Computer Aided Kinematic and Dynamic Analysis of Cam and Follower

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Abstract: **Cam and follower are widely used in regulating, opening and closing of valves (inlet and exhaust) in the internal combustion engines. Proper design of cam and follower is required for perfect tuning between opening and closing of valves with cam shaft speed. In this paper, the complete kinematic and dynamic analysis of cam and follower is done and critical angular speed is determined for each design to predict when the follower jumps off the cam. Analytical method is used, as it is more accurate and less time consuming and if programmed for the complete solution. The dynamic force analysis determines the cam contact forces and values of kinematic parameters at which the design fails. The analytical calculation is done in excel sheet for both kinematic and dynamic analysis of cam follower system for any rotational speed and angle of rise.**

Keywords— **Analytical Model, Cam–Follower, Constant Velocity Motion, Cycloid Motion, Parabolic Motion, SHM.**

I. INTRODUCTION

Cams are commonly used in opening and closing of valves in internal combustion engines. Both the inlet and outlet valves are regulated using cam and follower. The study of cam and follower mechanism becomes important for desired and required performance of the engines. In this paper, complete kinematic and dynamic analysis of cam and follower mechanism is carried out using analytical method. The equations for governing motion of the follower have been taken from the literature.[3]

The kinematic analysis of mechanism helps in answering many questions related to motion of the follower. In this present work displacement, velocity and acceleration values are calculated at each 10^0 rotation of cam using analytical relations. Fig.1 shows cam follower assembly.

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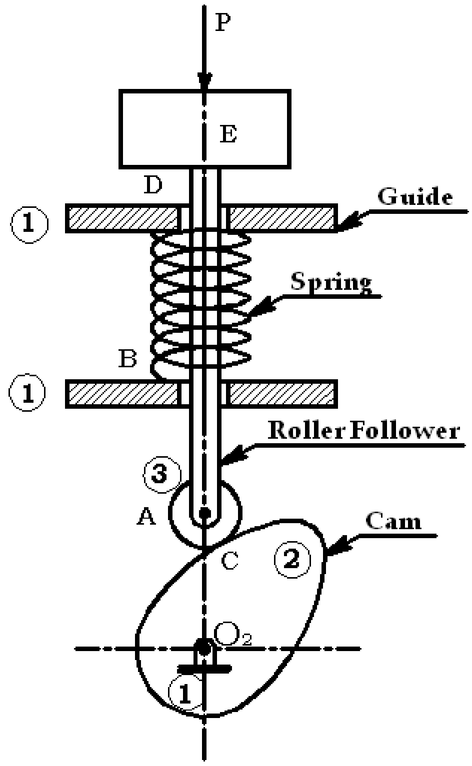

Fig.1: Cam follower assembly

The dynamic analysis includes the static and inertia force analysis of the follower. For normal working of mechanism, the resultant vertical force has to be in downward direction. If the instant force changes its direction, lifting of follower will take place and design will fail. In this paper kinematic parameters and forces are calculated analytically and critical angular speed of rotation is found for the design specification. The equations have been programmed for the computer solution for rotation of cam by an interval of 10^0.

II. KINEMATIC ANALYSIS

Kinematic analysis involves the calculations of displacement, velocity and acceleration of the follower at different instant. Empirical relations from the literature are used for displacement.[3] By differentiation we can get velocity and acceleration.

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Equations for various governing motions of follower [2]:-

1. Cycloidal Motion

$$y = h[(\theta/\beta) - (1/2\pi)\times\sin(2\pi\theta/\beta)] \quad (1)$$

2. Simple Harmonic Motion:-

$$y = (h/2)\times[1-\cos(\pi\theta/\beta)] \quad (2)$$

3. Constant Velocity:-

$$y = h\theta/\beta \quad (3)$$

4. Constant Acceleration and Retardation: -

$$y = 2h\times(\theta/\beta)^2, \quad for\ \theta \le (\beta/2) \quad (4)$$

$$y = h[1-2\times\{1-(\theta/\beta)\}^2], \quad for\ \theta \ge (\beta/2) \quad (5)$$

Where,

h = Lift of the follower,
θ = Angular displacement of cam,
β = Angle of rise,
y = vertical displacement of fillower.

Kinematic analysis of mechanism helps in determining the cam torque or torque delivered to the rotating cam. Using instantaneous centre of rotation of link 2 and link 4 we get torque delivered to the cam.

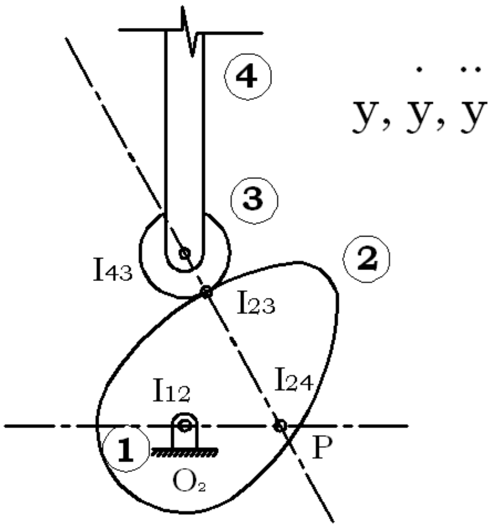

Fig. 2: Instantaneous centres of the cam.

Now we have,

$$v_p = \dot{y} = \omega_2 \times O_2P \quad (6)$$

$$O_2P = (\dot{y}/\omega_2) \quad (7)$$

$$T_2 = F_{32}^{Y} \times O_2P \quad (8)$$

$$F_{32}^{Y} = P + F_s + (-m\ddot{y}) \quad (9)$$

Where,

$\dot{y}$ = Velocity of follower,

$\ddot{y}$ = Acceleration of the follower,

ω 2 = Angular Velocity of Cam,

T_2 = Torque delivered to the cam,

F_{32} = Reaction of link 3 on link2,

m = Mass of follower,

F_s = Spring force,

P = Force due to load.

For finding F_{32}, dynamic analysis is done. Using the equations of displacement, values of all kinematic parameters are calculated with the help of computer program.

III. Dynamic Analysis

The resultant force acting on the follower, link 4 consists of the following forces:-

i. Reaction due to link3 on link4, F_{34},

ii. Reactions at support due to link1 on link4, $(F_{14})_B$ and $(F_{14})_D$

iii. Inertia force due to mass of follower, (-m $\ddot{y}$),

iv. Spring force, Fs,

v. Force due to load, P.

Dynamic analysis of follower gives resultant force acting on it in vertical direction which is directly related to the motion of follower. The negative sign of the resultant force ensures that the net downward force on the follower maintains its contact with the cam, through an idler roller. This remains so until it reaches a critical speed. Beyond the critical speed, the resultant force becomes positive and act in upward direction, which results in lifting of the follower, leaving its contact with the cam. Such situation is called jump of follower and the design fails to give desired performance.

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Free body diagrams of link2, 3 and 4 are shown in Fig.3

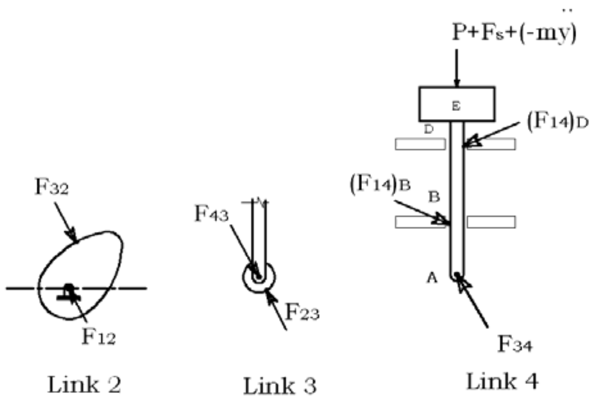


Fig.3: Free body diagrams of Cam, Roller & Follower

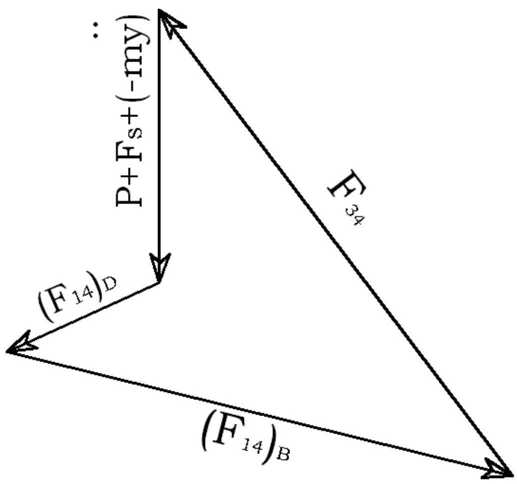


Fig. 4: Force Polygon of forces acting on link 4

IV. Result and Discussions

The results computed from the program developed for kinematic and dynamic analysis of the follower are given for each 10^0 rotation of cam.

The results of kinematic analysis of the follower gives values of displacement, velocity and acceleration at different instants, which is shown in table: I, for simple harmonic motion,

Considering h = 0.018m,
w_2 = 62.83 rad/sec,
m = 1.6 kg,
and β = 150^0.

Similar calculations may be done when motion of follower is constant velocity, parabolic and cycloidal.

The result from dynamic analysis gives the resultant vertical force on the follower and torque delivered to cam. Table: II shows Inertia Force, Spring Force, Resultant Force and torque according to cam rotation angle for simple harmonic motion.

The variation of velocity and acceleration is shown in Fig.5. Similarly the variation of different forces with respect to cam angle is shown in Fig.6.

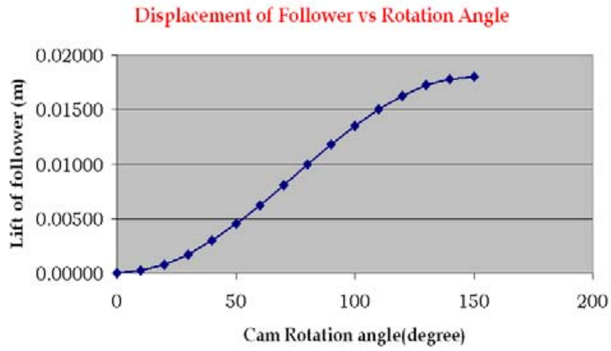
The knowledge of resultant force decides the critical angular velocity of the cam which is essential for the design of the cam mechanism.

Table: I: Displacement, Velocity and Acceleration of Follower according to Cam Rotation Angle.

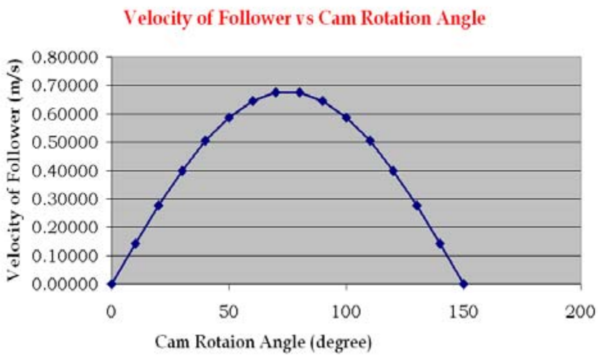
Angle of Rotation of Cam $[\theta]$	**Displacement of Follower** **m** $[y]$	**Velocity of Follower** **m/s** $[\dot{y}]$	**Acceleration of Follower** **m/s²** $[\ddot{y}]$
0	0	0	51.16403
10	0.00020	0.14109	50.04597
20	0.00078	0.27600	46.74067
30	0.00172	0.39886	41.39257
40	0.00298	0.50429	34.23542
50	0.00450	0.58767	25.58201
60	0.00622	0.64537	15.81055
70	0.00806	0.67487	5.34810
80	0.00994	0.67487	-5.34810
90	0.01178	0.64537	-15.81055
100	0.01350	0.58767	-25.58201
110	0.01502	0.50429	-34.23542
120	0.01628	0.39886	-41.39257
130	0.01722	0.27600	-46.74067
140	0.01780	0.14109	-50.04597
150	0.01800	0.00000	-51.16403

Table: II : Inertia Force, Spring Force, Resultant Force and torque according to Cam Rotation Angle.

Angle of Rotation of Cam [θ]	Inertia Force [N]	Spring Force [N]	Resultant Force [N]	Torque [Nm]
0	-81.86245	0	-69.96245	0
10	-80.07356	0.27534	-67.89822	0.00286
20	-74.78507	1.08933	-61.79574	0.00598
30	-66.22811	2.40639	-51.92172	0.00951
40	-54.77667	4.16895	-38.70771	0.01351
50	-40.93122	6.30000	-22.73122	0.01783
60	-25.29689	8.70639	-4.69050	0.02216
70	-8.55696	11.28294	14.62599	0.02608
80	8.55696	13.91706	34.37401	0.02904
90	25.29689	16.49361	53.69050	0.03054
100	40.93122	18.90000	71.73122	0.03017
110	54.77667	21.03105	87.70771	0.02768
120	66.22811	22.79361	100.92172	0.02306
130	74.78507	24.11067	110.79574	0.01657
140	80.07356	24.92466	116.89822	0.00866
150	81.86245	25.20000	118.96245	0.00000



(A)



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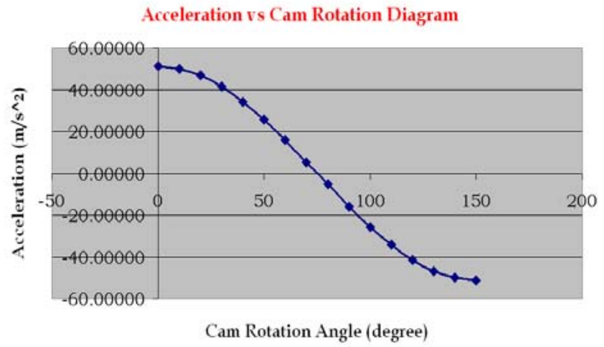
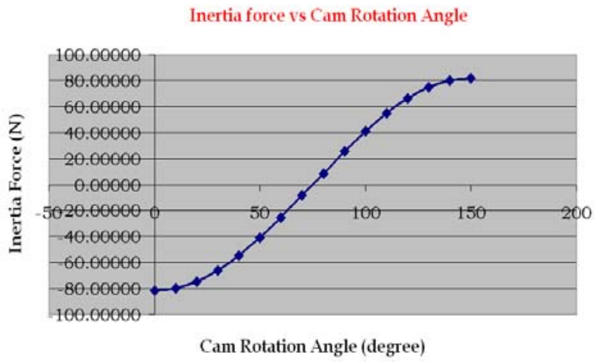
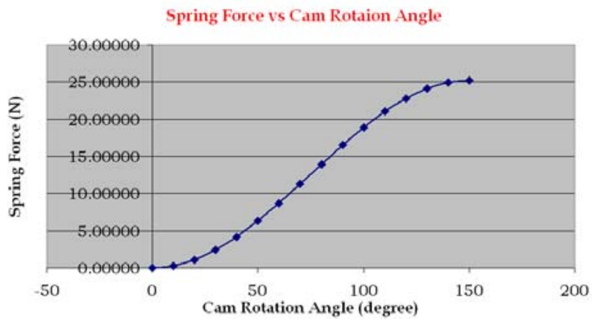


(C)

Fig.5: (A) Displacement, (B) Velocity and (C) Acceleration of follower according to Cam rotation Angle.



(A)



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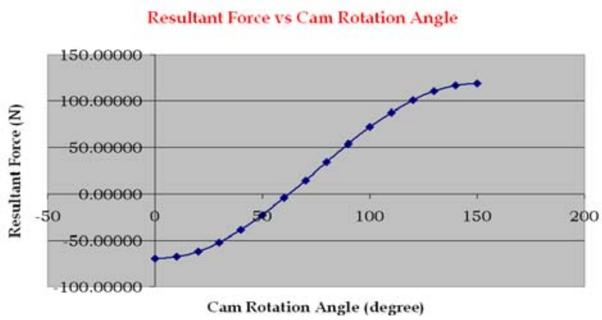

(C)

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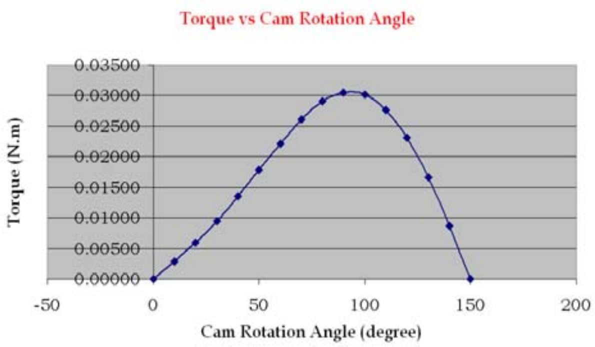

(D)

Fig.6 : (A)Inertia Force, (B) Spring Force, (C)Resultant Force on follower and (D) Torque Variation on cam according to Cam rotation Angle.

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