Experimental & FEA Assessment of Modification in Valve Operating System in IC engine

#1Vikas M. Kashid, #2A. B. Gaikwad

#1vikaskashid73@gmail.com  
#2amol24gaikwad@gmail.com

#12Department of Mechanical Engineering, Dr. D. Y. Patil School of engineering, Charholi(Bk), Pune-412105, Savitribai Phule Pune University.

ABSTRACT

The existing follower in single cylinder, four stroke petrol engines is a flat face roller follower. The contact between current cam and follower mechanism results in high frictional losses which show the low frictional efficiency. In this research an attempt is made to change the flat face of follower to a curved face follower, so that we get the required contact. Therefore it’s observed that the stress value in the both modified and existing roller follower remains almost same or within range. The stress analysis was done analytically, experimentally and was verified by simulation in ANSYS. By using this study we get low coefficient of friction of modified follower roller and also get low frictional efficiency of cam and follower mechanism. We also get required degree of freedom for variable valve timing (VVT) mechanism the cam shaft needed to be shifted along with its axis of rotation during regular operation of an Internal Combustion engine this will help to increase the frictional efficiency of a cam and follower mechanism. For comparisons of vibrations & stresses which induced on Existing as well as new follower, vibration analysis and the stress analysis is done. Details of roller follower vibration and Stress analysis are discussed in this project.

Keywords— Finite element approach, Point contact, Roller follower, stress analysis, vibration analysis.

I. INTRODUCTION

In the recent times with the advance technologies the various vehicles have been modified as per the requirement of a consumer. Sometimes there is modified ignition system, modified shape, different cylinder arrangements etc. Thus we have decided to change the shape of a follower. The follower of the cam follower mechanism is of flat face roller type; which have line contact with cam. This line contact of roller with cam will be changed to point contact by doing modification in the shape of a roller follower. The modified shape of a roller should satisfy conditions:
1. The follower should make point contact with cam.
2. The stress values of an original shape and modified shape should be within range or almost same of existing.
3. The frequencies of an original shape and modified shape should be within range.

The purpose of this research is to reduce the friction between roller and cam. For this there is requirement of modification in the shape of roller geometry. Thus roller is modified and check for the stress and vibration analysis. After doing modifications in the geometry and its iterations for the analysis, we will get the required results. As per the requirement, the simulation of a model should be done using software. For that we follow two basic steps as modeling and then analysis. We do modeling in CATIA V5 and analysis in ‘ANSYS’. The main part of this project is to do analysis using ‘ANSYS’. For this finite element analysis is required to study. The main motivation behind the work was to go for FEA of roller rather than empirical formulae and iterative procedures. The roller of rocker arm of a BAJAJ PULSER-180 bike is taken as the model for the analysis.

Since last decade advent of powerful finite element analysis (FEA) have proven good tool to analyses the
problem. The Various complicated geometries can be analyzed by FEA instead of doing analytical calculations. Optimized meshing And accurate simulation of boundary conditions along with the ability to apply complex load, provided by various FEM packages have helped the designer to carry vibration analysis with the investigation of critical stresses and contact stresses. FEM is used to find critical locations and quantitative analysis of stress distribution and deformed shape under loads. However detailed modeling and specialized knowledge of FEM theory are indispensable to perform these analyses with high accuracy. They also require complicated meshing strategies. Simulations of actual boundary conditions to equivalent FE boundary conditions have to be done carefully because a wrongly modeled boundary condition leads to erroneous results. The solution of such large scale FEM problem requires both large memory and disc space as computing resources.

II. LITERATURE REVIEW

Daisuke Yonekura et al. in, “Wear mechanisms of steel roller bearings protected by thin, hard and low friction coatings”, he find that the rolling contact fatigue wear processes such as pitting did not take place. The uncoated test rollers failed due to pitting caused by rolling contact fatigue. Life of the Roller was the almost same in both lubricants. Secondary wear, due to a type of polishing, also took place. [1]

Nagaraj Nayaka et al. in, “Predictions of cam follower wear in diesel engines”, he said that the rate of wear of cam followers mechanism is mainly a function of contact stress between the cam and the roller follower. The problem of surface fatigue wear becomes severe as the contact between cam and follower exceeds the plasticity limit of material. It finally leads to an increase in valve lash and loss of engine performance. The wear is minimized by reducing the coefficient of friction and by minimizing the compressive stress. [2]

R. Ipek et al. in, “The dry wear profile of cam shaft”, stated that the wear mechanisms of cam surface show difference along the contact surface. The maximum wear value is obtained just near to the cam nose where the follower is about to complete the climbing. [3]

Mahesh R. Mali et al. in, “Design Optimization of Cam & Follower Mechanism of an Internal Combustion Engine for Improving the Engine Efficiency”, he done work on modal analysis and find out mode shapes of existing and modified roller and concluded that the frequencies of modified roller is in the range of existing roller. Also conclude that by changing the profile of roller friction in the cam and follower decreases. [4]

III. PROBLEM STATEMENT AND OBJECTIVE

The existing cam & follower mechanisms used in Internal Combustion engines have a line contact between them causing frictional losses and results in low frictional efficiency. These frictional losses in present line contact are being considered on the higher side of the system. These frictional losses affect the total efficiency of an Internal Combustion engine. The degree of freedom required for variable valve timing (VVT) mechanism cannot be able to achieve in line contact. To get required degree of freedom for variable valve timing (VVT) Mechanism the cam shaft needed to be shifted along with its axis of rotation during regular operation of an Internal Combustion engine. This will help to increase the efficiency of an Internal Combustion engine.

IV. THEORETICAL ANALYSIS

A. The dimensions of roller follower

<table>
<thead>
<tr>
<th>Properties</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer diameter of a roller</td>
<td>17.46mm</td>
</tr>
<tr>
<td>Inner diameter of a roller</td>
<td>12.62mm</td>
</tr>
<tr>
<td>Thickness</td>
<td>6.43mm</td>
</tr>
<tr>
<td>Fillet</td>
<td>0.5mm</td>
</tr>
<tr>
<td>Contact Area of Existing Roller</td>
<td>5.93mm²</td>
</tr>
<tr>
<td>Contact Area of Modified Roller</td>
<td>2mm²</td>
</tr>
<tr>
<td>Cross sectional area of existing roller</td>
<td>6.43mm²</td>
</tr>
<tr>
<td>Cross sectional area of modified roller</td>
<td>5.870mm²</td>
</tr>
<tr>
<td>Maximum load from the cam is (P)</td>
<td>950N</td>
</tr>
</tbody>
</table>

B. The material properties of steel

The most commonly used material for the cam and follower is chromium steel with designation of 100cr6.

<table>
<thead>
<tr>
<th>Material</th>
<th>Yield strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>100Cr6</td>
<td>410MPa</td>
</tr>
<tr>
<td>Young’s modulus</td>
<td>2.1e5MPa</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.3</td>
</tr>
<tr>
<td>Density</td>
<td>7.850×10-3 tons/mm3.</td>
</tr>
</tbody>
</table>

So, first we have to find out static stress in existing & modified roller

For Existing Roller,

$\sigma_{ex} \text{ roller} = \frac{P}{A} = \frac{675}{6.43} \text{MPa}$

For Modified Roller,

$\sigma_{mod} \text{ roller} = \frac{P}{A} = \frac{950}{5.870} \text{MPa}$

C. Coefficient Of Friction

The basic principle in designing machine parts that are subjected to wear due to sliding friction is that the normal wear is proportional to the friction of work. The work of friction is proportional to the product of normal pressure (p) and the sliding velocity (V).

Let,

$P = \text{Intensity of tangential pressure with which the Contact surfaces are held together.}$

$W = \text{Normal load perpendicular to axis of roller in N}$

$\mu = \text{Symbol of coefficient of friction between Two contacting surface}.$

$A = \text{Real area of contact (mm}^2)\$

$Sy = \text{Yield strength of material N/mm}^2$
The experimental observation on friction over the centuries has led to the formulation PF laws of friction. The classical laws of dry friction, known as Amontons coulomb laws, are as follow.

The first law can be mathematically expressed as,

\[ F \propto W \]
\[ F = \mu \cdot W \]

Where,
- \( F \) = Frictional force (N)
- \( W \) = Normal load between two contacting surfaces.
- \( \mu \) = coefficient of Friction

Therefore, Coefficient of friction is given by

\[ \mu = \frac{F}{W} \]

Coefficient of friction is define as frictional force Per unit load.

Coefficient of force depends on,
1) The type of motion between the contacting surfaces.
2) The materials for the pair of contacting surfaces.
3) Surface finish of the two contacting surfaces.

The first of friction is applicable over the wide range of loads. Most of the materials obey the first law of friction except few material likes’ polymers. Therefore we use this theory for calculation of friction in case of existing and modified roller.

Now, first calculate the frictional force between existing followers.

D. Coefficient of friction of existing roller

\[ F \text{ (Existing)} = \text{Frictional force of existing roller.} \]
\[ = Sy \times A \]
\[ = 410 \times 22 \pi \times 5.93 \]
\[ = 133.36 \text{ KN} \]

Coefficient of friction \( (\mu) = \frac{F}{W} \)
\[ = \frac{133.36}{950} \]
\[ = 0.1522 \] ……………… (1)

E. Coefficient of friction of modified roller

\[ F \text{ (Modified)} = \text{Frictional force of modified roller} \]
\[ = Sy \times A \]
\[ = 410 \times 22 \pi \times 2 \]
\[ = 44.98 \text{ KN} \]

Coefficient of friction \( (\mu) = \frac{F}{W} \)
\[ = \frac{44.98}{950} \]
\[ = 0.04 \] ……………… (2)

F. Percentage of friction reduction in modified roller

\[ \% \text{ of friction reduction} = \]
\[ \left( \frac{\text{(Coefficient of friction of existing- coefficient of friction of modified)}}{\text{Coefficient of friction of existing}} \right) \times 100 \]

From equation (1) & (2) we get following \% of reduction

\[ \% \text{ of friction reduction in modified roller} = \left( \frac{(0.1522-0.04)}{0.1522} \right) \times 100 \]
\[ = 73.71\% \]

V. **FINITE ELEMENT ANALYSIS**

Static stress analysis of roller follower of cam follower mechanism is performed by ANSYS 14.5 software to determine the stress and strain values of both existing and modified roller follower.

A. Solid modeling of roller

Solid model of roller follower is created by CATIA software which makes modeling so easy and user friendly. Fig.1 shows a solid model of roller follower.

B. Stress analysis

Solid model of roller follower is created by CATIA software then this model is saving in IGES format and export into the FEA software ANSYS 14.5. The existing and modified roller follower is analyzed in FEA software. Following steps are used to find analysis results,

1) Material properties
2) Geometry/Model
3) Meshing.
4) Loads and boundary condition.
5) Results

C. Mesh generation

The meshing of existing and modified roller follower was done in ANSYS 14.5(Workbench) software. Fig.2 shows the meshing of existing roller and figure shows the meshing of modified roller.

D. Boundary Conditions

Static structural analysis was performed to determine equivalent (von-mises) stresses and total deformation of existing and modified roller follower by ANSYS software. For this above boundary conditions are used: Fixed support and Force. Existing and modified roller is fixed as shown in fig.4 and fig.5 Maximum load from cam is 950N. So, 950N load was applied on both followers in downward direction. For modified roller, Nodal force was used.
E. Analysis: Equivalent (von-mises) Stress and total deformation of existing roller follower

The fig.6 shows the stress value of the existing roller follower with line contact. Stress obtained from existing roller is 145.6MPa and Fig.7 shows deformation of existing roller is 0.0006mm.

F. Equivalent (von-mises) Stress and total deformation of modified roller follower

The fig.8 shows the stress value of the existing roller follower with line contact. Stress obtained from existing roller is 145.6 and fig.9 shows the deformation of existing roller is 0.0006mm.
Fig. 8 Equivalent (von-mises) stress in Modified roller

Fig. 9 Total deformation in existing roller.

VI. EXPERIMENTAL ANALYSIS

To verify the stress values and stiffness of roller follower experimentally we tested both the roller followers on universal testing machine in metallurgical laboratory. The readings from the machine are used to verify with the Finite element analysis results and calculate the stiffness of roller follower and further natural frequency is calculated by using the actual stiffness calculated.

In experimentation we find out results on the universal testing machine. Fig.10 shows the experimental setup of roller follower. Load is applied on roller follower by using load cells of universal testing machine. Fig.11 shows the roller follower is placed between load cell and fixture of universal testing machine. Load cell of universal testing machine is 980N. Load limit is set on the computer also put cross sectional area of both rollers to find out the stresses on the peak load. As the load apply on the roller the display of universal testing machine shows the graph of load vs. deformation at 1 to 3 points. And also shows the stress vs. Strain graph on the display.

By using this we can find out the stress of roller at deformation point. We take peak load value for both roller and take stress value on that peak load. Peak load for existing roller was 953N and modified was 944N, which shows the load value is near to the max load from cam 950N.

Fig. 10 Experimental setup

Fig. 11 loading on roller follower by load cell.

The stress value is taken at peak load and this value is compare with our FEA and theoretical results also calculate stiffness for both rollers from load vs. Deformation graph. By using stiffness we find out the natural frequency of both roller and frequencies of both rollers is in the range. Same procedure was applied for both roller followers.

A. Experimental results

From experimentation, we obtain graph of load Vs. deformation of both follower on that graph we also get the peak load value and stress on that load. So this stress was used to analized the results. Fig.11 & 12 shows the graph of load Vs. deformation of existing and modified roller follower respectively. On X axis it shows the load values and Y axis it shows the deformation of roller.

VII. RESULTS AND DISCUSSION

Stress analysis of existing and modified roller is carried out by theoretically, experimentally and Finite element method. By theoretically stress analysis obtained stress value for existing and modified roller is 153.22MPa and 161.84 MPa which shows the stress value is in the range.

Also calculated stress of modified is less than the allowable stresses.
Allowable stress = Yield strength / Factor of safety

\[ = \frac{410}{1.5} = 275 \text{ MPa} \]

If factor of safety is 2, Allowable stresses = Yield strength / Factor of safety

\[ = \frac{410}{2} = 205 \text{ MPa} \]

So, the calculated stress < allowable stress, i.e. 161.84 MPa < 273.333 or 205 MPa. Thus, our design of modified roller is proved to be safe.

By using FEA method stress values of existing roller and modified roller are 145.95MPa and 153.91MPa. These values also are in the range. Experimental analysis is also shows the stress values are in range.

For natural frequency of roller, theoretical analysis and experimental compression test is carried out. The natural frequencies value from theoretical analysis is 4.3Hz and 4.8Hz for existing and modified roller while from experimentation the natural frequencies are 4.3Hz and 5.04Hz.

**TABLE III**

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Type of Analysis</th>
<th>Existing Roller</th>
<th>Modified Roller</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Static stress</td>
<td>153.22MPa</td>
<td>161.84MPa</td>
</tr>
<tr>
<td>2</td>
<td>Coefficient of friction</td>
<td>0.1522</td>
<td>0.04</td>
</tr>
<tr>
<td>3</td>
<td>% of friction reduction in modified roller</td>
<td>73.71%</td>
<td>73.71%</td>
</tr>
<tr>
<td>4</td>
<td>Natural frequency</td>
<td>4.33</td>
<td>4.83</td>
</tr>
</tbody>
</table>

FEA Analysis using ANSYS (For Load-950N)

<table>
<thead>
<tr>
<th>1. static stress</th>
<th>145.95MPa</th>
<th>153.91MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Total deformation</td>
<td>0.0006</td>
<td>0.0011</td>
</tr>
</tbody>
</table>

Experimental analysis (Peak load from UTM, For existing 953N and for modified 944N)

<table>
<thead>
<tr>
<th>1. Static stress</th>
<th>148.32MPa</th>
<th>160MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Natural frequency</td>
<td>4.29</td>
<td>5.04</td>
</tr>
</tbody>
</table>

The coefficient of friction of modified roller is 0.04 and existing roller is 0.15 which shows the coefficient of friction of modified roller is very less than the existing roller follower. The % of friction reduction in modified roller is 73.71%. Therefore this design is increases the frictional efficiency of cam and follower mechanism.

**VIII. CONCLUSION**

As stress and natural frequency range of modified follower is within the stress range of existing follower. Thus, the modified design is safe. This shows change of the flat face of roller follower to a curved face roller follower mechanism results in low frictional losses due point contact which results in improved in Frictional efficiency of Cam and follower by 60% to 70%. This design and optimization of roller follower study also helps to increase the mechanical efficiency of engine.

**ACKNOWLEDGEMENT**

I take this opportunity to thanks Prof. A. B. Gaikwad and Prof. A. N. Patil for valuable guidance and for providing all the necessary facilities, which were indispensable in completion of this work. Also I sincerely thanks to all the authors who worked on valve operating system of IC engine.

**REFERENCES**


