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# Fatigue Life Estimation using Goodman Diagram

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## ABSTRACT

Fatigue of metals, is the failure of a component as a result of cyclic stress. And the number of stress cycle which can be sustained by a component for a given test condition is called its Fatigue Life. The paper presents proper methods to estimate the fatigue life of a piston accumulator during its design phase. The few applications of Piston Accumulator includes Shock absorption, Damping of pump pulsation, and Energy Storage .The rapid variation of stresses with respect to time in piston accumulator crafts it for fatigue failure .The Objective is to study a suitable failure method and to calculate the predicted life of the component for a given load conditions .

## Keywords

Fatigue life estimation, Goodman diagram, piston accumulator, prediction of fatigue life.

## 1. INTRODUCTION

Fatigue failure occurs due to appliance of fluctuating stresses that are much lower than the stress required to cause failure during a single application of stress. Fatigue contributes to approximately 90% of all mechanical service failure. The fatigue failure occurs in three phase a) crack initiation b) crack prorogation and c) catastrophic failure of the component .The duration of each of the phase depends on the factors such as material characteristics, magnitude and orientation of applied stress. Piston accumulator is used for shock absorption and damping which tends to induce fluctuating stresses leading to catastrophic failure. For the calculation of fatigue life of the component a suitable failure criteria is selected on the basis of magnitude and orientation of applied stresses .After calculation of predicted life design reviews are provided for better fatigue life.

## 2. MATERIAL SPECIFICATION

The piston accumulator is made up carbon steel pipe painted with a coat of rust inhibitor RAL8012. Stainless Steel AISI316L.Accumulator has been designed for working pressure of 415bar with a pre-assembly pressure of 145bar.

## 3. OVERVIEW OF FATIGUE

Fatigue failure is generally characterized as either High Cycle Fatigue (H.C.F) (>1000 cycles) or Low Cycle Fatigue (L.C.F) (<1000 cycles).The threshold value is generally based on material's behaviors in response to applied stress. The three major fatigue life methods used in design and analysis are the Stress life method, the strain life method and Linear Elastic Fracture Mechanics method. The Stress life method, based on stress level only, is the least accurate approach but is most

Traditional and easy to implement and represents high cycle application adequately. The stress life approach is a safe approach as if the stresses level are decreased we can attain a infinite life for an component.

### 3.1 The S-N Curve

The prediction of fatigue life of a component is characterized by the relationship between applied stress and expected life. One of the traditional methods is the S-N curve method. 'S' stands for cyclic stress range while 'N' represents the number of cycles to failure. To develop a curve a sample is tested to failure at various stress ranges. The locus of these results is the S-N Curve. The limitation of S-N curve is that it highly depends on test condition, the stress ratio Smin/Smax, sample geometry, and materials.

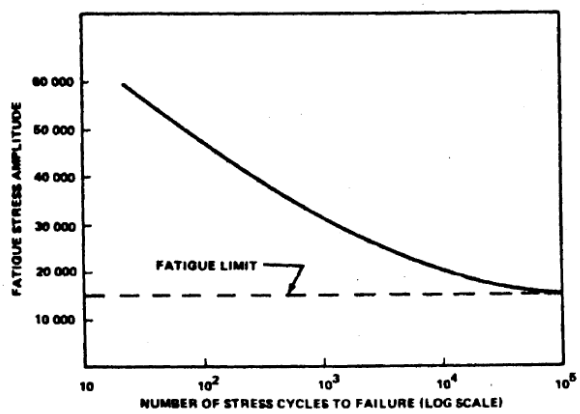


FIGURE E1-10. GENERAL FORM OF S-N CURVE

### 3.2 ENDURANCE LIMIT

Materials have fatigue limit or endurance limit which represents a stress level below which the materials does not fail and can be cycled infinitely. If the applied stress level is below the endurance limit of the material, the structure is said to have an infinite life. The concept of endurance limit is used in infinite life or a safe stress design.

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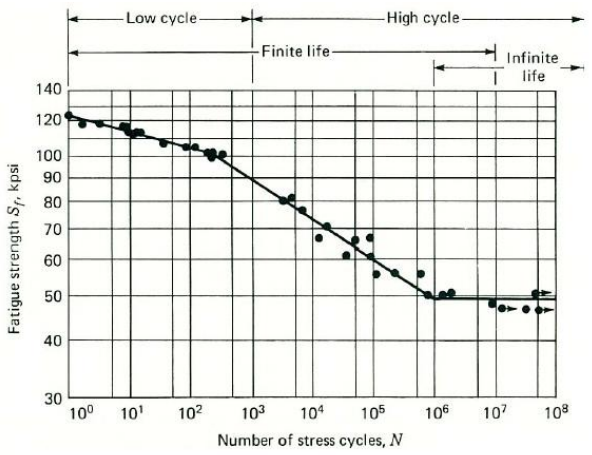
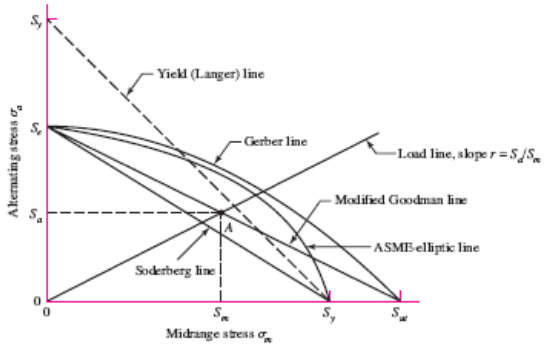



## 3.3 Modified Goodman Diagram

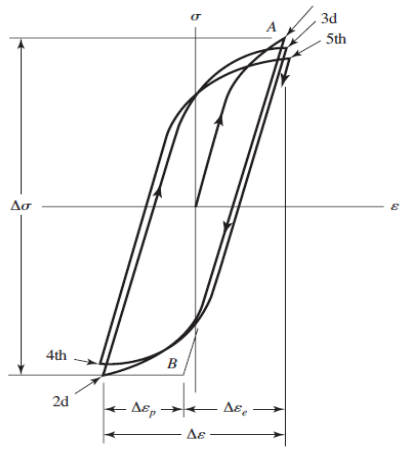
The key limitation of S-N Curve is the inability to predict life at stress ratios different from those under which the curve was developed. These diagrams are still limited by specimen geometry, surface condition and material characteristic. Modified Goodman diagram is used for fatigue analysis of piston accumulator because the material is ductile and exhibits high cycle fatigue.

In the S-N curve above, the region of low cycle fatigue extends from N=1 to 103 cycles. In this reason the fatigue strength $S_f$ is only slightly smaller than the tensile strength.




## 3.4 FATIGUE STRENGTH

A method of approximation of S-N curve in the high cycle reason is developed in the section. Following equation can be used for determining fatigue strength at $10^3$ cycles. Total strain for a component for a given stress range is the sum of elastic and the plastic components.




Therefore, the total strain amplitude is given by as the half the total strain range i.e.

$$\frac{\Delta\epsilon}{2} = \frac{\Delta\epsilon_e}{2} + \frac{\Delta\epsilon_p}{2}$$

The equation for plastic strain life is

$$\frac{\Delta\epsilon_p}{2} = \epsilon'_F\,(2N)^c$$

The equation for elastic strain life is

$$\frac{\Delta\epsilon_e}{2} = \frac{\sigma'_F}{E}(2N)^b$$

Therefore, the total strain amplitude is given as

$$\frac{\Delta\epsilon}{2} = \left[\frac{\sigma''_F}{E}(2N)^b + \epsilon'_F\,(2N)^c\right]$$

The above expression is known as Manson-Coffin relationship between total strain and fatigue life. It is assumed that high cycle fatigue domain extends from $10^3$ cycles to endurance limit which for steel is about $10^6$ to $10^7$ cycles. The elastic strain equation can be used to determine the fatigue strength at $10^3$ cycles. For defining the fatigue strength at a specific number of cycles as

$$(S'_f)_N = \sigma'_F(2N)^b$$

At $10^3$ cycles

$$(S'_f)10^3 = \sigma'_F(2.10^3)^b = fS_{ut}$$

Where f is a defined as a fraction of $S_{ut}$ represented by $(S'_f)_{10^3}$ cycles. So solving for f

$$f = \frac{\sigma'_F}{S_{ut}}(2.10)^3$$

On referring to the Fatigue design handbook, vol 4, society of Automotive Engineers, 1958. It can be recalled

$$S_f = aN^b$$

Where N is cycles to failure and the constants a and b are defined by the points $10^3$,$(S_f)_{10^3}$ and $10^6$ $S_e$ with

$(S_f)_{10^3}$=f ($S_{ut}$).

$$fS_{ut} = aN^b$$

$$a = \left(\frac{fS_{ut}}{S_e}\right)^2$$

And $$b = -\frac{1}{3}\log\left(\frac{fS_{ut}}{S_e}\right)$$

the number of cycles for failure can be expressed as

$$N = \left(\frac{\sigma_a}{a}\right)^{\frac{1}{b}}$$

## 3.5 CALCULATION OF PREDICTED LIFE

For the calculation of fatigue life of a piston accumulator a sample load cases for cylinder and end flanges are used .one case for maximum stress for cylinder of piston accumulator is used. Let us assume the cylinder goes undergoes a cyclic loading such that $\sigma_{max}$=60kpsi in tension and $\sigma_{min}$=20kpsi in

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compression .For the material $S_{ut}$=80kpsi , $S_y$=65kpsi and a endurance limit of $S_e$=40kpsi .and f=0.9.

For the given stress

Alternating stress $\sigma_a$ = ½ (60-(-20)) = 40 kpsi

Mean stress $\sigma_m$ = ½ (60+(-20)) = 40 kpsi

From the material properties as described in section 3.4

$a = \left(\frac{fS_{ut}}{S_e}\right)^2 =$ 129.6kpsi

$b = -\frac{1}{3}\log(\frac{fS_{ut}}{S_e})$ =-0.0851

$N = (\frac{S_f}{a})^{\frac{1}{b}}$

Now, $S_f$ replaced $\sigma_a$ in above equation.

Now using modified Goodman diagram where the endurance limit is used as infinite life. We have

$S_f = \frac{\sigma_a}{1-\frac{\sigma m}{S_{ut}}} =$ 53.3kpsi

So now the calculated life

$N = (\frac{S_f}{a})^{\frac{1}{b}}$

Fatigue life = 3.4(104) cycles

## 4. FUTURE SCOPE

- Fatigue life of the component can be improved by altering the design factor, metallurgical factors of the component.
- Fatigue Life Calculations of the component with taking in account the environmental effects.

## 5. REFERENCES

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