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Literature Review-Design and Analysis of Oval shape Flange for Chiller

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Abstract
Flange joints are very common in pressure vessel and piping systems. Flanges are primarily used where a connecting or dismantling joint is needed. These joints may include joining pipe to fittings, valves, equipment, or any other integral component within the piping system. The performance of joint is characterized mainly by its strength and sealing capability. However, recommended design procedures for bolted flange joints are available in international codes and standards. In this paper, bolted flange connections are analyzed by implementing the design method of ASME Boiler and Pressure Vessel Code. The results of a parametric study of the behavior of flanges and stresses in bolts are analyzed by varying the flange thickness, bolt preload and number of bolts, at the same time maintaining other flange dimensions constant. Theoretical results obtained using ASME design approach is compared.
Keywords: *Stresses, ASME code, flange.*

I. INTRODUCTION

Flanged joints are essential components in nearly all pressurized systems; however, they are also one of the most complex. A large number of factors enter into the determination of the successful design and operation of a flange joint in service. The bolted flange joint involves the interaction between the bolting, flange, and gasket, considering important nonlinear variables, such as friction and gasket properties. The pressure vessel and piping codes were developed for safety, and the rules developed for bolted flange joints were developed in the same spirit. The ASME Code design rules _1_ provide a method for sizing the flange and bolts to be structurally adequate for the specified pressure design conditions; however, the current design rules do not address external loads nor do they guarantee a leak-tight joint for all transient operating conditions.

Flanged joints on large diameter flanges can prove problematic to seal successfully with many factors contributing. One such factor is stud bolt loading contributing to stress and deflection of the flanged joint. This investigation involves the use of finite element analysis (F.E.A) to predict levels of stress and deflection of a particular flanged joint when the stud bolts are tightened.

II. LITERATURE REVIEW

Waters et al. (1927) initiated a method for calculating stresses and deflections in flange joints, the results will have good agreement with experimental results. **They** further refined the analysis in1937, and named as the ‘Taylor and Forge method’. This is the basis for ASME and BS5500 code of flange design. In a flange joint assembly, initially bolts are tightened and create tension and bolt-up stress in bolts in order to prevent leakage of the fluid from system. The initial bolt-up stress should be large enough for efficient sealing of the joint, but it should not large so as to allow the possibility of scratching and damaging the flange and gasket surface. The tightness of flange joints depends on the contact stress between the flange surfaces and gasket surface. Performances of gasketed flange joints are characterized mainly by its strength and sealing capability. However, ASME Boiler and Pressure Vessel Codes recommended design procedures for flange joints.

Hichem Galai et al. [2010] proposed an analytical model of metal-to-metal contact flange joints beyond the bolt circle. It provides additional considerations compared to the other method developed by them while designing flanges. Besides being more comprehensive, the model based on the plate theory gives more confidence on its ability to predict flange separation and increase in the bolt load during operation.

Koji Kondo et al. [2011] focused their study on the tightening coefficient developed by the impact of wrenches and bolt preload. A finite element analysis approach was used to determine the gasket stress during bolt tightening and results are compared with fundamental gasket characteristics. The experiments were conducted and bolt forces are measured during tightening process and evaluated the sealing performance using the bubble leak testing.

Tan Dan Do et al. [2011] proposed an analytical approach to determine the effect of bolt spacing and its impact on flange design based on the theory of circular beam. The model was tested for different bolted joints by varying number of bolts, flange and gasket stiffness. The analytical results were compared with FEA and suggested that the thickness of the flange and the stiffness of the gasket have a great effect on stress distribution. In this paper, a parametric study of the behavior of flanges and stresses in bolts are analyzed and results were discussed.

G. Mathan et al. [2011] conducted experiments on gasketed flange joint and analyzed bending loads in flange joints through FEA considering the non linear properties of the gasket. The contact stress distributions observed has significant variation along the gasket width and also in bolts under bending load and results were well compared with the experimental studies.

Abdel-Hakim Bouzid (2014) conducted a comparative study on bolt spacing requirements. A sophisticated model based on curved beam on elastic foundation is used to gage existing bolt spacing formulas bolted flange joints. The comparison methodology is applied to several flange sizes and gasket stiffness's. It was found that TEMA and Robert formulas are conservative and suitable for a small allowable contact stress difference around the circumference and predict higher bolt spacing with less rigid gaskets. Kove's formula is not only more accurate in determining bolt spacing as compared to TEMA formula but it is flexible in that it considers the allowable maximum contact stress variation. It is worth noting that the model used to estimate the contact stress is not suitable for small size flanges. In fact neither theory of beams or circular beams on elastic foundation is suitable in this case. Small size flanges behave like plates and therefore should be treated with the theory of circular plates on elastic foundation. Nevertheless, the results suggest that a correction factor based on the plate to beam flexural rigidity ratio could be used to accommodate small diameter flanges. The developed model could potentially be extended for use to improve bolt spacing designs and give guidance to achieve safe in-service bolt replacement.

Abdel-Hakim Bouzid et al. (2009) demonstrated over conservatism of the equivalent pressure method in this work. This is because the method is based on a rigid flange, and the entire gasket is assumed to be unloaded. An alternative and more realistic analytical solution for predicting leakage of bolted joints subjected to external bending moments is presented. The simple approach is based on the rigidity correction factor *Fm* and an integration of the leak rate over the circumference based on a sinusoidal distribution of the gasket contact stress. The analytical leakage predictions based on the ROTT gasket constants were found to be slightly higher than the experimental ones because the model considers the average radial stress to calculate the leak, while in the real flange, leakage is controlled by the gasket outer periphery higher stress caused by flange rotation. The developed approach gives a good estimate of the bolt load changes and the radial distribution of the gasket stress of the most unloaded region. The model could be improved to correct for leak based on the gasket stress at the outside periphery instead of the average stress. The full validation of the developed model would require comparisons to be conducted on large diameter flanges.
Finally, it is worth noting that the developed approach could be used with either ROTT gasket constants or any other leakage stress relationship obtained from a curve fitting technique including interpolation of real leakage data.

Singh (1984) studied one of the most common methods used for flange design is found in ASME VIII Division 1, Appendix S, Design Considerations for Bolted Flange Connections. Australian Standard AS1210 also follows this approach. These methods is Adapted from of the Taylor-Forge method developed by Waters, Wesstrom, Rossheim and Williams of the Taylor-Forge Company in Chicago in the 1930's and subsequently formed the basis of the ASME code for flanged joint design. Singh (1984) explains the Taylor Forge analysis in detail. The assumptions made by this method are now generally regarded as simplistic. This method gave rise to the 'm' and 'y' gasket factors in AS1210 and ASME VIII as well as other codes.

Some of the principal assumptions and simplifications involved in this method are summarized by Singh as follows:

- Materials of all of the elements are assumed to be homogenous and remain elastic under the loading conditions assumed in the design.
- The effect of the bolt holes in the flanges is neglected.
- Axial symmetry is used to reduce the problem to consideration of the conditions on a single flange, hub and shell cross section, neglecting variations due to location of bolts.

- All loading applied to the flange is reduced to a 'couple' involving a pair of equivalent loads located at the extremities of the flange.
- Stretching of the middle surface of the flange ring due to the applied couple is negligible.
- Displacements of the joint are small such that the theorems of superposition Are valid.
- When a ring moment is applied to the flange, the point of connection between the flange and the hub is assumed to have zero radial displacement.
- Hub and shell are assumed to act as thin shells.
- The inside bore of the hub and shell is used in the shell theory analysis instead of the mean thickness diameter. Effects due to interaction of elements are neglected.

Bickford (1995) has described a method to calculate the target bolt load based on the ASME VIII design calculation and taking into account such factors as bolt pre-load scatter, embedment, elastic interaction losses, hydrostatic end load, gasket creep loss for assembly purposes. Sears and King (2003) recommend a similar approach to calculating the target assembly load.

The target load bolt-up method has been employed to calculate the proposed bolt-up load, the output of which is documented in Appendix B in this document. This load will be used as the initial input load into the finite element analysis (F.E.A) model.

Hildegard Zerres et al. (2003) investigated BFC calculations with the Taylor Forge enable checking the admissibility of the BFC for the calculation conditions. The alternatives rules proposed by PVRC are more complete than the Taylor Forge method since they consider external forces and bending moments in the calculation, as well as the scatter of the tightening device. Moreover, it is based on gasket constants Gb; a and Gs instead of m and Y values. However, the deformations of the BFC components are not taken into account. As a consequence, the remaining gasket surface pressure in operation cannot be determined.

On the other hand, the new European calculation standard edited in 2001 is based on a mechanical model which includes the deformations of the BFC components.

The internal forces can be determined for all the load conditions. The admissibility of an initial bolts tightening is checked based on both leak-tightness and strength criteria, combined with the consideration of the scattering due to the tightening device.

William J. Koves (2007) This paper uses an analytical model based on the Pressure Vessel Research Council (PVRC) ROTT test gasket constants to compute leakage in gasketed flange joints subjected to internal pressure and external bending moments. The model results are compared to test data, and design recommendations are made, consistent with the ASME/PVRC tightness-based methodology.

Deininger and Strohmeier (1999) developed a method to establish and review targeted bolt loads of a flanged joint is Finite element analysis. They used the finite element approach to produce an axisymmetric model of a flanged ring joint and concluded F.E.A. was an acceptable tool for the analysis of flanged joints offering that for convergence of solution a fine mesh and small load steps were required. Welding Research Council Bulletin 341(1989) also describes using the axisymmetric approach but indicated care should be taken on the non-symmetric parts of the joint and non-linear gasket component.

Yasumasa & Satoshi (2000) discuss analyzing gasketed flange joint using ANSYS F.E.A. software and indicate they have developed a method to model non-linear gasket material using elements available in ANSYS 5.5 when using axisymmetric analysis. They go on to suggest other F.E.A. modeling software such as ABAQUS supports the use of gasket elements.

Raub (2002) discusses a method to accommodate nonlinear response in gaskets where by the response of the gasket material must be quantified experimentally.

M. Murali Krishna et.al (2007) studied the sealing performance of bolted flange joints with gaskets using finite element analysis. Gaskets play an important role in the sealing performance of bolted flange joints, and their behaviour is complex due to nonlinear material properties combined with permanent deformation. The variation of contact stresses due to the rotation of the flange and the material properties of the gasket play important roles in achieving a leak proof joint. In this paper, a three-dimensional finite element analysis (FEA) of bolted flange joints has been carried out by taking experimentally obtained loading and unloading characteristics of the gaskets. Analysis shows that the distribution of contact stress has a more dominant effect on sealing performance than the limit on flange rotation specified by ASME.

T. Sawa et al. (1991) this paper dealt with the characteristics of pipe flange connections with raised face metallic flat gaskets. The distribution of contact stresses, the load factor, and the stress produced on the hub of pipes, the effective gasket seating width and the momentum were all examined. The following results were obtained:

1. In order to analyze the distribution of contact stresses, a method of analysis was demonstrated using the three-dimensional theory of elasticity by replacing hubs of pipes, flanges and a gasket with finite hollow cylinders.
2. The load factor was analyzed and the analytical results were compared with the experimental results. They were satisfactorily consistent.
3. Concerning the stress produced on the hub, the analytical results were satisfactorily consistent with the experimental results. The results obtained from JIS (1976) code deviated substantially from the experimental results.
4. The effective gasket seating width and the moment arm were analyzed by using the distributions of contact stresses mentioned in 1 and the analytical results deviated from the results obtained from JIS (1976) code.

Akli Nechache (2006) developed an analytical model to account for the creep effect of the bolt, flange ring and gasket separately or simultaneously in the design of bolted joints.

The proposed analytical approach considers the flexibility of the bolts and the gasket in addition to the flange. Creep of these elements has been coupled to the axial deflection

Compatibility equations to determine the resulting gasket and bolt load relaxations. The model could be used to verify the suitability of the initial bolt-up load in high temperature applications where creep can have a major effect on bolt relaxation. The analysis was verified against the more accurate 3-D FEM on four different size flanges.

The analytical results of the bolt stress relaxation and the change of gasket contact stress compare quite well with those of FEM.

P. M. Desai et al. (2013) studied optimization of body flange and cover flange of steam condenser used in thermal power plant and improving the ability of gasket has not been carried out yet and is under the area of research. This paper will provide an exposure to design, analysis and optimization of body flange & cover flange by using FEM approach and its validation by analytical as per ASME .Numerical Simulation techniques can be effectively used for analysis of ring type flange. The result of numerical simulation overcomes the limitation of analytical approach which can be valuable as seen from the results of suggested model. The optimum Value of thickness of Cover Flange and Body Flange are 48 mm and 90 mm respectively.

Mael Couchaux et al. (2009) In this paper an extension of the analytical model of Cao & Bell (1996) is proposed and used to determine the stress concentration factor at the weld-toe of tube to flange plate welded connections and the bolt force on the bolt. A numerical model is developed using 3D brick and contact elements and the results are compared to analytical and experimental ones. The indications are that for an analytical model the effect of the tube radial displacement due to tensile force should not be neglected because it tends to lead to underestimating the SCF value at the weld toe. However the relation obtained via the analytical model proposed by the authors is relatively com- plex and simplifications may be required, possibly in the form of an improved empirical formula. Further study is required especially to clarify the influence of bolt preloading but also of initial fabrication imperfections of the flange due to the welding with the tube.

Vishwanath V. H et al. (2013) they analysed Bolted flange connections by implementing the design method for gasketed bolted flanged connections as per ASME Boiler and Pressure Vessel Code and results were validated with finite element analysis software ANSYS. A parametric study of the behavior of flanges and bolts stresses are analyzed by varying the flange thickness, bolt preload and number of bolts, at the same time maintaining other flange dimensions constant. Axial, radial and tangential stresses are obtained by varying flange thickness from 44.4 mm to 55 mm; bolt preload is varied from 35 % of yield strength to 75% in step of 5% and to obtain uniform stress numbers of bolts are varied from 6, 8 and 12 bolts.

Mael Couchaux et al. (2011) proposed an analytical model in the present paper to derive the moment-rotation curve of a bolted circular flange joint which can be calculated via the initial rotational stiffness and the bending resistance (Couchaux et al, 2011). A model, based on the component method, is proposed to determine the initial rotational stiffness. A coefficient of rigidity is evaluated for the compression area which could be used for different joint configurations. The results are compared with those of the numerical and experimental tests and quite good agreements are obtain. The rotational stiffness is underestimated in presence of thin flange. Finally, the present model could be applied to determine the initial rotation stiffness of circular base plate joint.

Pal Turan (2003) In this paper an analytical model will be described to determine the resistance of flange-plate pipe joints in tension. This model is based on the *Eurocode* T - stub model. Later, an experimentally verified 3D finite element model will be presented. The results of the numerical and the analytical models will be compared. Two configurations were investigated with different geometry and welding type. In the first, there is no hole in the middle of the flange-plate; in the other there is a hole, which size is equal to the diameter of tube. In the second connection type there is two-sided fillet welding, while in the other there is only one-sided welding. Finally a statistical evaluation was carried out.

III. CONCLUSIONS

Bolted flange joints are the most popular type of connection between pressure vessels and piping equipment. They are very attractive type of connection because they are simple to mount and offer the possibility of disassembly. However, they are very complex structures to design and analyze and often result in leakage failure. One of the reason is the loss of tightness that results from the uneven distribution of the gasket contact stresses in the radial and circumferential direction. Many factors contribute to such a failure; bolt load non-uniformity, inadequate flange to gasket stiffness, inappropriate bolt spacing requirements or a combinations of some of these.

Bolted flange connections are analyzed by implementing the design method for gasketed bolted flanged connections as per ASME Boiler and Pressure Vessel Code and results were validated with finite element analysis software ANSYS. A parametric study of the behavior of flanges and bolts stresses are analyzed by varying the flange thickness, bolt preload and number of bolts. Study the assembly stresses produced when bolting two flanges together. Stress linearization of stress concentrated areas. Calculation of Membrane, Bending & peak stresses along the thickness of highly stress concentrated zone. Compare above stresses with the allowable limit given by ASME.

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