International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 8, August - 2013

Low Cycle Fatigue Life Estimation of Steam Turbine Casing

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Abstract

Abstract – In this paper we are explaining the brief concept of the low cycle fatigue in the steam turbine casing because of the cyclic loads due. The analysis and the calculation of lifetime for the casing and the bolt of steam turbine is done using ANSYS tool. Using the stress values in the Coffin Manson equation, numbers of cycles are calculated. Strain Vs number of cycles graph is drawn. Technically we have calculated number of cycles and that is compared with the total number of cycles obtained by summing the cold start, hot start, warm start from the Finite Element analysis using ANSYS and thus compared them for life estimation.

Keywords –Steam turbine, Low cycle fatigue, Finite Element Analysis, ANSYS.

1. Introduction

Steam turbine section is a fundamental part of thermal power station. So, its development and improvement are also important aspects for the development of power industry. Steam in pressurized state can be changed into rotations by using a mechanical device, which is commonly called steam turbine [1]. The casing of steam turbine can withstands the steam pressure and it supports the internal components like turbine shaft with blades. Cyclic compressive and tensile stresses in the casing walls occur due to frequent start-ups and shutdowns in the turbine. The effect of thermal stress occurs across the wall and thus sustained pressure/stress is the effect. Because of the contact between stationary and rotary parts, the casing will get damaged. Damage caused by the distortion and cracking is due to high pressure turbine casings. Frequent start-ups, shut-downs and load changes causes unsteady temperature distribution with time in steam turbine casing high pressure (HP) which causes non-uniform stress and strain distribution. Stress corrosion problems [2] also cracking and fatigue on the turbine casing are all its results.

In this work the thermo mechanical analysis of steam turbine is explained, from the temperature and stress distribution for turbine casing and bolt is calculated here using the finite element analysis. The analysis and the calculation of lifetime for the casing and the bolt of steam turbine is done using ANSYS tool. Using the stress values in the Coffin Manson equation, numbers of cycles are calculated. Strain Vs number of cycles graph is drawn. Technically calculated number of cycles using FEM is compared with the total number of cycles obtained by summing the cold start, hot start, warm start from the analysis using ANSYS and thus compared them with technically calculated cycles for life estimation. All these are done using ANSYS tool. From the results we found that the bolt and casing are safe for 20 years for the estimated life cycles from analysis. Analyzed number of cycles is more in number when compared to the technically calculated one, which it usually withstands. Thus the main intention of this paper is to estimate the life of the steam turbine casing using ANSYS tool and compare it with the estimated casing life using technical datas.

The paper starts with a section of introduction which gives the brief idea of steam turbine, and the main problems affecting the casing. This section also explains the overall idea of this work and the structure of paper.

In the second section we will see the explored details of steam turbine, operation of steam turbines, finally start up patterns of steam turbines.

The effect of low cycle fatigue on the steam turbine casing is subject of interest in the third section.

Fourth section deals with experimental analysis using ANSYS and then comparing it with the results obtained using technical calculation.

Last section is for the conclusion and brief summary about the proposed work.

2. Steam Turbines

Steam turbine is most flexible mechanical machinery and it can be used to drive even generators. Steam turbine can work at highly elevated temperatures. In some particular power stations three distinctive stages are there for the steam turbine [3].

- High pressure stage
- Intermediate stage
- Low pressure stage

A. Operation Of Steam Turbine

Steam turbine has got a simple working principle. High pressure steam is used to drive it. Number of rows of closer buckets or blades is there on a rotor, which is the basic part. Fixed blades are also there in it, to direct the flow of steam against the blades which are moving. Steam's pressure, temperature and also volume vary as it moves through the turbine. At the inlet the turbine blades are short and at the outlet they are long.

B. Start Up Patterns In Steam Turbines

Electric power demand changes not only throughout the year, but also weekly and daily. A thermal power unit starts or stops in order to adjust its output to flexibly correspond to changes in power demand. The unit has the following start patterns from unit stop to unit start [4].

I. Cold Start

The unit is started after it has been stopped for an extended period of time, such as for periodic inspection. Cold Start, in relation to steam turbine, means start up after a shut down period exceeding 72 hours.

II. Hot Start

Hot Start, means start up after a shut down period of less than 10 hours (turbine metal temperatures below approximately 80% of their full load values).

III. Warm Start

Warm Start, in relation to steam turbine, means start up after a shut down period between 10 hours and 72 hours (turbine metal temperatures between approximately 40% and 80% of their full load values) [4].

IV. Weekly Starts and Stop

In WSS, the unit is stopped at night time on a Friday or on a Saturday when the electric power demand decreases, and then it is started early on Monday morning when the electric power demand starts increasing. The stop time is 12 to 36 hrs.

V. Daily Start and Stop

Difference in demand for power varies between daytime and night so this unit will be stopped at midnight and get started in the morning [4]. The stop time is from 6 to 12 hrs. Power system efficiency can be increased by the base load units for that daily start and stop is necessary. Service life and reliability will be considered in daily start and stop. The temperature difference between steam and turbine rotor forms the thermal stress. That temperature difference is called "mismatch temperature".

VI. Quick Start

The technique of quick start is to restart the unit after it has been stopped for a short time usually less than 6 hours because of system problems or power control. The quick start is otherwise called as 'very hot start' and it needs special attention [4].

3. Steam Turbine Casing

A turbine casing (cylinder) is a high pressure vessel with its weight supported at each end on the horizontal centre line. The important components steam turbine casing is shells, shaft-end packing head, flange, bolts, inlet section and a diffuser [5], [6].

There are usually different types of casing like

1. High Pressure: A double shell design is usually used steam fills the space between shells. Pressure and temperature range is 24.13-34.47MPa and 537.7-593.330C.
2. Low Pressure: often have double casing and double flow. Pressure and temperature range is 1.378 - 4.136MPa and 287.7 - 371.110C.

These frequent startup and shutdowns will cause fatigue failures in the steam turbine casing.

4. Fatigue

Fatigue is an issue which affects mainly the moving parts especially in automobiles, reactors etc. Initiation of crack, its progress and a sudden failure are the stages of fatigue. There are different kinds of fatigue such as Low cycle fatigue, High cycle fatigue and thermal mechanical fatigue. In our case we are interested in low cycle fatigue failure in steam turbine casing [7].

5. Low Cycle Fatigue

Low cycle fatigue occur at the number of cycles which are less than and it is characterized by high amplitude alternating stress normally greater than the yield strength of the material. Here stress is not proportional to strain [8], [9].

6. Methodology

It is very expensive to test a casing's capability to withstand the loads by experimental setup. So, we are going for the method of creating model of our casing system using the ANSYS modelling. Then we will apply the necessary conditions of pressure, strain, stress etc. which the casing and bolt model must withstand during its working. After this simulation process held in ANSYS we will get the Von Mises stress, Von Mises strain, Maximum, Middle and Minimum principal stress which the casing and bolt can withstand. Putting these values in the strain life equation and finding the number of cycles the model can withstand in each case of hot, warm and cold start up is calculated. Strain vs. Number of cycles is drawn graphically. Thus the total number of cycles which the casing and bolt can withstand can be calculated and thus estimates its life time. Also same calculation for life estimation is done using some technically available data. Then comparing the life obtained in two cases.

7. Strain Life Equation

When plastic strain occurs, the service life of material decreases, often no more than 10^4, in low-cycle fatigue range. The research of low-cycle fatigue was traditionally done for pressure vessels, power machinery that are exposed to a heat source/sink which induces thermal expansion (thermal stress) to the structure [10]. The low-cycle fatigue is usually presented as the plastic strain $\frac{\Delta\varepsilon_p}{2}$ in log scale against cycles to failure N also in log scale. The result of low-cycle fatigue is near a straight line for common metal materials such as steel and is often referred as Coffin-Manson relation:

$$\frac{\Delta\varepsilon_p}{2} = \varepsilon_f^{'}(2N)^c \qquad (1)$$

Where,

$\frac{\Delta\varepsilon_p}{2}$ is the amplitude of plastic strain.

$\varepsilon_f^{'}$ is fatigue ductility coefficient defined by the strain intercept at 2N = 1. For common metal materials, $\varepsilon_f^{'} \approx \varepsilon_f$. N is the number of strain cycles to failure and 2N is the number of strain reversals to failure. C if called fatigue ductility exponent. For common metal materials -0.7 < c < -0.5. A smaller 'c' value results in a longer fatigue life.

8. Calculation and Results

Life Estimation of Casing Using Analysis

In this section we are explaining analysis of our model under some defined condition of thickness and the pressure, force etc. applied on model as given in **table1** using ANSYS. **Figure 1** represents the equivalent Von Mises stress for casing, **figure 2** represents the Maximum principal stress for Casing, **figure 3** represents the Middle principal stress for Casing, **figure 4** represents the Minimum principal stress for Casing and **figure 5** represents the Equivalent Von Mises strain for casing

Casing Thickness Calculation

$$t_c = \frac{PR}{SE - 0.6} \qquad (2)$$

P – Inner pressure in MPa
R – Inner radius of casing in mm
S – Allowable stress in MPa
E – Joint efficiency

Flange thickness

$$h = \frac{D}{2} + t_c + \frac{d_{cap\,nut}}{2}\ mm \qquad (3)$$

h: flange thickness (3-5) times of
D: Inner diameter in mm
t: bolt pitch in mm
m: Distance between the centre of the bolt to the centre of the casing in mm

Table 1 Descriptions and units

Description			Units
Inside pressure	P_i	5	MPa
Outside pressure	P_o	0	MPa
Inner diameter	D	500	mm
Allowable stress	Σ	77.5	MPa
Assumed ratio of flange height to casing	h/t_c	2.9	
Bolt diameter	D	42	mm
Bolt thread pitch	P	4.5	mm
Bolt pitch	T	75.6	mm
Cap nut diameter	N	58	mm
K	K	20	mm
Allowable stress on bolt	σ_b	250	MPa
Casing thickness	t_c	31.78	mm
Flange thickness	h	92.16	mm
Force	Q	94500	mm
Force	P	33273.57	N
Flange bending stress	σ_f	54.08	MPa
Force on the bolts	R	164696	N
Bolt bending stress	σ_b	149.12	MPa
Required initial bolt tension (Preload)	$F_{P\text{-}Bolt}$	230575.1	N

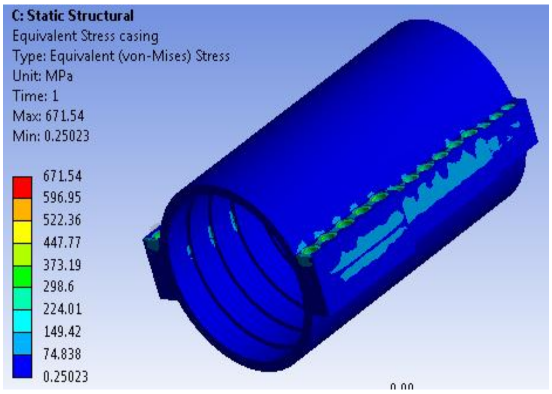

Fig 1: Equivalent Von Mises stress for Casing

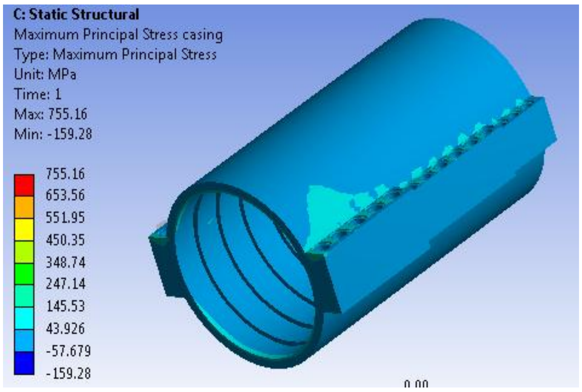

Fig 2 : Maximum principal stress for Casing

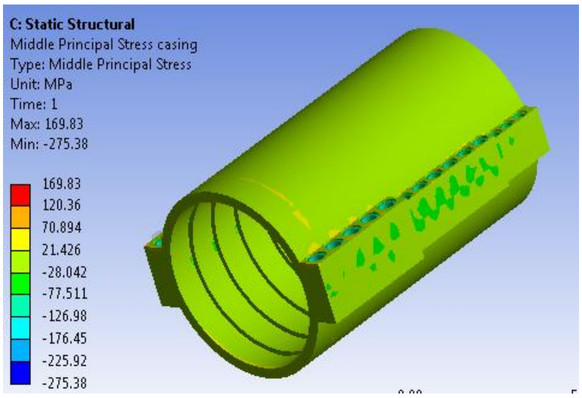

Fig 3: Middle principal stress for Casing

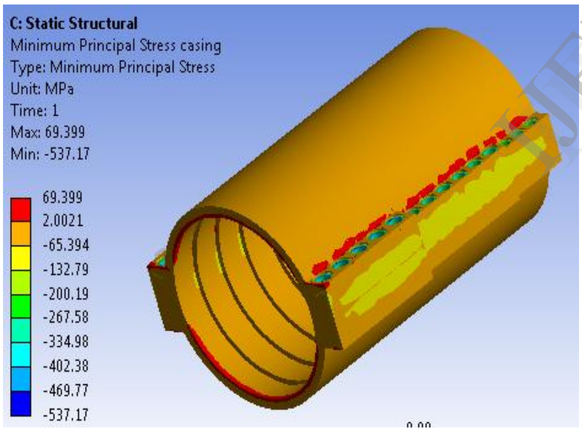

Fig 4: Equivalent Von Mises strain for casing

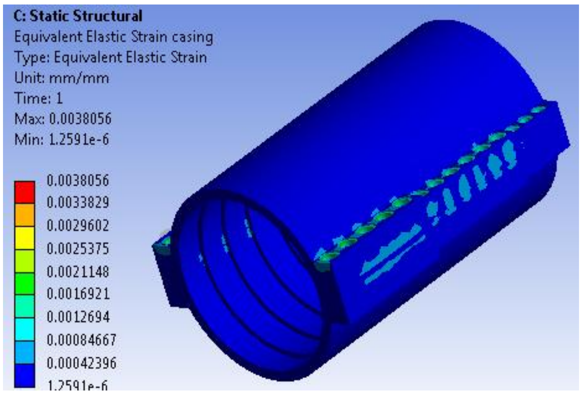

Fig 5: Minimum principal stress for Casing

From the analysis,

$$\sigma_{von} = 671MPa$$

$$\varepsilon_{von} = .003805$$

$$\sigma_{ult} = 880Mpa$$

$$\sigma_{mean} = \sigma_{von}/2 = 335.5MPa$$

Reduction in Area,

$$RA = 55\%$$

Ductility strength co-efficient,

$$D = \ln\left[(1)/(1-RA)\right] = .8737 \quad (4)$$

Substituting the above values in Coffin Manson equation, we get

$$003805 = 3.5(880-335.5)/210E3(N_f)^{-.12} + .8737^{.6}(N_f)^{-.6} \quad (5)$$

By iterations,

$$N_f = 32800cycles$$

Therefore, from the graph shown in figure 6,

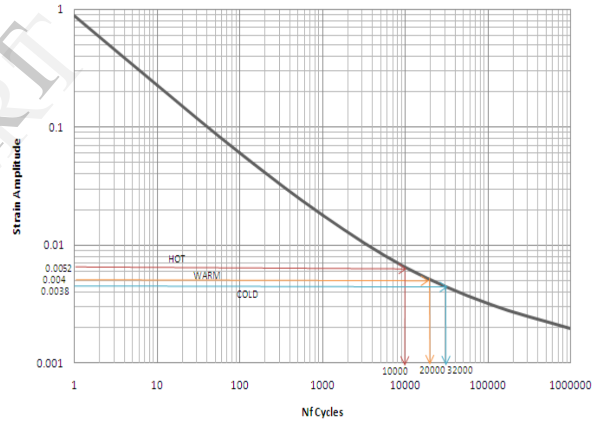

Fig 6: Plot between strains Vs No. of cycles for cold, hot, warm start conditions

$$N_{hot} = N_1 = 10000cycles$$

$$N_{warm} = N_2 = 20000cycles$$

We know that,

$$\frac{1}{N} = \frac{1}{N_1} + \frac{1}{N_2} + \frac{1}{N_3} \quad (6)$$

$$= 1.8125E-4$$

Therefore,

$$N = \left(1/1.8125E-4\right)$$

$$= 6.72313E$$

N=**5517cycles**

Life Estimation from Technical Data

Let us assume that the turbine trips 10 times a month, 5 times for hot start expansion, 2 times for cold expansion and 3 times for warm expansion.

For Hot start Expansion,
5 times in a month= 5 x 12 = 60 times in a year
Therefore, for 20 years= 20 x 60 = 1200 cycles

For Cold start expansion,
2 times in a month= 2 x 12 = 24 times in a year
Therefore, for 20 years= 20 x 24 = 480 cycles

Similarly,
For Warm start expansion,
3 times in a month= 3 x 12 = 36 times in a year
Therefore, for 20 years= 20 x 36 = 720 cycles
Total = 1200+480+720 = 2400 cycles

Assume knock down factor,
KDF = 2 (Service factor, size factor, for maintenance, temperature factor, quality of steam, etc).
Therefore,
Total Desired cycles = 2 x 2400 = **4800 cycles**

Results

From the analysis, the total life estimated cycles for casing is 5517 cycles which is greater than 4800 desired cycles. Hence casing is safe for 20 years

Life Estimation of Bolts Using Analysis

Life estimation of bolts using analysis under given conditions with ANSYS is given here in the figures given below. **Figure 7** represent Equivalent Von Mises stress for Bolts, **Figure 8** represents maximum principal stress for Bolts,
Figure 9 represents middle principal stress for Bolts, **Figure 10** represents minimum principal stress for Bolts, and **Figure 11** represents Equivalent Von Mises strain for Bolts

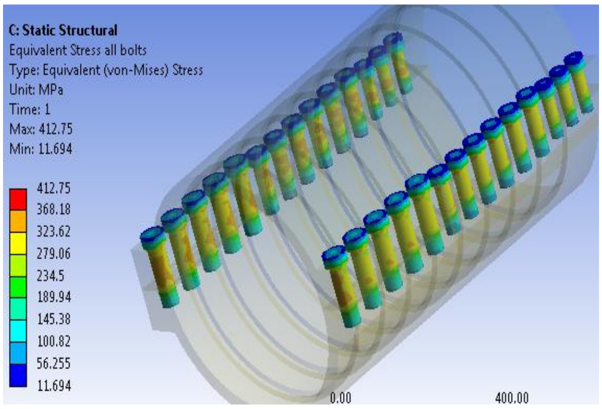

Fig 7: Equivalent Von Mises stress for Bolts life estimation

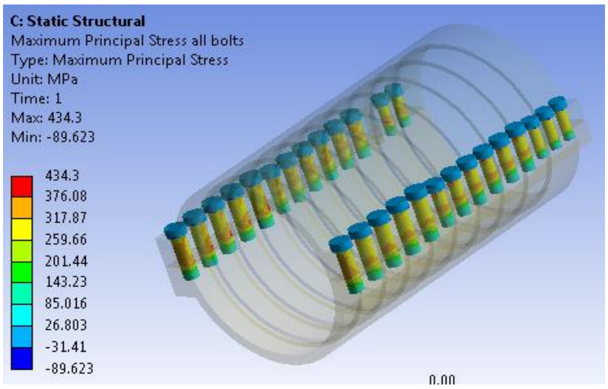

Fig 8: Maximum principal stress for Bolts

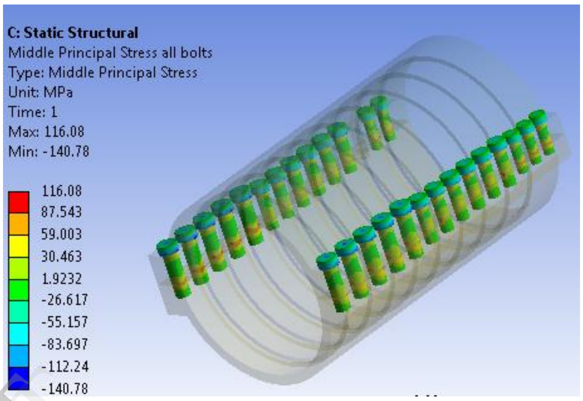

Fig 9: Middle principal stress for Bolts

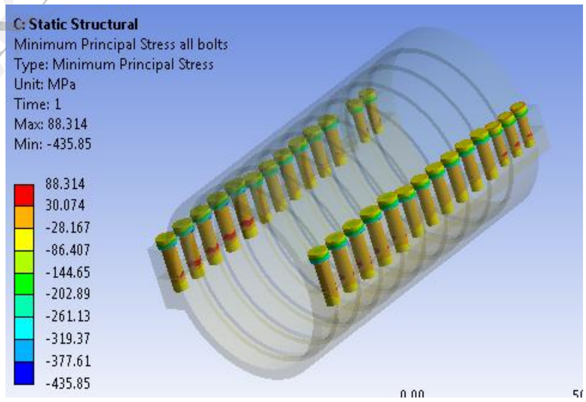

Fig 10: Minimum principal stress for Bolts

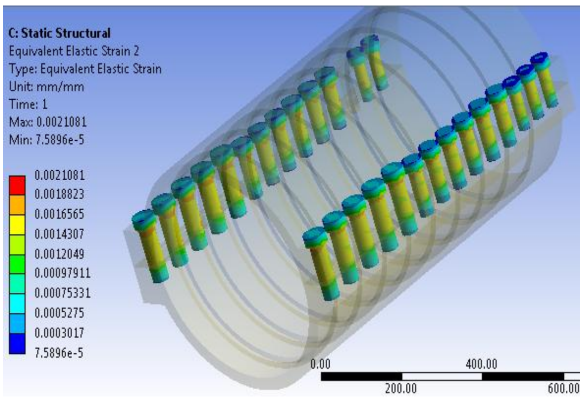

Fig 11: Equivalent Von Mises strain for Bolts

From the analysis,

$$\sigma_{von} = 413MPa$$

$$\varepsilon_{von} = .002108$$

$$\sigma_{meam} = \frac{\sigma_{von}}{2} = 206.5Mpa$$

$$\sigma_{ult} = 880MPa$$

Reduction in Area,

$$RA = 55\%$$

Ductility strength co-efficient,

$$D = \ln\left[\frac{(1)}{(1-RA)}\right] = .8737 \qquad (7)$$

Substituting the above values in Coffin Manson equation, we get

$$002108 = \frac{3.5(880-206.5)}{210E3(N_f)^{-.12}} + .8737^{.6}(N_f)^{-.6} \qquad (8)$$

By iterations,

$$N_f = 94875cycles$$

In similar fashion, the analysis for hot start and warm start expansion are carried out and results are shown graphically,

Therefore, from the graph shown in **figure 12**,

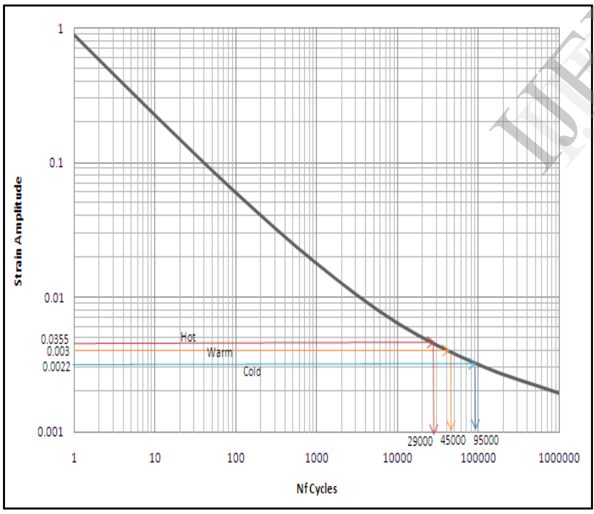

Fig 12: Plot between strain Vs no. of cycles for cold, hot, warm start conditions for bolts

$$N_{hot} = N_1 = 29000cycles$$

$$N_{warm} = N_2 = 45000cycles$$

$$N_{cold} = N_3 = 95000cycles$$

We know that

$$\frac{1}{N} = \frac{1}{N_1} + \frac{1}{N_2} + \frac{1}{N_3} \qquad (9)$$

Therefore,

$$= 6.72313E$$

$$N = \left(\frac{1}{6.72313E-5}\right)$$

N = **14874 cycles**

Life Estimation from Technical Data

Let us assume that the bolts trip 1 time a month.

For 1 year = 1 x 12 = 12 times in a year

For 20 years = 12 x 20 = 240 cycles

Assume KDF for bolt is 10 (size factor, service factor, maintenance)

Total = 240 x 10 = 2400 cycles

Assume knock down factor, KDF = 2 (Service factor, size factor, for maintenance, temperature factor, quality of steam, etc)

Therefore,

Total Desired cycles = 2 x 2400 = **4800 cycles**

Results

From the analysis, the total life estimated cycles for bolts is 14874 cycles which is greater than 4800 desired cycles. Hence bolts are safe for 20 years

9. Conclusion

Calculating the life time of casing and bolt using analytical method and compared that with the life time obtained using technical datas. All these analysis are done using ANSYS tool. From the results we found that the bolt and casing are safe for 20 years for the estimated life cycles from analysis. Analysed number of cycles is more in number when compared to the technically calculated one, which it usually withstands.

10. References

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