Research Methods – M7X01371

Assignment – Research Proposal

Stress concentration and in-service examination of boiler shell longitudinal seams due to angular misalignment

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Abstract

The research proposal questions the suitability of in-service examination of longitudinal seams of shell boilers where the stress concentration due to angular misalignment is a factor in fatigue failure. The historic background is discussed, and a literature review presented. Study objectives and methodology are proposed.

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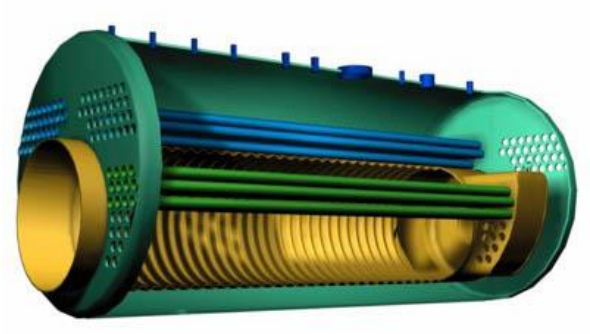
1.0 Study Problem/Project Aim

Analysis of peak stress due to angular distortion in shell boiler longitudinal seams using finite element techniques. The project aims to consider the suitability of current industry guidance regarding the periodic in-service inspection of longitudinal seams based on the results of finite element analysis and evaluation of limits imposed by design codes.

2.0 Background and Rational/Relevance of Project

Low pressure steam requirements for manufacturing processes and heating applications are predominantly met through the use of smoke or fire tube boilers. A typical industrial shell boiler of smoke or fire tube type is detailed in figure 1. The construction consists of a cylindrical shell incorporating a furnace and tubes through which the hot gases of combustion pass. The heat from which is transferred in to the surrounding water. The construction arrangement of a 3 pass wet back design is detailed in figure 3. The design of shell boilers manufactured and operated in the United Kingdom are in accordance with recognised design codes such as British Standard BS2790 Specification for the design and manufacture of shell boilers of welded construction, and the current British Standard implimentation of the EN 12953 Shell boiler series standard.

Figure 1. Typical industrial shell boiler (Cochran, 2018)



Pressure shell – green, furnace – yellow, smoke/fire tubes – blue/green

Figure 2. Cut away view of typical industrial shell boiler (Taijune, 2018)

The shell of the boiler is fabricated from pressure grade steel plate, the cylindrical shell profile being formed by a rolling process (figures 3 & 4). The process can result in flat sections at either end of the formed sheet which in turn results in an angular distortion from the circular form where the end of the plate join to form a butt at the cylindrical seam (figure 5). The angular distortion or *peaking*, whilst not desirable is catered for in design codes due to difficulty in achieving a true cylindrical profile during manufacture. The distortion can be either negative or positive.

Figure 3. Shell rolling process (Hurst Boiler, 2018)

Figure 4. Formed shell strake (Hurst Boiler, 2018)

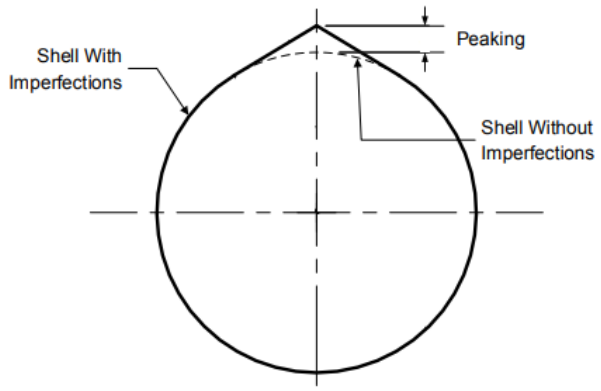


Figure 5. Local peaking of shell seam (Adapted from API 579, 2016)

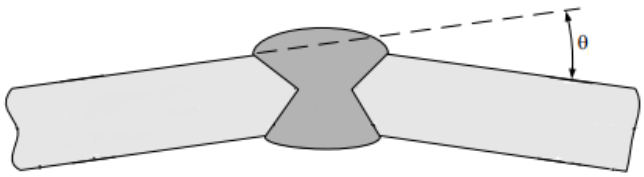


Figure 6. Angular weld misalignment due to peaking (Adapted from API 579, 2016)

The angular distortion in the shell results in an increase in localised stress in way of the longitudinal seam weld (figure 6). The localised increase in stress combined with cyclic operation and environmental corrosion can lead to a rare but catastrophic failure (figure 7) of the longitudinal seam due to corrosion fatigue (Moore, et al., 1993).

Figure 7. Catastrophic failure of a shell boiler, Gazipur, Bangladesh (Muhmud, 2017)

The operation of pressure systems in the United Kingdom is regulated by the Pressure Systems Safety Regulation 2000, which places a duty on the user of shell boilers to have periodic examinations completed by a competent person in accordance with a written scheme of examination to ensure the continued safe use. The written scheme of examination specifies examination of shell boiler longitudinal seams at a maximum 5 year period in accordance with inspection industry guidance published by the Safety Assessment Federation in the form of the Guidelines for examination of longitudinal seams of shell boilers – SBG2 (SAFed, 2012).

The period of examination being established by an initial assessment which considers the measured value of peaking and cyclic operating conditions. The examination focuses on the identification of cracks originating from the toe of longitudinal seam butt weld, which consists of ultrasonic flaw detection and magnetic particle examination.

Periodic examination of the longitudinal seam in shell boilers for cracking was implemented as a result of an investigation into the catastrophic failure of two shell boilers in 1988. (Moore, et al., 1993). In the 10 year period following the 1988 failures in the region of ten thousand shell boilers had been examined for longitudinal seam defects as part of in-service periodic inspection, the Safety Assessment Federation (SAFed, 2012) suggested in this time that a significant number had been identified as containing defects. They also state that there has been a marked reduction in identified defects due to manufactures addressing excessive peaking in formed shells since 1988.

Whilst the periodic examination of steam boilers remains an important diagnostic tool which reduces the risk of failure due defects that develop during service. The current guidance on the periodicity of examination of the longitudinal seam raises questions of suitability due to the number of boilers identified with defects. The author direct experience with in-service examination for Zurich Engineering over a ten-year period has noted no boiler failures that have been directly linked to defects identified in the longitudinal seam where peaking was recorded. The observation aligns with the comments made by the Safety Assessment Federation regarding reduction of defects since 1988.

3.0 Literature Review

The design of shell boilers is predominantly driven by rule in accordance with recognised standards such as BS 2790 and BS EN 12953, which incorporate high factors of safety allowing for localised and secondary bending stresses. The peaking allowance in design codes therefore allows for a significant concentration in stress where a measurable distortion in the longitudinal seam of the boiler shell is present. Moss (2004) argues that such discontinuity stresses are a significant factor in the design of pressure vessels which are subject to cyclic operating conditions. And comments that detailed stress analysis should be completed over the use of higher safety factors.

A shell boiler is considered an active system due to the cycling thermal and pressure loads present during operation, such cyclic conditions can lead to fatigue failure in poor designed and operated system. The number of cycles is an important aspect of pressure vessel design, both Harvey (1974) and Moss (2004) point to the number of cycles being a greater consideration than the time in service. Brown (2010) adds that the residual stress present from manufacture should also be considered. The manufacturing process can result in geometrical irregularities in the weld area which in turn results in high localised stress concentrations (Jaske, 2000).

Both stress and fatigue are factors which contribute to corrosion fatigue cracking (McIntyre, 2002) in shell boiler longitudinal seams as discussed earlier, however whilst it is prudent to minimise, it is seldom possible to exclude totally due to commercial constraints in the market place. Where the vast majority of boilers are designed to code rules which maximise profits due to cost reductions achieved by designing for standardised manufacture (Anderson, 2004). Which in turn results in the incorporation of unnecessary stress in the design. The supply of boilers typically being grouped due to steam raising capacity, leading to the operator in many cases specifying a boiler that is to large or small for the application, leading to unnecessary cyclic operation.

Angular misalignment on the longitudinal butt-welded seam of cylindrical pressure vessels is examined by Zeman (1993) which details the resulting forces and stresses local to the deviation from the true cylindrical form. Further work by Bock and Zeman (1994), presents formula for analysis of peaking, and is compared with findings of finite element analysis Stresses attributed to peaking in the longitudinal seam. A later study on bending stresses due to peaking completed by Ong and Hoon (1996) cast doubt on earlier studies where the results analysed using proposed

formulas were found to have considerable discrepancies from the findings of finite element analysis of the same study. Ong and Hoon propose that this discrepancy is due to the value of peak stress at the welded joint, and present an improved theory which proves to be accurate when compared to finite element analysis.

Separate studies on the misalignment in circumferential joints of cylindrical pressure shells comparing analytical methods with finite element analysis, by Aseer Brabin, et al (2010) considering Aluminium 2014-T6 alloy, and Abbas, et al. (2012) considering high strength low allow steel. The study found the finite element analysis discontinuity stresses aligned with analytical findings where the longitudinal seam had an offset misalignment. The study in both cases was based on earlier theoretical work completed on elastic stress distribution (Johns & Orange, 1961). Whist both studies consider the circumferential joints, the supporting theory is applicable to longitudinal joints, with Aseer Brabin, et al (2010) suggesting further investigation where misalignment is due to peaking. This was also considered in a study of spherical pressure vessels utilising finite element analysis (Sreelakshmi & Chitaranjan, 2016).

Stress concentration factors are analysed in fabricated pipe by Lotsburg (2007) where assembly tolerances are considered due to plate misalignment, and the effect of pipe bore out of round on stress concentration. In later work Lotsburg (2008), suggests stress concertation factors for consideration in use with design codes. Stress concentrations in misalignment of flat plate structure is considered by Xuesong, et al. (2016), where finite element techniques found good agreement. Both Lotsburg and Xuesong, et al, consider the requirements of BS7910 Guide to methods for assessing the acceptability of flaws in metallic structures, in their respective analysis. Zhao (2018) presents equations and analysis of pipe subject to joint misalignment verified through experiment and finite element methods.

A study completed on concave and convex angular distortions in pipelines allowing the estimation of stress concentrations from analytical formula derived by Adamkowski and Lewandowski (2015) was verified against measurements taken with strain gauge monitoring of fabricated penstock pipe work with agreeable results. And acknowledge earlier work by Yada, et al. (1989) where angular distortion is analysed by numerical methods, however point out that the findings of the study had not been proved by experiment.

4.0 Specific Study Objectives

4.1 Hypothesis

Considering the current application of industry examination guidance, the research hypothesis for the proposed study is stated as

Current examination frequency applied in accordance with industry examination guidance results in unnecessary examination of longitudinal seams for defects resulting from peaking inherent from manufacture where a maximum frequency of examination is specified at 5 years.

4.2 Research Question

Is the application of current industry guidance appropriate for the identification of defects in longitudinal seams of shell boilers due to an increase in peak stress due to shell peaking where boilers constructed to design code have an inherently conservative design methodology?

4.3 Research Objectives

The research study objectives are determined in accordance with the governing factors that determine the peaking stress values by design and in-service examination scope applicable to shell boilers discussed. The objectives are grouped and summarised as detailed below

Specify the limits of boiler to which study applies

- Shell material
- Design pressure
- Shell diameter
- Shell thickness
- Range of peaking

Determine peak stress due to peaking of shell

- In accordance with Safed SBG2 up to the peaking limit of design code
- In accordance with BS2790 design code
- In accordance with BS EN12953 design code
- By applying BS7910 analysis techniques
- By applying PD5500 analysis techniques
- By applying API579 analysis techniques

Model study boiler and simulate peaking to determine peak stress utilising finite element analysis techniques.

Evaluate the results of finite element analysis in comparison to values obtained for design code rules, analytical design methods and inspection industry guidance.

Consider the suitability of the current industry wide conservative examination approach to examination frequencies of longitudinal seams where boilers designed by code have inherent conservative design rules.

5.0 Methodology

5.1 Purpose of research

The proposed research analyses the requirements of examination of longitudinal seams of shell boilers and questions the inherently conservative examination requirements applied to boilers which are designed in accordance with rules which are conservatively based. The purpose of the research is considered as explanatory.

The analysis takes the form of cross-sectional research as the study will focus on industrial shell boilers manufactured to current design codes prevalent to boiler in service in the United Kingdom, being BS2790:1992 and BS EN12953:2012. Which come under the scope of the current SGB2 guidance (SAFed, 2012) where the boiler is of the characteristics detailed below

- Horizontal shell type only
- Operating pressure > 2 barg
- Operating temperature > 134°C
- Membrane hoop stress ≥39 N/mm^2

Where the maximum allowance for peaking is defined as e/4+0.5mm and e/3 for BS2790 and BS EN12953 respectively, where ‘e’ is the shell thickness.

The study of peak stress in the longitudinal seam will consider the following research methods in the analysis of the problem in the following section.

5.2 Study Design

The proposed research study adopts the following research classifications.

Class 1 – Applied

The indented use of the research is to improve the application of in-service inspection criteria relating to the examination of longitudinal seams in industrial shell boilers. Where the current industry practice specifies a 5-year examination period, the study aims to challenge the suitability of the current maximum period.

Class 2 – Data collection techniques

The design of the explanatory research will incorporate both Quantitative and Qualitative data collection techniques.

Quantitative

The analysis of peak stress due to shell peaking is considered as Quantitative as the calculation of peak stress for a given boiler configuration will result in measurable results.

Qualitative

To establish the predominant independent variables the cross-sectional study will utilise a qualitative case study that specifically analyses the predominant shell configuration. The peaking of shells applies to all classes of pressure vessel of fabricated construction where formed from flat plates, and as such not considered as part of this study where not designed to referenced design codes or described as vessels other than shell boilers.

Class 3 – Experimental

The Quantitative peak stress data is determined by experimental use of design code formula and finite element analysis. The Independent and Dependant variables subject to analysis are considered as

Independent variable

- Shell diameter
- Shell thickness
- Design pressure
- Magnitude of seam peaking

Dependant Variable

- Peak stress

6.0 Ethics

The authors sponsoring company, Zurich Engineering, is part of the global insurer Zurich, which is regulated in the United Kingdom by the Financial Conduct Authority. Data stored within Zurich Engineering is bound by strict data policies. Any records accessed, and data utilised as part of the proposed research will be censored with respect to customer identified or any other identifying data in accordance with the applicable data release policies.

To ensure that any extracted data is represented accurately the censored version of applicable records will be attached as an appendix.

The specified limits of the sample boilers subject to analysis must reflect those that are designed in accordance with recognised codes of construction and represent boilers that are in current common use. This is considered necessary to ensure that the results are not misleading.

7.0 Project Plan

	Action	Week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Review assignments specification																				
2	Formulate/review project proposal																				
3	Conduct literature review																				
4	Draft Introduction																				
5	Review design code rules vs fundamental pressure vessel theory																				
6	Review examination records to determine sample boiler group																				
7	Define limits of study analysis, principle boiler parameters																				
8	Determine peak stress in accordance with design codes																				
9	Determine peak stress in accordance with industry examination guidance																				
10	Determine peak stress by FEA																				
11	Collate data for analysis																				
12	Present results/analysis																				
13	Conclusions/recommendations																				
14	Finalise introduction/review assignment/finalise references and appendices																				
15	Summary and Abstract																				
16	Prepare viva voce presentation																				

Allow for overrun up to wk10 possible delays in data access and analysis

Allow for potential software familiarisation

Key project milestone

8.0 Resource Requirements

The resources required for the study of peak stress due to the peaking of boiler shells is detailed within the following groups.

8.1 Manufacture construction details

To ensure that the analysis is based on boiler models that accurately reflect those that are in service a representative sample of constructional details is required. This will be in the form of manufacture general assembly drawings held by the authors sponsoring company, Zurich Engineering. The requirements being the boiler principle dimensions, design operating parameters and material grade.

8.2 Published design and assessment codes

Access to applicable design and assessment codes relating to shell boilers, and also general pressure vessels where the peaking of formed shells is considered. The author has access to current publications through the sponsoring company, Zurich Engineering.

8.3 Computer analysis software

Suitable computer analysis software is required to assess the maximum peak stress values due to peaking within the limits imposed by design rules.

9.0 Constraints

Due to the variations in shell boiler design specifically relating to shell diameter and plate thickness, it is envisaged that a potential constrain could arise during the determination of the model sample boiler set for analysis.

Therefore, an analysis on examination data spanning a 5 year period is considered appropriate to establish the most common boiler shell diameter and plate thickness configuration in current use within the United Kingdom.

As the examination of steam boilers is subject to the statutory requirements of the Pressure Systems Safety Regulations regarding examination and record keeping, access to examination records spanning a 10 year period held by the authors sponsoring company, Zurich Engineering, is available for scrutiny.

The aim of the study is to consider the affect on peak stress at the longitudinal seam of boiler shells where peaking is inherent from manufacture. Whist it is acknowledged that peak stress due to peaking is one component mechanism which leads to catastrophic failure of the longitudinal seam due to corrosion fatigue. The remaining components, environment corrosion and fatigue due to cyclic loading are excluded from the scope of this study and are considered appropriate for further research.

10.0 Conclusion

The periodic examination of shell boiler longitudinal seams for defects associated with corrosion fatigue is well established within the United Kingdom, being implemented as a result of several catastrophic failures during the 1980's. However, further incidents and defects identified during periodic examinations is negligible. The literature review revealed that serval studies had been completed on the circumferential joints in both vessels and pipework due to misalignment, where the stress concentration was analysed by experimental and finite element methods and found to be in good agreement. The analysis of stress concentrations in the longitudinal seams due to angular misalignment in shell boilers, or indeed general vessels was not well represented in recent research, this would suggest that further research in this area would be beneficial in challenging the current application of the periodic examination of in-service shell boilers, where design codes incorporate conservative design rules.

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