</th>
<th>Number of start and stop $N_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_1$ ($\Delta \varepsilon_1$)</td>
<td>$N_1$</td>
</tr>
<tr>
<td>$\sigma_2$ ($\Delta \varepsilon_2$)</td>
<td>$N_2$</td>
</tr>
<tr>
<td>$\sigma_3$ ($\Delta \varepsilon_3$)</td>
<td>$N_3$</td>
</tr>
<tr>
<td>$\sigma_4$ ($\Delta \varepsilon_4$)</td>
<td>$N_4$</td>
</tr>
<tr>
<td>$\sigma_k$ ($\Delta \varepsilon_k$)</td>
<td>$N_k$</td>
</tr>
</tbody>
</table>

Fig. 8 Corrosion fatigue curve preparation procedure
Fig. 9 Corrosion fatigue curve
Fig. 10 Example of stress analysis at furnace wall rod weld
Stress occurs depending on temperature gradient around nozzle hole and temperature difference between perforated part and other part.

Fig. 11 Thermal stress at ligament
Fig. 12 Ligament crack reproduction test
Fig. 13 Reproduction of ligament crack
(a) Temperature distribution

(b) Equivalent stress distribution of TRESCA

Maximum stress occurs at clutch of circumferential section

Fig. 14 Results of temperature and stress analysis
OPERATING CONDITIONS

Conditions of analysis

At clutch of circumferential section

Stress-strain diagram

Fig. 15 Example of ligament crack analysis by BSAS-1D
Fig. 16  Non-destructive life evaluation method
Mitsubishi Metallurgical Life Assessment method (MLAS) has been developed as a life evaluation method for heat affected zone of Cr-Mo steel in which creep and creep fatigue damage are relatively large and has already been applied to more than 200 boilers. This is a method to obtain life consumption ratio by comparing a metal structure obtained by replica and extraction replica and with a standard structure.
Electric resistance method is a life evaluation method for evaluating creep damage non-destructively by measuring changes in electric resistance due to changes in mode of precipitates caused by accumulation of creep damage, initiation and development of creep voids. A high-accuracy monitoring method has been developed by removing noises by making the following improvements to the electric resistance method used previously.

1. Effects of temperature and noise were removed by detecting changes in ratio of potential difference (ratio of electric resistance) between damaged part and undamaged part at the same electric current input terminal.
2. Effects of electric current signals (noises) except measuring frequency and thermo electromotive force were removed by using alternating current method instead of the previously used direct current method.

This method has already been tested in boilers and its accuracy has been proved.

Electric field is disturbed by creep voids and coarse precipitates produced by accumulation of creep damage.

**Increase in electric resistance**

- **Unused material**
- **Material with creep damage**

**Block diagram of alternating current electric resistance measuring equipment**

- **Voltage output**
- **Signal switching circuit**
- **Lock-In amp.**
- **Power amp.**
- **Oscilloscope**
- **Data output**
- **PC**

**Notation**:

- $E_L$: Potential difference at loaded part
- $E_N$: Potential difference at non-loaded part
- $(E_L/E_N)_0$: Ratio of potential difference between loaded and non-loaded part of unused material
- $P_L$: Electric resistance ratio of loaded part
- $P_N$: Electric resistance ratio of non-loaded part
- $(P_L/P_N)_0$: Ratio of electric resistance at loaded part and non-loaded part of unused material
Fatigue damage evaluation by non-destructive test

Metallurgical damage
- Connection and propagation of cracks
  - Initiation of micro crack
  - Formation of coarse slip band
  - Occurrence of cell structure at dislocation
  - Occurrence of bundle structure of dislocation
  - Increase in dislocation density

Mechanical damage

Life evaluation method
- Thin membrane method
  - Directly observe dislocation structure with transmission electron microscope.
- X-ray diffraction method
  - Detect disturbance of crystal lattice due to changes in dislocation structure as changes in distribution of X-ray diffraction strength.

Number of cycles (Number of start and stop)

MT transfer method
- Transfer magnetic particles collected at crack by MT and measure crack length with microscope.

Replica method
- Transfer surface crack on replica and measure crack length with microscope.
Example of life evaluation by MT transfer method.

![Image of Crack Length Evaluation](image-url)

By MT transfer method, life computation ratio and time, evaluation standard diagrams are prepared showing relationships between surface crack length obtained and life. Evaluation standard diagrams are made by using simulated models of nozzle particle fracture initiating from MT transfer point. Fatigue crack lengths are extracted after growth of micro cracks at latter part of fatigue damage process. The evaluation is made by extracting.

Figure 20: Fatigue damage evaluation by MT transfer method.
(2) Inspection Technologies
UT Equipment for Thick-wall Vessels

**Inspection Procedure**

A, B and C scope and three-dimensional images can be displayed by position signal and defect signal from scanning device fitted on the inner surface of a vessel; i.e., drum nozzle, header etc.

---

**Features**

① Inspection period can be shortened.

② Internal defect can be detected as three dimensional image.

③ Propagation of defect can be monitored.
Inspection Procedure

Header inside surface can be inspected by remote control with TV camera inserted through inspection hole.

Features

1. Inspection equipment can be inserted easily.
2. Condition of damage can be observed directly.

Example of Inspection Result Display

*example of ligament cracks*
UT Equipment for Waterwall Tubes (Helical-skip type)

**Inspection Procedure**

Two probes are used in this method. Ultrasonic wave which is shot by Transferring probe is propagated helically and defect echo is received by receiving probe.

**Features**

1. Cracks on tube inner surface (corrosion fatigue crack) can be detected from furnace inside.
2. Removal of casing or insulation is not necessary.
3. Filling waterwall with water is not necessary.

**Example of Inspection Result Display**

Inspection result of artificial flaw test for membrane wall is shown below. ()...especially for tangent wall.

<table>
<thead>
<tr>
<th>Inspection part</th>
<th>Tension plate weld</th>
<th>Rod spacer weld</th>
<th>Windbox weld</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UT from outside furnace</td>
<td>UT from inside furnace</td>
<td>UT from outside furnace</td>
</tr>
<tr>
<td>Circumferential crack of root weld</td>
<td>O*</td>
<td>O*</td>
<td>(X)</td>
</tr>
<tr>
<td>Circumferential crack of toe weld</td>
<td>O</td>
<td>O</td>
<td>(O</td>
</tr>
<tr>
<td>Axial crack of root weld</td>
<td>(X)</td>
<td>(X)</td>
<td>(X)</td>
</tr>
<tr>
<td>Axial crack of toe weld</td>
<td>(MT)</td>
<td>(MT)</td>
<td>(MT)</td>
</tr>
</tbody>
</table>

○...possible, △...partially possible, ×...impossible, - - - No defect, MT...Magnetic particle testing
+1...Waterwall tubes must be filled with water

※display of circumference crack on inside surface of tube
※※display of axial crack on inside surface of tube

This technique can detect cracks over 0.5mm depth.
### Inspection Procedure

Crack on tube inner surface or at welds of attachment can be detected by UT probe from furnace inside by filling the tube with water.

### Features

1. Cracks at root of weld which can not be inspected from furnace outside can be detected from furnace inside.
2. Cracks on tube inner surface (corrosion fatigue crack) can be detected.
3. Removal of casing or insulation is not necessary.
Internal Inspection System for Boiler Tubes

**Inspection Procedure**

Revolving ultrasonic probe is inserted to tubes full of water from 2 cut points. Tube thickness and defects can be inspected continuously for entire tube circumference and length.

**Features**

1. Narrow space which is impossible to access can be inspected without lifting panels.
2. Inspection from tube inside eliminates the need for boiler tube polishing and scaffolding.
3. Boiler tubes can be measured continuously for entire tube circumference and length.
4. Residual life of boiler tubes can be evaluated and displayed in color.

Example of Inspection Result Display

(Measurement of wall thickness)

Now > 5 years later

-MRT: Minimum Required Thickness

-Now (Thickness)

-Operation time

(Circumference 360°)

-Root crack

-Sleeve bead

-Spread picture of after take off weld Bead

Testing of cracks (roots crack root crack)

-360° 0°

-Weld bead toe crack root crack
**5 Tube Thickness Measurement Robot for Horizontal Element**

### Inspection Procedure

Cleaning and inspection equipments enter narrow space between two Horizontal panels and clean and inspect automatically.

1. Cleaning
2. Thickness measurement
3. Moving to next tube

### Features

1. Narrow space can be inspected without lifting panels.
2. Cleaning and inspection is performed automatically.
3. Residual life of boiler tubes can be evaluated and displayed in color.

### Example of Inspection Result Display

- **Now**
- **5 years later**

**Operation time**

- **MRT**: Minimum Required Thickness
- **Original thickness**
- **Now**
- **5 year later**

**Tube thickness**

![Image of inspection result display]
6 Ash-erosion Monitoring Equipment

Inspection procedure

All area in horizontal panels can be inspected and tube thinning can be quantified by laser-Sectioning method using laser-slit projector and small CCD camera.

Features

1. As ash-erosion monitoring machine can inspect the narrow space, it is not necessary to cut tubes and lift panels.

2. As this machine can be used under atmospheric-temperature 100°C in furnace, early inspection is possible after boiler stopping.

Example of Inspection Result Display

Name: primary superheater panel No.224

Result of panel inspection

Result of tube inspection
High Accuracy Crack Measuring Equipment by TOFD Technique

Principle of TOFD Technique

TOFD technique obtains the crack height by measuring the propagation delay time of diffraction waves from the tip of the crack with two transmitting and receiving probes placed at equal distance from the crack.

Features

1. High accuracy of measuring crack dimensions.
   (Thin wall pipe: 0.2mm, Thick wall pipe: 0.8mm)
2. Capable of distinguishing and quantifying cracks, making it possible to classify crack types.
3. Capable of detecting microcracks before occurrence of cracks.
4. Eliminated human errors.

Results of Verification Test by TOFD Technique

Example of examination result display

- Photo 1: Tomoscan
- Photo 2: Results of measurement
Example of inspection of actual plant

Result of inspection by TOFD

Test Sample

Cross section picture

Representative example of detected defect by TOFD technique

Sphere type defect

Blowhole type defect

Check type defect
Type IV Cracking; The Typical Creep Damage of CrMo Welds

(ToFD is useful for its detection.)

Types of Creep damages in CrMo Welds

- **Type I**: Cracks in weld metal
- **Type II**: Cracks in coarse grain HAZ
- **Type III**: Cracks in fine grain HAZ or partially transformed HAZ

**Characteristics of Type IV Cracking**

- Creep damage, which tend to come about on materials with higher amount of trump elements.
- Cracks propagate on grain boundaries of ferrites which have transformed from bainites.
- Cracks tend to initiate at the interior of wall and to grow toward surface.

**Schematic Diagram of HAZ in CrMo steel**

**Types of Creep damages in CrMo Welds**

- Peak Temperature (Tp)

**Characteristics of Type IV Cracking**

- Creep damage, which tend to come about on materials with higher amount of trump elements.
- Cracks propagate on grain boundaries of ferrites which have transformed from bainites.
- Cracks tend to initiate at the interior of wall and to grow toward surface.

**Case 1**

TVA Colbert Unit 5, USA; Leakage at Main Steam Pipe (1978)

- Material: 0.5Cr-0.5Mo-V
- Temperature: 660°C
- Operation Hours: 75,000h

**Case 2**

A Unit, Japan; Cracks at seam weld of a Elbow of Main Steam Pipe (1990)

- Material: 2.25Cr-1Mo
- Temperature: 575°C
- Pressure: 177.5kgf/cm²
- Operation Hours: 145,000h
Power Boiler Safety Features and Technical Development

by

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Boilers & Pressure Vessels Division, Labour Department, Hong Kong
Mr. Jesson has worked for Mitsui Babcock for forty years. He joined the Company in 1956, graduated from London University in Mechanical Engineering in 1959 and, after completing a number of training assignments, took up his first appointment with the Company as a Field Service Engineer. In 1965 he was responsible for the commissioning of the first supercritical steam generator in the UK for large scale electricity generation. In 1969 he joined Mitsui Babcock's design department and has since occupied a number of posts managing design and engineering functions until appointment as Manager of Development and Computer Aided Design in 1995.
Power Boiler Safety Features and Technical Development.
by JE Jesson, Mitsui Babcock Energy Limited

1. SYNOPSIS

The continuing commercial evolution of the electricity supply business has been accompanied by some significant technical developments in the design of boilers for natural gas fired combined cycle generating plants and for solid fuel fired steam cycles.

This paper describes some of these under the headings of Heat Recovery Steam Generators (HRSGs) for Combined Cycle Plant and Coal Fired Boilers and highlights features to improve the safety and reliability of pressure and firing systems.

The importance of recognising and designing for cycling and two-shifting duties is stressed by reference to the analysis of the HRSGs operating in China Light & Power's 2500MWe CCGT station at Lan Kok Tsui (Black Point) and designs for natural Circulation and Pumped Circulation HRSGs for triple pressure reheat steam cycles are compared.

Reference is also made to developments in the firing of pulverised bituminous coals and anthracites in large capacity units especially to meet increasingly more stringent requirements for low NOx emissions without worsening combustion efficiency.

In conclusion, some features of advanced pulverised coal fired plant are reviewed as this type of plant is developed to remain competitive with Integrated Coal Gasification.

2. INTRODUCTION

The privatisation of state owned Electricity Generating Companies and the search for capital for new plant construction by encouraging Independent Power Producers are significant changes to the worldwide electricity business. These changes alter the way that Power Stations are managed and staffed and their daily priorities. In general these changes mean fewer staff in all areas and a keener and more competitive approach to plant operation and maintenance and they raise questions about safety.

These changes are flowing through to the equipment manufactures. They appeal as increased emphasis on low prices and plant reliability as plant operators attach greater importance than hitherto to achieving the budgeted financial returns from the investments that they and their partners have made. Running cost and efficiency remain important since fuel cost is such a large proportion of through life plant cost. However, there is little to be said for a highly efficient plant which is not in operation and therefore not generating revenue. The demand for return on investment has also made short construction programmes attractive. CCGT plant is attractive in these circumstances, requires a low staffing level and can attain a high thermal efficiency. Manufacturers have responded by developing large capacity gas turbines and HRSGs for dual and triple pressure steam cycles to go with them. With little experience to call on, units intended for system frequency control and two-shifting require careful analysis by the equipment designers to ensure long term performance and plant integrity are achieved.

The dash for gas has not halted the development of coal fired plants for the sufficient reason that in some areas gas is not readily available whereas coal is plentiful and the mining and transport infrastructures are in place to bring it to point of use. In the United Kingdom a policy of "coal by wire", ie transmitting generated electrical energy through a grid system, has been preferred to the long distance shipping of coal or piping of natural gas.
In a number of countries, the use in central power stations of lower grade coals which are not suitable for export has continued to expand, and the large scale use of coal in power stations provides a more cost effective opportunity to limit emissions. Pressure to reduce the use of premium fuels for ignition support has continued, increasing the importance of monitoring to avoid hazards from combustion systems which directly affect the safety of personnel and a plant's fitness to continue to generate revenue. MBEL have responded with improved combustion systems for Bituminous Coals and Anthracites.

Integrated Coal Gasification Combined Cycle systems offer the prospect of clean, fuel efficient electricity generation, but the technology is not yet sufficiently mature to be adopted widely in new plant construction. Nevertheless, the prospect of its development to this state has been a source of encouragement to those concerned with the development of high pressure and high temperature steam cycles utilising more conventional firing technologies to push forward with better process design and with the testing of improved materials and new methods of joining and forming components. Once-through Benson boilers can now incorporate ribbed tubing for furnace wall construction. Used in the right way, this reduces overall pressure losses and simplifies construction. In the United Kingdom, a high performance austenitic steel, used for many years to deal with a unique combination of 568°C steam temperature and an aggressively corrosive coal ash has the properties needed in advanced plant.

3. HRSGS FOR COMBINED CYCLE PLANT

Many HRSGs have been built to recover heat from the hot exhaust gas stream from Power Gas Turbines and generate steam. The HRSGs in early installations were required predominantly to operate under relatively steady load conditions, indeed many were equipped with firing systems to supplement the Gas Turbine (GT) exhaust energy at reduced output to sustain a steady steam supply. Furthermore, gas bypass stacks were generally installed to enable open cycle operation. With gas diverting dampers installed, this feature enabled gas flow through the HRSG to be increased as required on start-up.

Few of today's purchasers look for the option to operate in open cycle mode and most now require HRSGs to be installed without a gas bypass stack. At the same time the HRSG is expected to impose a minimum of restraints on start-up, load changing and shutting-down of the associated GTs, which are capable of very rapid load change rates and exhibit some rather unwelcome characteristics for the HRSG whilst being put on and taken off line. Furthermore, it seems to be accepted that GT components may be periodically renewed, but that for all boiler parts this should not be necessary.

3.1 HRSG Design for Cycling Duties.

The CCGT plant for Black Point will be mid-merit plant for most of its operating life with frequent two-shifting in addition to having a base load capability. A design based on steady load conditions only would not have been sufficient to ensure that these requirements could be met in the equipment installed.

If purchasers are to ensure a reliable return on their investments, good design and effective assessment will both assume critical importance in ensuring that the amount of damage to pressure parts is acceptable so that the plant will achieve both the required lifetime and target through-life costs.

The steady load operating requirements were derived in the normal way from the Gas Turbine (GT) steady state operating behaviour, as set down in Table #1.
Additionally a clearly defined set of transient events was provided by China Light & Power to represent through-life operation. These are set down in Table #2. Each of these was represented by a schedule of GT exhaust flow and temperature conditions. MBEL set about designing the HRSG to suit and by a comprehensive analysis have been able to demonstrate that the necessary endurance has been built-in to the HRSG pressure systems to last throughout the plant life.

### Table #1 - Base Load Operating Conditions for Gas Fuel.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT Exhaust Gas Flow</td>
<td>575 kg/s</td>
</tr>
<tr>
<td>GT Exhaust Gas Temperature</td>
<td>613 °C</td>
</tr>
<tr>
<td>HRSG HP Steam Output</td>
<td>92 kg/s</td>
</tr>
<tr>
<td>HRSG HP Steam Temperature</td>
<td>536 °C</td>
</tr>
<tr>
<td>HRSG HP Steam Pressure</td>
<td>106 bara</td>
</tr>
<tr>
<td>HRSG LP Steam Output</td>
<td>13 kg/s</td>
</tr>
<tr>
<td>HRSG LP Steam Temperature</td>
<td>5.4 bara</td>
</tr>
<tr>
<td>HRSG LP Steam Pressure</td>
<td></td>
</tr>
<tr>
<td>Condensate Return Temperature to HRSG</td>
<td>287 °C</td>
</tr>
<tr>
<td>Gas Static Pressure at Inlet to HRSG</td>
<td>285 mbar</td>
</tr>
</tbody>
</table>

3.2 HRSG Arrangement.

There are some important features of the HRSGs for Black Point HRSGs which contribute to their suitability for cycling and base load duties. The general arrangement is shown in the sectional side elevation of the HRSG at Figure #1.
Power Boiler Safety Features and Technical Development

Figure #1 - Elevation of HRSGs for Black Point Power Station

Figure #2 - Temperature Head Diagram Base Load Firing Natural Gas
Gas System:
The HRSG inlet diffuser is arranged to decelerate the GT exhaust gas flow and with the HRSG inlet bend to present a reasonable distribution of flow to the HRSG heat transfer surfaces. The silencer necessary to attenuate the GT exhaust noise is supported above the HRSG before the gas enters the outlet duct to the chimney. A damper is provided here to stop gas flow during outage times and thereby conserve energy. This is particularly important because of the height of the chimney, which is capable of a substantial natural draught, to avoid repeated cooling and de-pressurization of the HRSG and the resultant fatigue damage.

Steam and Water Systems:
Condensate is pumped from a water cooled condenser via a Low Pressure (LP) economiser to a deaerator. In order to prevent corrosion from acidic condensation on the heat transfer surfaces of the LP economiser, a flow of hot water, controlled to suit the dew point and taken from the deaerator, is added before entering. Additionally, a bypass line is used when oil firing to stop any water flowing in the LP economiser and to ensure that the deaerator is fed with water sufficiently below saturation to ensure its Oxygen removal performance.

The deaerator receives its steam supply directly from the HRSG LP steam drum and therefore operates at the same pressure. LP and High Pressure (HP) feed pumps transfer water from the deaerator directly to the LP steam drum and via an HP economiser to the HP steam drum. An integral deaerator would not have allowed the use of any solid reagents for LP evaporator chemical dosing. Treatment with solid reagents was considered important to ensure that water phase pH within the LP evaporator would be high enough to prevent erosion corrosion damage to pressure parts. Although "all volatile" treatments have been used successfully, return tube bend failures have been experienced in some plant.

The temperature head diagram in Figure #2 illustrates the pinch points and approach temperatures characteristic of this type of boiler. The extended surface used here is partly cut spirally wound finning, attached to the outside of the tube by a high frequency resistance weld. Production rates and quality have fully justified this product, which is used in all zones of the HRSGs. In fact at an early stage of the project, an accelerated creep test was successfully concluded on samples of finned tubing produced to the specified manufacturing standard, proving the necessary fatigue endurance.

Mechanical Aspects:
The mechanical design of the Black Point HRSGs dominates in the matter of fatigue. The heating surfaces are top supported, one below the other, by sets of un-cooled links and spectacle plates from transverse beams spanning the tops of the main structural steel columns. Thermal expansion is downwards and outwards. The supports run at local gas temperature.

The HRSG pressure casing is externally insulated and top supported from the same transverse beams. Thermal expansion is also downwards and outwards and matches that of the heating surface modules excepting some lag during transient conditions. These differential movements are handled by flexible seals at pipe penetrations. All headers are within the gas pressure casing although outside the gas flow path.

Each bank of heating surface is delivered and erected as four modules. In most cases the outlet headers for each module are separate with one or two radial outlet nozzles, whilst inlet headers are arranged for end flow and prepared for butt welding during erection. The axial expansion of inlet headers effectively controls relative lateral module positions.
Subdivision of the outlet headers is used to limit bending loads, which would otherwise be imposed by accumulated header versus module expansions, in both inlet and outlet tube to header welds without the need for long tube stubs.

Both LP and HP steam drums are supported by the steel structure. The suspension of circulating pumps in the pipe-work which forms the evaporator circulating system enables it to be arranged easily with sufficient flexibility and low end nozzle loads without excessive route lengths. Short, direct suction pipework also cases limits on permissible rates of depressurization of the evaporators.

The other interconnecting pipe-work, including the HP attemperator system, are similarly arranged to moderate loads at end connections with header, manifold and other welded junctions. It will be shown later that the HP steam drum, parts of the HP attemperator system and HP Secondary superheater outlet headers are components which experience significant thermally induced stresses.

As the need for flexibility was foreseen at an early stage in the development of the design, it was easy to build in measures to ensure an adequate fatigue endurance. Furthermore, during manufacture, welding standards and inspection levels were checked and raised as appropriate to ensure that the basis upon which the fatigue assessments were made corresponded with the condition of the as-built plant.

3.3 Fatigue Assessment.

The methods chosen to assess fatigue are those contained within Enquiry Case 5500/79 May 1988 to BS5500:1988 Issue 2 February 1990. It was accepted that notwithstanding the restriction of 375°C for ferritic steels, the enquiry case would be adopted for higher temperature components forming the superheater outlet. It was also agreed that to combine the effects of creep and fatigue, a creep-fatigue interaction diagram from N47 for 2.25% Chrome steel would be adopted in the final assessment.

Dynamic Performance Calculations:

At the outset it was clear that because of the unusually demanding service conditions the HRSG could not be exempt from the general requirement to perform a fatigue analysis on the basis of "satisfactory experience of strictly comparable service". However, a useful number of components met the conditions of Clause 2.2 due to their low working stress.

In the event, most HRSG components met the requirements of Clause 2.3. Even for this it was necessary to identify the operational events experienced by the HRSG in sufficient detail to quantify stress ranges and their frequencies as illustrated by Figure 2 of the code case.

Dynamic calculations were already being undertaken to generate curves of start-up and shut-down behaviour. These were aids to investigate variations and extremes of water level in the two steam drums and to confirm the selection of water level control valves, in particular a valve used to discharge water from the LP drum during start-up.

The amount of information required for dynamic calculations can be prodigious. The calculation method used for this work required substantially less data. Results were generated for a real time operation extending over 3-hours in the space of about 4-minutes.

In HRSGs, drum water level varies widely. Considerable care has been taken to predict the correct steam volumes and water displacements along the horizontal evaporator tubes, in part by calculating tube heat absorptions row by row, but also by incorporating slip allowances for differential velocities between the phases depending on conditions.
Routines were included to model the dynamic characteristics of the control functions and control valve stroke times in order to show their influence on plant performance and to develop specifications for these valves. The drum water level overflow control and feed valves and the HP spray attemperator controls were all put into the model. Control systems outside the normal scope of the HRSG, like turbine bypass valves and deaerator controls, were also included as all these impact the fatigue assessment.

**Results of Dynamic Calculations:**
Curves with a time base provide the most convenient way to show results. As is shown later all the operating events were calculated. Figures #3 and #4 illustrate the HRSG HP section behaviour during a routine shut-down and hot start-up eight hours later.

(a) As soon as the superheater outlet steam temperature starts to fall the HRSG HP steam output is diverted to a steam bypass system. The unloading ramp ensures that the HRSG outlet parts are cooled sympathetically before the GT exhaust temperature finally plunges after fuel trip, and condensate formed in the superheater tubes runs into the outlet headers.

(b) In the first 30-minutes of the hot start, a falling and rising pressure is due to the purging and subsequent fuel ignition sequences of the GT. Water level rises markedly at the beginning of this period due to the steam production needed to satisfy condensation in the HP Superheater induced by the purge air flow and causing the pressure to fall.

(c) At 32 minutes, as soon as pressure reaches the bypass set point, steam is delivered from the now hot secondary superheater tubes into the superheater outlet parts causing a rapid rise in temperature. This is the principal cause of thermal stress upon start-up in the Primary and Secondary Superheater outlet parts. This flow step induces a surge in the HP drum water level, which had been set to low in anticipation.

(d) At 37 minutes, recirculation of water to the HP Economiser inlet is discontinued after a sufficient feed flow is reached to prevent steaming. The valve has a slow travel time to limit thermal stress in the pipework system.

(d) At 65-80 minutes, as the final stages of GT loading are completed and the HRSG output rises towards full capacity, the peak GT exhaust temperature is encountered, causing a high spray rate for superheater temperature control.

**Output for Fatigue Assessment:**
Output has been generated for the assessment of two groups of components:
(i) High temperature group, comprising the HP Superheater outlet parts.
(ii) Lower temperature group, comprising the remainder of the HP section and the LP Economiser, which could not meet the requirements of Code Case Clause 2.2.

For the high temperature group, significant creep was expected coupled with some wide thermal stress ranges due to the situation of the superheater outlet tubes at the gas inlet to the HRSG. Here, rates of gas temperature change are clearly the greatest and condensate is formed during shut-down. Full 3-dimensional Finite Element Analysis was employed for this work, modelling tube to header, drain point to header and outlet nozzle to header junctions. For this work, the dynamic model provided schedules of steam temperature and pressure and steam side heat transfer coefficients, which depended on steam mass flow rates and the presence of condensate in these parts of the HRSG.

For the lower temperature group, the data management and calculations required by Enquiry Case 5500/79 were automated by creating schedules of flows, temperatures and pressures at each header location and at the HP Drum for each of the defined operating events. These data were stored on disc and subsequently called up for the fatigue damage calculation.
Power Boiler Safety Features and Technical Development

Figure #3 - HRSG Normal Shut-down Behaviour

Figure #4 - HRSG Start-up After 8-Hour Outage
Preparations for Fatigue Damage Calculation:
Enquiry Case 5500/79 introduces the "Alternative procedure for assessment of vessels subject to fatigue" by setting down five examples of sources of cyclic or repeated stresses to which pressure vessels may be subjected:

(a) fluctuations of pressure
(b) temperature transients
(c) restrictions of expansion or contraction during temperature variations
(d) forced vibrations
(d) variations in external loads

Vibration warrants particularly careful attention since relatively small stress fluctuations could cause fatigue cracking to occur. The design policy for MBEL HRSGs therefore has been to eliminate vibration as a mode of fatigue by specific anti-vibration measures based upon well established assessment criteria and experience, bearing in mind the powerful source of stimulus available in the exhaust of the GT.

In order to assess the fatigue endurance of every structural detail, a classification based on component type was devised, based on Figure #5. Five "Basic Component Types" were necessary; Drum, Header, Pipe, Tube and Manifold, each characterised by an appropriate set of details with its fatigue classification, based on the manufacturing procedure, to select the correct S-N curve from Enquiry Case 5500/79. For example:

Basic Component Type: Drum shell.
Component details:
- Longitudinal weld outer surface, class 'D'
- Longitudinal weld inner surface, class 'D'
- Circumferential weld outer surface, class 'D'
- Circumferential weld outer surface, class 'D'
- Drum nozzle inside crotch corner, class 'C'
- Drum to nozzle weld at toe on drum, class 'E'

Note that these details are for the drum shell only. Other details such as those associated with nozzles are classified under the Basic Component Type 'Pipe'.

Assessment Procedure:
By providing particulars of where, and in which pressure system of the HRSG, the component is located with component geometry, ligament efficiency, design pressure and flow connections, the computation of pressure, pressure related and thermal stresses can proceed by referring to the appropriate schedules of operating conditions generated by the dynamic calculations.

The pressure, pressure related and thermal stresses are summed algebraically so as to calculate the greatest stress ranges, ie rising pressure and temperature both give positive values of stress. The schedules of operating conditions are selected in turn, always commencing with the HRSG operating at 100% base load, as follows:

- Shut-down from base load followed by a start-up from cold.
- Shut-down from base load followed by a warm start.
- Shut-down from base load followed by a hot start after 8h.
- Shut-down from base load followed by a hot start after 12h.
- Trip from base load followed by an immediate restart.
- Load reduction from base load and return to base load.

Figure #6 shows an example of the results for the Steam Swept Portion of the HP drum.
**Rainflow Counting:**

For fatigue summation, the entire operating scenario was arranged as six groups of cyclic operations always commencing with the CCGT at full load. These are shown in Table #3. The first group contains every type of operating cycle, and is therefore repeated only as often as the least frequent cycle. The second group contains every type of cycle except the least frequent, which has been accounted for in the first group, and is therefore repeated as often as necessary to account for the balance of the occurrences of the second least frequent cycle. Further groups are set up similarly until all cycles are accounted for. The last group contains the most frequent cycle only.

<table>
<thead>
<tr>
<th>Table #3 - Arrangement of Plant Operations for Fatigue Summation.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group</strong></td>
</tr>
<tr>
<td>-------------------------</td>
</tr>
<tr>
<td>Shut-down and Cold Start</td>
</tr>
<tr>
<td>Shut-down and Warm Start</td>
</tr>
<tr>
<td>Shut-down and Hot Start</td>
</tr>
<tr>
<td>Shut-down and Hot Start</td>
</tr>
<tr>
<td>Unfired Trip and Hot Restart</td>
</tr>
<tr>
<td>Load Cycle between 100%-40% base load</td>
</tr>
</tbody>
</table>

In "rainflow", as in "reservoir", fatigue summing methods, a diagram is used as the basis of the mechanism. Each group above may be seen as one such diagram, and the total fatigue aggregated according to the number of events and the stress ranges within it. Figures #6 and #7 show sample figures for the HP Steam Drum for Groups 1 and 5 respectively.

**Results of Fatigue Assessment:**

The results presented for each component show the fatigue damage associated with each of the pre-set range of weld or crotch details and the allowable damage calculated as a function of the component thickness where the toe of a branch weld is present, all in accordance with EC5500/79. Should a detail show less than the required endurance, several possible courses of action are open to improve matters. If the detail is associated with the toe of a branch weld, locally machining or dressing the toe to reduce stress concentration and remove inherent flaws can increase fatigue life. If the principal cause is thermal stress range, then a review of modulating control action or a moderation of GT exhaust conditions may be possible.

If these approaches are not possible or sufficient, then more rigorous computational techniques using finite element methods will need to be adopted to come to more definitive conclusions.

For the Black Point HRSGs, the Superheater Outlet Header details required a full 3-dimensional Finite Element Analysis reliably to calculate the stress ranges brought about by the different GT operating schedules.
Note: For steam drums, details as shown plus longitudinal welds.

Figure #6 - HP Steam Drum Longitudinal Weld Stresses

Basis of Rainflow Calculations
(Steam swept portion)

Stress N/mm²

550 500 450 400 350 300 250 200 150 100 50 0

Events: 1 to 6 7 to 10 11 to 15 16 to 20 21 to 25 26

Shut down and cold start Shut down and warm start Shut down and hot start Shut down and hot start Unfired load cycle and restart

Full range of stop-start and load cycles, (n=100)
Table #4 lists the assessment results for the HP Steam Drum and Attemperator Outlet system components and gives fatigue damage as a percentage of that allowed by EC5500/79. Where components operate above 375°C, a creep fatigue interaction diagram has been used to derive a maximum allowable creep damage fraction. The assessment of creep in service has then enabled a conclusion to be reached as to fitness for long term operation. In Table #4, components are listed in ascending order of margin allowed and calculated fatigue damage.

Table #4 - Examples from Results of Fatigue Assessment

<table>
<thead>
<tr>
<th>HP Primary Superheater Outlet Headers:</th>
<th>Fatigue Damage</th>
<th>Permissible Creep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header butt weld outer surface, class 'D'</td>
<td>12.1%</td>
<td>12%</td>
</tr>
<tr>
<td>Header butt weld inner surface, class 'F2'</td>
<td>42.7%</td>
<td>8%</td>
</tr>
<tr>
<td>Header/branch crotch corner, class 'C'</td>
<td>7.6%</td>
<td>44%</td>
</tr>
<tr>
<td>Header tube hole crotch corner, class 'C'</td>
<td>7.6%</td>
<td>44%</td>
</tr>
<tr>
<td>Header/branch weld at toe on header, class 'F'</td>
<td>35.6%</td>
<td>9%</td>
</tr>
<tr>
<td>Header/tube weld at toe on header, class 'F'</td>
<td>35.8%</td>
<td>9%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Branch to HP Attemperator Outlet Tee:</th>
<th>Fatigue Damage</th>
<th>Permissible Creep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Branch weld at toe on nozzle, class 'E'</td>
<td>32.1%</td>
<td>9%</td>
</tr>
<tr>
<td>Branch weld at root face, class 'F'</td>
<td>29.3%</td>
<td>10%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Main from HP Attemperator Outlet Tee:</th>
<th>Fatigue Damage</th>
<th>Permissible Creep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manifold butt weld, outer surface, class 'D'</td>
<td>8.9%</td>
<td>35%</td>
</tr>
<tr>
<td>Manifold butt weld, inner surface, class 'F'</td>
<td>31.7%</td>
<td>9%</td>
</tr>
<tr>
<td>Pipe branch crotch corner, class 'C'</td>
<td>4.5%</td>
<td>67%</td>
</tr>
<tr>
<td>Branch weld at toe on pipe, class 'E'</td>
<td>22.4%</td>
<td>11%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HP Steam Drum - Steam Swept Portion:</th>
<th>Fatigue Damage</th>
<th>Permissible Creep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal weld outer surface, class 'D'</td>
<td>30.3%</td>
<td>NA</td>
</tr>
<tr>
<td>Longitudinal weld inner surface, class 'D'</td>
<td>30.3%</td>
<td>NA</td>
</tr>
<tr>
<td>Circumferential weld outer surface, class 'D'</td>
<td>12.6%</td>
<td>NA</td>
</tr>
<tr>
<td>Circumferential weld inner surface, class 'D'</td>
<td>12.6%</td>
<td>NA</td>
</tr>
<tr>
<td>Drum/nozzle weld crotch corner, class 'C'</td>
<td>19.3%</td>
<td>NA</td>
</tr>
<tr>
<td>Drum/nozzle weld toe on drum, class 'E'</td>
<td>27.9%</td>
<td>NA</td>
</tr>
</tbody>
</table>

**3.4 Influence of Cycling and Two-shifting on HRSG Selection.**

Combined creep and fatigue occurs only in the outlet parts of most HRSGs because temperatures are too low elsewhere. Here provisions in the design, attention to operational matters, including adequate drain connections, and on-line monitoring systems, are essential to enable these components to survive reliably throughout plant life.

Throughout the lower temperature sections of HRSGs mechanical flexibility to reduce self imposed system loads which act on pressure part welds is required to combat fatigue. The compact designs which have evolved in process steam installations represent a liability for electricity generators expecting to work in a load changing environment. Full penetration welds are required in most areas to handle the practical minimum residual system loads even with a good pressure part layout.

The damage predicted for the water swept portion of the HP drum is principally due to shell thickness. Increasing thickness increases damage. This endorses the use of BS1113 for design and high strength plate such as BS1501-271B for drum construction. See also section 4.2 below.
Power Boiler Safety Features and Technical Development

Figure #7 - HP Steam Drum Longitudinal Weld Stresses

Basis of Rainflow Calculations
(Steam swept portion)

<table>
<thead>
<tr>
<th>Stress N/mm²</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>550</td>
<td>1 to 8</td>
</tr>
<tr>
<td>500</td>
<td>7 to 10</td>
</tr>
<tr>
<td>450</td>
<td>11 to 15</td>
</tr>
<tr>
<td>400</td>
<td>16 to 20</td>
</tr>
<tr>
<td>350</td>
<td>21 to 25</td>
</tr>
<tr>
<td>300</td>
<td>26</td>
</tr>
</tbody>
</table>

Events:
- 1 to 6: Shut down
- 7 to 10: Shut down and cold start
- 11 to 15: Shut down and warm start
- 16 to 20: Shut down and hot start
- 21 to 25: Shut down and hot start
- 26: Utilised trip and cycle restart

Part range of stop-start and load cycles, (n=1200)

Figure #8 - Elevation of HRSGs for Keadby Power Station
In these areas thermal stresses due to through-wall or point to point temperature differentials are low, but stresses due to pipework movements and module growth differentials must be attended to by thoughtful design if a satisfactory fatigue endurance is to be achieved.

Creep damage during start-up and shut-down is minimal, and arises predominantly during on-load operation. The assessment has shown that there is no significant restriction in any of the components where creep damage limit has been identified. This is principally because margins were included in the determination of thickness to allow for this situation.

3.5 Design for Triple Pressure and Reheating HRSG.

The design analysis of the vertical gas flow pumped circulation design for Black Point has shown clearly that this type of design is well suited to load mid-merit and base load operating conditions. The triple pressure boiler and steam reheating unit for Keadby shows how the same type of HRSG can be designed equally well for a high performance cycle.

Figure #8 is a sectional side elevation of one of the two the HRSGs in this 660MWe plant, which was commissioned in 1993.

3.6 Natural Circulation HRSGs.

There has been a long record of successful operation with horizontal gas pass HRSGs with vertical tube natural circulation evaporators. To simplify construction, these have been internally insulated to create a cool external steel casing which can be very simply bottom supported. These units, built behind smaller capacity gas turbines, are frequently delivered in compact sub-assemblies. This type of layout at larger sizes and for cycling conditions requires new features to avoid the difficulties seen in earlier installations. MBEL have designed horizontal pass natural circulation HRSGs to meet the requirements of those in favour of this configuration. These have included the triple pressure and reheating type for a 220MWe class Gas Turbine as illustrated in Figure #9.

4. PULVERISED COAL FIRED BOILERS

Legitimate concerns over emissions into the atmosphere have lead to enforceable limits being imposed on the operation of Power Stations. The manufactures of boilers and combustion systems and flue gas cleaning equipment have responded to this situation by developing emission control equipment which can be retro-fitted to existing plant and installed in new.

4.1 NOx Control Systems.

MBEL have delivered several sets of Axial Swirl Low NO\textsubscript{x} Burners to the coal fired boilers at Castle Peak which have significantly reduced emissions. On some coals the reduction has been about 70% of the pre-retrofit level. Figure #10 shows that the reduction is related to the volatile content of the fuel. The fuel Nitrogen content has a greater influence on the actual level achieved.

**Bituminous Coals:**

Both the earliest and the most cost effective method of controlling NO\textsubscript{x} emission is by combustion modification. Oil and gas fired boilers were ordered to a MBEL design for Torrens Island 'B' Power Station near Adelaide in South Australia in 1975 in which NO\textsubscript{x} was reduced by mixing flue gas with combustion air, known as 'gas mixing' and by 'furnace staged combustion', in which the air to the burners was less than the theoretical amount, and the balance of total air was supplied through 'after air ports' built into the furnace walls above the burners. At that time staged burners for low NO\textsubscript{x} combustion were in their infancy.
Figure #9 - MBEL Natural Circulation HRSG

Figure #10 - NOx Reductions at Castle Peak 'B' Power Station

% reduction in NOx emission

% volatile in dry and ash free coal

Range of reduction
In 1981 MBEL started a burner development programme to improve reliability, to eliminate burner components needing frequent replacement such as the fuel diffuser, and to meet the requirements of a very poor high ash bituminous coal mined in South Africa. The highly stabilised axial swirl burner which emerged provided an ideal basis for a low NOx burner.

Our target was to develop a burner to retrofit existing boilers with a low NOx capability without significant pressure part modifications or changes to air pressure losses. Others' burners offered NOx reductions but were complex, physically larger and had higher pressure losses because of inefficient swirl generators.

MBEL built a full scale 65MWe test firing rig at its works in Renfrew to optimise the design. This facility is still used to prove burners of novel size or intended for an unusual fuel. The 60-burner installation at Drax Power Station in Boiler No 6 proved the Low NOx Axial Swirl Burner (LNASB) performance and provided a demonstration which has enabled the sale of LNASBs for over 19,000MWe of boiler plant. The burner is shown by Figure 11.

At Castle Peak 'B', a natural gas firing capability has been added to the LNASBs on two boilers.

Our development programme has continued with a more advanced Low NOX burner. This burner is capable of greater NOx reductions than the existing Mark III version, and a lower Carbon in Ash level. This will increase the opportunities to meet emission levels without need for two stage combustion. Figure #12 shows performance results.

**Low Volatile Bituminous Coals:**

There are many power plants having to use premium fuels, such as light oil, in order to maintain ignition of poor quality Bituminous Coals. Trials this year have demonstrated that the new MBEL Low NOx Burner can fire and maintain a stable efficient flame over a wide load range with coals of 16% volatile matter on a dry ash free basis without the need for any support fuel. Further tests will take place in the near future to prove operation with coals of even lower volatile levels.

**Downshot Firing Systems:**

Anthracites and semi-anthracites contain very low levels of volatile material. To obtain stable ignition and burn-out, firing systems which generate high furnace gas temperatures are required. The low volatile content itself, as well as the high temperature in the furnace, make the attainment of low NOx levels very difficult. This is recognised in European legislation, which sets a limit of 1300mg/Nm³ for solid fuel with volatile matter less than 10%. Table #5 shows the results of test work at a Power Station in the United Kingdom where some very encouraging NOx reductions have been secured firing low volatile coal.

<table>
<thead>
<tr>
<th>Boiler Test Results:</th>
<th>Baseline Results</th>
<th>Low NOX Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx - ppm @ 5% Oxygen dry</td>
<td>547</td>
<td>383</td>
</tr>
<tr>
<td>CO - ppmv</td>
<td>30</td>
<td>80</td>
</tr>
<tr>
<td>Carbon in Ash - %</td>
<td>13.8</td>
<td>11.7</td>
</tr>
</tbody>
</table>

4.2 Advanced Natural Circulation Drum and Once-through Boilers:

The trend to higher operating pressures to improve power station efficiency has continued. Drum boilers are capable of generating superheated steam at up to 183bar and the maximum pressure of Once-through boilers is limited only by the availability of suitable materials for construction of the pressure parts.
Power Boiler Safety Features and Technical Development

Figure #11 - Section of Mark III Low NOx Axial Swirl Burner

Figure #12 - Improvement in Low NOx Burner Performance

Low NOx Burner Performance - Mark III and Mark V

![Graph showing NOx emissions vs. furnace exit oxygen for Mark III and Mark V burners.]

Average unburned loss with Mark V Burner - 0.3%
Average unburned loss with Mark III Burner - 1.3%
Table #6 sets down for comparison the steam data for three operating plants designed by MBEL.

Table #6 - Steam Conditions at Castle Peak 'B', Meri Pori and Drax

<table>
<thead>
<tr>
<th>Boiler Design Conditions:</th>
<th>Castle Peak 'B'</th>
<th>Meri Pori</th>
<th>Drax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location of plant</td>
<td>Hong Kong</td>
<td>Finland</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>Nominal plant capacity, MWe</td>
<td>678</td>
<td>550</td>
<td>660</td>
</tr>
<tr>
<td>Main steam flow, kg/s</td>
<td>582</td>
<td>440</td>
<td>563</td>
</tr>
<tr>
<td>Superheater outlet temperature, °C</td>
<td>541</td>
<td>540</td>
<td>566</td>
</tr>
<tr>
<td>Superheater outlet pressure, MPa</td>
<td>17.0</td>
<td>24.0</td>
<td>16.6</td>
</tr>
<tr>
<td>Feedwater temperature, °C</td>
<td>252</td>
<td>265</td>
<td>252</td>
</tr>
<tr>
<td>Reheater outlet flow, kg/s</td>
<td>505</td>
<td>397</td>
<td>436</td>
</tr>
<tr>
<td>Reheater inlet pressure, MPa</td>
<td>4.1</td>
<td>4.8</td>
<td>4.3</td>
</tr>
<tr>
<td>Reheater inlet temperature, °C</td>
<td>335</td>
<td>299</td>
<td>365</td>
</tr>
<tr>
<td>Reheater outlet temperature, °C</td>
<td>539</td>
<td>560</td>
<td>560</td>
</tr>
</tbody>
</table>

Notes to Table #6:

The four boilers at Castle Peak are each equipped with low NOx burners in an un-staged furnace. The plant fires a wide range of internationally traded coals from sources including China, Indonesia, Australia, South Africa and Colombia. Two boilers are equipped additionally for gas firing.

The boiler at Meri Pori is equipped with low NOx burners in a staged furnace with after air ports. A selective catalytic system for further NOx reduction is fitted. The plant fires a wide range of internationally traded coals from sources including Poland, Russia, Australia, South Africa and Colombia.

The six boilers at Drax make up the largest power station in Europe. Each is each equipped with low NOx burners in an un-staged furnace. The plant fires a range of UK coals some of which have difficult slagging characteristics. A limestone-gypsum flue gas desulphurisation plant has been retro-fitted.

There are several features necessary to obtain reliable performance at high pressures from drum boilers.

High Pressure Steam Drums:

Several years ago, a Mn-Cr-Mo-V steel marketed under the trade name of Ducol W.30 became Babcock Energy's standard drum plate material. The material is included in British Standard BS EN 10028-2:1993 Steel 271. Table #7 gives the chemical analysis and room temperature properties.

Although the material has a much higher tensility than earlier steels, the real benefits were not realized until 1967 when design codes permitted the use of the 0.2% proof stress with a safety factor of 1.6, enabling a 2210mm i.d. high pressure drum to be designed with a thickness of 140 - 150mm. In addition to the weight and cost savings, this thickness reduces thermal stresses during start-up, shut-down and load cycling and starting and eases the operational restrictions needed to avoid fatigue which characterise thicker shells made from lower strength materials.
Table #7 - Properties and Analysis of BS EN 10028-2 : 1993 Steel 271

<table>
<thead>
<tr>
<th>Steel type: Manganese - Chromium - Molybdenum - Vanadium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical composition:</td>
</tr>
<tr>
<td>Carbon</td>
</tr>
<tr>
<td>Silicon</td>
</tr>
<tr>
<td>Manganese</td>
</tr>
<tr>
<td>Phosphorous</td>
</tr>
<tr>
<td>Sulphur</td>
</tr>
<tr>
<td>Chromium</td>
</tr>
<tr>
<td>Molybdenum</td>
</tr>
<tr>
<td>Nickel</td>
</tr>
<tr>
<td>Copper</td>
</tr>
<tr>
<td>Aluminium</td>
</tr>
<tr>
<td>Vanadium</td>
</tr>
</tbody>
</table>

Mechanical Properties at room temperature for plates 75 - 150mm thick:

| Yield strength | 430 N/mm²            |
| Ultimate tensile strength | 590 to 690 N/mm² |

Superheater Tube Material Development:

In 1948 austenitic steels were used for Meaford 'B' Power Station for a steam temperature of 574°C. Although these boilers operated successfully, the first central station units with steam reheating introduced in the 1950s were built with superheater outlet steam temperatures in the range 529 - 543°C. Three boilers ordered for West Thurrock in 1959 - 1961 for 300MWe units included steam reheating to 568°C. These plants established a policy, which has continued in the United Kingdom until now, to adopt high outlet steam temperature in coal fired stations using austenitic steel for tubing and other boiler pressure components.

The development of austenitic steel resulted in the introduction of Esshete grade 1250, offering exceptionally high yield strength compared with others. Table #8 gives the chemical analysis and some room temperature properties of the steel, now included in British Standard Specifications as BS 3059:Part 2:1990 CFS215S15.

Table #8 - Properties and Analysis of BS 3059 : Part 2 : 1990 CFS 215S15
(Esshete Grade 1250)

<table>
<thead>
<tr>
<th>Steel type: 15% Chromium - 10% Nickel - 6% Manganese, Niobium, Vanadium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical composition:</td>
</tr>
<tr>
<td>Carbon</td>
</tr>
<tr>
<td>Silicon</td>
</tr>
<tr>
<td>Manganese</td>
</tr>
<tr>
<td>Phosphorous</td>
</tr>
<tr>
<td>Sulphur</td>
</tr>
<tr>
<td>Chromium</td>
</tr>
<tr>
<td>Molybdenum</td>
</tr>
<tr>
<td>Nickel</td>
</tr>
<tr>
<td>Vanadium</td>
</tr>
<tr>
<td>Niobium</td>
</tr>
</tbody>
</table>

Mechanical properties at room temperature:

| Yield strength | 270 N/mm²            |
| Ultimate tensile strength | 540 to 740 N/mm² |
Figure #13 shows the design strengths of this material compared with other steels. This steel has been in service at Drax Power Station since 1972. High performance austenitic steel is needed in the United Kingdom to deal with the corrosive effects of ash from a large proportion of indigenous coals on high temperature superheater and reheater tubes.

Amongst the other steels in Figure #13 is Steel-91 (Modified 9% Chrome). MBEL made a major contribution to a United Kingdom programme to establish welding procedures and to prove completed headers and weldments in service. By 1985 MBEL had retro-fitted six superheater outlet headers at Drakelow, and since has retro-fitted superheater and reheater headers in more than twenty other boilers. The HRSGs at Black Point are amongst the first plants to be designed specifically to take advantage of the high strength and fatigue endurance of this material.

For headers and large pipework, load cycling and start-up and shut-down events imposed by varying electrical load demand has become an increasingly important issue. Experience on a significant number of plants has revealed header damage, especially in the region between tube holes. This requires controlling thermal stresses and designing with extended creep life so that combined creep and fatigue damage is within allowable limits. The advantage of high strength materials in designing for this situation is reduced thickness. However, in the case of austenitic steel, the reduced thermal conductivity and higher thermal expansion rate are disadvantages. Figure #14 compares four high temperature alloys using a thermal stress factor plotted against temperature derived as follows:

For steady state temperature ramps, the through wall temperature gradient is:

$$\Delta T = \frac{1}{2} t^2 \cdot \rho \cdot C / k$$

where:
- $t$ = wall thickness
- $\rho$ = density
- $C$ = specific heat
- $k$ = thermal conductivity

Thermal stress is taken for fatigue assessment purposes as:

$$S_{\text{Thermal}} = 2 \cdot \alpha \cdot \Delta T \cdot E$$

where:
- $\alpha$ = coefficient of thermal expansion
- $E$ = modulus of elasticity

Taking thickness as inversely proportional to design strength:

$$t = \frac{P}{r \cdot f}$$

where:
- $P$ = calculation pressure
- $r$ = radius of component
- $f$ = design strength

From the above a thermal stress factor can be derived to assess the relative thermal stresses in service conditions. This is:

$$F_{\text{Thermal}} = \text{Constant} \cdot \rho \cdot C \cdot \alpha \cdot E / k \cdot f^2$$

It can be seen that at low temperatures the ferritic alloys with their high low temperature yield strengths have low thermal stress factors are the best choice. At high service temperatures, Esshete 1250 has a clear advantage because of its exceptional yield strength, which gives much lower thermal stresses despite a higher thermal expansion coefficient and poorer thermal conductivity.

The use of small diameter headers to supply and collect steam for high temperature superheaters in coal fired boilers has become a standard for MBEL, not only as the practical solution to the problem of collecting a large number of parallel tubes from wide pitched surfaces, but also because the reduced diameter and wall thickness are also effective in improving start-up times without excessive thermal stressing and ligament cracking in the long term.
Figure #13 - Design Strengths of Alloy Steels

Design strengths based upon 200,000h design life

N/mm²

Design temperature °C

Figure #14 - Thermal Stress Characteristics of Alloy Steels

Base case taken at 630°C using Modified 9% Chrome

% of Base Case

Design temperature °C
Development of Very High Pressure Natural Circulation Boilers

Two other developments have made very high pressure coal fired natural circulation boilers possible; these are platen superheaters and ribbed (or rifled) bore furnace wall tubes. Both developments arise from the way that the properties of steam and water change as pressure is increased.

The proportion of the heat transferred in a boiler for superheating and reheating steam rises progressively as steam cycle pressures are raised. When this is combined with the need and convenience of constructing the furnace walls with water cooled tube circuits it becomes evident that the gas temperature needed at entry to the superheater and reheater surfaces needs to be in the range 1400 to 1500°C for high pressure coal fired plant.

Most coals exhibit an ash Initial Deformation Temperature (IDT) below this temperature range. These surfaces will need to deal with the ash in a potentially adhesive and therefore deposit forming condition. The Pendant Platen Superheater was developed specifically to operate in these conditions over 30 years ago. Table #9 lists MBEL plants equipped with platen superheaters to illustrate the range of conditions and considerable experience which now support their design.

Maintaining platen tubes clean depends on giving sootblower steam jets good access to deposits, particularly avoiding too large a blowing radius, and on minimising the load carrying capacity of the bond between tube and deposit. The Membraned Platen Tip was introduced as MBEL’s standard in 1983 and as can be seen in Figure #15, the control of tube alignment with a membraned tip section results in clean tube surfaces. The central cavity for sootblower access can be seen clearly in the two left hand elements.

The second enabling development was ribbed tubes. As pressure rises, a balance between pressure losses and driving head is established only at reduced water mass flux in the furnace circuits. Ribbed tubes, by rotating the water flow, have a remarkable ability to maintain a wetted internal tube surface at high steam fractions and low mass fluxes. They are therefore fitted widely in very high pressure natural circulation boilers, and used also in many medium pressure units to reduce circulating system pipework. More than 12000MWe of new MBEL plant, including high pressure pulverised coal fired boilers and highly rated high pressure oil and gas fired plant, at superheater outlet pressures up to 182bara, have been designed with ribbed tubes from the outset.

Figures #16 shows the boiler design for Fuzhou Power Station in the Peoples Republic of China. These two 350MWe units will deliver steam at 183 bar and include both ribbed tubes and a platen superheater in their design.

Furnace Construction for Benson Boilers

One of the main areas of continuing development in Benson boilers has been the layout and supporting of the furnace wall tubing. The number of parallel tubes of practical diameter necessary to give a high enough water mass velocity has required a band of tubes to be arranged either to meander or, more recently, to wind their way around the walls. It is essential that spiral tubes receive substantially equal heat inputs and have equal resistance to flow to have an acceptable temperature distribution at the circuit outlet.

Several types of tangent tube layout were used successfully before a method of supporting membrane tube walls was evolved to gain the advantages of a fully welded, and consequently well sealed, furnace enclosure; MBEL uses the term "spiral membrane" to describe this system. It is illustrated by Figure #17. The vertical loads normally carried by furnace tubes such as self weight, framing, windboxes, sootblowers etc., would cause unacceptable bending stresses in the hot face of furnace tubes arranged near horizontally as in a spiral membrane design.
Table #9 - Platen Superheaters in Boilers designed by Mitsui Babcock Energy

<table>
<thead>
<tr>
<th>Power Station</th>
<th>Number and Size of Units</th>
<th>Platen Inlet Temp °C</th>
<th>Final Inlet Temp °C</th>
<th>Platen Pitch mm</th>
<th>Final Pitch mm</th>
<th>Coal Ash IDT °C</th>
<th>Boiler Start-up Date(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Thurrock</td>
<td>2 - 200</td>
<td>1350</td>
<td>1152</td>
<td>514</td>
<td>343</td>
<td>1150-1100</td>
<td>1960-1961</td>
</tr>
<tr>
<td>Willington</td>
<td>2 - 200</td>
<td>1350</td>
<td>1152</td>
<td>514</td>
<td>343</td>
<td>1150-1100</td>
<td>1960-1981</td>
</tr>
<tr>
<td>West Thurrock</td>
<td>3 - 300</td>
<td>1435</td>
<td>1099</td>
<td>533</td>
<td>457</td>
<td>1150-1100</td>
<td>1964-1965</td>
</tr>
<tr>
<td>Thorpe Marsh</td>
<td>1 - 550</td>
<td>1454</td>
<td>1149</td>
<td>610</td>
<td>462</td>
<td>1200-1050</td>
<td>1965</td>
</tr>
<tr>
<td>Ferrybridge</td>
<td>4 - 500</td>
<td>1474</td>
<td>1079</td>
<td>610</td>
<td>305</td>
<td>1200-1220</td>
<td>1966-1967</td>
</tr>
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<td>Kagisza</td>
<td>2 - 120</td>
<td>1322</td>
<td>1054</td>
<td>772</td>
<td>386</td>
<td>980</td>
<td>1966-1967</td>
</tr>
<tr>
<td>Ratcliffe</td>
<td>4 - 500</td>
<td>1474</td>
<td>1082</td>
<td>610</td>
<td>305</td>
<td>1200-1020</td>
<td>1967-1969</td>
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<tr>
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<td>1143</td>
<td>610</td>
<td>305</td>
<td>1082</td>
<td>1969</td>
</tr>
<tr>
<td>Fynsvearket K5</td>
<td>1 - 220</td>
<td>1393</td>
<td>1116</td>
<td>457</td>
<td>305</td>
<td>1100</td>
<td>1968</td>
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<tr>
<td>Stalowa Wola</td>
<td>2 - 120</td>
<td>1332</td>
<td>1054</td>
<td>772</td>
<td>386</td>
<td>980</td>
<td>1968-1969</td>
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<tr>
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<td>980</td>
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<td>Drax</td>
<td>6 - 660</td>
<td>1477</td>
<td>1107</td>
<td>762</td>
<td>457</td>
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<td>1972-1986</td>
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<td>Matla</td>
<td>6 - 600</td>
<td>1473</td>
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<td>1160</td>
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<td>1200-1180</td>
<td>1979</td>
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<tr>
<td>Nijmegen</td>
<td>1 - 580</td>
<td>1500</td>
<td>1128</td>
<td>610</td>
<td>305</td>
<td>1075</td>
<td>1981</td>
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<tr>
<td>Castle Peak 'A'</td>
<td>4 - 350</td>
<td>1483</td>
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<td>686</td>
<td>457</td>
<td>1350-1230</td>
<td>1982-1985</td>
</tr>
<tr>
<td>Castle Peak 'B'</td>
<td>4 - 680</td>
<td>1480</td>
<td>1147</td>
<td>686</td>
<td>457</td>
<td>1200-1050</td>
<td>1985-1989</td>
</tr>
<tr>
<td>Lethabo</td>
<td>6 - 800</td>
<td>1398</td>
<td>1099</td>
<td>1143</td>
<td>600</td>
<td>1190</td>
<td>1987-1992</td>
</tr>
<tr>
<td>Hwange</td>
<td>2 - 200</td>
<td>1490</td>
<td>1159</td>
<td>600/686</td>
<td>343</td>
<td>1380-1250</td>
<td>1987</td>
</tr>
<tr>
<td>Yue Yang</td>
<td>2 - 362</td>
<td>1518</td>
<td>1162</td>
<td>690/575</td>
<td>575/460</td>
<td>1500-1400</td>
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<td>Hemweg</td>
<td>1 - 650</td>
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<td>1200-1080</td>
<td>1993</td>
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<td>Meri Pori</td>
<td>1 - 600</td>
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<td>805/690</td>
<td>575</td>
<td>1060-1200</td>
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<td>Dan Dong</td>
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<td>1421</td>
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<td>575</td>
<td>1250-1300</td>
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<td>1350-1450</td>
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Power Boiler Safety Features and Technical Development

Figure #15 - Platen Superheater in Matla Power Station

Figure #16 - Side Elevation of Boiler for Fuzhou Power Station
Power Boiler Safety Features and Technical Development

Figure #17 - Arrangement of Spiral Membrane Furnace Walls

![Diagram of Spiral Membrane Furnace Walls]

Figure #18 - Side Elevation of Boiler at Meri Pori Power Station

![Diagram of Side Elevation of Boiler]

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The auxiliary supporting system used in modern designs comprises a number of vertical high tensile steel straps arranged in pairs closely behind the furnace tubes and welded to saddle blocks. These are in turn welded to the wall membrane to provide both support and a heat flow path. This construction imposes rate limits during operations such as start-up and shut-down, which are calculated according to the thermal behaviour of the heat path and the stress limits for the tubing. In general, these limits do not dominate plant operation, which has also to be limited by other components and systems.

The boiler at Men Pori, as per Figure #18, includes this type of furnace wall system.

Current development work strongly suggests that vertical ribbed tubes will be adopted in the near future for the furnace walls of supercritical Benson boilers of 350MWe and above. This will have the advantages of a simpler construction, lower pressure losses and reduced feed water pump power than current spiral wall designs. By selecting a low water mass velocity, dynamic losses are reduced, enabling a positive flow characteristic to be achieved in the furnace wall tubes. Thus, as in a natural circulation boiler, water flow will increase with increased heat absorption, compared with the negative characteristic of a spiral design in which flow is reduced. This is shown in Figure #19.

The overall characteristics, that is of flow increasing to reflect heat absorption, will be particularly suitable for coal firing due to the constantly changing extent, location and weight of furnace ash deposits. It should also be possible to reduce the load below which the circulating pump must be introduced from 35% BMCR to about 20% BMCR, improving the flexibility in respect of low load operation.

5. CONCLUSION

The integrity and safety of modern power boilers can be ensured by good design and layout backed up by both testing and design analysis. Good design depends on the manufacturer's experience in design, supply, erection and commissioning, and a staff culture committed to quality and excellence.

Purchasers and operators have not only to take due care in implementing operating and inspection procedures laid down by the manufacturer to meet safety and performance standards, they also need to recognise their responsibilities at the time when their plant is being specified. Their operating requirements and the economic and electricity generating environment in which their plant will run must be clearly laid down so that designers can offer the right plant.

6. ACKNOWLEDGMENT

The author would like to acknowledge the contributions of China Light & Power, GE and GEC-A in focussing these issues and the support of his colleagues in Mitsui Babcock Energy Limited in undertaking work described in this paper.
Figure #19 - Flow Characteristics of Furnace Tubes

Comparison of vertical and spiral designs

Tube flow % of mean

Tube heat absorption - % of mean

Vertical tube furnace

Spiral tube furnace
Non-destructive Evaluation of Boiler Tubes
Using Electronic Shearography

by

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The Hong Kong Polytechnic University, Hong Kong.

Boilers & Pressure Vessels Division, Labour Department, Hong Kong
Non-destructive Evaluation of Boiler Tubes using Electronic Shearography

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Abstract:
Shearographic interferometry has been employed to measure displacement gradients of boiler tube under internal pressure. A charged coupled device (CCD) camera together with a digital image processing system were used to process the speckle patterns. The method has the advantage of being real-time. It measures the effect of defects on the strain distribution rather than merely detecting the presence of defects.

Introduction:
Ash deposited on the surface of coal firing boiler tubes and tube tank was removed by an on-load cleaning process called soot-blowing. The method is an effective way to clean the boiler tube surface. However, the use of high pressure steam on the tube will lead to tube thickness reduction. This may result in stress concentration around the affected areas, which leads to cracking and forced outage of the tube. Defective tubings, when operating under high internal pressure and high furnace temperature, will concentrate stress at areas around defective site. Crack may form around here and finally lead to frequent forced outage by tube leakage. During annual overhaul, boiler tubes will be visually inspected for thickness reduction. Tubes with thickness reduction exceeding a certain upper limit will be replaced and those below the lower limit will be treated as in good condition. While those lying in between these two limits will be repaired. The aim of the present investigation is to assess thickness reduction of a boiler tube on the stress distribution around the defective area using electronic shearographic interferometry.

Interferometric non-destructive evaluation techniques, such as holography, electronic speckle pattern interferometry (ESPI) and shearography, are important tools for the detection of internal damage in engineering components [1]. These methods are non-contacting, fast, sensitive to a wide array of flaws, and provide a permanent record of the inspection process. Holography and ESPI combine a separate reference beam with the object beam needed for the interference pattern. Shearography uses an optical device to shear the object beam in order to obtain the second beam needed for the interference pattern. The generation of the interference fringes defines the operating characteristics of these techniques. Shearography, which is a common path interferometer, is much less sensitive to external vibrations than holography. The shearographic fringes represent lines of constant displacement derivatives where the fringe separation is proportional to λ/2, in contrast to holography and ESPI fringes that trace out lines of constant displacements on the target surface. These methods utilize their high sensitivity to detect small anomalies in the surface displacement caused by internal flaws.
The Digital Shearography Method:

The object to be tested is illuminated with laser light, and it is imaged by an image-shearing camera. The camera produces a pair of laterally sheared images in the image plane, and hence the method is called shearography. When the object is deformed, the relative displacement between the interfering points induces a relative phase change between the two speckle patterns before and after deformation, producing a "beat" fringe pattern which depicts the relative displacement of two neighboring points. If the separation of the points (i.e. the magnitude of shearing) is small, the fringe pattern approximately represents the derivative of displacement with respect to the direction of separation. In the double exposure method, a photographic plate or any other recording media such as a thermoplastic film capable of resolving the speckle pattern in the image plane of the image-shearing camera is doubly exposed, first with the object in the undeformed state and then with the object deformed. The double exposed photographic transparency, after being developed, records the superposition of the two speckle patterns, one before deformation and the other after. Superposition of the speckle patterns yields a beat fringe pattern depicting the distribution of the surface displacement derivatives due to the additionally applied deformation [2] [3].

Shearography detects flaws in materials by looking for flaw-induced fringe anomalies which are identifiable without knowing fringe orders. The size and location of a flaw are directly determined by the size and location of the fringe anomalies [4]. Shearography has not been widely used yet. One of the reasons is the need of using photographic film as the recording medium, which is slow and costly. Furthermore, the subsequent high-pass Fourier filtering process needed for the readout of fringe pattern further delays the output of the test results. Nakayama in 1982 [5] has published a paper on the application of electronic version of shearography; i.e. the electronic shearography. In the method a video camera is employed as a recording medium instead of the photographic plate. The method allows nondestructive evaluation be performed at video rate and without consumable films or chemicals. One drawback of the method is that the fringe quality is currently poor due to the limited resolution of today's video cameras and frame image digitizers.

The Present Experimental Investigation:

Figure 1 shows the general arrangement for the optical path in the experiment. A 30 mW HeNe Laser with wavelength of 632.8 nm was used as the light source. Laser beam from the source was expanded and filtered using a spatial filter, it then illuminates the tube specimen. The illumination and viewing directions were made immediately beside the camera. The specimen surface was sprayed with white emulsion paint to provide a better scattering surface. A Wollaston Prism has been used as an image shearing device and was placed in front of the camera.

The two sheared images were then polarized to the same oscillating direction and captured using a charge couple device (CCD) camera. The two images then formed a primary interference pattern on the image plane. To measure the spatial derivative of surface displacement, two primary interference patterns, one before loading and one after loading, were captured. A secondary interference pattern which reveals bright and dark fringes was observed upon subtraction of the two primary interference patterns. These fringe patterns can be shown to be related to the derivative of the surface displacement.
Tubular specimen with dimension of 60 mm diameter and length of 100 mm was blinded at both ends by steel covers. Pressure was applied through one of the ends. A Pulnix CCD camera was used to capture the image and the image was then digitized to 512x512x8 bits resolution by the Advanced Frame Grabber (AFG) image processing board from Imaging Technology Incorporation. The specimen was first preloaded with some initial pressure and the first speckle pattern was captured. Pressure was then slightly reduced with the capture of the second speckle pattern. The two speckle patterns were real time subtracted and displayed absolutely on the monitor. For defective specimens, defects of thickness reduction were simulated along the circumferential direction on the external surface. Four sets of shearograms were captured by varying the shearing directions and the pressure.

**Optical Path Analysis:**

Figure 2 shows the object surface illuminated by a coherent light. The light beam propagates along the direction parallel to the xz-plane. The angle between beam direction and the z-axis is $\theta$. Because of the Wollaston prism, the object is split into two virtual images with polarization angle orthogonal to each other. A polarizer is placed at 45° to the two images. Then a lens is set at a location where the two virtual images can be imaged into two real images.

Coordinates of the object and image spaces are stated to be $(x,y,z)$ and $(x',y',z')$ respectively. Assume the image shift is $\delta x$ in the x-direction only. The real images of the object surface on the object plane are on the image plane. One image point $P$ will receive the light which come from two object points ($P$ and $Q$) whose shifted distance is $(\delta x, 0, 0)$. 
Figure 2 Schematic diagram for measuring displacement derivatives using a shearing camera

Figure 2 shows the object surface illuminated by a coherent light. The light beam propagates along the direction parallel to the xz-plane. The angle between beam direction and the z-axis is θ. Because of the Wollaston prism, the object is split into two virtual images with polarization angle orthogonal to each other. A polarizer is placed at 45° to the two images. Then a lens is set at a location where the two virtual images can be imaged into two real images.

Coordinates of the object and image spaces are stated to be (x,y,z) and (x',y',z') respectively. Assume the image shift is δx in the x-direction only. The real images of the object surface on the object plane are on the image plane. One image point P will receive the light which come from two object points (P and Q) whose shifted distance is (δx, 0, 0).

Optical field $U(x,y,z)$ on the object surface is given as:

$$U(x,y,z) = a(x,y,z)e^{j\psi(x,y,z)}$$

where $a(x,y,z)$ is the light amplitude and $\psi(x,y,z)$ is the phase before the object deforms.

Thus the light at an image point P(x,y,z) will be the superposition of the complex amplitudes at the object points P(x,y,z) and Q(x+δx,y,z). The coordinates of the object plane, i.e. (x,y,z) is used to represent the optical field of the image plane. Assume the amplitudes of the two virtual images to the object are equal, then the total light field $U_T(x,y,z)$ at the image plane before the object deforms is given as:

$$U_T(x,y,z) = U(x,y,z) + U(x+\delta x,y,z)$$

and the intensity is:

$$I_I(x,y,z) = |U_T(x,y,z)|^2$$

where $\phi(x,y,z)$ is the phase difference between two shifted images before the object deforms. i.e.

$$\phi(x,y,z) = \psi(x+\delta x,y,z) - \psi(x,y,z)$$
The object will be deformed after loading is applied. Let the displacement field in the coordinate \((x,y,z)\) be \((u,v,w)\) and assume \(\delta x\) is small, it can be shown that the optical intensity \(I_2\) after displacement will become:

\[
I_2(x,y,z) = 2a^2(x,y,z)[1 + \cos \phi'(x,y,z)]
\]

where \(\phi'(x,y,z) = \psi(x+\delta x+u+\frac{\partial \psi}{\partial x} \delta x, y+v+\frac{\partial \psi}{\partial y} \delta y, z+w+\frac{\partial \psi}{\partial z} \delta z) - \psi(x+y+z+w)\)

Because of the very short wavelength of light, the change of the phase should not be neglected. The speckle images before and after deformation are subtracted. The signal after subtraction is subjected to point by point non-linear processing. A fringe pattern contouring the derivative of surface displacement is displayed on the monitor. Therefore

\[
I(x,y,z) = |I_1(x,y,z) - I_2(x,y,z)|
\]

where \(\Delta \phi(x,y,z)\) is the difference of the absolute value of \(\phi(x,y,z)\) and \(\phi'(x,y,z)\) respectively.

The absolute value of \(I(x,y,z)\) is taken to make sure that the value is non-negative. As expected, there is no background light to disturb the optical field. The spatial frequency of \(\sin(\phi+\Delta \phi/2)\) is too high for either the eye or the CCD camera to analyse. On the other hand, \(\sin(\Delta \phi/2)\) has a better spatial frequency, so it dominates the distribution of fringes.

Fringe Analysis:

Consider an arbitrary point \(P(x,y,z)\) on the object surface which is displaced to become \(P'(x+u,y+v,z+w)\) after deformation (see figure 3). The change of the optical path \(\delta l\) for the ray travels from the light source \(S(x_s,y_s,z_s)\) to the observer (camera position) \(O(x_0,y_0,z_0)\) via point \(P\) is:

![Figure 3 Displacement optical path diagram](image-url)
\[ \delta l(x,y,z) = (SP' + PO') - (SP + PO) \]

where

\[ SP' = \left[ (x - x_o + u)^2 + (y - y_o + v)^2 + (z - z_o + w)^2 \right]^{1/2} \]

\[ SP = \left[ (x - x_s)^2 + (y - y_s)^2 + (z - z_s)^2 \right]^{1/2} \]

\[ P'O = \left[ (x - x_o + u)^2 + (y - y_o + v)^2 + (z - z_o + w)^2 \right]^{1/2} \]

\[ PO = \left[ (x - x_s)^2 + (y - y_s)^2 + (z - z_s)^2 \right]^{1/2} \]

As \( R_o^2 = X_o^2 + Y_o^2 + Z_o^2 \) and \( R_s^2 = X_s^2 + Y_s^2 + Z_s^2 \). Since \( Z \) equals \( z(x,y) \) on the object surface, \( P(x,y,z) \) can be described by \( P(x,y) \). By retaining the first order terms in the expansion of the above right hand side terms, it can be shown that:

\[ \delta l = \left( \frac{x - x_o + x - x_s}{R_o} + \frac{y - y_o + y - y_s}{R_o} + \frac{z - z_o + z - z_s}{R_o} \right) w \quad \text{eqn 8} \]

Similarly for the neighbouring point \( Q(x+\delta x, y, z) \), which is displaced to \( Q'( x+\delta x+u+v, y+v+\delta y, z+w+\delta w ) \), the path change \( \delta l' \) due to deformation is:

\[ \delta l' = \left( \frac{x - x_o + x - x_s}{R_o} + \frac{y - y_o + y - y_s}{R_o} + \frac{z - z_o + z - z_s}{R_o} \right) (u+\delta u) + \left( \frac{x - x_o + x - x_s}{R_o} + \frac{y - y_o + y - y_s}{R_o} + \frac{z - z_o + z - z_s}{R_o} \right) (v+\delta v) + \left( \frac{x - x_o + x - x_s}{R_o} + \frac{y - y_o + y - y_s}{R_o} + \frac{z - z_o + z - z_s}{R_o} \right) (w+\delta w) \quad \text{eqn 9} \]

Thus the relative phase change is given as:

\[ \Delta = \left[ \frac{2\pi}{\lambda} \right] \left[ \delta l' - \delta l \right] = \left[ \frac{2\pi}{\lambda} \right] \left[ A \delta u + B \delta v + C \delta w \right] \quad \text{eqn 10} \]

where \( \lambda \) is the wavelength of light, and

\[ A = \left( \frac{x - x_o + x - x_s}{R_o} \right), \quad B = \left( \frac{y - y_o + y - y_s}{R_o} \right), \quad C = \left( \frac{z - z_o + z - z_s}{R_o} \right) \quad \text{eqn 11} \]

Equation 10 indicates that \( \Delta \) is a function of the relative displacements \( \delta u, \delta v, \delta w \) between the points \( P(x,y,z) \) and \( Q(x+\delta x,y,z) \). The equation may be rewritten as:

\[ \Delta = \left[ \frac{2\pi}{\lambda} \right] \left( A \frac{\delta u}{\delta x} + B \frac{\delta v}{\delta x} + C \frac{\delta w}{\delta x} \right) \delta x \quad \text{eqn 12} \]

Thus \( \Delta \) depicts the derivative with respect to the direction of shearing. With the light captured on the \( xz \)-plane and let the viewing direction be along the \( z \)-axis direction, and in addition if the object is small compared with \( Z_o \) and \( R_o \), \( \Delta \) can further be simplified to:

\[ \Delta = -\frac{2\pi}{\lambda} \left[ (1 + \cos \theta) \frac{\partial w}{\partial x} + \sin \theta \frac{\partial u}{\partial x} \right] \delta x \quad \text{eqn 13} \]

where \( \theta \) is the angle between the illuminating and viewing directions. When the light source is very close to the observer, \( \theta = 0 \), and \( \Delta \) can be shown to be:

\[ \Delta = -\frac{4\pi}{\lambda} \left[ \frac{\partial w}{\partial x} \right] \delta x \quad \text{eqn 14} \]
Results and Discussions:

Figure 4 Shearogram of good circular metallic tubing

Figure 4 shows the electronic shearogram of good tubing under internal pressure with image shear in the longitudinal direction. No fringes are observed in the shearogram. This is due to the fact that strains along this direction are constant [6].

Figure 5 a and b show the results of two defective tubes with different configurations of defects. Defects of thickness reduction are simulated on the tube. It can be observed a pair of "bulls eyes" are revealed around the defect site in the images. Moreover, the direction of the "bull eye" are rotating with the direction of image shear.

Figure 5 Shearograms of defective tubings

Electronic shearography technique is reliable and convenient to be employed to detect defects on boiler tubing specimens. With the use of real-time image subtraction technique, the test results can be displayed immediately. However in order for this method to be widely adopted in the industries, digital image processing techniques have to be developed to enhance and analyse the shearograms obtained in the test.

References:


Inspections Intervals and Techniques of Power Station Boilers

by

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Inspections Intervals and Techniques of Power Station Boilers

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Generation Business Group
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Introduction

For the past nine decades China Light & Power’s corporate mission has been clear and simple—"To provide a reliable and sufficient supply of electricity at the lowest reasonable cost to our customers of Kowloon and New Territories."

From the early 1980s, CLP has depended on coal as the primary energy source. Natural gas became available to CLP for power generation in 1995, and this has resulted in a significant change in the overall fuel mix. The current diversity of available energy sources such as coal, natural gas, nuclear and pumped storage should ensure long-term security of electricity for our 1.7 million customers.

Ever since the start of commercial operation of the Castle Peak Power Station, CLP has enjoyed a truly remarkable service record. There has been no system black out for the past fifteen years. This achievement is not accidental. It is achieved through clear direction from senior management, constant refinement of the maintenance philosophy/strategy, and total commitment from staff.

This paper firstly compares boiler statutory inspection requirements in Hong Kong, the United Kingdom and The People’s Republic of China regulatory bodies; secondly describes the maintenance approach adopted by CLP over the years; and finally attempts to compare CLP’s inspection practice with the UK’s written scheme of examination.

CLP Generation Facilities

CLP’s current main electricity generation facilities in Hong Kong are located at four sites - Black Point, Castle Peak, Tsing Yi and Penny’s Bay:

Black Point Power Station (BPPS)

The Black Point Power Station will consist of eight identical units with a total capacity of 2,500MW and is being constructed in two phases. The phase one consisting of four combined cycle units will be fully available in 1997. Each unit is of single shaft configuration comprising of a GE Frame 9FA gas turbine, a MTM steam turbine and a heat recovery steam generator (HRSG). The HRSG is a dual pressure, non reheat, forced circulation type, with a vertical gas flow and serpentine horizontal finned tube boiler.
Castle Peak Power Station (CPPS)

Castle Peak Power Station has an installed capacity of 4520MW consisting of 4x360MW and 4x680MW Babcock dual-fuel (coal and oil) fired boilers and 6x60MW gas turbines, and became fully operational in 1989. It remains the primary generating plant for the CLP system and is one of the largest in the world. For the 680MW Units, steam supply to drive the turbo-generator is provided by a radiant type dual coal and oil fired boiler which generates steam at a continuous maximum rating of 582.3 kg/sec at a pressure of 16.89MPa(g) and a temperature of 541°C when firing coal to achieve 677.5MW, and a maximum rating of 440 kg/sec at a pressure of 16.6 MPa.(g) and a temperature of 540°C when firing oil to achieve 500MW. In addition, two of the 680MW units were further equipped with natural gas firing capability in 1995.

Tsing Yi Power Station (TYPS)

The Tsing Yi Power Station which consisted of 4x200MW and 6x120MW heavy fuel oil fired units plus 2x76MW gas turbines, played an important role in the supply of electricity from the 1960s through to the late 1980s. However, the main plant TYPS is now decommissioned for high running cost and environmental reasons and only the two gas turbines remain operational.

Penny’s Bay Power Station (PBPS)

The Penny’s Bay Power Station has three 100MW gas turbines operating in simple cycle for peak lopping.

Statutory Inspection Requirements

In Hong Kong, the statutory examination of pressure system plant is governed by the Boilers and Pressure Vessels Ordinance (Chapter 56). Section 25 of the ordinance stipulates that every boiler together with its auxiliary equipment shall be examined by an appointed examiner before it is put into use. Section 27 of the ordinance stipulates that water tube boilers shall be subject to periodic examination every 26 months by an appointed examiner. A table showing a comparison of statutory inspection requirements in Hong Kong, The People’s Republic of China, and the United Kingdom is included in Attachment 1.

CLP Maintenance Strategy

Maintenance is a fundamental requirement for the safe and efficient operation of the steam generator. Maintenance functions should be integrated wherever possible with ongoing operations to guard against unsafe operating conditions, which can result in injury or unplanned unit outage, and to maintain the highest level of power system efficiency given the constraints of fuel and overall equipment condition. While once a relatively straightforward job of restoring damaged or broken components, maintenance has evolved
into a sophisticated systematic programme of condition assessment, predictive techniques, corrective steps preventive activities, and ongoing observation and evaluation of plant operations while minimizing costs and the impact on the environment.

Traditionally, it has been common practice to approach maintenance on the basis of carrying out major overhauls, consisting of opening the whole turbine and steam generator, every four to five years, with minor inspections of limited plant components in the intervening period. The outage duration for minor turbine overhauls is taking the opportunity by the needs of the boiler statutory inspection.

However, the current trend is that the Reliability Centered Maintenance (RCM) approach (adopted by CPPS) has become more popular. It is a systematic and rational method for determining why a preventive maintenance (PM) action should be considered, how important it is with respect to other completing tasks, and finally what criteria a PM task must meet to be considered acceptable. By adopting RCM, resources are closely focused on maintenance and inspection tasks only on "need-to-do" basis. The need is based on the actual defects experienced by CLP maintenance engineers plus other utilities. This approach is technical sound, efficient and cost effective.

General speaking, CLP have adopted a maintenance strategy in optimizing the production and life of steam generating facilities. Whenever possible, CLP would plan all the preventive maintenance, minor defect rectification, and plant modification activities to be carried out in phase with the statutory boiler inspection of 26 months operation.

Normally the planned outage period is scheduled in winter months when electricity demand is low, and the outage duration depends on the planned maintenance activities. Most preventive maintenance activities of boiler pressure part are such as Non-Destructive examination of boiler tube and drain pipes, safety valves overhaul, boiler drum and boiler slings inspection, boiler hydrostatic test, chemical cleaning, water/fire side corrosion inspection and etc.

**Preventive Maintenance**

**Non Destructive Examination of Welds (NDE)**

A strategic NDE inspection programme for boiler pressure parts is set up for each boiler. We make use of ultrasonic test to detect cracks at headers, CMV welds, furnace wall tubes. DPI/ MPI methods are used to detect the cold formed bends and membrane attachment welds defect. The defective tubes are then removed and replaced with inserts. The welding of these tubes is carried out by competent high pressure welders and the weld joints are examined by radiographic test.
CMV welds Inspection

CMV weld inspection has been carried out systematically in all CPPS units. The inspection has been focused on Type IV cracking and reheat cracking. The first such Type VI cracking occurred in UK and other countries, which was found to be related to the system stress. Reheat cracking was related to improper post-weld heat treatment and the material itself, particularly in the partially repaired welds. No Type IV cracking has been detected in the CPPS CMV pipework welds. This is in line with the experience in the UK, where boilers operated at a temperature at or below 540°C have lower risk of such type of cracking than those at higher temperatures.

Water and Fire side Corrosion/ Erosion

Metal loss of tubes on the furnace walls and the convection passes are well monitored, mainly by visual inspection and ultrasonic thickness measurements wherever necessary. The major concern of fire side corrosion is the flue gas and/or flyash corrosion/erosion, and the sootblower erosion. Water/steam side corrosion is controlled by the water chemistry. Regular checks are carried out in leading units, as a preventive measure as well as a predictive measure. Tube samples are also examined metallurgically when tube samples are available.

Post-service acid cleaning

Boiler chemical cleaning is conducted under the following conditions;

- after an interval of typically 5 to 7 years, subject to the tube water side oxide thickness exceeding 50μm.
- after major tubing replacement.

Acid cleaning involves 4 stages; i.e. alkaline degreasing boil-out, iron oxide removal, citric rinse, copper removal and passivation. Tube samples are collected to check the effectiveness of the acid clean.

Boiler Weighing

Uneven load distribution of pipe supports or boiler slings is believed to be one of the contributing factors to CMV pipe weld cracking and boiler tube leak failures. Boiler weighing is an operation involving the transfer of load between load support hangers and pipe clamps to a hydraulic jacking unit. The hydraulic pressure is then related to the actual loading, which is then compared with the design loading. Any variation will be studied and the spring support or pipe hanger will be adjusted as necessary.
Safety Valves (consolidated max/flow type)

The boiler safety valve is crucial to the safe operation of modern boilers. All safety valves are overhauled at every statutory inspection and a functional test is conducted to confirm its set pressure has been correctly set with correct blowdown.

In addition, CLP have been using the Trevitest system to test safety and relief valves on line under normal operating conditions for the following reasons. Firstly, service experience shows that the test results are within plus or minus one per cent of the set pressure. Secondly, it is possible to Treviteste the valve with no interruption to plant production, thus achieving considerable cost savings and operational advantage. Thirdly, the valve is free to function normally throughout the Trevitest operation. Lastly, it is claimed that there is less chance of damaging the valve by Trevitest instead of full floating. In addition to Trevitest after every boiler overhaul, one superheater safety valve is selected for a full float test.

Control and Alarm/ Trip devices

In order to ensure that the boiler can be safely shut down in the event of abnormal situations (i.e. high furnace pressure, high or low drum levels, loss of flame etc.), periodic functional checks of essential control circuits and alarm/trip, such as hydrastep equipment, plant running interlocks, earth circuit breaker etc. have been carried out as part of the routine maintenance.

Predictive Maintenance

Metallurgical Replication

Metallurgical replication is an in situ test method which enables an image of the metallurgical structure to be non-destructively printed from a component. Replication is important in evaluating high temperature tubes, headers and piping because it allows creep damage to be identified. All critical pressure part components have been examined in this way as part of the creep life assessment programme.

Boiler Life Assessment

The Plant Life Usage Surveillance (PLUS) system in CPPS is an on-line monitoring system for assessing the residual service life of the critical boiler pressure part components. By computing the life utilization of these components, the PLUS system will highlight which of those components should be subject to on site assessment by NDE. The major NDE methods are surface replication, hardness measurement, diametrical measurement, internal inspection, UT and MPI.
**Corrective Maintenance / Modifications**

**Boiler Tube Repair**

Boiler tube leak is typically one of the major causes of outages in utility boilers. Normally, the tube leak will be detected by an acoustic detecting system. Most tube leak failure in CLP boilers can be repaired within 24 hours after boiler shut down. The cause of each failure will be identified, followed by an investigation report with recommendations. The finding and recommendation of the investigation will be considered for establishing future maintenance policy. Examples of tube leak repair techniques are;

- Replacement of failed tubes by tube inserts.
- Blanking-off tubes at header ends of individual tube elements. This technique is particularly useful in convection zones.
- In-situ weld repair by grinding out cracks and weld buttering, followed by tube insert replacement in next boiler planned outage.

**Addition of Platen Superheater drain**

It was found that condensation could form in the 680MW boiler platen superheater during plant start-up, and this would cause thermal shock in the platen superheater thereby reducing the tube service life. In order to prevent tube failures in the platen superheater, an additional drainage system was installed. This system will be operated to drain away the condensate during start-up.

**Erosion shield**

It was found that frequent tube leakage occurred within the vicinity of steam sootblower areas because of the sootblowing steam impingement. To mitigate the effect, erosion shields were installed on the eroded tubes with satisfactory result achieved.

**Periodic Examination**

In addition to above maintenance activities, the boiler will subject to the following testing;

- Hydrostatic test
- Functional test of the safety valves
- Functional test of all boiler safety protective devices
Training for competency

The provision of skills and knowledge training is essential to attain the highest quality in all aspects of operations and maintenance within CLP, and is always stressed by the senior management. Training can be in-house, or through external parties; local or overseas. For example, boiler operators have attained their competency by attending courses arranged by CLP, Labour Department or other recognized Authority. Training in safe boiler operation and maintenance of natural gas firing equipment was provided to all staff in power station by the manufacturers and UK natural gas specialists before the commissioning of the natural gas firing system. Moreover, pressure vessel training courses and safety courses related to ionizing radiation used during NDE were also arranged with HK Occupational Health and Safety Council. Other technical courses provided by external expertise include Heat Treatment, Welding Inspector, NDE, Scaffolding, Advanced Vibration Monitoring etc. On the other hand, in-house courses include Confined Space Safe Entry, Competent Person operation courses as well as the technical refresher courses for tradesmen and management courses for staff etc.

UK Written Scheme of Examination

In the UK, the statutory examination of pressure system plant is governed by the 1989 UK Pressure Systems Regulations which superseded the requirements of the 1961 Factories Act (FA). The Pressure Systems Regulations include provision whereby, subject to an authoritative review of the plant, the examination periodicity (previously prescribed in the FA) may be extended. Under this provision, the periodicity of examination of some UK power plants have been extended to 50 months. This is almost double the period between inspections required in Hong Kong.

For the in-service examination of plant, the Pressure Systems Regulations require that all pressure systems have a written scheme of examination which identifies the type and extent of plant examination required during the statutory outage. The plant is examined in accordance with the written scheme, by an appropriate examination authority (competent person) and the report of examination specifies the date by which the plant must be re-examined. The Content List of a typical written scheme of examination is appended in Attachment 2.
Concluding remarks

1) All CLP power stations are manned by teams of professional, competent and dedicated staff

2) All in-service inspections and periodic examinations carried out by CLP are in line with Hong Kong statutory requirements.

3) Current CLP inspection and maintenance practices are in line with other world class utility operators.

4) Current CLP in-service inspection would fulfill the spirit of the 1989 UK Pressure Systems Regulations requirements.

5) An increase in the interval between statutory inspections should be considered. This would allow overhaul costs to be reduced, with consequent savings to CLP’s customers.

References

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4. CLP Annual Report 1995

Acknowledgment

The authors wish to acknowledge the permission of China Light & Power Company, Limited to publish this paper. Thanks are also due to CPPS, BPPS and GPD colleagues, particularly to Dr. A.R. Jack, Mr. C.T.K. Wong and Mr. L.M. Wong for their suggestions and moral support.

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### Attachment 1: Comparison of inspection requirements in UK, HK & China

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<tr>
<th>Control/Administration Body</th>
<th>UK</th>
<th>HK</th>
<th>CHINA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control Regulation</strong></td>
<td>Health &amp; Safety Commission</td>
<td>Labour Department</td>
<td>China National Standards Committee of Pressure Vessel</td>
</tr>
<tr>
<td><strong>Pre-service Inspection</strong></td>
<td>Required</td>
<td>Required</td>
<td>National Standards &amp; Provisional Standards</td>
</tr>
<tr>
<td><strong>Periodic Inspection Interval</strong></td>
<td>Subjected to the Competent Person's recommendation which is depending on design details, method of construction, condition of use, standard of maintenance... etc. The inspection interval can be up to 48 months</td>
<td>A/ 14 months Interval Applicable to all boiler except those stipulated in item B below.</td>
<td>I. Internal &amp; External inspection every year &amp;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>II. Hot examination every two years (e.g. functional test of protective devices) &amp;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>III. Hydraulic test every six years. But if internal inspection is not feasible, hydraulic test every year</td>
</tr>
<tr>
<td><strong>Scope of Examination</strong></td>
<td>Subjected to the Written Scheme which will be approved and revised by the Competent Person, i.e. varies from plant to plant. The following is a general practice. A/ Internal &amp; External inspection B/ Every safety valve and pressure gauge shall be examined and tested for accuracy and correct functioning C/ Hydraulic testing if required D/ Hot examination including external visual examination, functional test of the protective device... etc.</td>
<td>Stipulated in the BPV Ordinance and summarized as below</td>
<td>Please refer to inspection interval</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A/ Internal and External inspection B/ Hydraulic test if the boiler is new, relocated, internal inspection not feasible, after extensive repair or the boiler is uncertified. C/ NDT if the boiler is uncertified D/ Pressure accumulation test if the appointed examiner considers it necessary. E/ Verify the MPWP</td>
</tr>
</tbody>
</table>
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Professional Status and Development Issues of Appointed Examiners

and

Safety Control and Management of Boilers and Pressure Vessels in Industry

by

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Professional Status and Development

Issues of Appointed Examiners

Appointed Examiners (AEs) are competent Certificated Marine Engineers appointed by the Boiler Pressure Vessel Authority (BPVA) in compliance with the Boilers and Pressure Vessels Ordinance Chapter 56, the Law of Hong Kong. The appointment and continuing appointment are subject to the requirements stipulated by the Authority.

The Authority has a thorough scheme in appointing individual professional engineer as Appointed Examiner, whose duty is to carry out examinations, inspections and testing of pressure equipment in the industry. Appointed Examiners are required to be familiar with the legislation requirements, the recognized engineering standards and codes applicable to the design, construction, inspection and testing of different type of pressure equipment covered under the Ordinance. They are required to carry installation inspection and periodic routine inspection.

Appointed Examiners also serve as technical advisers to owners of pressure equipment to ensure its safety in use.

Appointed Examiners are required to comply with the Ordinance, its subsidiary regulations, relevant engineering standards and instructions, notices, and Code of Practice issued or approved by the Authority. They also have the obligation to provide familiarization training to prospective candidates for Appointed Examiner.

The candidate’s qualification, training, experience, skills, knowledge, character and integrity are assessed for eligibility. All Appointed Examiners’ performance in their practice are strictly monitored and audited by the Authority.

The professional status of Appointed Examiners shall be judged by the general public in consideration of the appointment scheme and monitoring system executed by the Authority, and the Appointed Examiners have the responsibility in maintaining the status.
However, there is room for enhancing the professional status of Appointed Examiners. As individuals undertaking pressure equipment examination in public practice are subject to regulation, employers of Appointed Examiners should also be subject to regulation.

In the Engineers Registration Ordinance Section 29 (4), it quotes:

A person, including a firm or company, shall not use the description of “registered professional engineer” or the initials “R.P.E.” unless at each place where the person carries on the business of engineering, that business is conducted under the supervision of a registered professional engineer of the appropriate discipline who does not act at the same time for any other person other than for a firm or company that has substantially the same beneficial ownership and management as the person (where the person is a firm or company).

It requires that R.P.E. should either be self employed under sole proprietorship or organized in partnership company and should not be employed by any other person or company.

By substituting “registered professional engineer” with “appointed examiner” this section, if added to the Boilers and Pressure Vessels Ordinance, is useful and beneficial to better serve the public for safety in industry. This requires the consideration and work of the Legislators and the Authority. Contract employees and non-engineers doing engineering work is an enforcement issue.

In Hong Kong, Appointed Examiner serving the public, practises in one of the following organizations:–

1) Individuals self employed full time under sole proprietorship,

2) Individuals self employed part time under sole proprietorship,
3) Individuals organized full time in partnership company,

4) Individuals employed full time by other person or company,

5) Individuals organized in partnership company and meanwhile are employed full time by other person or company in business other than pressure equipment examination.

In the last two types of organization, irregularities and impediments to carrying out professional responsibilities are inevitable, since contract employees are committed to employers who have the commercial benefits to pursue.

The Appointed Examiners should provide financial protection for the public, including third party public, in the form of professional liability insurance. This requirement of financial protection, although it does not directly translate into improved public safety, is appropriate to reinforce the credibility, professional values and status of the profession.

For the sake of openness and accountability to the public, Appointed Examiner should declare to the public and the Authority whether he is self employed or employed by other person in serving the public. He should also declare the time and working hours available for the public practice.

To pursue continuing competence in the Profession, professional development is necessary which includes technical work in the field of specialization, formal and informal education, preparation and publication of papers and active participation in professional and technical societies. Appointed Examiners have been enthusiastic in attending Annual Seminars and Specialized Training Courses organized by the Boilers and Pressure Vessels Division, Occupational Safety & Health Branch, Labour Department and the Occupational Safety and Health Council.
Safety Control and Management of Boilers and Pressure Vessels in Industry.

In the Boilers and Pressure Vessels Ordinance Chapter 56, it requires that the pressure equipment be subject to initial and periodic examination, and the operation of the pressure equipment be supervised by certificated competent persons. Periodic examination of the pressure equipment ensuring its safety in operation is the responsibility of the appointed examiners, and maintaining it in safe working order during operation relies on the owners and their employees, the certificated attendants.

The safety record of pressure equipment in the local industry is remarkable in comparison with that of other countries. We have no casualty from operating boilers but a few cases from pressure vessels.

In my thirty years of public practice, I have the observation that, other than two cases of fire in boiler room due to leaky fuel or electric cable problem and one case of furnace explosion due to passage restriction in chimney by soot and ash deposit, the cause of break down with boiler was invariably due to shortage of water resulting in furnace collapse in which case, boiler attendants had neglected in their routine testing of the automatic water level control device.

One case of pressure vessel casualty was due to the accident resulting from the blowing off of an end plate from the shell. This equipment was not registered and manufacture of the equipment was not supervised by an appointed examiner, as required by the Ordinance.

Another case was due to the accident resulting from the blowing off of a bolted cover of a pressure vessel. This pressure equipment had been modified by unauthorized contractor without the supervision of an appointed examiner, it was not properly maintained and was not attended by a certificated attendant at the time of the accident.
Two cases of opening of door under pressure resulting fatal scalding.

The trend in the industry to assign extra work to the competent person in maintenance of other machinery or in other production process, thus attention to the pressure equipment is neglected.

Although the attendants are certificated competent persons, it still requires the Authority to closely monitor the performance to enhance safety of the pressure equipment. It is advisable to require the owner of pressure equipment to maintain daily record of testing the safety devices for ready inspection.

The services to advise owners that sufficiently maintaining their pressure equipment in good working condition especially boiler water treatment would help in achieving safety operation, and to conduct training tuition to pressure equipment attendants are ready offers by appointed examiners contributing to enhance safety in Industry.
The Essentials of Water Treatment
in the Operation and Maintenance of
Power Plant Boilers

by

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About the Author

Jack C.M. Chiu joined the The Hongkong Electric Co. Ltd. in 1980 and is currently the Senior Generation Chemist for the Generation Division. His fields of interest include boiler water treatment, demineralization process, environmental protection, laboratory quality system and failure investigations. He received a B.Sc. in Chemistry from the University of Hong Kong in 1979 and a M.Phil. in the same subject from the same institute in 1986.
Abstract

The chemical condition of the steam and water cycle in power plant boilers has profound effects on the machine's reliability and performance. Inadequate control on the steam/water quality can lead to serious problems or even failures on almost any component of the cycle. The success of a particular type of boiler water treatment relies not only on the selection of the treatment method but also on the continuous monitoring of the chemical condition as well as the appropriate corrective actions taken in case of deviations. Preserving the cycle components during standby periods is important to maintain their integrity. Pre-operational boiler chemical clean, regular assessment on the oxide scale of boiler tube and post-operational boiler chemical cleans at appropriate interval are essential activities in the life of the unit.

Introduction

In a coal-fired power plant, the production of electricity works on a steam/water cycle. In the first place, steam is produced, using heat from the combustion of coal, in the boiler. Steam is then used to turn the turbine-generator couple for electricity generation. In the course of doing this work, heat energy is given up and the steam condenses back to water. The latter is recovered back to the boiler and the cycle repeats.

For reliable operation of the steam turbine, steam produced from the boiler should have the designed temperature, pressure, quantity as well as quality. The performance of the whole unit is obviously affected by the mode of operation and the strategies of maintenance adopted by the power station. There is, however, another factor, viz. cycle chemistry, which is often not treated with the appropriate priority in the daily operation of the unit and ultimately causes loss of efficiency or generation. In fact, problems and failures caused by improper steam/water quality are extensively documented [1] and they are often expensive to restore or repair.
In any steam/water cycle, the fact that contaminants can easily invade through the region which is operated under vacuum should never be neglected. This is particularly important for condensers using sea water as the cooling medium. The problem can then proliferate as the contaminants will be swiftly carried to the other parts of the system and, in the boiler, they can concentrate to a level sufficiently high to attack the boiler or steam tubes. The attack is further accelerated by the very high temperature of the steam/water and, in the worst case, failure can occur within days.

Good cycle chemistry therefore has to fulfil the following objectives.

- To produce high purity steam for driving the turbine
- To maintain an environment of minimum corrosion throughout the cycle under various operating modes
- To provide means of early detection of contaminants
- To provide means of removing or counteracting contaminants

Design Features of Lamma Power Station Units

At present, Lamma Power Station has seven units of boiler and steam turbine. By the end of 1997, the erection of the eighth unit will be completed giving a total generating capacity of 2,500 MW from burning coal. All these steam units have the following common features.

- Drum type boiler employing forced circulation
- Condensers using sea water for cooling
- No condensate polisher is installed
- Some units have copper alloys in the condensers and/or feedwater heaters (titanium tubes are only used in the condensers of the more recent units)
- Most units have high pressure feedwater heaters using carbon steel tubes (stainless steel tubes are only employed in the more recent units)
- All units have reheat system
- Low alloy steel is the major material of boiler tubes (stainless steel is only used in the superheater region)
Common Problems with High Pressure Boilers and Turbines

Because of deviations from the optimal chemical condition and the invasion of contaminants, every component in the steam/water cycle can be exposed to different modes of attack resulting in the loss of either efficiency or operation of the unit. A summary of the common problems and failures in high pressure boilers and turbines is given in Table 1.

The condensers are by far the commonest location where contaminants can invade the system. Various modes of failure can occur in condensers [2] but copper alloy tubes, if employed, are susceptible to attack by ammonia on the steam side. Ammonia, which is a highly soluble gas, tends to concentrate in condensate droplets and cause localized corrosion on the cooling tubes. When the tubes are holed, the cooling water will be sucked into the condenser by its own vacuum. The use of sea water for cooling poses a greater problem under this situation due to the very high concentration of chloride, which is notorious for its corrosive nature. Reducing the condensate pH and hence its ammonia content can help to alleviate steam side ammonia attack but often the problem is more affected by the design of the condenser. In this case, it is our practice that non-destructive test is conducted on the condenser tubes and those severely corroded ones are plugged before failure occurs.

Copper alloy tubes are also commonly used in low pressure feedwater heaters and are therefore subjected to steam side ammonia attack. The consequence is either the introduction of copper into the boiler where the copper can deposit on the boiler tube surface or an outage of the heater as a result of tube leak. Again, lowering the condensate pH can help to alleviate the problem.

Deaerator is the equipment downstream of the low pressure feedwater heaters and where removal of insoluble gases takes place. Gas removal is performed by both mechanical and chemical means. In the former method, low pressure steam is injected into the vessel to drive out the dissolved gases. In the latter method, hydrazine is injected to react with dissolved oxygen and reduce it to a very low level. Pitting is a common problem with deaerator and in the extreme case can result in cracking of the vessel [3]. In Lamma Power Station, maintaining a very low level of dissolved oxygen and painting the internal surface of the vessel have been proved to be effective means of protection.

After the deaerator is a series of high pressure heaters which are normally made of carbon steel or, in recent years, stainless steel. The former material is easily attacked by acidic (low pH) species or dissolved oxygen. The result can be either pitting or, if the heater is not properly sized, erosion corrosion [4]. Maintaining a low level of dissolved oxygen in feedwater is obviously essential to protect these heaters. Keeping a higher pH for the feedwater can help to protect the high pressure feedwater heaters against erosion corrosion, however, it must be carefully balanced with the impact on the copper alloy of the low pressure feedwater heaters.
For drum type units, boiler is a place where contaminants can easily concentrate to a level high enough to damage the boiler tubes. The high heat flux zone of the boiler is particularly vulnerable. The presence of pits, cracks or deposits further aggravates the problem as they are sites ideal for this concentration effect. Initiating from this concentrated corrodent can be under-deposit corrosion or stress corrosion cracking. Two incidents of hydrogen damage occurred sequentially in June 1996 on one of the 350MW units of Lamma Power Station. The damage not only resulted in expensive outages for repair but also required a boiler chemical clean subsequently for the removal of undesirable deposit on the boiler tubes.

Almost every kind of solute becomes volatile under the high temperature and pressure of the boiler. Chloride and hydroxide are the more corrosive ones and have been reported to cause stress corrosion cracking of the blades [5]. Silica and phosphates can also be vaporized inside boiler. The former tends to deposit on the low pressure turbine blades whilst the latter tends to deposit on the high pressure turbine blades. Copper oxide deposit is also commonly found on high pressure turbine blades and is basically carried to that location by the attemperation spray water. All these deposits inevitably reduce the turbine capacity and efficiency. At present, removal of these deposits relies mainly on mechanical means but this requires a long outage for lifting up the turbine. In recent years, foam cleaning has been developed for removal of high pressure turbine blade deposit and the work can be completed in 2-3 days [6].

Selection of Boiler Water Treatment

There are basically four types of chemical treatment that can be applied to steam units. The advantages and disadvantages of each type are summarized in Table 2. None of them is perfect. The selection of which type of chemical treatment depends on the design features and the materials of the steam units [5,7].

In Lamma Power Station, the absence of condensate polisher basically rules out the possibility of using all volatile treatment and oxygenated treatment. In principle, either phosphate treatment or caustic treatment can be adopted. The former is chosen in view of the experience gained from the older stations and the advice from the boiler manufacturer.
Chemicals Employed

The prime objective of any type of water treatment is to maintain a condition of minimum corrosion. For mild steel, this condition falls in the pH range of 9-12 (Figure 1). However, copper alloys tend to have higher corrosion rate at higher pH, particularly in the presence of ammonia, and therefore for a system of mixed materials, it is common to operate in the pH range of 8.8-9.2. Even for systems consisting of ferritic material alone, it is not advisable to operate above pH 10 because of the high level of solutes (chemicals) that has to be introduced into the boiler under this condition.

Hydrazine and ammonia are used for treatment of the feedwater system. Hydrazine remains to be commonest oxygen scavenger because of its effectiveness and availability. At moderately high temperature, it also decomposes to produce ammonia which is the main pH adjustor in the feedwater system.

\[
N_2H_4 + O_2 \rightarrow N_2 + 2H_2O
\]

\[
3N_2H_4 \rightarrow N_2 + 4NH_3
\]

Ammonia can also be injected into the system to supplement the pH if necessary.

In Lamma Power Station, a mixture of disodium phosphate and trisodium phosphate at a Na/PO_4 mole ratio of 2.6 is used to condition the boiler water. Phosphates has the benefit, other than giving an alkalinity to boiler water, of keeping calcium and magnesium ions in solution; otherwise these two species tend to form undesirable oxide scale on the heat transfer surface of boiler tubes.

Monitoring System

Locations of sampling for units in Lamma Power Station are shown in Figure 2.

Conductivity and pH meters are installed throughout the steam/water cycle to measure the general chemical condition. These instruments are employed to detect that the alkalinity is maintained at the best working condition for mild steel and/or copper alloys.

On-line hydrazine meter is installed in the feedwater line to check that an adequate amount of hydrazine is present to eliminate oxygen. Dissolved oxygen meters are installed along the same route to measure the residual oxygen level.

Monitoring of chloride is essential due to its corrosiveness even at low concentrations. However, because of instrumental limitation, on-line monitoring is not easy. Frequent checks on the chloride concentration in boiler water is recommended to avoid excessive accumulation. Furthermore, sea water ingress can also be detected by the measurement of sodium ion and acid conductivity. On-line monitors for these two items are readily available.
Acid conductivity is a control parameter of great importance in modern power generating units nowadays. It measures the conductivity of the water sample after it passes through a column of strong acid cation-exchange resin. The latter converts cationic contaminants, such as sodium, into hydrogen ions which then shows a much higher conductivity to facilitate detection.

Monitoring of silica is important if the deposition on low pressure turbine blades is to be minimized. On-line monitoring of this species is desirable but not essential. Our experience shows that silica will rise to a high level only during cold start of a unit and it is adequate to perform manual test more frequently in this period.

Phosphates in boiler can exhibit complex behaviour and therefore its monitoring is important. An excessive amount of it in boiler can cause turbine blade deposition as mentioned above. An inadequate amount, on the other hand, means weak alkalinity and insufficient phosphate ions to complex with calcium and magnesium. Besides, its concentration can also vary with unit load, a phenomenon known as "hide-out", because of its retrograde solubility. The problem is more acute for two-shifting units which will experience the greatest change in load. However, if the concentration can be kept on the low side of the operating range, the operating limits should be comfortably met at all time. On-line monitoring of phosphate is desirable but similar to silica, it is not absolutely necessary.

Finally, monitoring of metal (mainly iron) pick-up from the feedwater system should also be performed at least occasionally in order to confirm that corrosion is not excessive.

Chemical Control Standards

Chemical control standards for the steam/water cycle of Lamma Power Station are summarized in Table 3.

Corrective Actions

The steam/water cycle is huge and dynamic. Despite check points are provided throughout the cycle, abnormal condition can arise any time. It is important that corrective actions are taken promptly when there are deviations. This can only be achieved with a strong link established between the chemists, the operators and the engineers. The chemists are responsible for doing the manual analysis items, evaluating the cycle condition and proposing appropriate adjustments. The operators should exercise close surveillance on the on-line signals and perform the countermeasures (chemical dosing or blowdown) as suggested by the chemists. The maintenance engineers should ensure that all the on-line monitors and chemical dosers are functioning properly to facilitate the work of the operators. Frequent communication between the three parties should never be neglected.
Standby Storage of High Pressure Boilers

There are times when the unit has to be shut down for maintenance or put on standby. The outage or standby time can vary from a few days to a few months. During this period, components of the steam/water circuits are also subjected to attack, mainly by atmospheric contaminants. In fact, the problem can become quite serious if appropriate precautions are not taken as the low alkalinity of the water in the system will be rapidly neutralized by the carbon dioxide in the air admitted into the system. The dissolved oxygen content will also rapidly increase. Such a condition is particularly undesirable for low alloy steel components.

Different equipment have different storage requirements in light of the duration of standby, the required speed of return to service, materials and design adopted. Basically, either one or both of the following storage techniques can be used.

**Dry Storage**

Water in a component is drained while it is still hot so as to make use of the residual heat to dry up the surface. Alternatively, if the equipment has been allowed to cool, hot air/nitrogen is blown through the equipment until all moisture is driven out. The equipment is then sealed with nitrogen.

**Wet Storage**

If the component cannot be drained, the remaining water should be strongly alkalised with hydrazine (up to a few hundred ppm). The method is less desirable for components having copper alloy. Furthermore, if the component cannot be fully filled, the space above the water level should be purged and sealed with nitrogen.

**Boiler Chemical Clean**

Prior to the initial operation of a power generating unit, undesirable substances (such as mill scale, rust spots, siliceous matter) have to be removed otherwise they are sites ideal for contaminants to concentrate. This cleaning exercise is normally done by carrying out a pre-operational boiler chemical clean. In this process, the unhealthy oxide layer and foreign matters are removed to expose a fresh iron surface which is then passivated to produce a thin, continuous and protective magnetite film.

On the other hand, the magnetite film will grow in thickness with time even under the most favourable chemical condition. At some stages in the life of the boiler, this film will reach a thickness which can affect heat transfer and in the worst case, tube failure due to localized heating. It is therefore necessary to conduct regular assessments on the thickness and quality of the magnetite film and to carry out, when appropriate, a post-operational chemical clean to remove the film completely. Subsequently, a fresh film is re-built and the operational life of the boiler is extended.
Various solvents are available for both the pre- and post-operational chemical clean. The selection of the cleaning solvent and the cleaning process normally depends on the economy, film removal effectiveness and the operational history of the unit [8].

Summary

Cycle Chemistry plays an important though sometimes inconspicuous role in the life of a boiler and turbine. However, every step taken will eventually have an impact on the performance or availability of the unit. Care should therefore be exercised to conduct the following activities.

- Select a suitable chemical treatment method in view of the unit design
- Carry out a proper pre-operational boiler chemical clean
- Set up appropriate chemical control standards
- Carry out proper maintenance on the monitoring instruments
- Carry out proper maintenance on the chemical dosing equipment
- Perform routine surveillance and regular review on the chemical condition
- Apply appropriate corrective actions to counteract deviations
- Apply appropriate measures to preserve the unit during standby periods
- Conduct regular assessments on the magnetite film thickness and quality
- Perform post-operational boiler chemical clean at appropriate time

It should be emphasized that the above activities cannot be performed by the chemists alone. It requires close communication and coordination between the chemists, the operators and the maintenance engineers.

CMC/-
November 1996
Acknowledgement

The author would like to thank Mr. A. Fretwell, Chief Engineer (Generation) of The Hongkong Electric Co. Ltd., for his permission of publishing this paper.

References


6. Private communication with Ontario Hydro.


Figure 1  The relationship between relative corrosion rate and pH for mild steel at 310 °C.
Figure 2 Schematic diagram showing the sampling locations and monitoring items of the steam/water cycle of Lamma Power Station.
Table 1  
Common Cycle Chemistry Related Problems

**Water/Steam Tubes**
- Under-deposit corrosion - *(hydrogen damage)*; caustic gouging; phosphate corrosion
- **Pitting**
- Overheating caused by internal deposit buildup
  *(Corrosion fatigue)*
- Stress corrosion cracking

**Turbine**

*Deposit on turbine blades*
- Stress corrosion cracking
- Corrosion fatigue
- **Pitting**
- Erosion corrosion

**Condenser/Low Pressure Heater**

*(Steam side ammonia attack)*
- Stress corrosion cracking
- **Pitting**

**Deaerator**

- **Pitting**
- Corrosion fatigue

**High Pressure Heater**

- **Pitting**
  *(Erosion corrosion)*

**Remark:**  
Cases which occurred in the steam units of Lamma Power Station are marked in bold.  
Cases which resulted in failure are shown in brackets.  
Cases which resulted in deterioration of performance are shown in italic.
Table 2
ADVANTAGES AND DISADVANTAGES OF DIFFERENT TYPES OF BOILER WATER TREATMENT

1  **Caustic Treatment**

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. A very strong alkaline which provides rapid neutralization of acidic contaminants.</td>
<td>1. Only suitable for drum type boilers.</td>
</tr>
<tr>
<td>2. Only a very low concentration is required.</td>
<td>2. Requires a separate treatment for feedwater.</td>
</tr>
<tr>
<td>3. Condensate polisher is not absolutely necessary.</td>
<td>3. Slightly volatile in steam at high pressure and exhibits 'carry-over'.</td>
</tr>
<tr>
<td>4. Produces low solid level in boiler water and high steam purity.</td>
<td>4. Caustic may concentrate at 'hot spots' and cause 'caustic gouging' of boiler tubes.</td>
</tr>
<tr>
<td></td>
<td>5. Cannot react with Ca(^{2+}) and Mg(^{2+}) to prevent the formation of scale on boiler tubes.</td>
</tr>
<tr>
<td></td>
<td>6. Dangerous if over-dosed.</td>
</tr>
<tr>
<td></td>
<td>7. Caustic, in the presence of oxygen, constitutes a stress corrosion risk on turbine components.</td>
</tr>
</tbody>
</table>

2  **Phosphate Treatment**

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Less corrosive than caustic. Less dangerous than caustic in case of 'over-dosing'.</td>
<td>1. Only suitable for drum type boilers.</td>
</tr>
<tr>
<td>2. Produces low solid level in boiler water and high steam purity.</td>
<td>2. Exhibits 'hide-out' phenomenon in load-cycling units due to its retrograde solubility. Difficult to control the boiler water pH under this condition.</td>
</tr>
<tr>
<td>3. Counteract formation of scale in case of seawater ingress.</td>
<td>3. Ratio of sodium phosphate should be carefully controlled to avoid 'free alkalinity' which may cause 'caustic corrosion'.</td>
</tr>
<tr>
<td>4. Condensate polisher is not absolutely necessary.</td>
<td>4. Deposit on turbine blades is common and causes a drop in turbine capacity.</td>
</tr>
<tr>
<td>5. Less frequent chemical cleaning for the boiler.</td>
<td></td>
</tr>
<tr>
<td>6. Phosphate deposit on turbine was reported to offer protection against stress corrosion cracking.</td>
<td></td>
</tr>
</tbody>
</table>
### 3 All Volatile Treatment

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Simple; only one treatment for both boiler and feedwater.</td>
<td>1. A weak alkali which can only offer limited protection against accidental impurity intrusions.</td>
</tr>
<tr>
<td>2. Applicable to both drum type and once-through boilers.</td>
<td>2. Ammonium compounds are generally relatively volatile. Impurities would be easily carried over to superheater and turbine and cause corrosion there.</td>
</tr>
<tr>
<td>3. Zero solid in boiler water and produces high purity steam under ideal feedwater condition, i.e. no 'carry-over'.</td>
<td>3. Full-flow condensate polishing is generally required to protect the boiler against corrosive contaminants.</td>
</tr>
<tr>
<td>4. No 'hide-out' effect like phosphate.</td>
<td>4. Higher chance of ammonia attack on copper alloy feedwater heaters which should be avoided.</td>
</tr>
<tr>
<td>5. There are reports that boilers adopting this treatment have a faster growth of oxide scale in boiler tubes leading to more frequent chemical cleaning.</td>
<td></td>
</tr>
</tbody>
</table>

### 4 Oxygenated Treatment

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Simple; only one treatment required for both boiler and feedwater.</td>
<td>1. Nearly no protection against accidental impurity intrusion. Even ingress of air can cause rapid corrosion (due to CO₂).</td>
</tr>
<tr>
<td>2. Applicable essentially to once-through boilers. Experience on its use in drum-type boilers is limited.</td>
<td>2. Very tight control on feedwater purity is crucial. Full flow condensate polisher must be provided.</td>
</tr>
<tr>
<td>3. Formation of hematite which is almost insoluble in near neutral water. Chance of oxide build up on feedwater heater and boiler is greatly reduced. Pressure loss across steam generator is reduced. Chemical cleaning of boilers is also reduced or even eliminated.</td>
<td>3. Very little neutralization/buffer capacity for corrosive deposit on turbine blades.</td>
</tr>
<tr>
<td>4. No problem of exfoliation with magnetite scale.</td>
<td>4. Copper alloys in the system should be avoided.</td>
</tr>
<tr>
<td>5. Zero solid; no scale formation in boiler under normal condition.</td>
<td></td>
</tr>
<tr>
<td>6. Ferritic components can be used for the whole system.</td>
<td></td>
</tr>
<tr>
<td>7. A lower concentration of ammonia is used and therefore the service life of condensate polisher is lengthened.</td>
<td></td>
</tr>
<tr>
<td>Control Parameter</td>
<td>Limit</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-------</td>
</tr>
<tr>
<td><strong>Boiler Water</strong></td>
<td></td>
</tr>
<tr>
<td>pH @ 25 °C</td>
<td>9.0 - 9.5</td>
</tr>
<tr>
<td>Conductivity @ 25 °C</td>
<td>20</td>
</tr>
<tr>
<td>Phosphate ppm</td>
<td>0.1 - 3.0</td>
</tr>
<tr>
<td>Silica ppm</td>
<td>0.2</td>
</tr>
<tr>
<td>Chloride ppm</td>
<td>2</td>
</tr>
<tr>
<td>Turbidity FTU</td>
<td>30 [START UP]</td>
</tr>
<tr>
<td><strong>Feedwater</strong></td>
<td></td>
</tr>
<tr>
<td>pH @ 25 °C</td>
<td>9.1 - 9.3</td>
</tr>
<tr>
<td>Conductivity @ 25 °C</td>
<td>3.8 - 4.6</td>
</tr>
<tr>
<td>Acid conductivity @ 25 °C</td>
<td>0.5</td>
</tr>
<tr>
<td>Dissolved oxygen ppm</td>
<td>0.10 [START UP]</td>
</tr>
<tr>
<td>Hydrazine ppm</td>
<td>2 X [O2] min</td>
</tr>
<tr>
<td>Ammonia ppm</td>
<td>0.46 - 0.60</td>
</tr>
<tr>
<td>Total iron ppb</td>
<td>20</td>
</tr>
<tr>
<td>Total copper ppb</td>
<td>5</td>
</tr>
<tr>
<td><strong>Condensate</strong></td>
<td></td>
</tr>
<tr>
<td>pH @ 25 °C</td>
<td>9.1 - 9.3</td>
</tr>
<tr>
<td>Conductivity @ 25 °C</td>
<td>3.5 - 5.5</td>
</tr>
<tr>
<td>Acid conductivity @ 25 °C</td>
<td>0.5</td>
</tr>
<tr>
<td>Sodium ppb</td>
<td>15</td>
</tr>
<tr>
<td>Silica ppm</td>
<td>0.02</td>
</tr>
<tr>
<td>Turbidity FTU</td>
<td>10</td>
</tr>
<tr>
<td><strong>Main Steam &amp; Saturated Steam</strong></td>
<td></td>
</tr>
<tr>
<td>Acid conductivity @ 25 °C</td>
<td>&lt;0.3</td>
</tr>
<tr>
<td>pH @ 25 °C</td>
<td>9.1 - 9.3</td>
</tr>
<tr>
<td>Sodium ppb</td>
<td>5</td>
</tr>
<tr>
<td>Chloride ppb</td>
<td>5</td>
</tr>
<tr>
<td>Sulphate ppb</td>
<td>5</td>
</tr>
<tr>
<td>Dissolved oxygen ppb</td>
<td>10</td>
</tr>
<tr>
<td>Silica ppb</td>
<td>10</td>
</tr>
<tr>
<td>Total iron ppb</td>
<td>20</td>
</tr>
<tr>
<td>Total copper ppb</td>
<td>2</td>
</tr>
<tr>
<td><strong>Make-up Water</strong></td>
<td></td>
</tr>
<tr>
<td>Conductivity @ 25 °C</td>
<td>0.5</td>
</tr>
<tr>
<td>Silica ppm</td>
<td>0.02</td>
</tr>
</tbody>
</table>
Hazard Identification & Risk Assessment of Pressure Vessels & Systems

by

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Started working life as a Apprentice in Steel Industry with Steel Company of Wales and moved to BOC in 1970.

Had experience in Production, Distribution, Production Planning, Work Study and General Management. Mostly in line Management.

Prior to leaving U. K. in 1995 was Manager of a Major BOC Site in U. K. serving the Sheffield Steel Industry.
INTRODUCTION

This paper is a personal view that is a result of some 33 years experience in gas and associated industry in U. K..

The Hazard Identification and Risk Analysis is not meant to replace a QRA.

BACKGROUND

Up to the late 1980s Pressure system management was "prescribed" in the Factories Act.

This Legislation became inappropriate given the Technology and Material changes in recent years.

As an example the prescribed inspection frequencies were 'set' and could not be extended whatever the findings.

The legislation changed in the Early 90s following the introduction of "The Pressure Systems and Transportable Gas Containers Regulations. 1989, SI 2169" These regulations were introduced into U.K. via 1974 Health and Safety at Work Act.

Along with other Industry Regulation in U.K. it puts the onus on companies to install an appropriate system to safely manage pressure vessels and systems. AND requires the undertaking to demonstrate this.

Typically HSE Inspectors nowadays ask to see the system and verify compliance by talking to the staff who maintain and operate the plant. They also physically check a sample.

They are no longer happy to talk to the Plant Manager or Works Engineer in isolation!. They are keen to establish that the people who manage the system on a day to day basis understand the requirements.

An extract from a BOC Document is below GASES STANDARD 160 - PRESSURE SYSTEMS REGULATIONS.
EXTRACT FROM BOC STANDARDS

Introduction

The overall intention of the Regulations is to prevent the risk of serious injury from the uncontrolled release of stored energy as the result of the failure of a pressure system or part of it, by ensuring that:

- pressure systems are properly designed and constructed, with adequate protective devices and facilities for examination. Any repairs or modifications must not cause danger or impair the operation of any protective device or examination facility

- defined parts of pressure systems are the subject of Written Schemes of Examination, for those examinations to be carried out on time and for adequate records to be kept. This applies equally to new and existing plant

- adequate and suitable instructions are available for the safe operation of the pressure system, including the action to be taken in an emergency. Users must only operate the pressure system in accordance with the instructions

- pressure systems are properly maintained, so as to prevent danger.

The Regulations do not necessarily deal with all hazards arising from the operation of a pressure system.

Scope

This standard covers the Regulations applicable to Pressure Systems and defines the procedures to be followed with BOC plant and equipment to ensure compliance with the Regulations.

In particular, detailed procedures are included for the preparation of a Written Scheme of Examination and the production of a Register of Written Schemes.
Details of the following Regulations and Schedules are included:

- Regulation 4: Design, construction, repair and modification
- Regulation 5: Provision of information and marking
- Regulation 6: Installation
- Regulation 7: Safe operating limits
- Regulation 8: Written scheme of examination
- Regulation 9: Examination in accordance with the written scheme
- Regulation 10: Action in case of imminent danger
- Regulation 11: Operation
- Regulation 12: Maintenance
- Regulation 13: Keeping of records
- Regulation 14: Application to vessels vented to atmospheric pressure
- Regulation 15: Precautions to prevent pressurization of vessels vented to atmospheric pressure
- Regulation 24: Power to grant exemptions
- Regulation 25: Extension outside Great Britain
- Regulation 26: Repeals, revocations and modifications
- Regulation 27: Transitional provisions
- Schedule 1 to 6.
**Operation** (Reg 11, Effective Date 1 July 1994)

The:

- user of an installed pressure system

or

- owner of a mobile pressure system

or

- owner of a hired or leased installed system, who has agreed in writing to accept responsibility under Schedule 3 of the Regulations as appropriate, shall provide for any person operating the system adequate and suitable instructions for:

  - the safe operation of the system
  
  - the action to be taken in an emergency.

The user of a pressure system shall ensure that it is only operated in accordance with the above instructions.

From the above changes, responsible organisations can now **safely** manage their Pressure Systems in a cost effective manner.

A key Paragraph from Introduction however is:
“The Regulations do not necessarily deal with all hazards arising from the operation of a pressure system”.

Whilst **TOXIC** and **FLAMMABLE** Pressure Systems are handled separately, **some** process legal requirements from an operational point of view merely state (simplistically) that the people operating a pressure system have adequate instructions for safe operation and emergency actions. The employee should ensure that the above instructions are complied with.
PRESSURE SYSTEM OPERATIONS

My experience of above in the Steel and Gas Industry, where large expensive plant is expected to have a lifetime of 15-20 years, most of the failures occur have been due to conditions arising that are not understood, foreseen, or described at the design stage.

In the last 10-15 years HAZOPS, HAZANS, Etc. have been conducted to prevent the above. But are Lessons learned or remembered after 10 years?.

Many organizations do not have a good memory?.

SOME EXAMPLES OF CHANGED CONDITIONS

CORROSION - Equipment not designed for offshore duty used on oil plant forms.

IMPACT DAMAGE - Change in mechanical handling systems and potential for FLT to drive into pressure vessel.

LAND MOVEMENT - Should not be unexpected in Hong Kong.

FLOODING - Are foundations likely to be washed away.

CHANGE OF USE - Has system been 'uprated' (unknowingly).

ENVIRONMENT - Is LPG being stored next to Liquid Oxygen?.

WIND DAMAGE - Is vessel exposed/have trees grown nearby.
OPERATOR AWARENESS

HSE in U. K. have focused their efforts on Major Risk Sites and in particular those that due to large hazards inventory pose an off-site risk.

A Quantified Risk Assessment is required at these sites.

For example if in excess of 1000T LOX or 200T Propane is stored on a site.

From the above process HSE and Industry have learned that Plant Operators (as distinct from Engineers) can better understand the Operational Risks by doing a Hazard Identification/Consequence Analysis.

HSE 'encouraged' operators with Large Inventory (but below TOP TIER CIMAH) to conduct a simple exercise INVOLVING PROCESS OPERATION STAFF.

The example below is a 560T Low Pressure Liquid Oxygen Storage Tank (see simple schematic).
SIMPLE SCHEMATIC 600 TON BULK LIQUID OXYGEN STORAGE

LOX IN

PROCESS BACKUP SYSTEM

TANKER FILLING
<table>
<thead>
<tr>
<th>MAJOR ACCIDENT SOURCE</th>
<th>SIGNIFICANT INITIATING CONDITIONS/EVENTS</th>
<th>CONSEQUENCES</th>
<th>PREVENTION, CONTROL AND MITIGATION MEASURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. FAILURE OF T83 560 TONNE BULK LOX STORAGE TANK</td>
<td></td>
<td>1. LOSS OF UP TO 560 TONNES OF LOX</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1A. EXTERNAL EVENTS</td>
<td></td>
<td>i) No mine workings. No history of ground settlement. Tank supports checked by independent body during 1992/93 tank revalidation. 5 Yearly checks will be carried out. Reference lugs fitted for this purpose.</td>
</tr>
<tr>
<td></td>
<td>i) Land Movement</td>
<td></td>
<td>ii) Designed for 48 m/s.</td>
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<tr>
<td></td>
<td>ii) Wind Loading</td>
<td></td>
<td>iii) Well above sea level. 10m above local water course. No history of flooding.</td>
</tr>
<tr>
<td></td>
<td>iii) Flood</td>
<td></td>
<td>iv) Tank mounted on raised plinth on pillars.</td>
</tr>
<tr>
<td></td>
<td>iv) Ground movement / frost heave</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>v) Sabotage</td>
<td></td>
<td>v) Site perimeter fence. Site manned 24 hours. Gate-house security 24 hours. Closed circuit TV cameras at strategic points with monitors in control room.</td>
</tr>
<tr>
<td></td>
<td>vi) Missile Impact</td>
<td></td>
<td>vi) Electrical transformers at adjacent YEB substation provided with concrete walls to reduce risk of missile in event of transformer explosion. BOC own transformers decommissioned.</td>
</tr>
<tr>
<td></td>
<td>vii) Power failure/ PRV air supply failure</td>
<td></td>
<td>vii) Does not affect integrity of storage tank. Emergency shut off valves (flap valves) close on power failure or air supply failure. Pressure</td>
</tr>
</tbody>
</table>
viii) Vehicle Impact

ix) Crane/Load Impact

x) Fire Engulfment

xi) Aircraft Impact

1B. INTRINSIC WEAKNESS

i) Design

ii) Materials

iii) Construction/Assembly (e.g. Weld Defects)

control valve closes on air failure (to prevent depressurisation and air being sucked in forming ice plug) but there is a passive PRV system as a back up.

viii) Speed limit on site 15 mph. Vehicle access to area limited and one way system. Tank location makes vehicle impact very unlikely. Kerbs provided but to be extended.

ix) Formal rules for use of cranes on site as set out in gases standards GS 101.4.

x) Tank separated from combustibles and bulk LPG tank and its pipework. Separation distances to BCGA Code of Practice CP20. Tank perlite insulated. Site rules prohibit LPG tankers from going near LOX tank. Tank perlite insulated which would afford protection pending arrival of fire service.

xi) Not close to take off/landing corridor of an airport. No helicopter activities.

i), ii), iii) Tank’s design, materials and construction fully revalidated during tank refurbishment 1992/1993. Revalidation dossier of records held on file include records of detailed internal inspections carried out and 50% weld radiography checks. No defects or weaknesses found except some evidence of oil stains suggesting carry over of oil from oil lubricated machinery in original plant (now replaced with oil free equipment). Tank and TPV system
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| iv) Commissioning error  
  (e.g. too rapid cool down) | HAZOPED March 1993. Revalidation exercise confirmed tank complies with BS 5387: 1976, BCGA Code of Practice CP20, IGC document 24/83E (cryo vessel pressure protection), IGC document 16/85 (LOX storage), IGC document 21/95E (Bulk LOX storage). All refurbishment/ revalidation work supervised by chartered engineer overseen by BOC head office Design Authority. See revalidation dossier held on site.  
 iv) Written commissioning procedures (involving method statement) followed by competent commissioning engineers. |
| 1C. IN SERVICE DEFECTS  
i) Internal Corrosion | i) No history of corrosion on LOX duty. No evidence of internal corrosion found during 1992/93 refurbishment.  
ii) Perlite filled inter-space (between inner tank and outer shell). Inter-space purged with nitrogen to eliminate water vapour. Outer shell painted externally, inspected periodically.  
iii) No cyclic loading. No history of fatigue on this type of plant.  
iv) Filters/molecular sieves on air separation unit. Routine analysis for hydrocarbons and acetylene (weekly). Some evidence of oil carrying over from original 1960s production plant (now shut down). Current production plants use oil free lubricant.  
v) Nitrogen purge eliminates moisture. |
| ii) External Corrosion |   |
| iii) Fatigue |   |
| iv) Hydrocarbon/oil/  
  acetylene contamination |   |
| v) Compaction of Insulation |   |
| vi) Cryogenic liquid on outer shell |
| vii) Ice formation in pressure/vacuum relief system. |
| viii) Failure of inter space bellows |

**1D OPERATIONAL ERROR**

i) Over-pressure due to:

a) Overfill

b) High ingress to tank
c) Tanker imports
d) TPV pump recycles
e) Falling barometric pressure
f) Line cool down
g) Product line heat inleak
h) Plant production (sub cooler failure)
i) Gas break through from production plant
j) Failure of pressure raising
k) Liquid transfer

vi) Pressure relieves and overflow designed located to avoid cryogenic liquid splash on outer shell. Remotely operable shut off valves for use in event of pipework failure.

vii) Ullage gas space pressure maintained by pressure raising system (vaporising LOX) and low level alarm. Plus active pressure control valve (fails shut on air failure). High and low pressure alarms.

viii) Remotely operable shut off valves (flap valves) located inside inner tank.

i) Passive PRV (in addition to active PCV) and high pressure alarm.

a) Remote level indication in control room, high level alarms (via PLC and hard wired), tape and float level indicator. Liquid overflow line sized for maximum production.

b) Perlite insulation kept dry by nitrogen purge.

b) to k) Calculations carried out during tank.

) Revalidation confirm adequate PRV
) Capacity taking account of (b) to (k).
) Summary attached.
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<tbody>
<tr>
<td>I) PRV accidentally isolated</td>
<td>l) PRV arrangement such that relief always available (i.e. PRV cannot be isolated).</td>
<td></td>
</tr>
<tr>
<td>m) Ice plug in relief line</td>
<td>m) See 1C (vii) above.</td>
<td></td>
</tr>
<tr>
<td>ii) Under-pressure due to:-</td>
<td>ii) Ullage gas space pressure raising system (see 1C (vii) above designed for worst case plus Vacuum Relief System and low pressure alarms plus:-</td>
<td></td>
</tr>
<tr>
<td>a) Tanker exports</td>
<td>a) Calculation carried out during tank</td>
<td></td>
</tr>
<tr>
<td>b) TPV withdrawal</td>
<td>b) Revalidation confirm adequate vacuum</td>
<td></td>
</tr>
<tr>
<td>c) Rising barometric pressure</td>
<td>c) Relief</td>
<td></td>
</tr>
<tr>
<td>d) Sub cooler liquid</td>
<td>d) Capacity taking account of (a) to (d). See summary attached.</td>
<td></td>
</tr>
<tr>
<td>e) Vacuum relief accidentally isolated</td>
<td>e) Relief arrangement such that vacuum relief always available (i.e relief cannot be isolated).</td>
<td></td>
</tr>
<tr>
<td>f) Ice plug in relief</td>
<td>f) See 1C (vii) above.</td>
<td></td>
</tr>
<tr>
<td>iii) Use of non oxygen compatible materials in maintenance</td>
<td>iii) Purchasing and QC control system. Trained maintenance staff working to BOC rules.</td>
<td></td>
</tr>
<tr>
<td>iv) Over-pressure of tank inter-space with nitrogen</td>
<td>iv) Pressure relief provided on inter-space.</td>
<td></td>
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</tbody>
</table>
Involving the Process Operators is a Brainstorming session of above highlighted situations that the Managers were unaware of.

Participation in the exercise increased operator awareness of conditions and events that could compromise the storage tank integrity.

I believe this is a good tool to improve Process Staff Awareness of the design envelope and afford some additional protection from "unauthorised change".
Aspects of Shell Boiler Design

by

Mr. David YOUNG
Chief Engineer,
Cochran Boilers, U.K.
ASPECTS OF SHELL BOILER DESIGN

1. INTRODUCTION

Name: David Young, Chief Engineer, Cochran Boilers

I would like to thank our hosts for their kind invitation to this seminar, and I hope that you will find this short presentation of interest.

There are a number of important factors and considerations that must be made before and during the design and manufacture of a shell boiler. It is the objective of this presentation to highlight some of these areas and bring attention to two particular areas of shell boiler detail design.

Firstly I would like to give some information on my own background and also some information on the codes and standards that are commonly used for shell boiler design and manufacture and possible future developments of these codes.

2. GENERAL

My own particular background, as the Chief Engineer of Cochran Boilers and leading UK boiler manufacturer is with the design and construction of shell boilers to a number of national and International standards and codes of practice.

As Chief Engineer I consider that I have a reasonably ‘good’ working knowledge of a number of British Standards particularly those relating to shell boilers. For example BS2790 and BS855 which are used in the design and construction of these type of boilers. In addition to these UK standards we also work to a number of other national and international standards. e.g. ASME, Stoomvezen, TRD, Lloyds and the Chinese National Standard to name but a few.

With regard to the British Standards, these are written by a committee that is made up of a number of interested bodies and not only boiler manufacturers:

  Independent Insurance Companies
  Boiler Manufacturers Associations
  Combustion Equipment Manufacturers Association
  Surveyors
  Government Health and Safety Executive
  Lloyd’s Register

These standards and the general rules used are applicable over a wide range of sizes and design pressures. In the UK Cochran manufacture a range of shell boilers, which range in outputs from 50 kg/hr up to 32000 kg/hr in a single unit and with operating pressures ranging from 3.5 barg up to 25 barg and sometimes in excess of 30 barg, depending upon the boiler size.
The standards and the design rules have to be flexible enough to accommodate all of the boiler types used.

These standards are based on long established design criteria and a history of successful design and manufacture, backed up with ongoing research and development programmes. These long established design criteria are augmented by incorporating the latest technical developments in design, manufacturing techniques, particularly welding, and also non destructive testing and examination techniques.

Having said all of that, fundamentally there is nothing new under the sun as far as the general pressure vessel part design of the shell boiler is concerned.

There are only basically two types of boiler that are being manufactured by the main European Boiler manufacturers. These are both three-pass wet back units and are either of the conventional three-pass type with 2 tube passes or a reverse fired type where the first two gas passes are maintained within the furnace itself.

In shell boiler terms the reverse fired boiler is the 'new kid on the block' and has only come onto the scene within the last 15 to 20 years, where as the conventional 3-pass wet back boiler has been a long established design for well over 35 years.

The main focus for development work associated with shell boilers is directed at improving the methods and quality of manufacture and inspection and also on associated ancillary equipment, i.e. low emission combustion equipment and automated control equipment, e.g. self-monitoring and self-checking water level controls which can allow for extended periods of unmanned operation.

3. DESIGN STANDARD HARMONISATION

One area where a significant amount of work is currently being undertaken is in the harmonisation of a number of national standards.

Currently within the UK the British Standard Specifications used are continually under review and reappraisal taking into consideration developments from manufacturers and inspection bodies.

However, in addition to this ongoing exercise, as many of you will no doubt be aware, currently within the European Community there is a certain amount of effort being put into a harmonisation of its standard specifications.

This is being undertaken to create a single design standard which will be used and accepted by all of the member states within the union and remove any barriers to trade within the union that currently exist.

Obviously some countries are more keen on this initiative than others and it is a time consuming exercise. As you can image reaching agreement on technical aspects of boiler design between a number of national committees is not easy to achieve.
Many countries within Europe obviously have their own national standards, each of which has its own particular design requirements. Although they normally all share the same basic principles they all have their own peculiarities which makes them very different to one another.

For instance a French or a German boiler designed to produce the same flowrate and pressure of steam as each other will typically be of the same size and from the outside appear very similar. However on the inside they may be fundamentally different, incorporating different types of tubeplate attachment and different staying arrangements.

The proposed harmonised European Standard will have to take all of these many peculiarities into consideration and produce a design standard that is mutually acceptable to all ....

4. ENDPLATE ATTACHMENT

4.1 FLAT FLANGED ENDPLATES V’s T-BUTT WELDED ENDPLATES

I would like to discuss one area of boiler design, that highlights the difference between two styles of boiler manufacture.

This concerns the method of attachment used to connect endplates to shell belts.

Many manufacturers and certain codes specify boilers with flanged tubeplates butt welded to the shell ends and indeed my company regularly manufactures boilers which incorporate flanged endplates. However the majority of boilers manufactured within the UK have T-butt welded endplates.

At the start I would suggest that the flanged endplate in principle is a far better design than the T-butt welded type. However I would like to demonstrate how we can confidently and safely use T-butt welded endplates.

The flanged endplate was a requirement when boilers were riveted together and all joints had to be lapped together.

As welding technology developed riveting was replaced by welding, however as the technology available was still in its infancy and confidence was low, many designers were reluctant to subject welds to any other loads than direct stress. This resulted in the retention of flanged endplates.

However as welding techniques and more importantly, the techniques for examining welds have advanced considerably since the early days, the integrity and reliability of welded joints can be guaranteed. As a result the majority of boilermakers, certainly within the UK have abandoned the flanged joint in preference to the most up-to-date, consistent method of attachment, namely the T-butt welded tubeplate.
National and International codes of design and construction for shell boilers continue to allow the use of flanged endplates whilst accepting the principle of T-butt welded endplates if the boiler is designed and built to a suitable standard. The emphasis, certainly within the UK is given to the T-butt welded type.

4.2 WELDING TECHNOLOGY

There have been many advances in material and welding technology. Research and development over the years has led to 'cleaner' parent materials with much improved through thickness properties and fewer laminar type inclusions. In addition, there have been improvements in the quality of consumables such as the advent of modern low hydrogen consumables, which are of a consistently high quality.

Due to these improvements, manufacturers have been able to advance techniques for the fabrication and welding of boilers. These involve the use of special alloyed root consumables combined with other processes, such as mechanised submerged arc welding, to achieve a high integrity weld deposit. Procedural controls ensure that heat affected parent material is undamaged and meets all design requirements.

These procedures have been proved by repeated tests, by long years of field service and by years of non-destructive examinations. It has been establishment that the weld is the strongest part of the joint and that in destructive tests the parent plate will fail before the weld metal.

4.3 INSPECTION DURING MANUFACTURE

Today's shell boiler is intensely scrutinised at every stage of design and manufacture by independent inspection authorities. As well as visual inspection, there are x-ray, magnetic particle, dye penetration and ultrasonic inspections carried out throughout production.

For the joint in question between the tubeplate and shell, a comprehensive series of tests are carried out to ensure that both the weld and the parent plate are free from defects.

Before ultrasonic inspection commences all equipment is carefully checked and calibrated to the requirements of BS3923 Pt 1 - "Ultrasonic Examination of Welds". Ultrasonic probes are calibrated to detect defects much smaller than the basic requirements of BS2790 - "Design and Manufacture of Shell Boilers and Welded Construction". This is achieved by increasing the signal amplitude by 50% for compression probes and by 150% for angle probes, enabling extremely small defects to be detected and evaluated.

A number of ultrasonic scans are applied to the weld to ensure full coverage of the weld and heat affected zone.

With reference to Figure 1:
COMPRESSION PROBE - SHELL

The beam path from this probe is perpendicular to the shell to ensure the weld is free from defects such as centre line cracking, lack of root fusion, lack of side fusion to shell, weld body defects (slag and porosity), plate lamination and laminar tearing.

ANGLE PROBES - SHELL

This is an enhancement of the compression check with gives additional reassurance at weld toes.

COMPRESSION PROBE - TUBEPLATE

This is used to ensure that the plate is free from abnormalities which may effect the results from subsequent angle scans.

45° PROBE - TUBEPLATE

This probe is used from cap to full skip and gives full volumetric coverage of the weld. This ensures that the weld is free from defects such as lack of side fusion on angle preparation, lack of inter-run fusion, slag inclusion and porosity.

60° PROBE - TUBEPLATE

This probe is again used from cap to full skip and gives volumetric coverage of the weld, but also gives an accurate scan on the root area. This provides cross confirmation of the results of the 45° probe and also confirms that the weld is free from lack of root fusion and any other root related defects.

4.4 VISUAL INSPECTION

Although often discounted as superficial and subjective, the visual inspection is just as important as the most technologically advanced inspections. An experienced inspector can tell much about the quality of a joint from it.

During manufacture 100% of the weld is visually inspected on the water and the gas side. This inspection ensures the weld does not possess profile defects such as undercut, shrinkage, fillet shape, fillet dimension and overlap. This reduces any risk from in-service defects, for example toe cracking.

4.5 MPI INSPECTION

During manufacture 10% of the weld is subjected to magnetic particle inspection on the internal backing fillet. Any indications found mean an immediate increase to 100% inspection. MPI acts as an enhancement to visual inspection, and ensures that surface porosity, surface lack of fusion and roll over are not present.
4.6 TECHNICAL ASPECTS

Technically the main difference between the butt welded flanged tubeplate and the T-butt welded tubeplate is that the former is effectively under direct load whereas the latter is under combined shear and bending. The shear component is, as would be expected, small compared to the bending load.

The different loading conditions on the plate and joint are taken into account during the design stage. The majority of national and international shell boiler codes do this by effectively halving the allowable stress in the joint for the fillet welded case, thus building in a considerable factor of safety.

With respect to fatigue of any joint, be it in a direct loading mode or in a bending mode, can experience the phenomena. The life time of that joint is predominantly a function of the level of stress and the number of load cycles to which it is exposed. Therefore, given the same working environment, the flanged tubeplate is as prone to fatigue as the T-butt welded endplate.

Furthermore, the T-butt welded endplate design avoids the deformation in manufacture that is inevitable with the flanged version. Flanging brings about thinning at the knuckle of the plate with the associated risk of non-homogeneous plate properties.

The risk is increased if the flanged end manufacturer cold forms the plate or does not use the correct temperature when attempting to hot form.

4.7 IN-SERVICE INSPECTION

There are many different rules for in-service inspection depending on in which country they are carried out and who carries them out. Invariably, however, the investigation is carried out from the outside surface of the shell in the same manner as has been previously described.

In-service inspectors often find difficulty in gaining access to this area and have to remove large sections of sheeting to do so, which is a time consuming and expensive operation. Many manufacturers, however, provides easily removable sections to allow convenient access to the shell to tubeplate joint. Access to the tubeplate to carry out scans is also possible should that prove necessary.

4.8 CONCLUSIONS

With current inspection methods and procedures, combined with the high quality of plate and welding consumables available, there is no doubt that the integrity of a fillet weld is as high as that of a butt weld.
Inspection of fillet welds during manufacture is exhaustive and with the advent of ultrasonic examination in the early 1980’s, nothing is left to chance. All tests carried out by my company are under the scrutiny of an independent inspection authority.

As well as being equally good at avoiding fatigue failure the fillet welded joint does not experience the uncertainties of forming which the flanged tubeplate does.

Furthermore, careful design of the boiler and its insulation ensures easy access to the weld joint in order that ultrasonic examinations can be performed as part of the in-service inspection programme.

5. LONGITUDINAL STAYBARS

As has been mentioned previously, the design codes form the basis of the design methods used on shell boilers, however these are augmented by additional design requirements.

I would like to give an example of one of my own company’s design features that is used in addition to the standard design specification.

The example I will use concerns the longitudinal stay bars used in the construction of the boilers. These bars are used to distribute the load carried between the two shell tubeplates.

In one particular boiler that was designed and manufactured to a current design code experienced a failure of a single stay bar during hydraulic test at site and before it was put into service.

Although no other parts of the boiler, were affected as a result, it was obviously an extremely serious incident, one which gave great cause for concern.

On receipt of the inspection report an extensive examination was carried out to determine the cause of the failure.

Firstly the design calculations were checked to ensure that there were no errors, then the material certificates for the bar material, the manufacturing procedures used and examination test reports were all checked. All of this confirmed that the design, materials used and method of manufacture were found to be acceptable, therefore we were no closer to the cause of the incident.

From the boiler, prior to commencement of the repair work a sample of the material was taken and a metallurgical examination was carried out.

This revealed that the stay bar had failed due to fatigue. At the time this conclusion was somewhat confusing as the boiler had not yet been placed into service and therefore had not been subject to any significant loads.
It was concluded from the reports that the stay bar must have been subject to a fatigue during its transportation from the UK to site. This most likely occurred by way of vibration during transportation.

The boiler itself was fitted with stay bar supports at its mid span which were a requirement of the design code and normally these are found to be sufficient. In the last 20 years alone Cochran has manufactured over 7000 units and had no previous record of an incident of this nature.

However, based on the inspection report and to avoid the possibility of further repeat incidents of this type, additional stay bar supports are now fitted to all of our larger boilers. This reduces the unsupported span of all long stay bars and thereby reduces the effect of vibration experienced during transport. This eliminates the potential of further fatigue failures of this nature.

This has been adopted as a standard design feature of all Cochran boilers, and is a typical example of how an internal company design requirements can easily be adopted to improve the quality and safety of the product.

6. SUMMARY

It is hoped that this presentation sheds some light on how the boiler design standards are created and updated, in line with the latest technical developments.

In addition I have concentrated on two particular areas of boiler design. One of which highlights the difference the style of boiler design used by different manufacturers. And shows how technical developments are incorporated into design standards.

The second details the need for addition requirements for aspects of design that are not covered in depth by the national design standard. This highlights how a responsible manufacturer needs to consider every detail and cover for every eventuality, even if they are unlikely to occur.

These additional design requirements will ensure that only a safe and quality product is placed into service.
This book is due for return or renewal on the date shown unless previously recalled. Fines may be incurred for late return.

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Seminar on Boilers and Pressure Vessels Safety and Technical Development (12th : 1996 : Hong Kong)

Boilers and pressure vessels safety and technical