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Design and Fabrication of Fatigue Testing Machine

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ABSTRACT

Many engineering machines and mechanical components are subjected to fluctuating stresses, taking place at relatively high frequencies and under these conditions failure is found to occur. This is called fatigue failure. And this led to the invention of a fatigue testing machine. In view of effective design that will not fail accidentally, this research is conceived. This testing machine will determine the strength of materials under the action of fatigue load. Specimens are subjected to repeated varying forces or fluctuating loading of specific magnitude while the no. of cycles are counted till the breakage of specimen and results are plotted.
Keywords : Fatigue Failure, Fatigue Stress, S-N Curve, Endurance Limit, Fatigue Testing, fatigue load.

I. INTRODUCTION

Fatigue is the process of progressive permanent structural change occurring in a material which is subjected to conditions that produce fluctuating stresses and strains at some point and that may turn in cracks or complete fracture after a sufficient number of fluctuations. If the maximum stress in the specimen does not exceed the elastic limit of the respective material the specimen returns to its initial condition when the load is removed. A given loading may be repeated many times provided that the stresses remain in the elastic range. These conclusions are correct for loadings repeated even a few more times. However it is not correct when loadings are repeated thousands or millions of times. In such cases rupture will occur at a stress much lower than static breaking strength and this phenomenon is known as fatigue.

A. Fatigue Failure

A fatigue is a failure of material or machine due to the action of repeated or fluctuating stress on a machine member for some number of times. This failure begins with a small crack. The initial crack is so minute that it cannot be detected by the naked eye and is even quite difficult to locate in a magniflux or x-ray inspection. The crack will develop at a point of discontinuity in the material such as a change in cross section a keyway a hole or a notch. Less obvious points at which fatigue failure are likely to begin are inspection or stamp marks internal cracks or even irregularities caused by machining. Once a crack is initiated the stress concentration effect becomes greater and the crack progresses more rapidly. As the stressed area decreases in size the stress increases in magnitude until finally the remaining area fails suddenly. A fatigue failure therefore is characterized by two distinct regions. The first of those is due to the progressive development of crack while the second is due to sudden fracture. Unlike other failures fatigue failure gives no visible warning in advance. It is sudden and totally dangerous. This sudden failure which is dangerous and can lead to not just minor accident but fatal accident and loss of lives triggered the quest to invent a machine that can test and give or predict the effect of fatigue on various metals such as aluminum cast-iron mild steel etc. In most testing of those properties of materials that relate to the stress-strain diagram the load is applied gradually to give sufficient time for the strain to fully develop. Furthermore the specimen is tested to destruction and so the stresses are applied only once. Testing of this kind is applicable then to what are known as static conditions. Such conditions closely approximate the actual conditions to which many structural and machine members are subjected. The condition frequently arises however in which the stresses vary or they fluctuate between levels. For example a particular fiber or aluminum on the surface of the rotating shaft subjected to the action of bending loads undergoes both tension and compression for each revolution of the shaft. Since the shaft is part of an electric motor rotating at 1400revolutions per minute the aluminum metal is stressed in tension and compression 1400 times each minute. If in addition the shaft is also axially loaded as it would be for instance by a helical or worm gear) an axial component of stress is superposed upon the bending component. In this case some stress is always present in any one metal but now the level of stress is fluctuating. These and other kinds of loading occurring in machine members produce stresses that are called variable repeated alternating or fluctuating stresses. Often machine members are found to have failed under the action of repeated or fluctuating stresses yet the most careful analysis reveals that the actual maximum stresses were below the ultimately strength of the material and quite frequently even below the yield strength. The most distinguishing characteristic of these failure is that the stresses have been repeated a very large number of times. Hence the failure is called Fatigue Failure. When machine parts fail statically they usually develop a very large deflection because the stress has exceeded the yield strength and part is replaced before fracture actually occurs. Thus many static failures give visible warning. It is sudden and total and dangerous. It is relatively simple to design against a static failure because our knowledge is comprehensive. Fatigue is a much more complicated phenomenon only partially understood and the engineer seeking competence must acquire as much knowledge of the subject as possible. Anyone who lacks the knowledge of fatigue can double or triple designs factors and formulate a design that will not fail.

B. Different phases of fatigue life

Microscopic investigation in the 20th century has revealed that the nucleation of fatigue cracks occurs at a very early stage of fatigue life. The crack starts as a slip band within a grain. The cyclic slip occurs as a result of cyclic shear stress this slip leads to formation of slip steps in the present of oxygen the freshly exposed surface of the material in slip steps get oxidized which prevents slip reversal. The slip reversal in this case occurs in some adjacent slip plane thereby leading to formation of extrusions and intrusions on the surface of the material as shown in the figure below.

The fatigue life is generally divided into three periods.

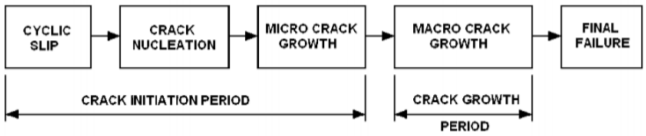

Fig.1 Different phases of the fatigue life, its end or result.

II. METHODS AND MATERIAL

C. Working principle

Fig.2 Rotating beam Cantilever Type Fatigue Testing Machine

The fatigue-testing machine is of the rotating beam type. The specimen functions as a single beam symmetrically loaded at two points. When rotated one-half revolution the stress in the fibers originally above the neutral axis of the specimen are reversed from compression to tension for equal intensity. Upon completing the revolution the stresses are again reversed so that during one complete revolution the test specimen passes through a complete cycle flexural stress.

D. Components of Fatigue Testing Machine

- Pedestial Bearing
- Bearing spindle (Shaft)
- Bearing and its housing assembly
- Weight hanger assembly
- Proximity sensor
- Digital Counter
- Switch
- AC Electric Motor
- Specimen

1) Pedestal Bearing

All components of the pedestal bearing assemble to a single unit and coupled to a rotating shaft for intermediate support. According to our purpose we need to support the shaft transmitting power and hence we concluded to use pedestal bearing.

Fig.3 Pedestal bearing

2) Bearing Spindle (Shaft)

The bearing spindle are machined from a bar of high grade steel 310 stainless steel and is thicker than specimen by 5/8 inches to prevent the machine parts from experiencing fatigue due to the loading of the specimen. The stainless steel can withstand adverse temperature and corrosive environment due to its high carbon content it does not fail-easily.

Two shafts were employed in this work. One is the driving shaft which is connected to the motor shaft extension by means of bolting. The other end of this shaft is machined to fit into a drill chuck. The other spindle the driven shaft is machined to fit into a drill chuck at one end while the other end carries a gear that transmits motion to the dynamo. Both shafts are allowed to pass through the bearing housing which help to check any misalignment and give the shaft rotational support.

3) Bearing and Its Housing Assembly

The particular bearing used in this project is the single row deep groove bearing that can take both radial load and some thrust load. The bearing is shouldered in a housing made of cast iron to secure adequate support for the bearing and resist the maximum thrust load.

4) Weight Hanger Assembly

This consists of small bar made of cast iron which is fitted into the frame of fatigue testing machine. The head of this bar is designed to be hanged on the loading hardness assembly.

The choice of cast iron for the material for hanger is due to the fact that cast iron has the modulus of elasticity E as 60 to 90 MPa and can withstand the maximum weight of which the machine can carry.

5) Proximity sensor

The proximity sensor utilized in the design is presented in Figure 4. The sensor is utilized to detect the oscillation of nearby objects without having any physical contact with the object so far the objects are not more than a distance of 15mm from it. A proximity sensor often emits an electromagnetic or electrostatic field or a beam of electromagnetic radiation infrared for instance and looks for changes in the field or return signal. It has been found suitable for detecting the number of revolutions of rotating materials hence it was selected to detect the number of revolutions of the shaft under the applied bending moments leading to fatigue failure. The sensor was placed on the end of the shaft at the left arm of the main frame of the machine to detect every cycle the shaft rotates. The rotating motion of the shaft and sends signal to the counter.

Fig.4 Proximity Sensor

6) Digital Counter

A 6 digit digital counter was selected for recording the number of stress cycles a specimen undergoes during testing. It was ensured that the digital counter was compatible with the proximity sensor selected that is it should be able to translate the signals from the sensor to a numerical output. The digital counter utilized can relay digital outputs but can be programmed to run for a specified number of cyclic revolutions utilizing an analog input bottom incorporated into the counter Figure 5. It can also be programmed to evaluate number of cycles at a given time. Conventionally an 8 – digit counter is utilized for the design of rotating bending fatigue machines. The unavailability of the 8 – digit counter led to the use of the 6 – digit counter which was readily available within the country.

Fig.5 Digital counter

7) Electrical Connectivity

The motor is connected with heavy duty wires and an miniature circuit breaker is used to avoid extra current being drawn into the machine.

The proximity sensor is aligned and connected to the digital counter. The proximity sensor is setup in such a way that the protruding part of the shaft in opposition to the motor revolute the digital counter and as the specimen breaks the counter stops.

E. Design and Calculations of Machine Components

1) Specimen Dimension and Machine Capacity

For the solid specimen the diameter of the test specimen is 9 mm.

Assuming the shear yield stress as 350mpa.

The torque required to start yield at the outer fibers of a specimen is

$$T=\tau_y \times \pi \times \frac{d^3}{16} \quad \ldots\ldots\ldots(1)$$

$$T = \frac{350\times\pi\times(9)^3}{16}$$

T=50098.58 N-mm

In this design a machine capacity of 50100 N-mm is assumed.

2. Design of C Channel

The Maximum tensile strength may also be calculated using the Simple Bending Equation.

$$\frac{M}{I} = \frac{\sigma_t}{y} \quad \ldots\ldots\ldots(2)$$

The Simple Bending Equation applies to simply supported beams (and arches if the radius of curvature is greater than 10 times the depth).

Where, M = the Maximum Bending Moment in N-mm.

σ = the Tensile Strength of the material (obtainable from tables or by experiment) in N/mm².

I= the Moment of Inertia about the Neutral Axis (for a rectangular beam this is its breadth times the depth cubed divided by 12) in mm⁴.

y = the distance of the Neutral Axis from the maximum stress (for a uniform rectangular beam this is half the depth) in mm.

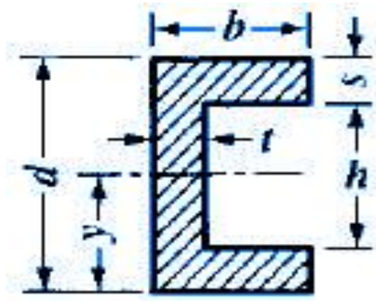

Fig.6 C-Channel

TABLE I. PARAMETERS USED FOR C-CHANNEL CALCULATIONS AND THEIR VALUES.

Width 'b' (mm)	**Depth 'd' (mm)**	**Thickness 'a' (mm)**	**Height 'h' (mm)**
38.1	76.2	68.2	30.1

Here, a=b-t

Moment of inertia I for this section is given by

$$I = \frac{bd^3}{12} - \frac{ah^3}{12} \quad \ldots\ldots\ldots(3)$$

$$I = \frac{38.1(76.2)^3}{12} - \frac{30.1(68.2)^3}{12}$$

$I = 609101.1867 mm^4$

$$y = \frac{d}{2} = \frac{76.2}{2} = 38.1mm$$

from (2).

$$\frac{50098.58}{609191.1867} = \frac{\sigma}{38.1}$$

$$\sigma = \frac{50098.58\times38.1}{609191.1867}$$

σ = 3.1332 N/mm²

3) Design of Shaft

Design of shaft subjected to combined torque and bending moment including shock and fatigue factors

Torque transmitted by the shaft

$$T = \frac{6 \times 10^7 \times P}{2\pi N} \quad \dots\dots\dots (4)$$

Where P =power transmitted by the shaft in kW
N =number of revolutions in rpm
T = torque in N-mm

Here P = power transmitted by the shaft is 1.1Kw

$$T = \frac{6 \times 10^3 \times 1.1}{2\pi \times 2880}$$

T= 3647.300 N-mm

Loading on Shaft,
Max bending moment M= $-Fa$
M= -147.15×200
M= -29430 Nmm
Torque induced in the shaft

$T_e = \sqrt{(k_m M)^2 + (k_t T)^2}$ ……… (5)
$T_e = \sqrt{(1.5 \times -29430)^2 + (1 \times 3647.300)^2}$
T_e=44295.41535 N-mm
Bending moment induced in the shaft

$M_e = \frac{1}{2}[k_m M + \sqrt{(k_m M)^2 + (k_t T)^2}$ ……… (6)
M_e= 22125.6351Nmm
The shear stress induced in the shaft is given as

$$\tau = \frac{16 \times T_e}{\pi \times d^3} \dots\dots\dots. (7)$$

$\tau = 5.2616$N/mm^2
The ultimate shear stress of steel which was used in making the shaft is $\tau = 241$N/mm^2
Hence the design is safe.

The bending stress induced in the shaft is given as

$$\sigma_b = \frac{32 \times M_e}{\pi \times d^3} \dots\dots\dots (8)$$

$$\sigma_b = \frac{32 \times 221256.6351}{\pi \times (35)^3}$$

$\sigma_b = 5.2564$ N/mm^2

The ultimate shear stress of steel which was used in making the shaft is
$\sigma_b = 482$N/mm^2
Hence the design is safe.

4) Bolt Design

Two bolts are used to hold the shaft to the motor shaft. The bolt diameter is 4.75mm. They are separated 20mm apart. For a torque of 50098.58 N-mm.

Shear force on each bolt = $\frac{1}{2} \times \frac{50098.58}{10}$= 2504.929
Average shear stress (σ) = $\frac{F}{A}$
Where F=load applied on the bolts in N
A=area of the bolts in mm^2

$\sigma = \frac{2504.929}{\frac{\pi}{4} \times (4.75)^2}$
σ = 141.35 N/mm^2

D. Testing of Specimen

A) Standard Specimen Size

The ASTM specification specimen is used for industrial purposes.

A typical fatigue test specimen has three areas the test section and the two grip ends. The grip ends are designed to transfer load from the test machine grips to the test section and may be identical particularly for axial fatigue tests. The transition from the grip ends to the test area is designed with large smoothly blended radii to eliminate any stress concentrations in the transition. The design and type of specimen used depend on the fatigue testing machine used and the objective of the fatigue study. The test section in the specimen is reduced in cross section to prevent failure in the grip ends and should be proportioned to use the upper ranges of the load capacity of the fatigue machine; i.e. avoiding very low load amplitudes where sensitivity and response of the system are decreased. fatigue test specimen is illustrated in Fig below.

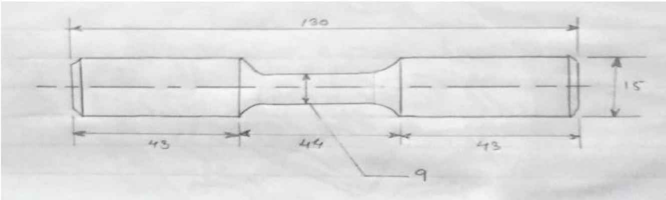

Fig.7 Fatigue test specimen size and its dimensions

B) Fatigue Life of specimen.

Once the fabrication process is completed the testing of specimen is carried out to find the fatigue strength by gradually increasing load. We know that rpm of motor and by calculating time taken for breaking of specimen we get number of cycles.

Rpm of motor=2880 rpm

Therefore,

1 minute(i.e. 60 sec)→2880 rev

1 sec→$\frac{2880}{60}$=48 rev = 48 rps

Number of cycles = time taken (s) × 48 rps

Time Taken (sec) $= \frac{\text{Number of cycles}}{48}$

TABLE III

LOAD APPLIED & CORRESPONDING TIME TAKEN FOR THE SPECIMEN TO BREAK

S.No	Load (kg)	No. of cycles (N)	Time Taken (sec)	No. of cycles (N)
1	4	135552	2824	135552
2	8	59040	1230	59040
3	12	5376	112	5376

C) Fatigue Strength Calculation

Length of shaft,L= 490 mm

Diameter of shaft,D= 15 mm

- for Load = 4 kg ,

W = 4 × 9.81 =39.24 N

M = L×W

From eqn.1.

M = 490×39.24

M = 19227.6 N-mm

$\sigma = \frac{32\times19227.6}{\pi\times15^3}$

σ = 58.02Mpa

- For Load = 8 kg,

W = 8 × 9.81 =78.48 N

M = L×W

From eqn.1.

M = 490×78.48

M = 38455.2 N-mm

$\sigma = \frac{32\times38455.2}{\pi\times15^3}$

σ = 116.06 Mpa

- For Load = 12 kg,

W = 12 × 9.81 = 117.72 N

M = L×W

From eqn.1.

M = 490×117.72

M = 57682.8 N-mm

$\sigma = \frac{32\times57682.8}{\pi\times15^3}$

σ = 174.09 Mpa

The following observations were obtained after testing and calculations

TABLE III
THE TABLE BELOW SHOWS THE LOAD VALUES WITH CORRESPONDING STRESS VALUES

S.No.	Load(kg)	Load(Newtons)	Stress(MPa)
1	4	39.24	58.02
2	8	78.48	116.06
3	12	117.72	174.09

III. RESULTS AND DISCUSSION

The fatigue testing machine can help us understand the material strength and hence calculate its fatigue limit. This calculation would help us understand the limit up to which the material can variable stresses and prevent its failure as we understand the maximum stresses which the material can withstand.

The machine can test various different specimens of standard specifications and help us generate various graphs and understand the material better.

The digital counter and proximity sensor used help us know real time revolutions and also help us identify the number of revolutions required to fracture the specimen with respect to corresponding weights.

A. Testing Result

The Standard AISI type specimen was used to test the Aluminium Material and hence the S – N curve was plotted.
With the help of No. Of revolutions and the load being applied the S-N curve

The following results were obtained after testing

TABLE IV
STRESS AND NO. OF CYCLES AFTER CALCULATIONS

S.No.	Stress (MPa)	No. of cycles (N)
1.	58.02	135552
2.	116.0	59040
3.	174.09	5376

Fig.8 Aluminium Test specimen used for Testing.

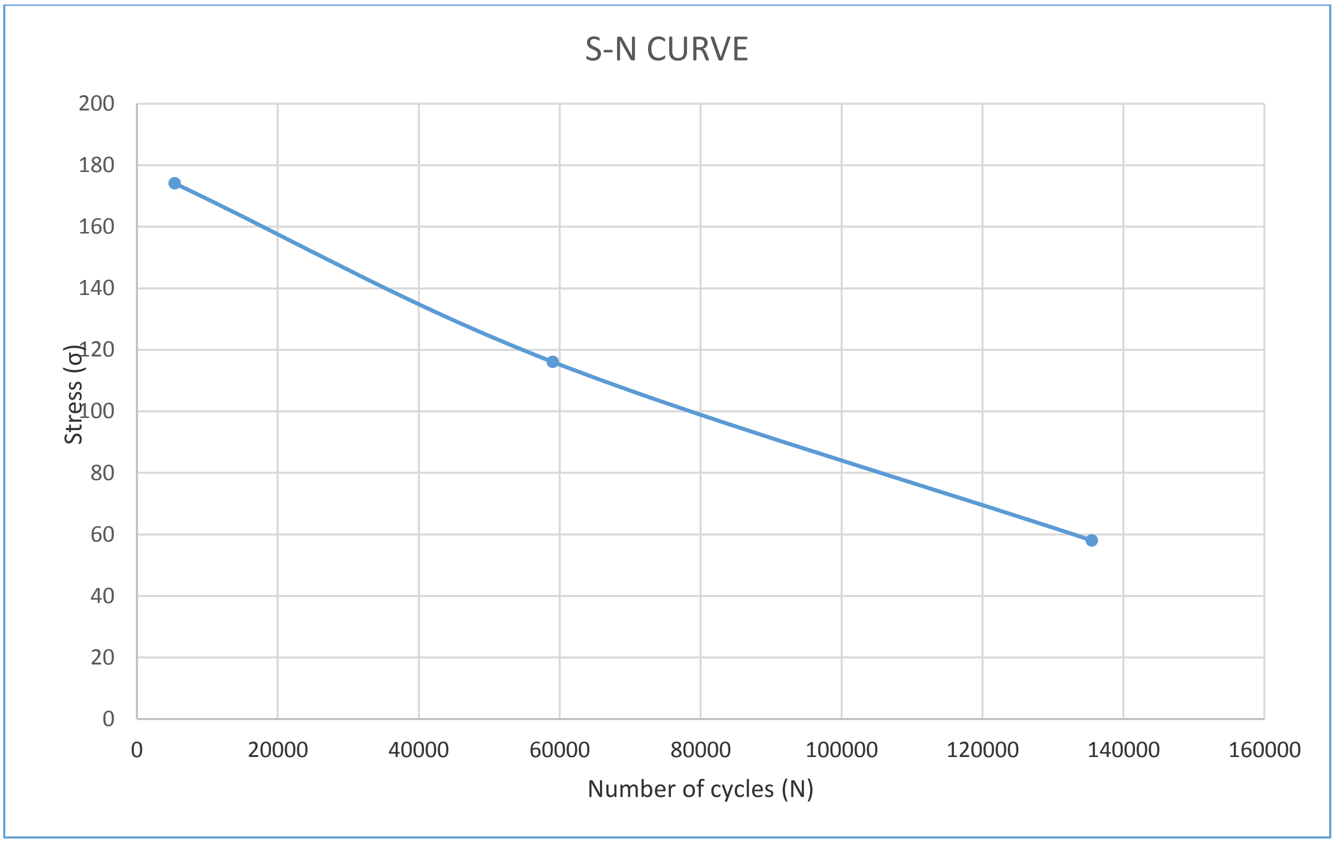

Fig.9 An S-N graph of a test conducted on the machine using aluminium specimen.

IV.CONCLUSION

When fatigue stress is induced on a material due to the action of force reversing and fluctuating, a failure known as fatigue failure takes place. The study and test conducted so far shows that fatigue failure cannot be predicted accurately since material failure under fatigue are affected not by just reverse loading also number of revolutions cycles per minute and fluctuating stress and other factors such as temperature, atmospheric condition, both internal and external defect on material subjected under fatigue stress. Such defect includes notch, inclusion, stress concentration and non-homogenity.

At such, fatigue failure is sudden and total, hence dangerous and leads to major accident characterized by loss of lives, valuable goods and devices. Thus all precautions and measures should be taken to checkmate this failure since it cannot be cured entirely.

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