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Simulation of Valve Train System of a Six Cylinder Internal Combustion Engine using Mathematical Modelling in MATLAB

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Abstract: ***The optimum designing of a cam and cam follower mechanism involves numerous parameters and considerations and hence it is a time consuming task. In the present work, the problem of cam wear and the design parameters of a translating flat-face, push rod type cam follower mechanism is investigated from a multi-objective point of view. The design parameters like the cam base circle radius, follower face width, follower offset, valve displacement, valve train natural frequency and hertzian contact stresses are considered as optimization criteria by developing a mathematical model program in Matlab to pretest the input parameters prior manufacturing, which in turn reduces the risk of faulty manufacture of cam. This program will eliminate the need for calibration of faulty cam and hence save time and reduce the cost of production. Finally, the dynamic behaviour of the designed cam mechanism is investigated in Matlab programming and numerical study of valve train dynamic analysis of a six cylinder internal combustion engine is done.***
Keywords: Cam, Flat – Faced Follower, MATLAB

I. INTRODUCTION

Camshaft can be defined as a machine element having the curve outlined or a curved grooved, gives the predetermined specified motion to another element called the follower. In automotive field, Camshaft and its follower take importance roles to run the engine. Nowadays the car maker have developed the vary schemes of cam profile to match with the engine performance. Since the system deals with high load and high speed and many analyses have been carried out on the failure of the components. The analysis is done either by experimental or finite element analysis. The result from the finite element analysis is an approximate of the component failure. In the meantime, the software development is improving in this few decades A cam–follower kinematic pair works under complicated conditions of mechanical load, and wears during operation. The contact surfaces of the cam and the follower are usually surface hardened. The hardening may be due to phase transformation or precipitation processes occurring in the material during heat treatment or thermo chemical treatment. Depending on this increasing capacity, its stable growth is anticipated in the world economy. In high cycle fatigue, as the cyclic stress is comparatively low, a large fraction of the fatigue life is used in micro crack initiation. Wear is another major failure of engine camshaft material. The aim of our thesis work is to analyse the problem of cam wear and design parameter of translating flat face follower through with the help of mathematical modelling in Matlab. In Matlab we solved the problem through the usage of Genetic Algorithm method to find the optimal solution.Genetic Alogarithm. Genetic algorithm uses selection, elitism, crossover and mutation procedures to create new generations. The new generations converges towards a minimum that is not necessarily the global one. After some repetitions when the maximum generation number is achieved, the variables values corresponding to the minimum fitness function value are selected as the optimum variables values of the genetic algorithm.

II. MATLAB

The full form of mat lab is matrix laboratory. MATLAB is the high level language and interactive environment use by millions of engineers and scientists worldwide. Matlab is an interactive program for Numerical computation and data Visualization. It is mainly been used for analysis and design. There are mainly different tool boxes available which extended the basic functions of matlab into different application areas. The Matlab application is built around the Matlab language, and most use of MATLAB involves typing Matlab code into the Command Window. Matlab can execute a sequence of statements stored on disk files. Such files are called "M-files" because they must have the file type of ".m" as the last part of their filename. There are two types of platforms in matlab 1) Normal coding 2) Simulink. We have used normal matlab coding to create the program “Cam Profile Tester”

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1) *M FILE*: An m-file, or script file, is a simple text file where you can place MATLAB commands. When the file is run, MATLAB reads the commands and executes them exactly as it would if you had typed each command sequentially at the MATLAB prompt. All m-file names must end with the extension '.m' (e.g. test.m). If you create a new m-file with the same name as an existing m-file, MATLAB will choose the one which appears first in the path order (type help path in the command window for more information). To make life easier, choose a name for your m-file which doesn't already exist. To see if a filename already exists, type help filename at the MATLAB prompt.
2) *Tool Box Used:* Symbolic Math Toolbox provides functions for solving and manipulating symbolic math expressions and performing variable-precision arithmetic. You can analytically perform differentiation, integration, simplification, transforms, and equation solving. You can also generate code for MATLAB, Simulink, and Sims cape from symbolic math expressions. Symbolic Math Toolbox includes the MuPAD language, which is optimized for handling and operating on symbolic math expressions. It provides libraries of MuPAD functions in common mathematical areas, such as calculus and linear algebra, and in specialized areas, such as number theory and combinatory. You can also write custom symbolic functions and libraries in the MuPAD language. The MuPAD Notebook lets you document symbolic math derivations with embedded text, graphics, and typeset math.In our thesis work Symbolic Math Toolbox is been used.
3) *MATLAB Codes Used For CAM Profile Tester*

Code of CAM Profile Tester Program

```
function CamTester(varargin)
%% Main Figure
figure('units','normalized',...
   'position',[.1 .1 .8 .75],...
   'color','w',...
   'numbertitle','off',...
   'menubar','none',...
   'name','Cam Profile Tester')
```

Figure 1 Cam Profile Tester

Displacement Diagram, Velocity Diagram, Acceleration Diagram, Jerk, Cam Profile and Radius of Curvature

Result which is shown below is the graph of SVAJ Diagram, Radius of Curvature which is been plotted through with the help of Math Lab. Through Coding the graph is been plotted. One coding example is explained below

4) *Displacement Diagram*

```
            axes(a1)
      cla
      hold on
rb=str2double(get(BC,'string')); % get base circle radius
      e=str2double(get(off,'string')); % offset
load input1.txt
h=input1(:,3);
ca= input1(:,1);
cra=e+ca;
plot(ca,h,'b');
xlabel('camangle(deg)');            % add axis labels and plot title
ylabel('Displacement(mm)');
title('Displacement vs camangle');
```

The Same way the rest of the coding is been explained.

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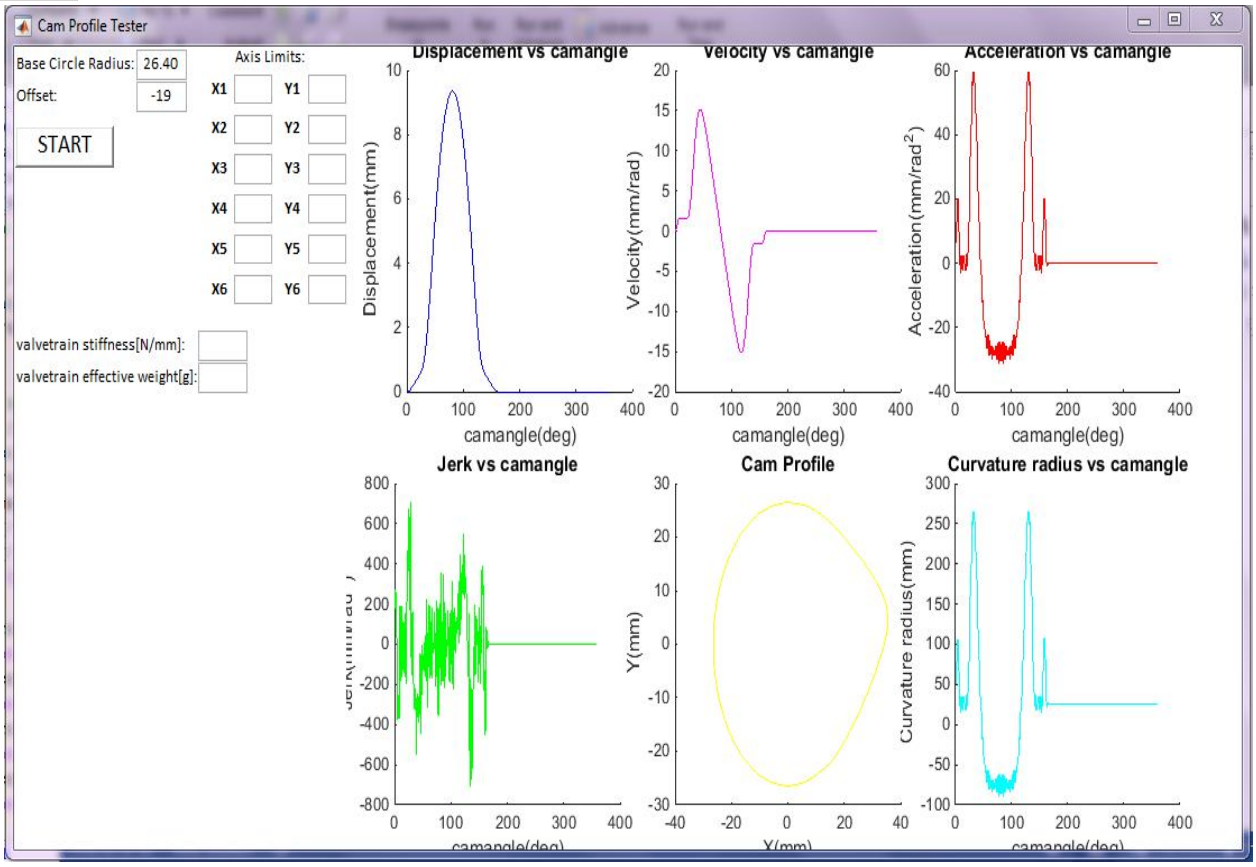

Figure 2- Displacement, Velocity, Acceleration, Jerk, Cam Profile, Radius of Curvature

A part from this SVAJ , Cam Profile and Radius of Curvature diagram, the natural frequency, Herzian Tensile stress , Herzian Shear Stress is also been calculated. The code used for Natural Frequency, Herzian Tensile Stress, Herzian shear stress is been given below

A. Natural Frequency

1) Formula Used

$$\text{Natural frequency, } \mathbf{Nf} = \frac{1000}{2\pi} \times \sqrt{\frac{k}{mv}}$$

Where,

K = valve train stiffness [N/mm]

mv = valve train weight [g]

2) Code Used

```
d1=2.*pi;
d2=1./d1;
d3=vs./vw;
d4=sqrt(d3);
nf=1000.*d2.*d4;
set(nf1,'string',nf);
```

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B. Hertzian Max Tensile Stress

1) Formula Used

$$\sigma max = 0.798 \times \sqrt{\frac{b^2}{2.56 \times CE^2 \times (2R)^2}}$$

Where,
R = cam nose radius [mm],
b = contact width [mm]

CE= $\frac{1-V1^2}{E1} + \frac{1-V2^2}{E2}$

V1=poison ratio of Cam
V2= poison ratio of Tappet
E1= Young's modulus of Cam [Mpa]
E2= Young's modulus of Tappet [Mpa]

2) Code Used

```
%CE
v1=1-prc.^2;

v2=1-prt.^2;

v3=v1./yc;

v4=v2./yt;
ce=v3+v4;
b2=cw.^2;
kd=nr.*2;
v5=kd.^2;

v6=ce.^2;

v7=2.56.*v5.*v6;
v8=b2./v7;
v9=sqrt(v8);
sc=0.798.*v9;
set(sc1,'string',sc);
```

C. Hertzian Max Shear Stress

1) Formula Used

$$\tau max = \frac{\sigma max}{3}$$, Acts at 0.4b mm below the surface

Where, B=contact width [mm]

2) Code Used

```
ss=sc./3;
sa=0.4.*cw;
set(ss1,'string',ss);
set(sa1,'string',sa);
```

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Result

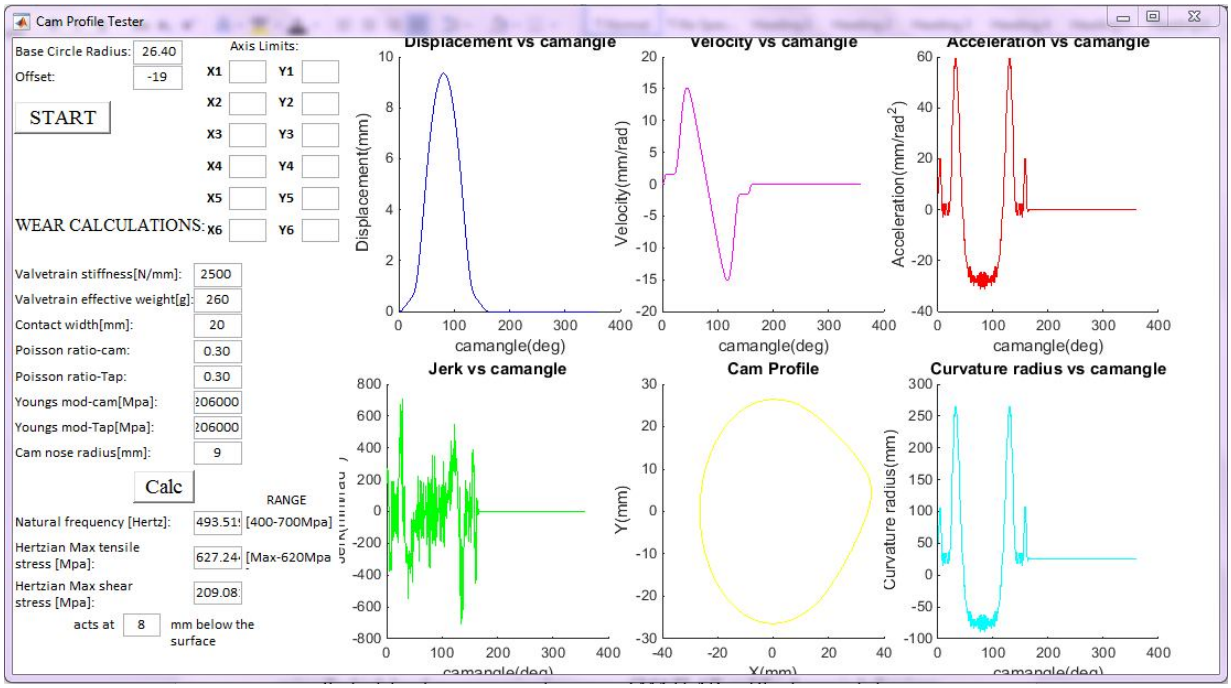

Figure 3 - To calculate hertzian max shear stress, Herzian Tensile Stress and the final output.

III. CONCLUSION

The design parameters of a cam mechanism of a flat faced push rod type follower are analyzed and a mathematical model simulation is programmed. For this task high level programming language of MATLAB is used and the dynamic behavior of the designed cam mechanism is investigated and numerical study of valve train dynamic analysis of a six cylinder internal combustion engine is done. The program is used to detect cam wear prior manufacturing using the basic cam designing parameters and calculations such as hertzian stresses and natural frequency. This program can be used as a warning system for the designers to check their input parameters prior manufacturing. This program can eliminate the calibration costs of cams and hence reduce production costs. This procedure is user friendly, automatic and gives fast results with high accuracy.

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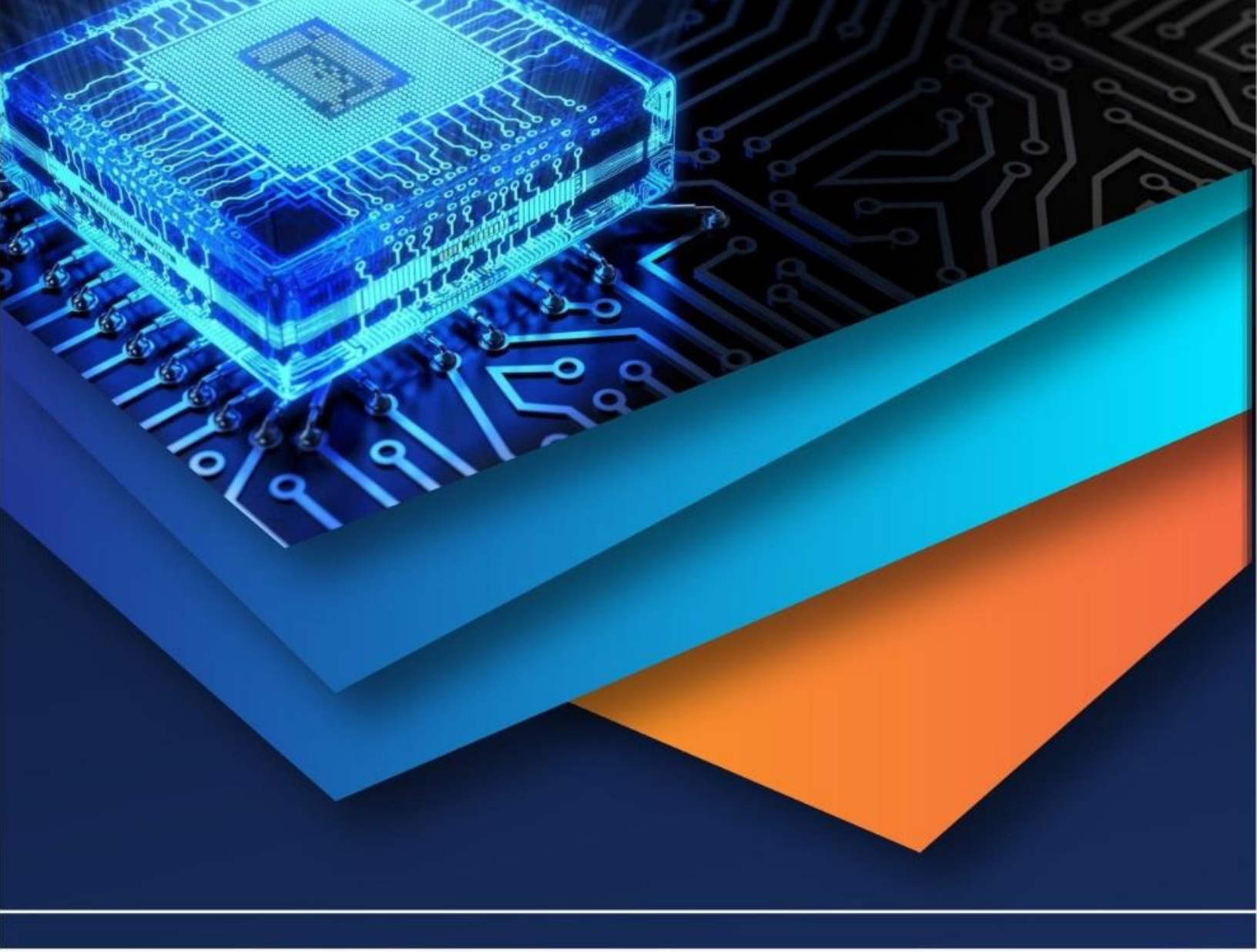

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