



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

# IJRSET

International Journal of Innovative Research in  
**SCIENCE | ENGINEERING | TECHNOLOGY**

# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 12, Issue 6, June 2023

**ISSN** INTERNATIONAL  
STANDARD  
SERIAL  
NUMBER  
INDIA

Impact Factor: 8.423

9940 572 462

6381 907 438

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# Study of cam-Tappet Force using N-Harmonic cam Profile

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**ABSTRACT:** Valve jump is a transient condition that occurs in high-speed engines. With jump, the cam and the follower separate owing to excessively unbalanced forces exceeding the spring force during the period of negative acceleration. This is undesirable since the constraint and control of follower motion is not maintained. Valve jump results in short life of the cam flank surface, high noise, vibrations, and poor action. Present work focuses on the development of N-harmonic curve for valve acceleration improvement. Mathematical model of N-harmonic cam profile for high speed diesel engine is constructed. Simulation and experimental analysis shows N-harmonic cam profile has improved dynamic performance compared to polydyne cam.

**KEYWORDS:** Valve jump, polydyne cam, N-harmonic cam, cam-tappet, contact load

## I. INTRODUCTION

Overhead valve train (OHV) is a widespread mechanism for internal combustion engine. In most of internal combustion engine valve cam has polydyne cam profile, however, in this type of valve train a serious problem known as valve jump is likely to occur at high speed. One of the major trends in engine development is increasing operating speed. With increasing engine speeds, the importance of cam-valve train design and its dynamic behaviour become more critical. When the valve mechanism runs at a relatively low speed, the dynamic effect is not significant and kinematic analysis is enough to predict valve motion. But as the running speed becomes high, the dynamic characteristics of valve system take on a more important role as mentioned by Bagciand Kurnool (1997), Dresner and Barkan (1995), Horeni (1992) and Takashi et al.(2002). Objective of this paper is to propose N-harmonic profile for valve cam to minimize jump at high speed. Jump model of N-harmonic cam profile is constructed. Simulation and experimental analysis is carried out to analyse the jump characteristics of polydyne and N harmonic cam.

## II. DYNAMIC ANALYSIS OF VALVE JUMP

The critical design point is where the inertia forces of follower maximum and tends to eliminate contact between the cam and follower. This point occurs in the vicinity of the maximum negative acceleration as shown by Chavan and Joshi (2011). Jump will occur when the negative inertia force of the system exceeds the available spring force. During negative acceleration period of valve opening event, the inertia forces tend to oppose the spring force. If at any instance, the load offered by valve spring is not adequate, then due to surplus inertia force, valve train mass lose contact of cam profile. This phenomenon is called valve jump and it results in unbalanced forces exceeding the spring force during the period of negative acceleration. Jump affects the life of cam flank surface, high noise and vibrations.

### Valve Jump Model:

The valve train system shown in Fig. 1(a) is modelled as a two degree-of-freedom as described by Chen (1982) and Rothbart (2004), lumped-mass system taking into account the mass distribution, the elastic flexibility of all links, the Hertzian contact stiffness, the backlash in joints, and the resulting dynamic model is illustrated in Fig. 1(b). The system has the spring that closes the cam joint at the end effectors (valve) with most of follower train elasticity between it and cam. All the masses in the follower train are lumped into two effective masses  $m_1$  and  $m_2$ . The cam acts against mass less cam shoe that connects to  $m_1$  through spring  $k_1$  and damper  $c_1$ . Spring  $k_2$  and damper  $c_2$  connect to  $m_2$  to ground and represent the physical valve spring used to close the joint between cam and follower. The cam lift profile is the input to the dynamic model. The equations for condition of contact between cam and follower mass  $m_1$  ( $z = s$ ) can be written as mentioned by Norton, (2002)

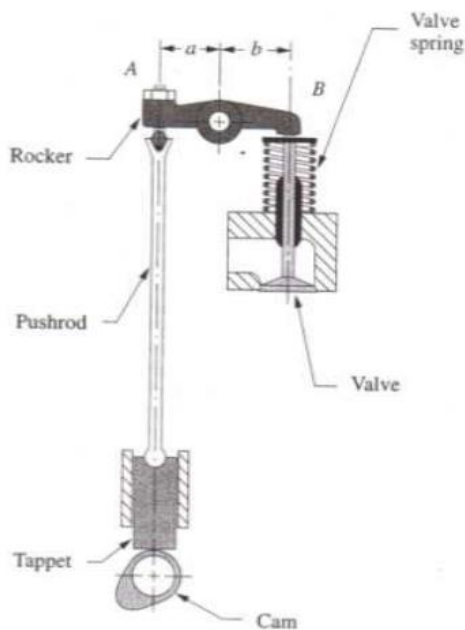
$$\ddot{x} = \ddot{z} + \frac{k_2}{m_2} (z - z_1) + \frac{c_2}{m_2} \dot{z}' - \frac{c_1 + c_2}{m_2} \dot{z} - \frac{k_1 + k_2}{m_2} z \quad (1)$$

$$F_c = m_1 z'' + c_1 x' + k_1 x \tag{2}$$

If  $F_c$  is positive, then the value of  $x$  is valid. If  $F_c$  is negative, then separation can be occurred. Equations are solved simultaneously with  $F_c$  set to zero at time step, maintaining the initial velocity and displacement conditions. As the solution continues for additional time steps,  $s$  and  $z$  are compared at each step. When  $z \leq s$ , the cam and follower have regained contact.

**Construction of N- harmonic cam profile:**

In N-harmonic cam, lift expression is function of sine and cosine values. The lift expression is then differentiated to get velocity and acceleration. In this method, values at certain points on lift curve and acceleration curve are defined, which forms the boundary conditions for the equations. These equations are then solved to get the required lift curve.



a) Physical Model  
b) Simplified two-mass model

Fig. 1. Mathematical model of Valve train

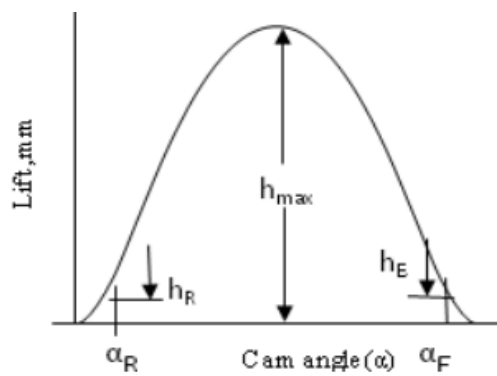


Fig. 2. Theoretical cam lift

For N-harmonic cam, the lift expression of cam follower can be expressed as follow mentioned by Gao and Feng. (2004):

$$h(\alpha) = \sum_{i=0}^N A_i \cos i \alpha + \sum_{i=0}^N B_i \sin i \alpha \tag{3}$$



Where:  $A_i$  and  $B_i$  are undetermined coefficients;  $\alpha$  – the cam angle.

The velocity expression of cam follower is:

$$\frac{dh}{d\alpha} = \sum_{i=0}^N iA_i \sin i\alpha + \sum_{i=0}^N iB_i \cos i\alpha \quad (4)$$

The acceleration expression of cam follower is:

$$\frac{d^2h}{d\alpha^2} = -\sum_{i=0}^N i^2 A_i \cos i\alpha - \sum_{i=0}^N i^2 B_i \sin i\alpha \quad (5)$$

### III. EXPERIMENTAL ANALYSIS

The polydyne and N-harmonic cam (Fig. 3) are manufactured and tested for jump speed on test bench (Fig. 4). Since measuring the cam tappet contact loads on an actual operating engine is extremely difficult, therefore indirect measurement was applied to the actual engine tests, in which the valve jump occurrence engine speed was detected by hearing the thumping sound. When jump occurs, the follower pounds on the cam surface giving a good thumping sound. The machine is a motorized unit consisting of a cam shaft driven by a D.C. Motor. At the free end of cam shaft a cam can be easily mounted. The arrangement of speed regulation is provided.



a) N-harmonic

b) Polydyne

Figure 3 N-harmonic and Polydyne cam



Figure 4 Test-Bench

### IV. RESULTS AND DISCUSSIONS

In present investigation, MATLAB simulink tool is used as employed by Chavan and Joshi (2010) to solve equations of N-harmonic cam. The valve motion is simulated using polydyne and N harmonic profile as valve cam.

The cam contact force varies at each point on the periphery of cam profile and is higher at nose. Cam contact force at nose for different speeds is simulated. Jump occurs when cam tappet contact load becomes zero as shown in Fig. 5a. Simulation and experimental result shows that when cam speed increases beyond 750 rpm, the polydyne cam can't operate normally and jump occurs. However, N-harmonic cam still works well beyond 750 rpm keeping the contact between cam and follower as shown in Fig. 5b. In case of N-harmonic cam, cam tappet contact load increases with increase in cam speed and reverse is the case for polydyne cam. Thus, acceleration constraints provided in N-harmonic cam profile development provides enough flexibility in cam design. Inertia forces increase with the square of the engine speed. The valve spring must have enough force to counteract the inertia forces on the nose. Intersection points (jump speed) of inertia force and spring force curve are found by simulating the forces as shown in Fig. 6 and 7.

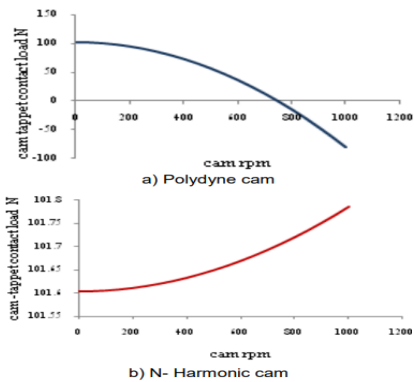


Fig. 5. Variation of contact force at different speed

Table 1. Results of dynamic computation at 1050 rpm

Quantity	Polydyne cam	N-harmonic cam
Maximum lift of valve (mm)	6.110	6.161
Fullness Factor ( $\xi$ )	0.718	0.952
Area under displacement curve (mm <sup>2</sup> )	9.123	11.672

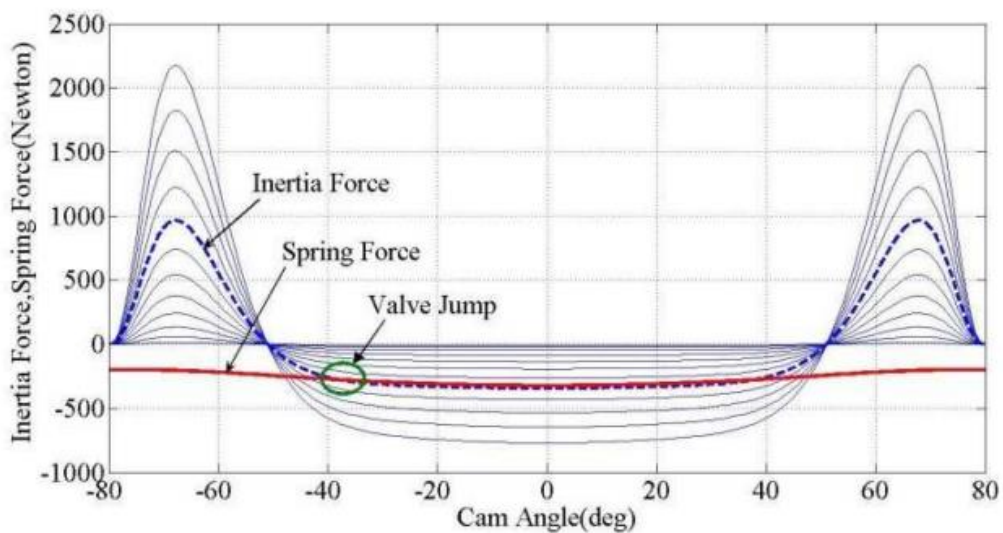


Fig.06. Variation of inertia force at different polydyne cam speed

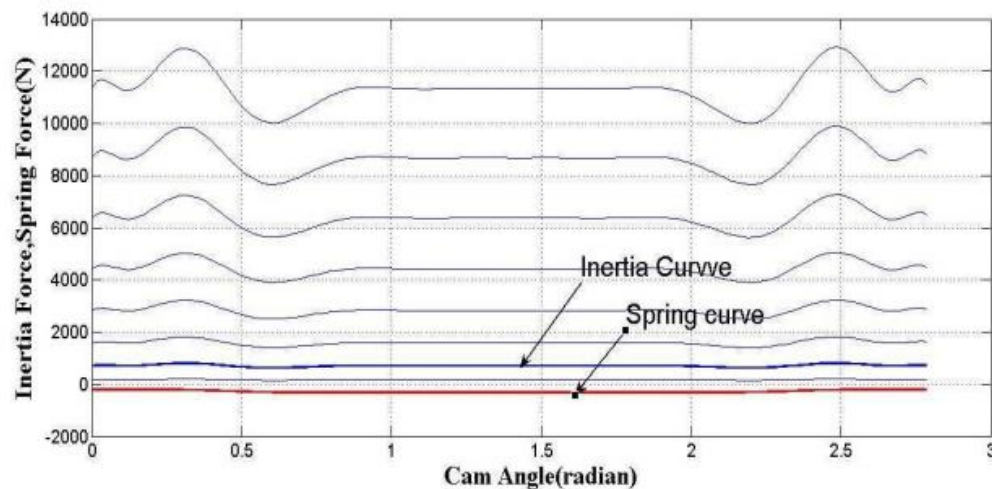


Fig. 07. Variation of inertia force at different N-Harmonic cam speed

#### V. CONCLUSION

N-harmonic cam has smooth operation, large fullness factor, and it provides greater flexibility in cam design. It works without jump at relatively higher speed. N harmonic cams are more suitable for high speed engines as compared to polydyne cams

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