DESIGN AND DEVELOPMENT OF ROTATING BENDING FATIGUE TEST-RIG

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Abstract: As industrial engineering machines and mechanical components are subjected to fluctuating stresses, due to which component fails below the ultimate tensile strength. This type of failure is called as fatigue failure. For this purpose, fatigue testing machine is used for finding fatigue life. This project consists of design and development of rotating bending fatigue test-rig. This work was undertaken considering high cost of presently available fatigue testing machines to carry out test. The main function of fatigue testing machine is to provide the number of cycles for failure of specimen of materials with respective of different stress values. From this number of cycles, we can plot S-N curve, from which fatigue life and endurance limit of components material can be find out.

Index Terms - **Fluctuating stress, Fatigue failure, RBF testing machine, RBF Testing.**

I. INTRODUCTION

Fatigue failure is sudden, progressive, unpredictable and structural damage of material subjected to a reversed, repeated, fluctuating cyclic loading [1]. There are 80 % failure occurs due to fatigue in industrial components [7]. Engineering of machines and structure needs to consider the effect of the fatigue stresses to prevent the complete fatigue failure. Due to fatigue, brittle like failure occurs in ductile materials with small gross plastic deformation priority to fracture. Fatigue failure consists of crack initiation and crack propagation. In brittle materials crack propagation time is more as to compare to ductile. Crack propagation is generally perpendicular to maximum tensile stress [6]. For preventive purpose we make use of the Fatigue testing machine, this machine calculates the fatigue life of that materials subjected to reversed, repeated and fluctuating cyclic load of various magnitude [6]. Applied stress may be various type-axial (tension-compression), flexural (bending), torsional (twisting). Generally, three types of fluctuating stress time modes are observed-

1) Simplest completely reversed constant amplitude stress cycles in which alternating stress variation is from maximum tensile stress to minimum compressive stress. Both maximum tensile stress and minimum compressive stress having same magnitude but opposite in directions [7].
2) Repeated constant amplitude stress cycle in which maximum stress and minimum stress are asymmetrical to zero stress level [7].
3) Fluctuating variable amplitude stress cycles in which stress level may vary randomly in amplitude and frequency [7].

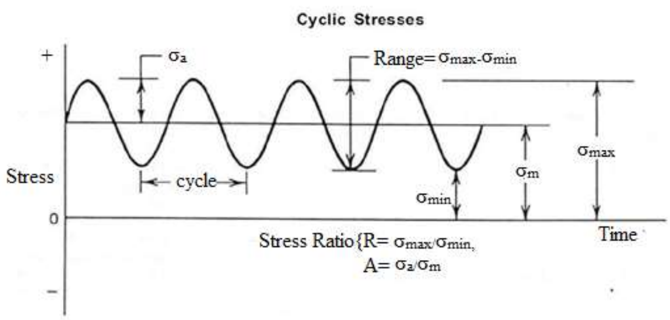


Figure: fluctuating stress time mode [5]

Mean Stress: It is a algebraic average of maximum stress and minimum stress in one cycle. In the completely reversed cycle mean stress is zero [5].

$$\sigma_m = \frac{(\sigma_{max} + \sigma_{min})}{2}$$

Stress Amplitude: It is one half of stress ranges [5].

$$\sigma_a = \frac{(\sigma_{max} - \sigma_{min})}{2}$$

Stress Ratio: It is the ratio of minimum stress to maximum stress in one cycle [5].

$$R = \frac{\sigma_{max}}{\sigma_{min}}$$

Stages of Fatigue Failure:

Fatigue life (N_f)**:** The fatigue life of component is defined by the total number of stress cycles required to cause failure. Fatigue life can be separated into two stages before final failure of component.

$$N_f = N_i + N_p \text{ [5].}$$

Crack Initiation (N_i): It is calculated by taking number of cycles required initiating the crack.
Crack Propagation (N_p): It is the number of cycle's required propagating crack in stable manner to critical size.
Final Failure: It is the stage at the end of crack propagation at which component fails suddenly.

II. Rotating Bending Fatigue Testing Machine

The rotating bending fatigue testing machine was the first machine used to generate fatigue data in greater effect. The most widely used fatigue-testing device is the R.R Moore high-speed rotating beam machine. This machine subjects the specimen to pure bending (no transverse shear). The R.R. Moore, recognized as the standard for rotating beam fatigue testing, has been serving industry faithfully for more than 70 years. Over that time, R. R. Moore has demonstrated an unsurpassed quality of machine design. In this test, when specimen 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 undergoes through a complete cyclic flexural stress i.e. the specimen is subjected to the tension and compression cycle alternatively [7]. The test mechanism counts the number of rotations (cycles) until the specimen fails. A large number of tests are carried out at each stress level of interest, and the results are statistically manipulated to determine the expected number of cycles to failure at that stress level. In below figure R. R. Moore fatigue test machine, specimen loading arrangement and test specimen subjected RBF is shown [6][8].

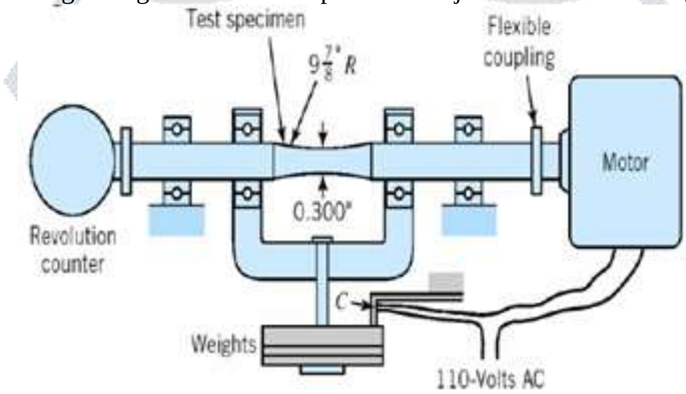
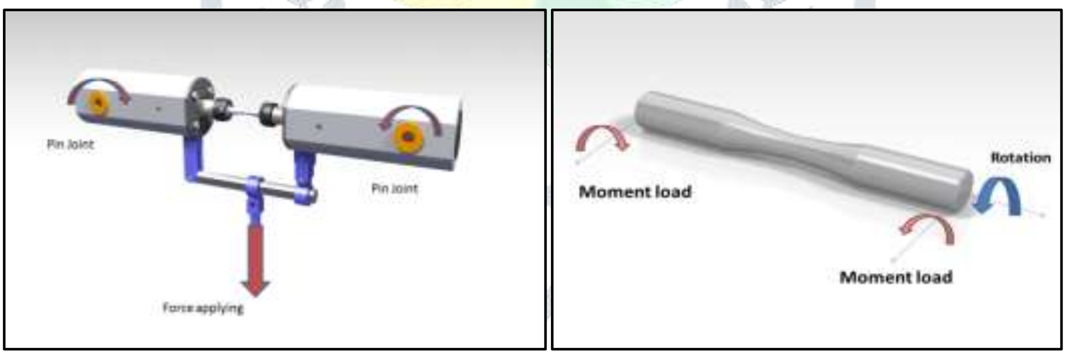


Figure: R. R. Moore fatigue test machine [5].



(A) (B)

Figure: (A) RBF loading arrangement (B) Specimen subjected to RBF *.
[*citation-Dr. Ahmad Al Ramahi's PPT from Slideplayer]

III. Design of rotating bending fatigue Test rig

Design Principle

The design of test rig is fully based on R.R. Moore RBF testing machine. In which specimen acts as simply supported beam which is subjected to elastic 4 - point bending. Beam supports loads perpendicular to its axis and applied bending moments that tends to bend it. Due to this, fibers of beam specimen subjected to compression in lower layer and tension in upper layer. There is constant bending stress due to bending moment on specimen held between two bearings [6].

Test rig design consideration

For test rig, required components are electric motor, flexible coupling, shaft, bearings, drill chuck base frame, loading arrangement and data recording instruments, specimen, rubber tip and electrical equipment's. Design and selection of each component is totally as per our requirement.

3.1 Design of Electric Motor

The selected motor is Crompton Greaves single phase, 0.5 hp, AC motor having 1425 r.p.m. speed. To find the torque of motor, the power and speed of motor are known.

Therefore,

$$P(Power) = \frac{2\pi NT}{60}$$

Power of the motor, P = 0.5 hp = 0.373 KW

Speed of the motor, N = 1425 r.p.m

$$T(Torque) = \frac{0.373 \times 60}{2\pi \times 1425}$$

T = 2.4995×10^{-3}N-mm

Figure: Selected Electric Motor.

3.2 Design of Bearing

Expected life for 90 % of bearing is 5000hrs

$$(\text{Total Load})\ P = XVP1 + YP2\ [7].$$
$$= 1\times1\times500 + 0\times0$$
$$= 500\ N$$

Where,

Radial load acting on the bearing P1= 500N

Axial load acting on the bearing P2 = 0

Radial factor X =1

Thrust factor Y=0

Race rotation factor V

If inner race is rotating, V = 1

Rated Bearing life in million revolution, $L_{10} = (\frac{C}{P})^n$ [7].

Where,

C: Dynamic load capacity (N)

P= 3 for Ball Bearing

For all type of ball bearing,

Load Factor = 1.4

$$L_{10} = \frac{60nL_{10}h}{10^6}\ [7].$$

Where, $L_{10}h$ = rated bearing life (43200 hours for 3 and half year assumed)

n = speed of rotation (rpm)

$\therefore L_{10} = \frac{60\times1425\times151200}{10^6}$

=12927.6 million revolutions.

Dynamic load capacities of bearing (C) = P× $(L_{10})^{0.33}$ [7]

= 500× $(12927.6)^{0.33}$×1.4

C = 11734.80 N

Hence for C = 11734.80 N and the bearing selected is Bearing No. – 6205.

It having outer diameter D = 52 mm, inner diameter d =25 mm and thickness t =15 mm. The reason of bearing is chosen as ball bearing because it has less wear and long-life time for different application.

Figure: selected bearing with casing, and bearing without casing

3.3 Design of Shaft

In many applications Transmission shafts are subjected to axial tensile force, bending moment or torsional moment or their combinations. In our test rig, the shaft portion subjected to pure bending moment. So, design of transmission shaft includes determination of correct shaft diameter from strength and rigidity considerations. But bearing already has been designed, so shaft diameter selected as inner diameter of bearing.

Diameter of shaft selected 25mm as standard dimension. First shaft on motor side is selected of 250 mm in length, out of which one end has made threaded for mounting drill chuck up to 20 mm length. Second shaft has made of 200 mm as per required. It's one end was also threaded up to 20 mm length.

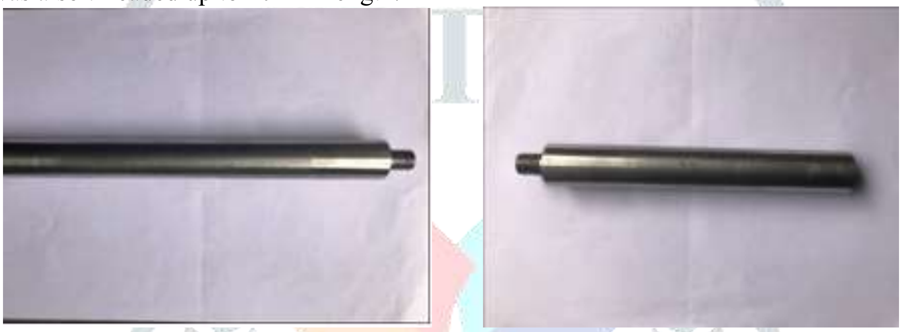


Figure: designed and machined shaft 1 and shaft 2

3.4 Selection of Coupling

The coupling selected is flexible coupling. It has following dimensions after machining.
Front side inner diameter =16 mm, outer diameter =50 mm and section thickness = 23 mm.
Middle section thickness = 14 mm, outer diameter = 52 mm.
Rear side inner diameter = 25 mm, outer diameter = 50mm and section thickness = 23mm.

Figure: selected flexible coupling

3.5 Selection of Drill Chuck

Three jaw drill chuck is selected. Rear side threaded hole diameter =12 mm with 1mm thread, 25 mm deep.
Front side specimen holding capacity =Diameter from 0-13 mm, up to 30 mm deep (Tightening key provided for specimen holding.)

Figure: Selected 3-jaw Drill chuck

3.6 Selection of Weight Disk

Weight disk selected is of round geometry. Total 20 numbers of round disks of 2250gm and one number of 1800 gm and 3600 gm each disk is selected as readily available in market.

- First disk of 2250 gm, thickness of disk = 16 mm, Diameter of disk = 152 mm,
- Second disk of 1800 gm, thickness of disk = 30 mm, Diameter of disk = 100 mm,
- Third disk of 3600 gm, thickness of disk = 30 mm, Diameter of disk = 140 mm.

Figure: selected weight disk of, 1800, 3600, 2250 gm

3.7 Design of Load Frame & Weight Hanger

Load frame is made of 2 mm thick MS strip, SS rod of 12 mm diameter 350 mm in length, two round tightening clips for mounting load frame on loading bearing and two clips for holding rod to load bearings. MS bar of square cross-section of 10 mm side is used to manufacture weight hanger cage. Weight cage is designed so that weight disk can easily place and removed. Weight of load frame is 670 gm and 2090 gm of that weight hanger.

Figure: load frame and weight hanger manufactured as per required design arrangement.

3.8 Design of Mounting Frame

Square hollow pipe of 25mm×25mm of M.S 16 gauge and rectangular hollow pipe of 50 mm×25 mm and 74 mm× 25 mm has been selected for fabrication of mounting frame. Rubber tip are used for vibration damping purpose at four legs of base frame. Frame dimensions are as follow:

- Length=1050mm, Width= 400mm, Height= 910mm.

Figure: manufactured mounting frame

3.9 Digital Revolution Counter

6-digit revolution counter selected for counting numbers of cycles and input to this counter is Proximity Sensor. It has following specifications-

- Display: 6 digit, 0.3" height, Red 7 segment LED
- Input: 3 to 30V DC from Proximity switches, Encoders, Potential free contacts, Limit switches etc.
- Supply voltage: 230 AC (+-10%)
- Mounting: Panel mounting
- Temperature: operating: 0-50 C, weight is 140 gm.

Figure: 6-digit digital revolution counter

3.10 Proximity Sensor

Proximity sensor selected for input to counter which sends impulses to counter. Proximity Sensor of Inductive type product has been purchased.

Figure: selected proximity sensor

3.11 Design of Sensor fitting arrangement

For sensor mounting is made of MS strip of 23 mm width and 260 mm length. Arrangement is shown in below picture,

Figure: sensor fitting arrangement

3.12 Design of Sensor sensing arrangement

There has been made special arrangement for sensing number of cycles of specimen undergoing test. For that PUC pipe used and high glazed steel strip paste on round PUC pipe with the help of transparent cello tape. Arrangement is shown in picture.

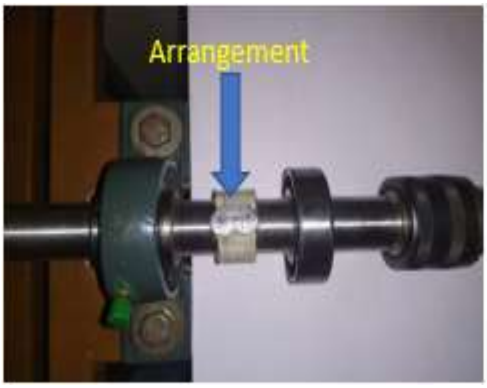


Figure: sensor sensing arrangement

3.13 Selection of Rubber tip

For vibration damping purpose, four number of rubber cock used at mounting frame's leg shown bellow picture.

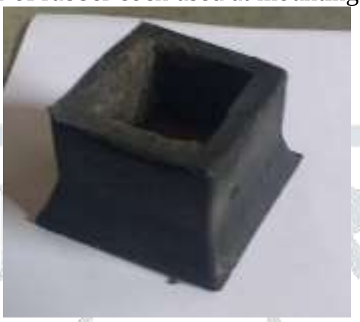


Figure: rubber tip

3.14 On/Off Switch

For starting and stopping of motor purpose electric on-off switch selected, shown in below picture

Figure: on-off switch used in set up

3.15 Specimen:

The material selected for the testing specimen is Stainless Steel 304 grade, which having following composition:
It is austenitic, also known as 18-8 SS because it content 18 % chromium and 8% nickel and used without annealing.
C- 0.08 %, Mg-2 %, P- 0.045%, S- 0.03 %, Si- 0.75 %, Cr- 18-20 %, Ni- 8-12 %, N- 0.10 %, Iron balance.
Modulus of elasticity: 193GPa
Ultimate Tensile Strength = 828.86MPa (Tensile Test)

3.16 Selected Geometry of Specimen:

Total length of specimen = 106 mm, Front and rear section diameter = 12 mm, Front and rear section length = 40 mm, Middle section diameter = 6mm, Middle section curve radius = 30 mm, Middle section length = 26 mm.

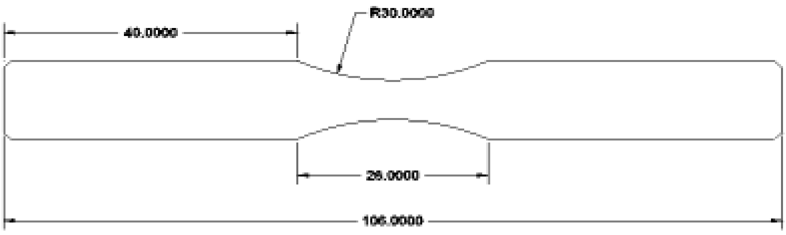


Figure: Selected Specimen geometry (all dimensions are in mm)

Figure: manufactured Stainless steel test specimens

3.17 Manufacturing and Assembly

For manufacturing of rotating bending fatigue test rig, first of all, purchase designed and selected material, components of test rig i.e. electric motor, coupling, shaft material of stainless steel 202 grade, bearings, drill chuck, specimen material of stainless steel 304 grade, MS weight disk of 2250 gm, 1800 gm, and 3600 gm. After purchase of all material prepare 2D drawing of assembly, and then all parts are modeled in CATIAv5. Then make assembly of those parts in CATIA. Select material for specimen and prepare specimen for testing purpose as per testing standards. With the help of prepared drawings, fabrication has been done.

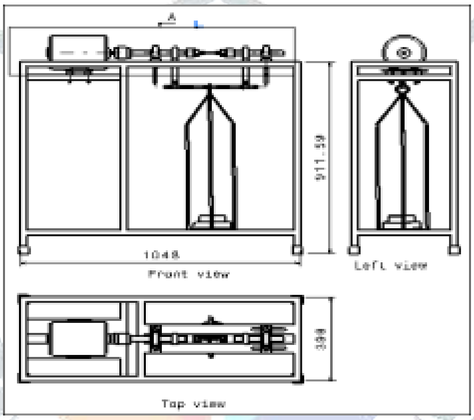


Figure: 2D drafted drawing of RBF test rig-front, left side and top view.

In fabrication, different manufacturing process operations such as cutting, welding, drilling, milling, grinding, painting etc. are used. In fabrication of test rig, different parts that should be manufacture or machined such as specimen, base frame, load frame hanger, shaft etc. as per design requirement.

3.18 Manufacturing challenges:

In fabrication of test rig, lot of problems occurred. Different problems, such as availability of materials, working schedule of electricity, working days of fabrication workshop, etc. have been occurred. First, the test rig components have been designed, and then went for purchase it. But it is not available in the market, so first purchase material and go for its design procedure. For motor output shaft, transmission coupling is not available. Also shaft for bearing mounting is of not standard size, there has to make it true by turning. Shaft material has to purchase according to designed bearings inner diameter. Frame material has to select from available material. Load frame arrangement has been developed as per suitable arrangement and machining cost of weight disk available in market. For weight disk manufacturing, designed thickness is not available, so selected available thickness plate. Material purchased for shaft is machined and shaft is obtained, but it is come to know it is slight bend. So, there has to purchase again shaft material and machining cost is added. For digital counter, there has to face lot of problems due requirements of project. Product is available, but its specifications not meeting to requirements. After long duration search counter is available with sensor. But sensor is also functioning in specific manner. It senses the metal, counter aimed to count revolution of the shaft, so during one revolution of shaft it sense the metal and sends impulse to counter which reads more than one counts. For this purpose, special arrangement for sensor has been developed, which results in same counting by sensor as well as counter.

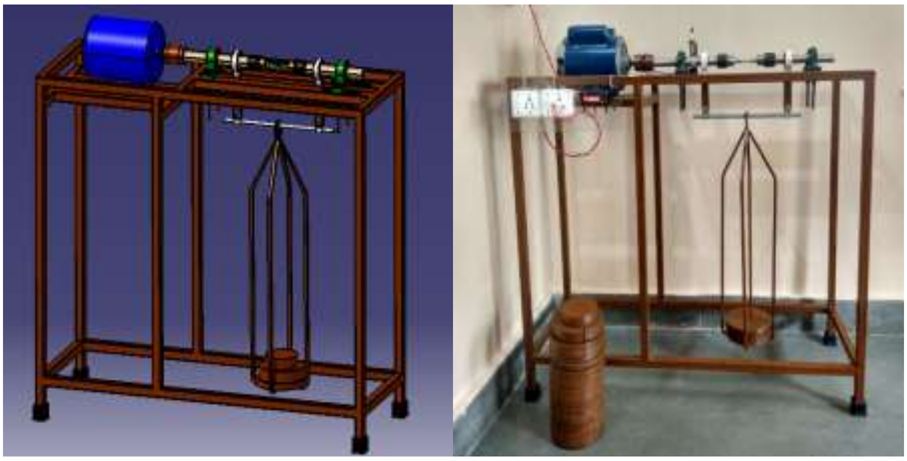


Figure: cad model of assembly of all parts of test-rig & fabricated and assembled test rig.

IV. ADVANTAGE OF TEST RIG

- Simple in construction, compact, easy to understand and carry out fatigue testing.
- One can find fatigue life of any material with variation of length of specimen. From this S-N curve of that metal can be plotted and endurance limit can be find out.

V. CONCLUSION

- This manufacturing process gives very important and useful knowledge regarding the Development of Rotating Bending Fatigue Test Rig.
- As new to proceed, a successful project has been made.
- Cost effective and unique RBF test rig has been developed.
- Testing has been done successfully.

FUTURE SCOPE

- Test rig can be used for industrial purpose.
- Combine to above set up, use of computer desktop on which required software will be installed and directly recorded data can be used to plot the S-N curve.
- Different metals, non-metals materials can be tested on this test rig with help of production of specified testing procedure manual.
- Thus, RBF test rig efficiently has been developed, which can be used at institute level for student to study the fatigue and fatigue life prediction with preparing testing manual.

COST ESTIMATION OF TEST RIG

Total cost for manufacturing test rig has been spent is totally Rs. 30,000 only

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