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EXPERIMENTAL AND FINITE ELEMENT ANALYSIS OF ROCKER ARM FOR BENDING FAILURE

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Abstract- *A rocker arm, in the context of an internal combustion engine, is an oscillating lever that conveys rotating motion of cam lobe to linear motion of the inlet or exhaust valve of an engine. Rocker arms oscillate about rocker arm shaft because of action of push rod on one side and spring action on other side, which causes bending of rocker arm. As the result, the bending stresses are induced. Failure of rockers may take place due to these stresses. Theoretical analysis can been done using theoretical formulae but is necessary to carry out experimental analysis of rocker arm in working condition for better understanding of stresses. The paper deals with theoretical and finite element analysis of rocker arm. The results obtained from these two methods were compared with the results of experimental analysis.*

Keywords: *Rocker Arm, Valve, Bending moment, Finite Element analysis, Strain gauge*

I. INTRODUCTION

Design engineers always aim at improvement in each and every part of automobile system. Automobile industry, since many years, is conducting constant efforts for the purpose of modification of the mechanical parts of vehicles in order to improve the performance. In addition, redesigning the mechanical parts play an important role in improving the sustainability of the system against the resultant stresses and strains, therefore, significant consideration should be taken for this when parts are designed by engineers.

Rocker arm is a mechanically advantaged lever which is pivoted at pivot point so that it can transmit camshaft motion to the valve. Jonathan Rundle Bacon created Rocker arms in the 19th century. In the early phase of development, the pivot point was based on less efficient theories which led to wear of valve tips, valve guides and other valve train components. It was observed that cam lobe motion, which transferred through the pushrod and rocker arm to the valve, was less effective. James Miller's Mid-Lift Patent set a new standard of rocker arm geometry which defined each engine's valve train specific angle between push-rod and valve. The exact perpendicular geometry on both sides of the rocker arm was attained with the valve and the pushrod by redesigning the rocker's pivot point. Throughout the history of the rocker arm, its function has been studied and improved upon. Some designs can actually use two rocker arms per valve, while others utilize a roller bearing to depress the valve. These variations in design result in rocker arms that look physically different from each other, though every rocker arm still performs the same basic function.

A rocker arm is designed to pivot on a pivot pin or shaft that is fixed to a bracket. The bracket is mounted on the cylinder head. One end of the rocker arm is in contact with the top of the valve stem, and the other end of rocker arm is actuated by the camshaft. In installations where the camshaft is located below the cylinder head, the rocker arms are actuated by pushrods. The lifters have rollers which are forced by the valve springs to follow the profiles of the cams. Failure of rocker arm is a measure concern as it is one of the important components of push rod IC engines. Present work is carried out stress analysis of rocker arm under extreme load condition.

II. LITERATURE SURVEY

Prashant Patil et. al. carried out experimental analysis of helical gear for bending stress. In this paper study of effect of pressure angle on bending stress at critical section of a helical gear is evaluated. The results are compared with results of Finite element analysis and experimental analysis using 3D photoelasticity method. Results showed that there was fairly good agreement between the results from the methods used for analysis.

Jafar Sharief et. al. has stated that failure of rocker arm is a measure concern as it is one of the important components of push rod of IC engines. Rocker arm is parts of the valve-actuating mechanism. A rocker arm is designed to pivot on a pivot pin or shaft that is fixed to a bracket. The bracket is mounted on the cylinder head. One end of a rocker arm is in contact with the top of the valve, and the other end is actuated by the camshaft. In this thesis it was observed that by changing different materials how the stresses in the rocker arm varied under extreme load condition. And after comparing results he proposed best suitable material for the rocker arm under extreme load conditions.

Syed Mujahid Husain et.al. have studied and concluded that the extensive research in the past clearly indicated that there are problems in rocker arm that have not yet been overcome completely and designers are facing lot of problems specially, stress concentration and effect of loading and other factors. The finite element method is the most popular approach and commonly used for analysing fracture mechanics problems. Lightweight rocker arms are used for high rpm applications, but strength is also essential to prevent failure. In recent years, steel roller tip rockers have become a popular upgrade for the most demanding racing applications. Some of these steel rockers are nearly as light as aluminium rockers. But the main advantage is that steel has better fatigue strength and stiffness than aluminium.

Mohd Moesil Muhammad et.al. observed that the rocker arm of diesel engine, used in ships and boats, failed in service. The fracture occurred at the threaded part of the rocker arm. A detailed metallurgical investigation was conducted to identify the mode of failure and the point at which the crack was initiated. The failure was dominated by fatigue due to the appearance of beach mark patterns on the fracture surface. The fractographic study showed the presence of metal particles and scratches adjacent to the crack region which contributed to stress localisation, resulting in the crack being initiation and propagation.

III. THEORETICAL ANALYSIS OF ROCKER ARM

- **Force analysis of rocker arm**

The various forces act on the rocker arms during the operation. These forces can be mainly categorized into:

1. Gas load on valve, which comes into play when valve opens
2. Inertia force, which oppose the downward movement of the valve
3. Initial Spring force, which hold the valve on its seat against the suction

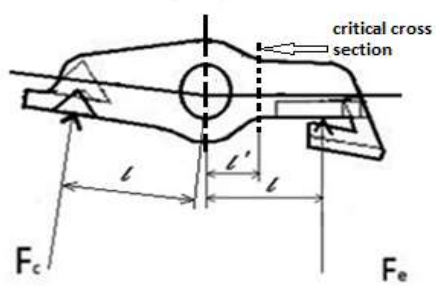

Fig.1.Distance of critical section

Detailed information of rocker arm of TATA Sumo Engine is as follows [4]:

mv = Mass of the valve
= 0.09 kg
dv = Diameter of the valve head
= 40 mm
h = Lift of the valve
= 13 mm
r = amplitude of reciprocating valve
= h/2
= 6.5 mm
=.0065 m
Pc = Exhaust gas pressure in cylinder
= 0.4 N/mm^2
Ps = Maximum suction pressure
= 0.02 N/mm^2
N = speed of engine
= 3000 RPM
ϴ = Angle of action of cam
= 110°
l = Length of arm,
P_1 = Gas load on the valve
a = Acceleration of the valve,
w = weight of the valve and associated parts
t = time of action of cam
P = Total load on the valve

- **Calculations for theoretical analysis**
  - Gas load on the valve is calculated using equation 1

$$P_1 = \frac{\pi}{4}(d_v)^2 \cdot P_c \tag{1}$$

Put values of d_v & P_c in equation 1

P_1 = 502.65 N

- Weight of the valve is given by equation 2

$$w = m \cdot g \tag{2}$$

= 0.8829 N

- Total load on the valve is given by equation 3

$$P = P_1 + w \tag{3}$$

= 503.5329 N

- Initial spring force considering weight of the valve is given by equation 4

$$F_s = \frac{\pi}{4}(d_v)^2 \cdot P_s - w \tag{4}$$

Put values of d_v, P_s & w in equation 4

Fs = 24.25 N

- The force due to valve acceleration (Fa) may be obtained as discussed below:

  As speed of engine is 3000 RPM

  The speed of camshaft = 1500 r.p.m

- Angle turned by the crankshaft per second

  ω = 9000 deg/sec

- Time of action of cam is

  t = 0.012 sec

- Maximum acceleration of the valve

  a = 1782.011 m/s^2

- Force due to valve acceleration is given by equation 5

$$Fa = m_v \cdot a + w \tag{5}$$

Fa = 161.26 N

- Maximum load on the rocker arm is given by equation 6

$$Fe = P + Fs + Fa \tag{6}$$

Put values of P, Fs & Fa in equation no.6

Fe = 689.04 N

Since the length of the two arms of the rocker are equal, therefore, the load at the two ends of the arm are equal, i.e., Fc = Fe= 689.04 N.

- The maximum bending moment (M_{max}) at the critical cross section is determined using equation 7

$$M_{\max} = F_e(l - l') \tag{7}$$

$M_{\max}$ = 7234.5N-mm

The cross sectional area is as given in the fig.2.

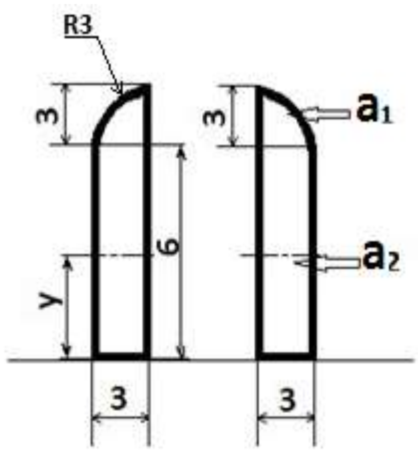

Fig.2.Cross Section area of Rocker arm neck at critical section

y = Neutral axis distance

Z = Section modulus

r = radius of curved surface

= 3mm

a_1= area of curved section as shown in fig 2
y_1 = distance centroid of area a_1
y_2 = distance centroid of area a_2
a_2 = area of rectangular section as shown in fig 2
h_1 = distance of centroid of curved section to neutral axis
h_2 = distance of centroid of rectangular section to neutral axis
I = Area moment of inertia

- Equation 8 gives Area moment of inertia

$$I = 2 \times [I_1+a_1h_1^2] + [I_2+a_2h_2^2] \quad (8)$$
$$I = 254.1\ mm^4$$

- Distance of neutral axis for are of cross section of rocker arm is

$$y = 4.2mm$$

- Section modulus Z is given by equation 9

$$Z = \frac{I}{y} \quad (9)$$

$$Z = 60.5\text{mm}^3$$

- Bending stress is obtained by equation 10

$$\sigma_b = \frac{M\text{max}}{Z} \quad (10)$$ [12]

$$= 119.6\ \text{N/mm}^2$$

Maximum bending stress in the rocker arm for maximum bending moment is 119.6 N/mm^2.

IV. FINITE ELEMENT ANALYSIS

FEA solution of engineering problems, such as finding deflections and stresses in a structure, requires steps as given below:
1. Modelling
2. Pre-processing
3. Processing
4. Post-processing

Finite element analysis of rocker arm is carried out as per following steps

- **Modelling**
  Using Solidworks software the rocker arm was modelled. It contains model of rocker arm along with two rods at the two ends. The model is then converted into IGS (.iges) file or STEP (.stp) file which was imported in ANSYS 16 workbench.

- **Pre-processing**
  In the pre-processor phase, along with the geometry of the structure, the mechanical properties of the material of structure were defined.

o The FEA of modelled structure or geometry is done in ANSYS workbench static structural module. This is started as follows
➢ Start menu > ANSYS 16.0 > Workbench 16.0

o In this module material properties were assigned by editing Engineering data tab.
➢ The material of rocker arm is AISI1040 steel. Material properties are
1) Density 7845 kg/m32
2) Young's Modulus (E) 210 KN/mm^2
3) Poisons Ratio 0.3
5) Yield stress 415 N/mm^2
o After material properties were assigned, geometry was imported using geometry tab
o Using Edit option the imported assembly was opened. The contacts of the assembly were checked (new contact can be added if necessary).
o Meshing is one of the important steps in analysis using ANSYS. Mesh tool is used to discretise the geometry into elements.

- Type of mesh is “hexahedral”.
- Element type is taken by default as “Solid186”.
- Mesh size - 0.5x0.5

- **Processing**

In this step, the geometry, constraints and loads are applied to the model. The load obtained from theoretical analysis is 689N. This load is transferred at the two ends of rocker arm, at 20mm from the pivot centre, using two rods. The rocker arm is fixed at the pivot shaft as shown in fig.3. When boundary conditions are input in the ANSYS it generates equations at each node. These equations are then solved for deflections. Using the deflection values, strain, stress, and reactions are calculated.

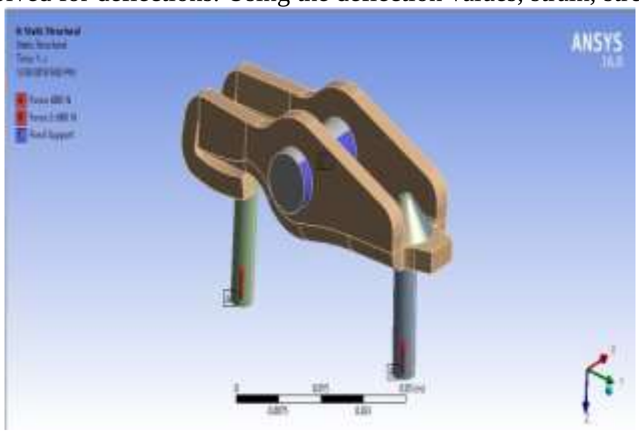

Fig.3. Loading of rocker arm in ANSYS

- **Post processing**

This is the last step in a finite element analysis. Results obtained in step two are usually in the form of raw data and difficult to interpret. In post analysis, a CAD program is utilized to manipulate the data for generating deflected shape of the structure, creating stress plots, animation, etc. The Static Analysis gives a results of rocker arm is showing principal strain and maximum principle stress. The direction of the principal stress is obtained in ANSYS as shown in fig.5. It is 14^0 inclined to Y-axis. Also the stress at the required point is 128.02N/mm^2 is shown in fig.4.

Fig.5.Figure of direction of principal strain

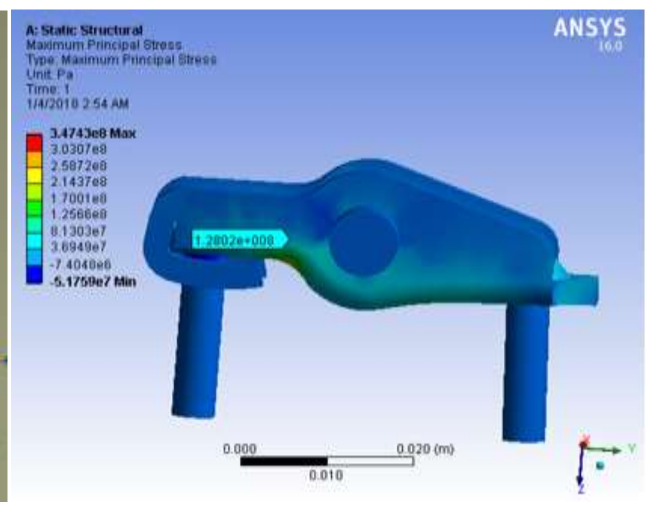

Fig.4.Figure of principal stress is MPa

V. EXPERIMENTAL ANALYSIS

The rocker use for our experimentation is of Tata sumo victa. While there are several methods of measuring strain the most common is with a strain gauge. Experimental analysis has carried out using electrical resistant strain gauge as follows:

- **Design and Development of loading fixture**

As rocker arms are used to transmit force, a loading fixture is necessary to simulate static loading condition. First the fixture was modelled in solid work. Fig.6. shows the CAD model assembly of experimental loading fixture in solidworks which is to be fabricated to carry out experimental analysis.

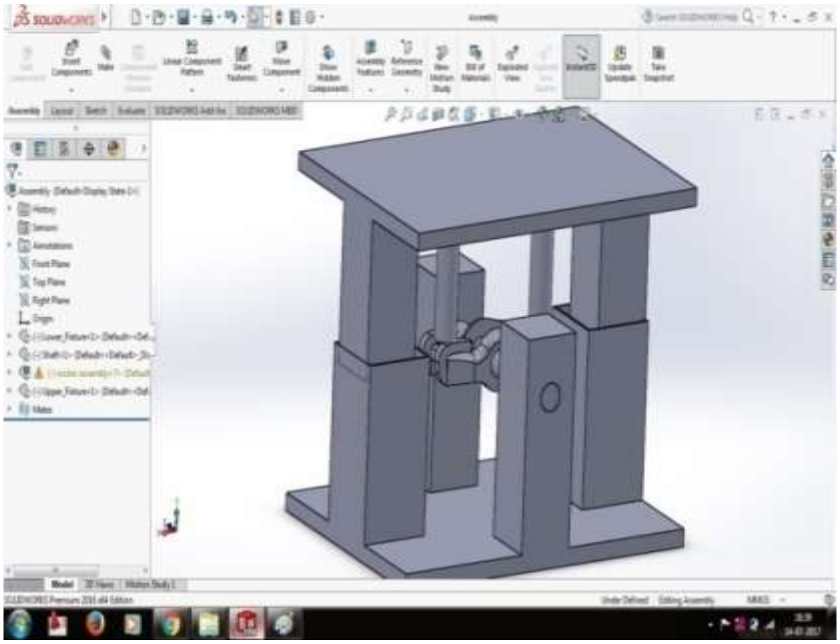

Fig.6.CAD Model of assembly of loading fixture

- **Fabrication of Fixture**

For experimental analysis of Rocker arm the fixture is fabricated. Material used for the fabrication of fixture was Mild steel. The parts of fixture were welded together.

- **Selection of Strain Gauge**

The initial step in preparing for any strain gage installation is the selection of the appropriate gauge for the task. Careful, rational selection of gauge characteristics and parameters can be very important in: optimizing the gauge performance for specified environmental and operating conditions, obtaining accurate and reliable strain measurements,contributing to the ease of installation, and minimizing the total cost of the gauge installation.

- **Specification of train Gauge selected**

1. Make	Tokyo Sanyo(Japan)
2. Gage Length	3.5mm
3. Gage Resistance	350Ω ±0.3%
4.Foil Material	Steel
5.Base Material	Polyester

- **Bonding of Strain Gauge**

Accurate strain measurement requires a mirror like surface to bond the strain gauge on it. So the rocker arm surface at the neck was prepared using police paper. Then the surfaces were washed with help of acetone. After preparing the surface strain guage was bonded with the help of adhesive cynoacrylic by following standard procedure. Fig.7 shows the strain gauge mounted on the rocker arm.

Fig.7.Strain Gauge Mounted on rocker arm

- **Experimental Setup**

A Universal testing machine (UTM) is used to test the tensile strength, compressive strength, bending strength, etc of of materials or parts. The experimental analysis of rocker arm was carried out on UTM. The equipments required to evaluate the stress in rocker arm are as under

1. Universal Testing Machine – 100kN capacity
2. Rocker Arm – 1 sample to be tested
3. Fixture – Mild steel
4. Strain gauge – 350 ohm
5. Strain gauge setup – Dewsoft

The lead wires of strain gauge, mounted on rocker arm, are connected to external circuit using a wire and the connections are sealed using glue. This setup is mounted on the lower fixture. The wire is then connected to strain gauge setup, a shown in fig.8, such that the strain is directly recorded by the software when load is applied.

Fig.8.Experimental Setup of Strain Gauge

Fig.9.Experimental Testing on UTM

For the experiment load was applied gradually on UTM as shown in fig.9 and the digital load display panel indicated the force. Starting from zero, load was increased by 50N up to 1600N, as it gets divided into two components in two vertical rods. The readings of strain gauge developed in rocker arm are recorded using Dewsoft software.

- **Measurement of strain**

After application of load using UTM the strain developed in rocker arm is recorded using Dewsoft Software. Steps of 100N are taken in result table. Fig.10. shows the force and strain relation which is approximately linear.

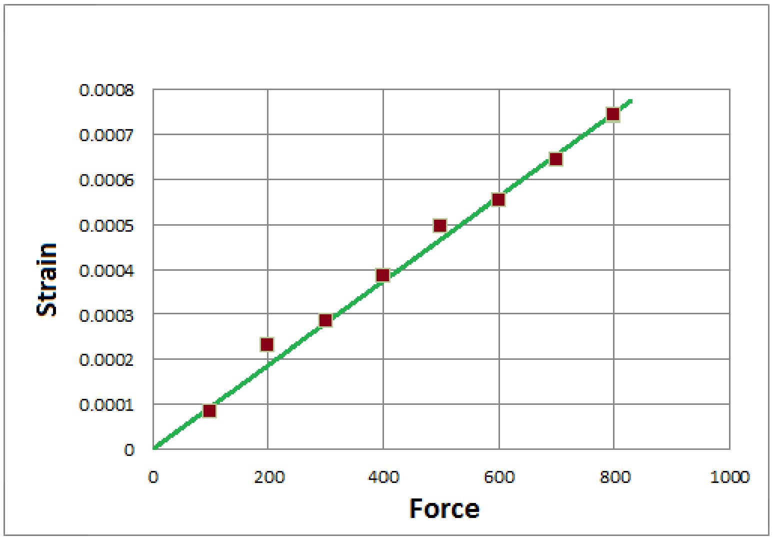

Fig.10. Force vs Strain

- **Evaluation of stress**

Table 1 shows loads, strain and corresponding stresses. The stress can be found by using the stress and strain relationship (Hooke's Law).

$$\text{i.e.} \quad \sigma = eE \tag{11}$$

Load (N)	Strain (e)	Stress(N/mm^2)
100	0.000083	17.181
200	0.000232	48.024
300	0.000286	59.202
400	0.000385	79.695
500	0.000495	102.465
600	0.000553	114.471
700	0.000643	133.101
800	0.000739	152.973

Table.1.Load ,strain and calculated stress

Using interpolation for load 689N strain is calculated as follows

$$\text{Strain } (e) = 0.000553 + \frac{(689-600)(0.000643-0.000553)}{(700-600)}$$

$$e = 0.000633$$

This is the strain obtained at the point where the strain gauge is mounted. The stress at required area is given by equation no.11. (For steel modulus of elasticity is 2.1×10^5)

$$\sigma = 0.000633 \times 2.1 \times 10^5$$

$$\sigma = 131.03 \text{ N/mm}^2$$

VI. RESULTS AND DISCUSSIONS

Accurate assessment of stress in rocker arm in the static state is essential. Neck of Rocker arm has critical area where stress analysis is necessary. So bending stress at neck of the rocker arm was carried out using theoretical, experimental and finite element methods under static conditions. The results of bending stress analysis by theoretical, experimental method and finite element method have been summarized in Table 2.

Load (N)	Theretical Stress (N/mm^2)	FEA Stress (N/mm^2)	Experimental Stress (N/mm^2)	% Error between		
	A	B	C	A & B	B & C	A & C
689	119.6	128	131.03	7.02	2.37	9.56

Table.2.Result table

CONCLUSION

Bending stress at neck region of rocker arm under static condition is evaluated using theoretical, finite element and experimental methods. There is fairly good agreement between the three methods. Following conclusions have drawn from this study

- The percentage error observed between theoretical and finite element analysis result is 7.02%.
- The percentage error recorded between finite element analysis and experimental analysis result is 2.37%.
- The error percentage observed between theoretical and experimental analysis result is 9.56%.
- Maximum error recorded is 9.56% and the minimum error recorded is 2.37%.
- Maximum error is less than 10% which is acceptable

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