CIRCUMFERENTIAL LUG FOR SUPER-CRITICAL BOILER ANALYTICAL DESIGN AND COMPUTATIONAL ANALYSIS USING ASME CODE

Nirmal Kumar Balaguru[1], Garima Sharma[2], Gopinath Sampathkumar[3], Ram Mohandas[4]

[1] *Student – M.Tech.(CFD), University of Petroleum and Energy Studies, Uttrakhand, India*
[2] *Student – M.Tech.(CFD), University of Petroleum and Energy Studies, Uttrakhand, India*
[3] *Junior Engineer/ Design, EagleBurgmann KE PVT. LTD.,Tamilnadu, India*
[4] *Planner, B.Kay Agencies, Tamilnadu, India*

Abstract

The paper consist of design of a circumferential lug analytically using ASME Section II Part-d for Material properties and ASME Boiler and Pressure Vessel Code. The configurations of the lug and the necessity of their configuration, the materials that can be used and supporting computational results are included. Since the divisions of boilers cannot be kept in ground to avoid irregular expansion. Lug should be perfect in width and thickness so that it will not leave the header from structure as well as lug should not tear the circumferential material. Hence the analytical Lug which is designed with the formulas proposed is analysed in software computationally and it is verified with stress intensity, von misses stress and also with different kind of principle stress namely first second and third. The plots namely Lug Span Factor, Header Unit Hoop Stress, Stress Ratio for W/D , Reduction Slope, Reduction applied to Lug Width Ratio (S_R) are also derived and plotted for future use.

Keywords: *Super-critical boilers, Lug, SA properties and ASME CODES*

--***--

1. INTRODUCTION

Lug is a component in which the pressure parts is used to hang the parts of a boiler, designing the circumferential lug for super critical header which will be present in super critical boiler before turbine.The lug is mainly used to suspend the header in support to make expansion of metal disperse uniformly. The lug, just a word make it simple but designing that makes the process tricky so ASME codes are to be followed so that its width will be in optimum range so that the header is not affected.The width and thickness should be in a range so that neither the lug shouldn't break nor header's circumference shouldn't crack or made weaker. The design of the lug should satisfy the ASME specifications and the lug should be under the safe pressure and the loads applied on it. Though enough works are available lugs that are used for subcritical boilers, necessary efforts are not available for supercritical boiler still. Circumferential Lug is most important part in either subcritical or supercritical boiler to connect peripherals to support[1][2][3].

2. LUG CONFIGURATION:

The lug configurations are of two types namely
1. C980 -0203
2. C990 -999

- C980- 0203 is the preferred lug. This lug is preferred because of lower cost.
- C990- 999 is the alternate lug. This is used only where the tight tolerances are required.

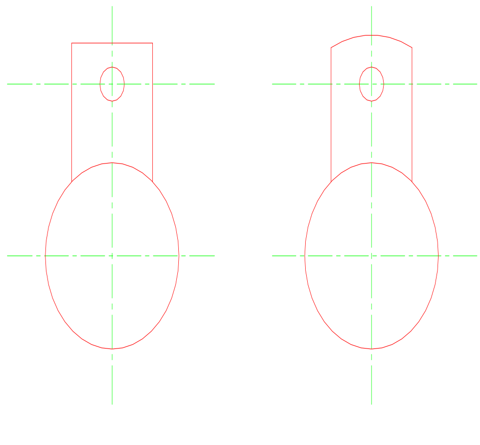


Figure 1: Lug Configuration

3. MATERIAL SELECTION:

Material is selected for the two components:
- Tube
- lug

SA335 P22 material is selected for tube. SA 387 GR22 CL2 is selected for the lug.

- **Sa335 P22:**

SA335 P22 is the part of ASTM A335, The pipe shall be suitable for bending, flanging, and similar forming operations, and for fusion welding. The steel material shall

conform to chemical composition, tensile property, and hardness requirements.
Each length of pipe shall be subjected to the hydrostatic test. Also, each pipe shall be examined by a non-destructive examination method in accordance to the required practices.
This specification covers seamless ferrite alloy-steel pipe for high-temperature service. The pipe shall be suitable for bending, flanging (vans toning), and similar forming operations, and for fusion welding. Grade **SA335 P22 Seamless Pipe** shall be made by coarse-grain melting practice. The steel material shall conform to chemical composition, tensile property, and hardness requirements**.**

- **A387 GR22 CL2:**

ASME SA387 Gr 22 CL 2 is a chromium molybdenum alloy steel plate intended primarily for welded boiler and pressure vessels designed of elevated temperatureservice. The Cr con tent 2.25 % and the Mo content 1.00 %. The most important characteristics of Mo and Cr-Mo are:
The addition of molybdenum improves the mechanical properties at high temperatures while chromium improves the corrosion resistance of steel. Manganese is added to increase these resistance at higher temperatures.

4. CALCULATION PROCEDURE:

DESIGN APPROACH:

The design steps for the most part, concerned with determining a lug width such that stress imposed on the header shell do not exceed the allowable stress, and the lug direct stress is acceptable. The lug width range under consideration is between 0.36D and 0.75D.

It is necessary to first check that the stress on the inside of the header at about 80^o from the lug centreline is less than the allowable stress. The inside header stress is independent of lug width and lug thickness. The inside header stress must be calculated for the acceptance of stress and to design.

5. HEADER DESIGN STRESS:

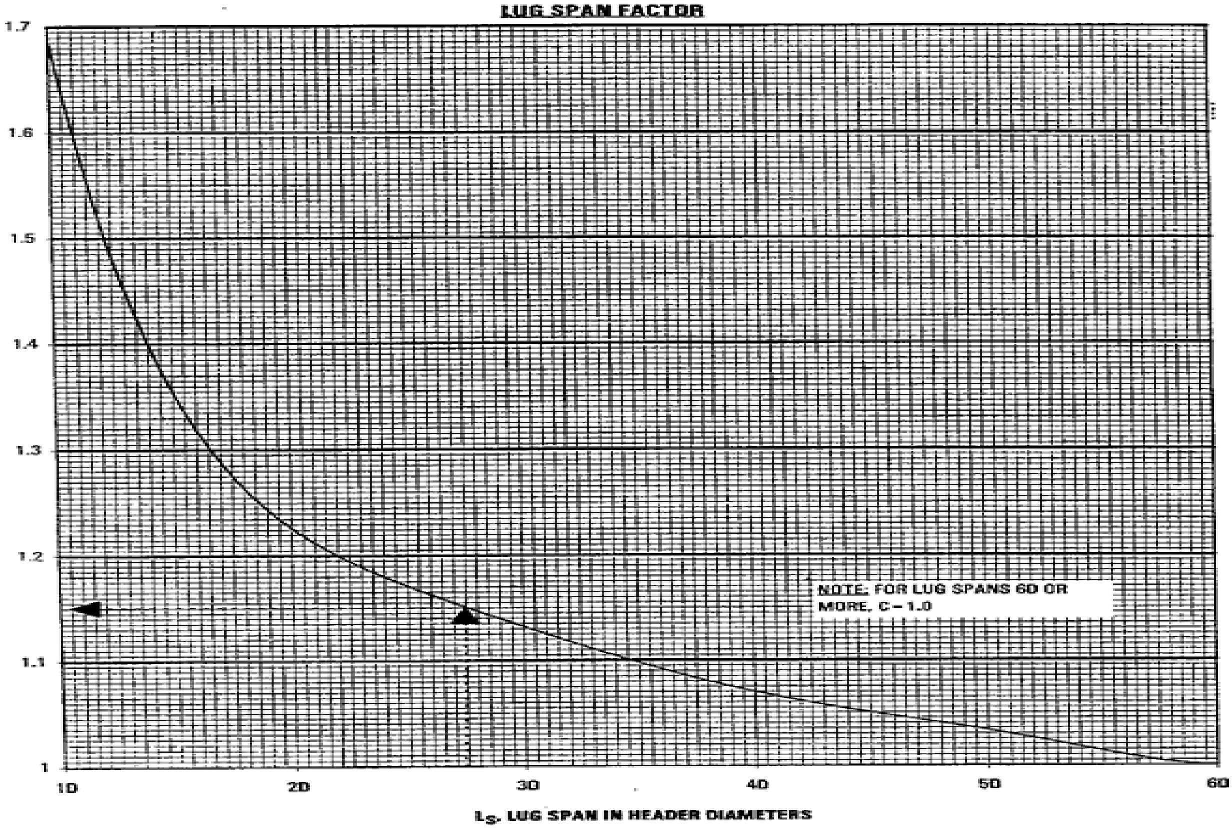
Header design stress S_{ha} is determined by using the ASME code, pressure and diameter of header and header minimum wall thickness.

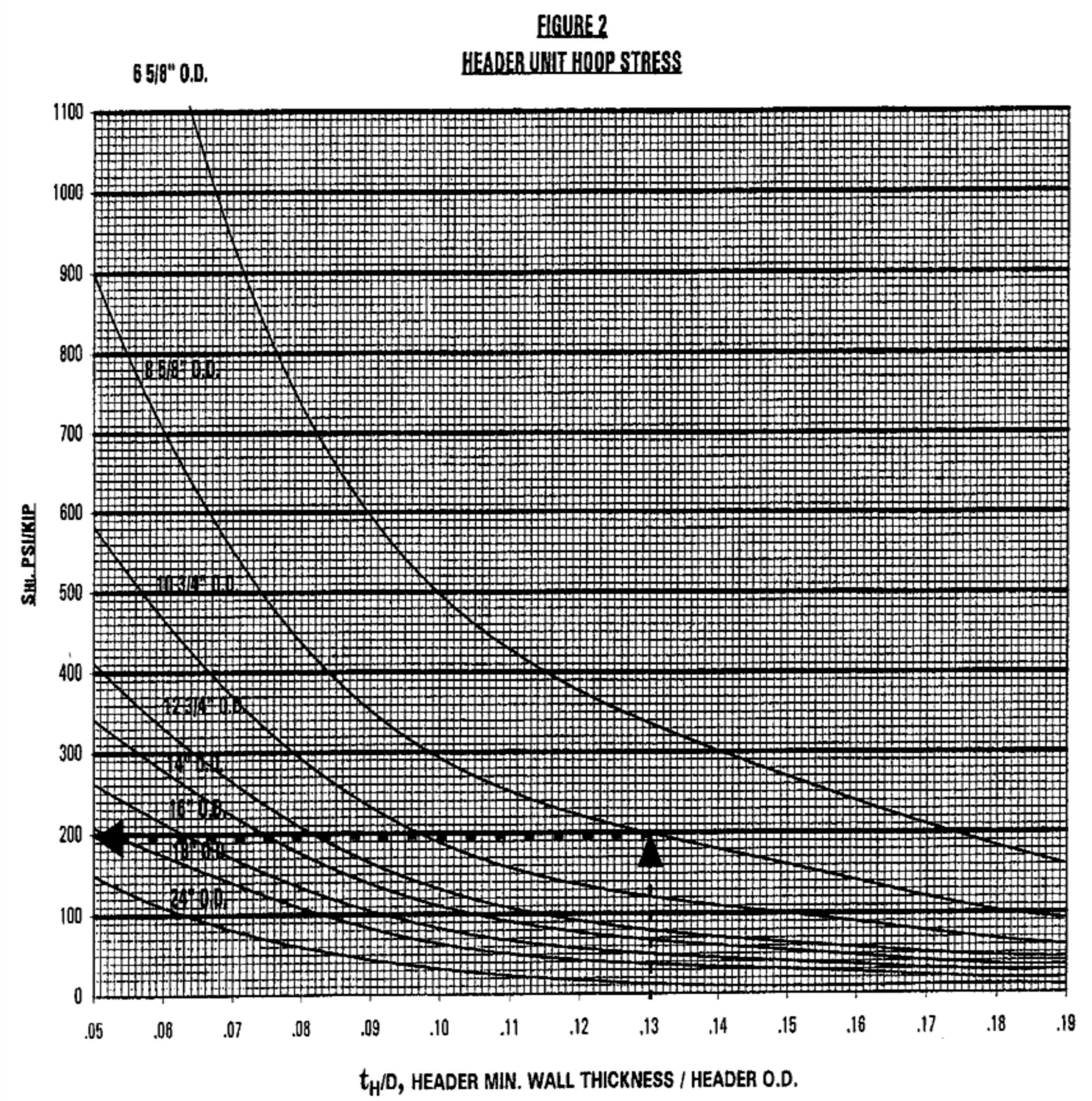
$$S_{HA} = 1.5 \times S - pressure \times [\frac{D}{2t_H} - 0.4]$$

6. STRESS CHECK AT THE INSIDE SURFACE OF HEADER:

- Steps to be followed to determine the inside surface header stress are as follows:
- Find the distance between 2 lugs that are closest to each other.
- Determine L_s by dividing the distance in inches by D.
- Lug span factor C is found by using figure3.
- Based on D and t_h/d, SHI is determined by using figure4.
- To obtain the inside surface header stress S_{ha}, multiply S_{HI} by C and P(kips).
- If the inside header stress is less than $S_{HA,}$ the load is acceptable. If not reduce the load, increase the $t_{H.}$
- If t_h/D for the header exceeds 0.19, then the value should be taken as 0.19.

FIGURE 1
LUG SPAN FACTOR





DESIGN STEPS:

Bearing stress on lug:
The lug thickness must be selected so the following is satisfied:

$$\frac{P}{(pindia)(t_L)(1.15)} \leq S_L$$

Determining W Based On Outside Header Stress:

1. From the values of t_L/D and t_H/D, the stress ratio S_R is found by using the figure3.
2. Finddirect lug stress.

$$DIRECTLUGSTRESS = \frac{1000 \times P(kips)}{\left(\frac{W}{D}\right) Dt_L}$$
$$= \frac{2780 \times P(Kips)}{Dt_L}$$

3. Multiply S_R with the direct lug stress to obtain the outside header stress.

$$S_{HO} = S_R \times \frac{2780}{Dt_L} \times P(Kips)$$

4. If the outside header stress obtained is less than the header design stress, S_{HA}, then
W_C =0.36D;
5. If the outside header stress is greater than the header design stress, find N, M.
6. Divide the outside header stress by header design stress to obtain the stress ratio reduction N.
7. Based on t_L/D and t_H/D, determine the reduction slope,M.
8. Based on M and N, determine W/D, then W_C=(W/D)*D.

FIGURE 3

STRESS RATIO FOR W/D=0.36

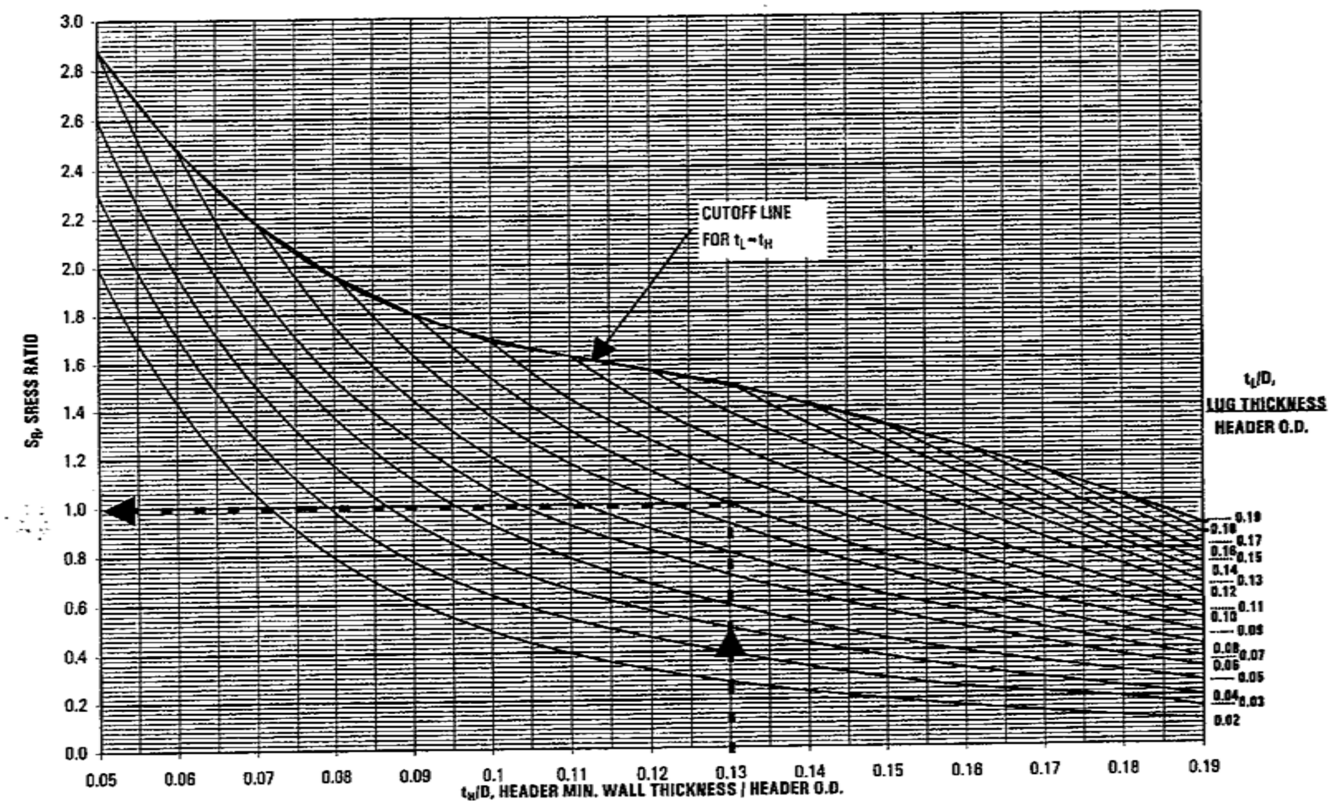
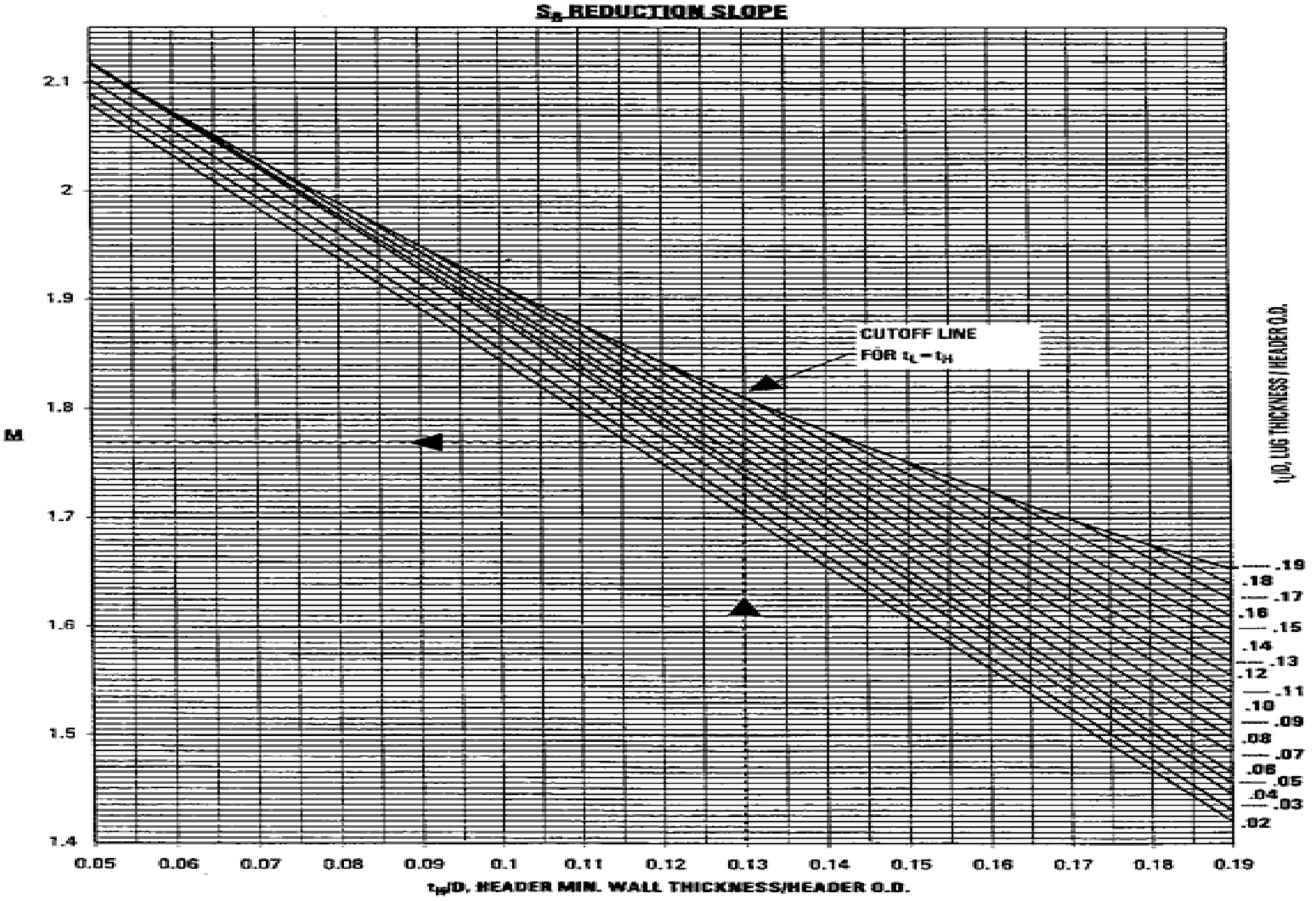


FIGURE 4

S_R REDUCTION SLOPE



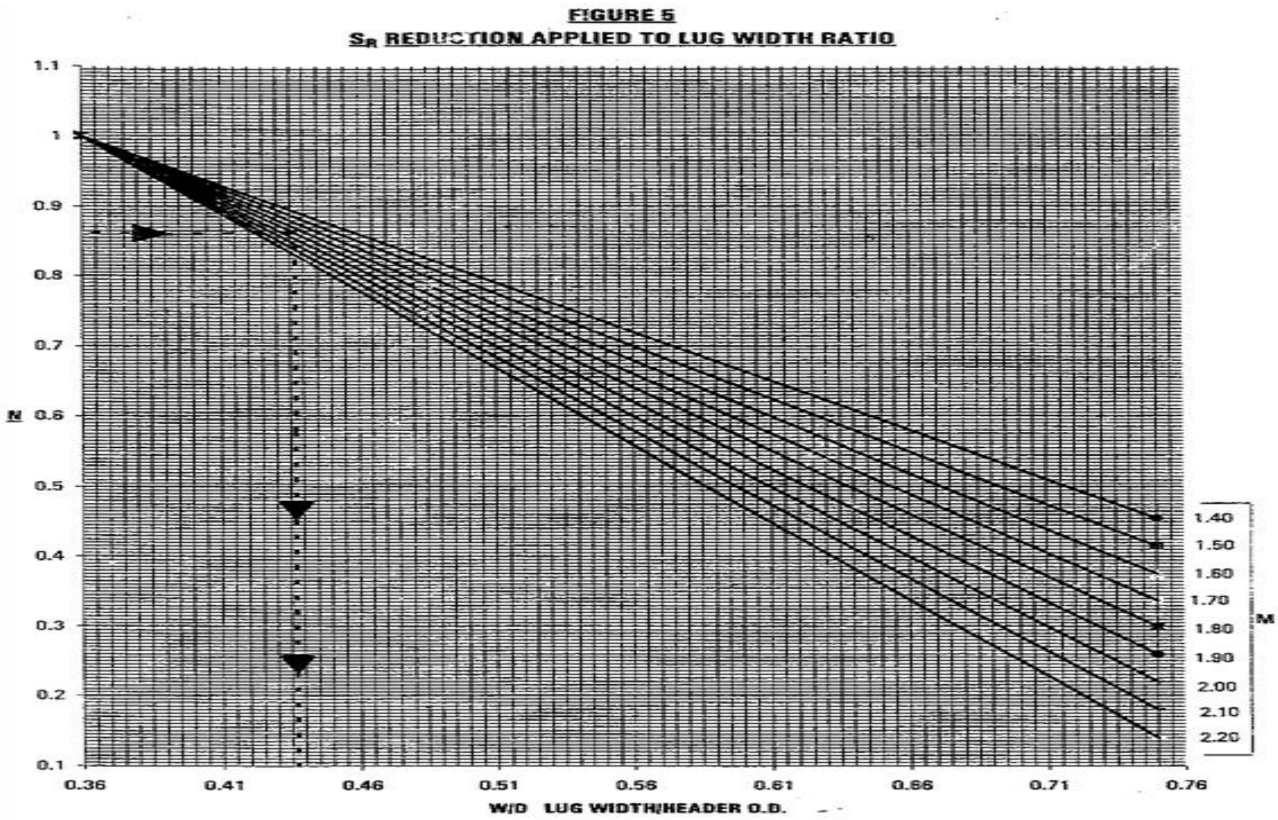


Table 1. Notation and Explanation for Stress:

NOTATIONS	EXPLANATION
S_{HA}	HEADER DESIGN STRESS
D	HEADER OUTSIDE DIAMETER
t_h	HEADER MINIMUM WALL THICKNESS
S	HEADER ALLOWABLE STRESS
L_S	SMALLEST LUG SPAN
C	LUG SPAN FACTOR
P	LOAD PER LUG
T_L	LUG THICKNESS
S_L	LUG ALLOWABLE STRESS
W	LUG WIDTH
S_R	HEADER STRESS RATIO
S_{HO}	HEADER OUTSIDE STRESS
M	REDUCTION SLOPE
N	STRESS RATIO REDUCTION

INEQUALITY CALCULATIONS:

Load imposed on the walls by welded or mechanical attachments, which produce bending stress that are additive to bursting stress. The following inequality equation should be proved.

The inequality formula are

$$\mathbf{L \leq L_a}$$

Calculations for L:

$$\mathbf{L = W_r/l \pm 6We/l^2}$$

Procedure for determining L_a:

1. Determine **k** from table 1
2. Determine**load factor L_f**, for compression or tension loading on lug

FOR COMPRESSION LOAD:

$$\mathbf{L_f = 1.618X^{[-1.020-0.014\log X+0.005(\log x)2]}}$$

TENSION LOAD:

$$\mathbf{L_f = 49.937X^{[-2.978+0.898\log X-0.139(\log X)2]}}$$

Where X=D/t

3. Determine S_t

$$\mathbf{S_t = 2.0S_a - S}$$

4. Find L_a

$$\mathbf{L_a = k(L_f)S_t}$$

Finding S value: $\boldsymbol{t = \frac{PD}{2sw+P} + 0.005D + e}$

$$\boldsymbol{P = Sw\left[\frac{2t - 0.01D - 2e}{D - (t - 0.005D - e)}\right]}$$

Table 2. Notations And Explanations For Load

NOTATIONS	EXPLANATION
L	ACTUAL UNIT LOAD
La	MAXIMUM ALLOWABLE UNIT LOAD
E	ECCENTRICITY OF W
L	LENGTH OF ATTACHMENT OF TUBE
W	ECCENTRIC LOAD APPLIED TO LUG
W_r	LOAD COMPONENT NORMAL TO TUBE AXIS.
L_f	COMPRESSION OR TENSILE LOAD FACTOR
D	OUTSIDE DIAMETER OF TUBE
T	TUBE WALL THICKNESS
K	TUBE ATTACHMENT WIDTH DESIGNFACTOR
S_t	AVAILABLE STRESS
S	PRESSURE STRESS IN TUBE
S_a	ALLOWABLE STRESS VALUE

7. MODEL CALCULATION:

HEADER DESIGN STRESS:

S_{HA}=(1.5*13704.615)-4055*[12.75/2(2.5625)-0.4]
=20556.92-(2.08*4055)
=12.094*10^3 Psi

STRESS CHECK AT INSIDE SURFACE OF HEADER:

T_h/D=0.19(recommended)
L_s=12inch L_s/D=12/12.75
=0.94D
Lug span factor C=1.7 (from fig1)
S_{hi}=45psi/kip(from fig 2)
INSIDE SURFACE HEADER STRESS=45*1.7*54.095

=4.138*10^3psi.
INSIDE SURFACE HEADER STRESS< S_{HA}
4.138*10^3<12.094*10^3
:: load is acceptable.
S_L=108.3392 mpa=15.713*10^3 psi.
Design steps:
t_L=45mm=1.77inches
pin dia=64mm=2.519inches.
bearing stress on lug:
0.224*240.63/(2.519*1.77*1.15)<S_L
10.55<S_L 10.55<15.713
t_L/D=1.77/12.75=0.138
t_H/D=2.5625/12.75=0.19(recommended)
stress ratio S_R =0.68
S_{HO}=0.68*(2780/12.75*1.77)*54.095

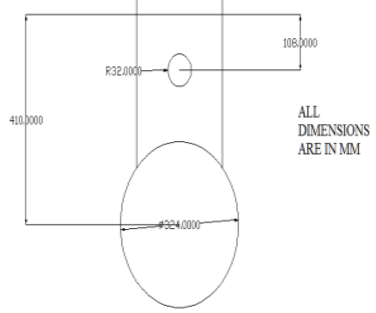
=4.531*10^3 psi.
W_c=0.36*12.75
=4.59 inch.

INEQUALITY:

L<L_a
K=2.876(from table)
Tensile loading:
Lf=49.937(0.076)^[-2.978+0.898log(0.076)-0.139(log0.076)^2]
=49.937*0.076^(-4.156)
=2.237*10^6
St=2.0Sa-S
=2.0(963.53)-643.66 =1283.4
S=1283.4(from calculation of t formula)
L=240.63/236
=1.019. La=(2..876)(2.237*10^6)(1283.4)
=8.25*10^9 from the values of La and L the inequality is PROVED

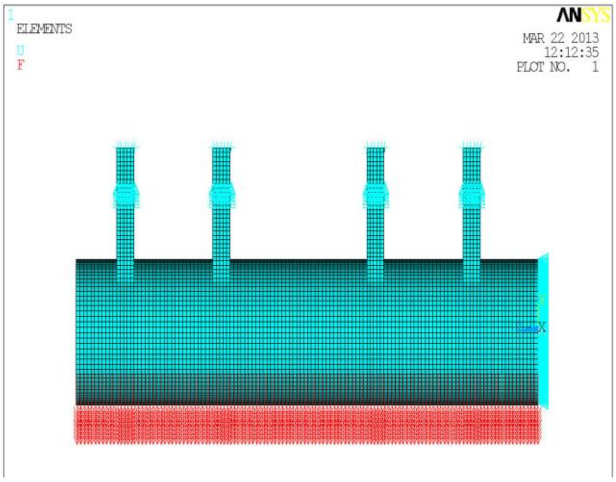
8. COMPUTATIONAL RESULTS

This is the front view of the lug with dimensions that has to analysed computationally



LUG-FRONT VIEW

In this it has been mentioned that where load and displacement should be applied.

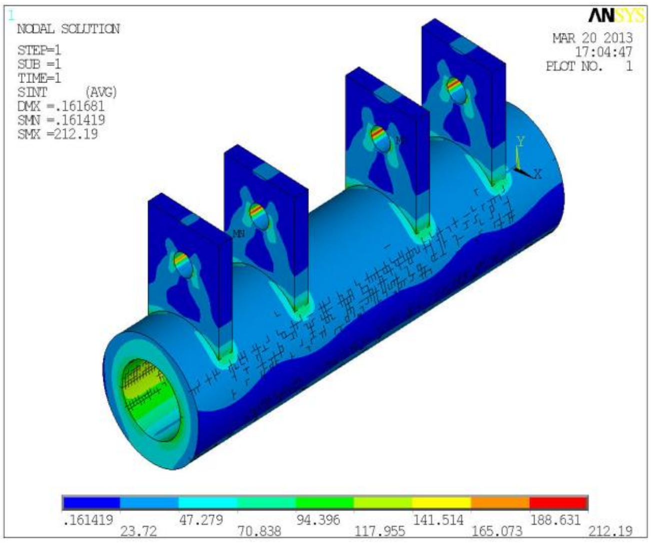


Load and Displacement View

9. STRESS INTENSITY:

Stress Intensity Factor, K, is used to accurately calculate the crack at tip where the cotter pin will be present due to nearby load in terms of fracture. When this type of stress reaches the state of critical the crack will be developed and the material will reach the state of failure. So the fracture strength is the new term which gives the load at which material fail. The experimental fracture strength of solid materials is 10 to 1000 times below the theoretical strength values, where tiny internal and external surface cracks develop higher stresses lowering theoretical value.

STRESS I



NTENSITY

9.1 Von Mises Stress:

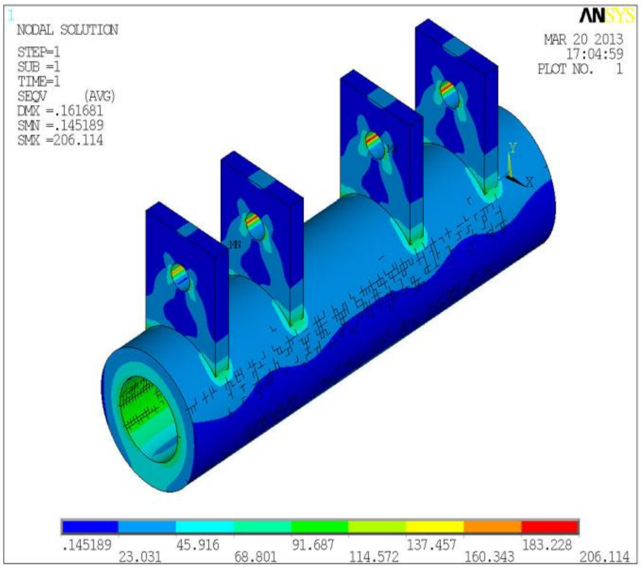
The von Mises criterion states that failure occurs when the energy of distortion reaches the same energy for yield/failure in uniaxial tension. Mathematically, this is expressed as,

$$\frac{1}{2}\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right]\leq\sigma_y{}^2$$

In the cases of plane stress, The von Mises criterion reduces to,

$$\sigma_1^2-\sigma_1\sigma_2+\sigma_2^2\leq\sigma_y^2$$

In addition to bounding the principal stresses to prevent ductile failure, this stress gives the reasons for the fatigue failure, in cases of repeated tensile and tensile-shear loading



VON MISES STRESS

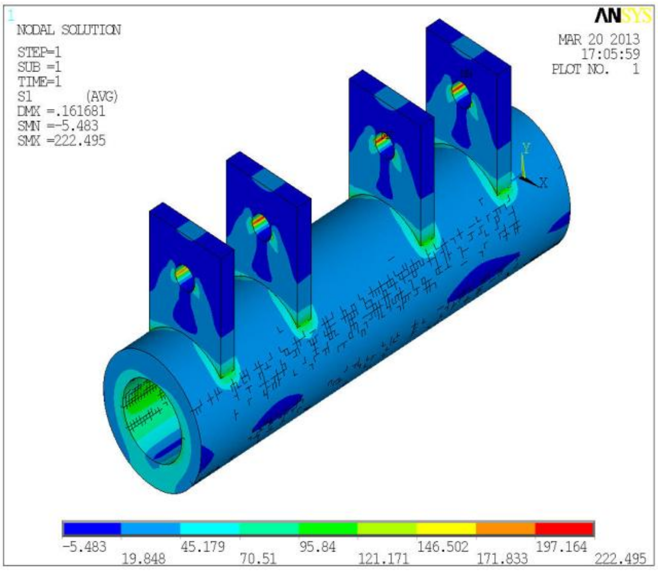
9.2 Principal Stress:

Stress is defined as the internal resisting forces that each molecules will resist to the load which is offered externally.When pressure is given to the liquid the partticles present gets pushed inwards so as a result of stress pushes them outward.These forces are result of average of all intermolecular forces present in continues material and collision between the molecules between them.

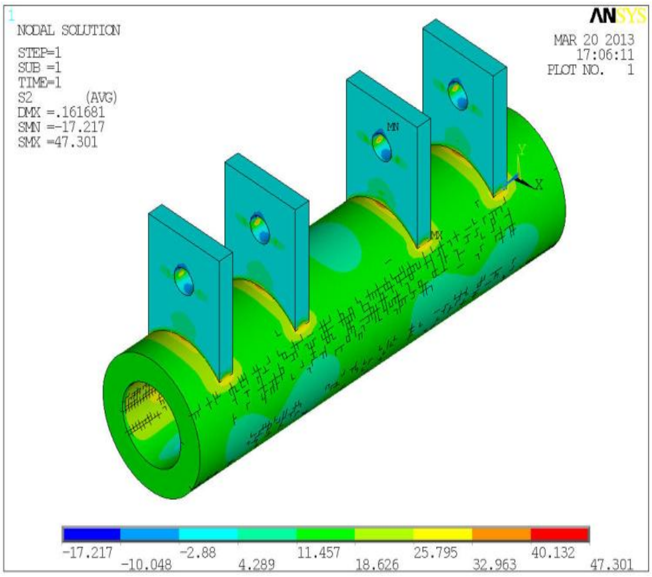
Stress, which is present in the body will arise due to several reasons. For instance the forces that acts in a body externally, so reaction force will be offered that resist the force. Likewise the weight and normal reaction. In terms of fluids the deformation changes the volume of the fluid element which creates elastic stress, but if the deformation is transient, fluids will also offer some viscous stress to resist the change due to deformation. Mechanical stress includes elastic and viscous stress.

Stress is defined as the resisting force per unit area that the particle of the continues body offers on the neighbouring particle through the surface that is separates them

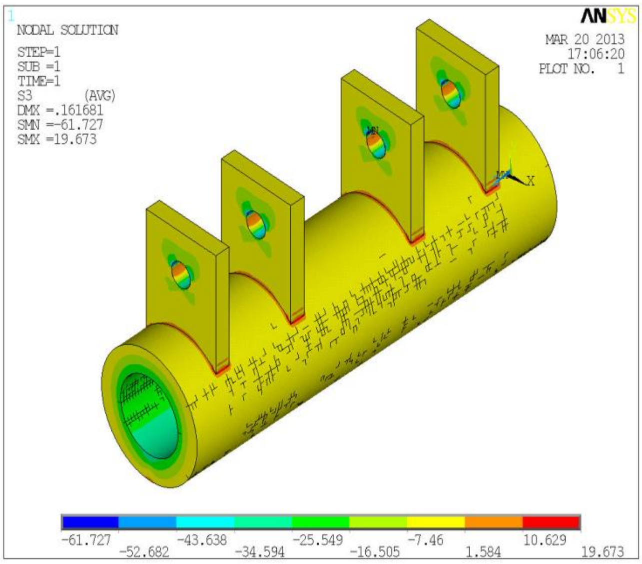
The body may have stress as a result of one plane or another plane. There are three planes that are mutually perpendicular to each other so that the stress at a particular point at that instance can be solved by the stress normal to the planes and these planes will pass through that point such that the stress present across will be the normal stress and that is what is known as principle stress, normal stress across these planes is termed as principle stress.



First Principle Stress



Second Principle Stress



Third Principal Stress

From ASME:

- ASME Section II Part-d For Material properties.
- ASME Boiler and Pressure Vessel Code.

CONCLUSION:

- The lug is an important component that must be designed only using ASME codes.
- The method to design a circumferential lug is kept in front and it is also verified computationally.
- The lug should be proper in dimension so that, neither the peripheral will not crack nor the lug will leave the support due to weakness.
- The purpose of stresses, its types and its impact has been discussed.
- The weak regions has been identified (RED), it is mainly due to presence of cotter pin and the force that will give to inside circumference of hole that is present in the lug so the stresses are maximum, but stress didn't propagate since proper material has been selected.
- Material selection plays the major role so that the stress developed will be suppressed in the small area, to save the element and to prevent crack.

REFERENCES

[1]. Research of Steam Boiler Using High Temperature Heat Pipe Based on Metal Phase Change Materials by Mao Ling Boin IEEE explore

[2]. A Research of Simplified Method in Boiler Efficiency Test by Tai Lv, Linghao Yu and Jinmin Song in science direct Volume 17, Part B, 2012, Pages 1007–1013

[3]. Opportunities For Improving The Performance And Reducing The Costs Of Bagasse-fired Boilers by A.P. Mann, T. F. Dixon, F. Plaza and J A Joyse in http://eprints.qut.edu.au