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Research Article

Kinematic, Dynamic and Tribological Analysis of Push Rod Type Valve System

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Abstract

The push rod type cam and follower mechanisms are extensively used in many mechanical systems prominent among them being the internal combustion engine. It comprises of several tribo pairs: cam and follower, valve and its guide, valve and its seat, rocker arm, tappet and its guide. The tribological performance of the various tribo interfaces affects the overall working of the mechanical system. The paper presents the kinematic and dynamic analysis of push rod type valve system for the determination of the friction between the various tribo pairs.

Keywords: *Design, tribology, engine valve, cam profile, lubricant film thickness.*

1. Introduction

The cam and follower mechanisms are used in variety of machines and devices. The push rod type cam and follower mechanism is shown in figure 1.

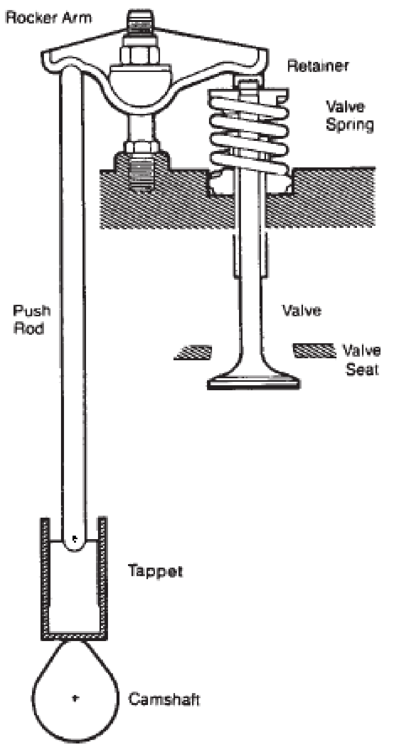

Fig.1 Push rod type valve train

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2. Design of the cam profile

The determination of the cam profile is based on polynomial cam design in which equivalent two mass system of valve train is considered as shown in figure 2.

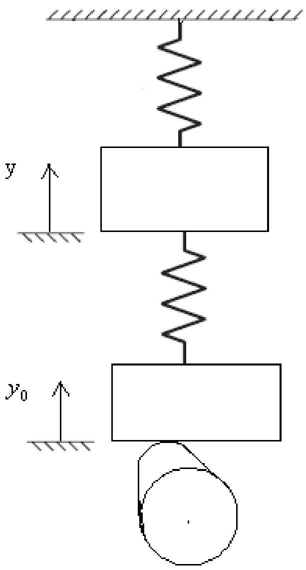


Fig.2 Dynamic model of cam and follower system

The two masses are connected by spring representing valve train linkage stiffness and hold in contact with this spring by the valve spring.
The valve end effective mass (m_1) includes all moving parts of valve train at valve end.

$$m_1 = m_v + m_{sr} + m_r + m_s / 3$$

The cam end effective mass (m_2) includes all moving parts of valve train at cam end.

$$m_2 = m_t + m_p$$

Valve train stiffness (K_0) is determined by the ratio of certain force applied to the rocker arm valve end divided by the total deflection occurring at the rocker arm valve end due to this force.

Let, y = valve lift

y_0 = equivalent tappet lift

Considering the equilibrium of forces acting at valve end mass, we can write,

$$-K_1.y - S - K_0\,(y - y_0) = m_1 . \frac{d^2y}{dt^2}$$

Solving for y_0,

$$y_0 = \frac{S}{K_0} + \frac{K_1 + K_0}{K_0}.y + \frac{m_1}{K_0}.\frac{d^2y}{dt^2}$$

$$y_0 = \frac{S}{K_0} + \frac{K_1 + K_0}{K_0}.y + \frac{m_1}{K_0}.36.N_c^{\,2}.\frac{d^2y}{d\theta^2}$$

$$y_0 = h_R + \sigma.y + \delta.y''$$

Thus for push rod type valve train, equivalent tappet displacement y_0 can be determined for given valve motion y. A suitable valve lift versus cam angle (θ) may be assumed and cam profile (y_c) may be developed to fulfill that motion at the desired speed. In this analysis valve lift is evaluated by using the polynomial,

$$y = L(1 + C_2x^2 + C_4x^4 + C_px^p + C_qx^q + C_rx^r + C_sx^s) \quad (1)$$

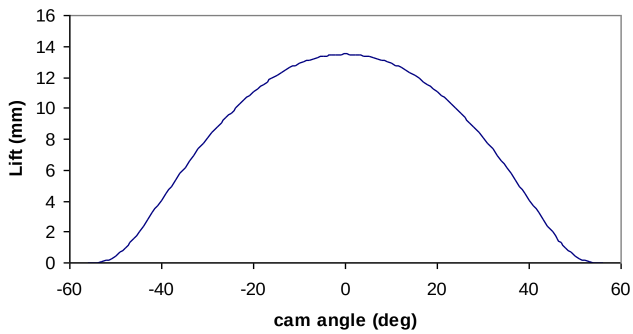
Where, $x = \frac{\theta}{\beta}$, $C_2 = -1.430657$, $C_4 = 0.1$,

$C_p = 0.712394$, $C_q = -0.650403$,

$C_r = 0.331145$ and $C_s = -0.06246$

θ = Angle turned by cam

Variation of y , $\frac{dy}{d\theta}$ and $\frac{d^2y}{d\theta^2}$ versus cam angle θ is shown in figure 3.



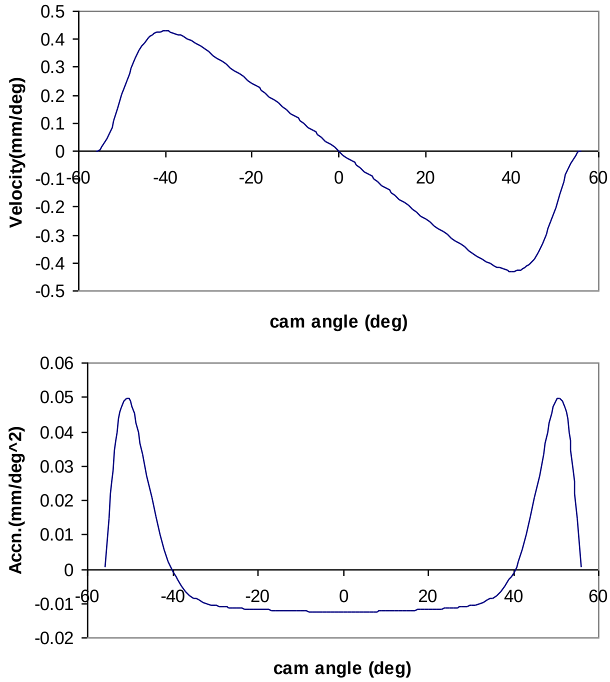


Fig.3 Lift, velocity and acceleration variation of valve with respect to cam rotation

Then by using equation (1) equivalent tappet lift is determined. Cam lift (y_c) for each degree rotation is then determined by dividing equivalent tappet lift by rocker ratio.

$$y_c = \frac{y_0}{i} = \frac{1}{i}(h_R + \sigma.y + \delta.y')$$

Similarly,

$$y_c' = \frac{1}{i}(\sigma.y' + \delta.y''')$$

$$y_c'' = \frac{1}{i}(\sigma.y'' + \delta.y^{iv})$$

3. Kinematic analysis of the cam and follower mechanism

Radius of curvature at point of contact between cam and follower is given by,

$$R = y_c''.(\frac{180}{\pi})^2 + R_b + z$$

Consequently, the velocity of point of contact on the cam surface is

$$V_c = \omega.R$$

and velocity of point of contact on the follower surface is

$$V_f = \omega.y_c''.(\frac{180}{\pi})^2$$

Hence, the mean entraining velocity (V_e) and the sliding velocity (V_s) are given by,

$$V_e = ½(V_c + V_f)$$

$$V_s = V_c - V_f$$

4. Dynamic analysis of the cam and follower mechanism

The forces associated with the operation of valve mechanism are inertia force, spring force, forces due to dynamic deflection and damping of the components and friction between moving parts. It is assumed that the valve train is rigid and therefore the dynamic deflection and damping characteristics of the system are neglected.

In push rod valve mechanism, rocker arm plays role of transferring motion of push rod to valve. Figure 4 shows free body diagram of forces acting at rocker arm.

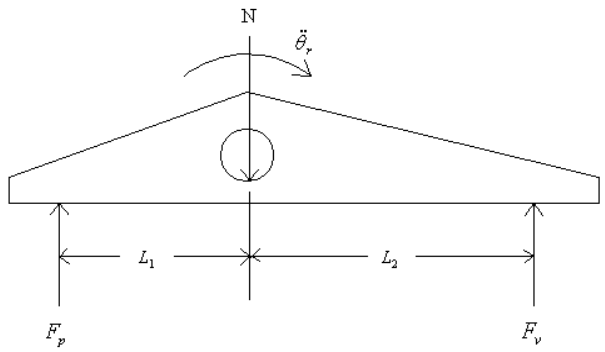


Fig.4 Free body diagram of rocker arm

Let, F_v be the force acting at the contact of rocker arm and valve, is given by

$$F_v = S + y.K_1 + m_v.a_v$$

where $a_v = \omega^2.(\frac{180}{\pi}).\frac{1}{1000}.y''$ and F_{vg} is the friction force between valve and its guide. This interface is modeled according to fluid film lubrication assuming that the valve and its guide remain concentric and clearance space is filled with lubricant. Friction is then determined from the simple shear of lubricant film using Petroff's equation,

$$F_{vg} = \frac{\eta_0 \pi d_v l_{vg} v_v}{c_{vg}}$$

+ve sign for the friction force corresponds to the opening valve and –ve sign to the closing valve. Let, N be the reaction at rocker arm bearing and F_p be the force at the contact between push rod and rocker arm.

$$N = F_v + F_p$$

Torque equilibrium equation for rocker arm can be written as,

$$J.\ddot{\theta}_r = F_p.L_1 - F_v.L_2 - \mu_R.r_R.N$$

where μ_R is coefficient of friction in rocker arm bearing and its typical value is taken as 0.1.

Rearranging torque equilibrium equation for F_p for valve opening event,

$$F_p = \frac{J.\ddot{\theta} + F_v.L_2 + \mu_R.r_R.F_v}{L_1 - \mu_R.r_R}$$

Similarly, for valve closing event,

$$F_p = \frac{J.\ddot{\theta} + F_v.L_2 - \mu_R.r_R.F_v}{L_1 + \mu_R.r_R}$$

Let, W be the contact load between cam and tappet,

$$W = F_p + m_t.a_c$$

where $a_c = \omega^2.(\frac{180}{\pi})^2.\frac{1}{1000}.y_c''$

$$F_{tg} = \frac{\eta_0 \pi d_t l_t v_c}{c_{tg}}$$

+ve sign for the friction force corresponds to the opening valve and –ve sign to the closing valve.

5. Lubricant film thickness

Lubricant film thickness is calculated by using Dowson and Higginson formula:

$$\frac{h}{R} = 2.65 U^{0.7} G^{0.54} W'^{-0.13}$$

Where U is dimensionless speed parameter, G is dimensionless material parameter and W' is dimensionless load parameter. Their values are given as:

$$U = \frac{\eta_0 V_e}{E'R}$$

$$G = \alpha.E'$$

$$W' = \frac{W}{E'.R.t}$$

Minimum film thickness is calculated by using above formula. The variation of film thickness along cam profile for various speeds is shown in fig. 5.

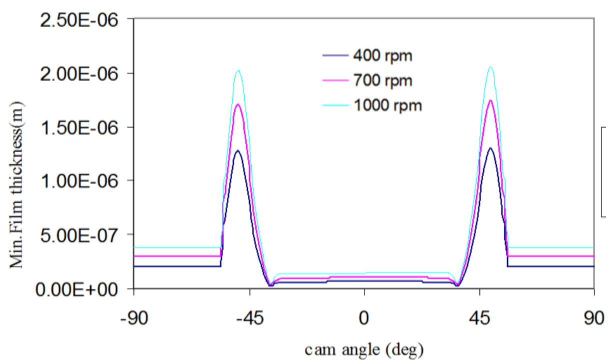


Fig.5 Comparison of Minimum film thickness for different speeds

From above graph it is clear that film thickness between cam and follower increases as speed increases.

6. Friction force and torque

The cam and follower pair experiences elastohydrodynamic and boundary lubrication in one cycle. To determine friction force at the contact 'friction transition model' is used as shown in figure 6. For SAE 40W/20 oil limiting value of boundary friction coefficient is 0.12. Where λ is ratio of film thickness to composite surface roughness.

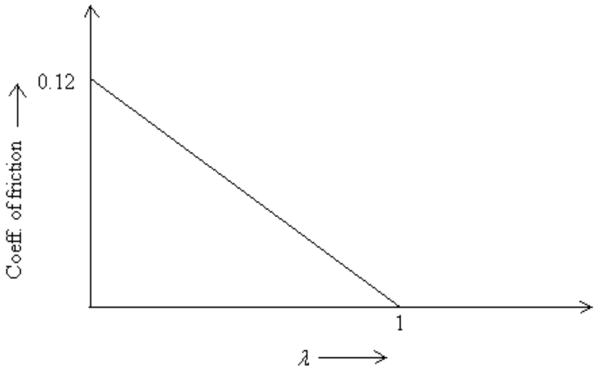


Fig.6 Friction Transition Model

According to this model, when λ >1 friction force is determined for elastohydrodynamic lubrication and for λ <1 friction force is determined according to boundary lubrication. The elastohydrodynamic lubrication friction force between cam and follower is,

$$F = \int_0^t \int_{-b}^{+b} \tau . dx . dy$$

Where, b is half contact length and τ is shear stress which is given by $\eta . \frac{du}{dz}$. Velocity gradient ($\frac{du}{dz}$) for sliding contact of cam follower can be taken as,

$$\frac{V_c - V_f}{h}.$$

Hence,

$$F = \int_{-b}^{+b} \eta . \frac{V_c - V_f}{h} . t . dx$$

The elastic deformation between cam and follower contact is large compared with the lubricant film thickness and therefore the contact pressures and dimensions can be approximated to a dry Hertzian contact. Therefore pressure at the contact can be taken as,

$$p = p_{\max} . (1 - \frac{x^2}{b^2})^{\frac{1}{2}}$$

where, $p_{\max} = \frac{2.W}{\pi . b . t}$

$$b = (\frac{8.W.R}{\pi . t . E'})^{\frac{1}{2}}$$

According to Barus, viscosity at elevated pressure can be written as,

$$\eta = \eta_0 . e^{\alpha p}$$

Friction force is then,

$$F = \frac{\eta_0 . V_s . e^{\alpha . p_{\max}}}{h} . \int_{-b}^{+b} e^{(1 - \frac{x^2}{b^2})^{1/2}} . dx$$

During boundary lubrication coefficient of friction is calculated according to λ and then friction force as,

$$F = \mu . W$$

where, $\mu = 0.12.(1 - \lambda)$

Friction torque is then calculated for each degree of cam rotation using relation,

$$T = F.(R + y_c)$$

Using above model average friction torque is calculated for different speeds.

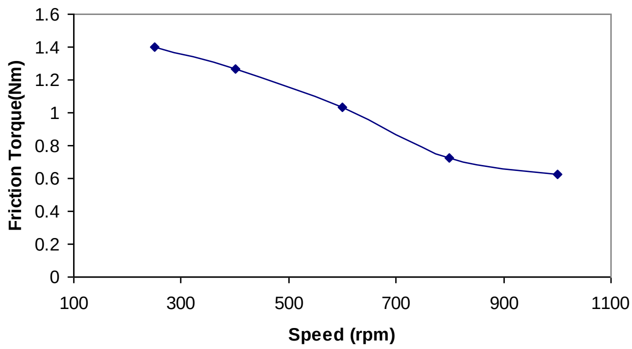


Fig.6 Variation of friction torque for different speeds

From above graph it is clear that as the increase in camshaft rotational frequency decreases the friction torque due to improved lubrication conditions at higher frequencies arising increased lubricant entrainment and reduced cam load at nose. At relatively low engine speeds, the cam load is dominated by valve spring compression, resulting in high friction around cam nose. At high speeds, however, inertia plays a major role as the acceleration of the tappet has negative value around the cam nose, and it becomes more negative as engine speed increases resulting in decrease in load around the cam nose.

Conclusions

The theoretical modeling of push rod type valve system has been carried out for the determination of frictional losses. The theoretical results indicates that increase in camshaft rotational frequency decreases the friction torque due to improved lubrication conditions at higher frequencies thus resulting in reduced losses. This reduction in friction is due to the increased lubricant film thickness at higher speeds. The load around the cam nose decreases with increase in the cam rotational speed.

References

S M Muzakkir, K P Lijesh, H Hirani, and G D Thakre, 2015, Effect of Cylindricity on the Tribological Performance of Heavily-Loaded Slow Speed Journal Bearing, Proc. Institute Mech. Engineers., Part J, Journal of Engineering Tribology, 229(2), 178-195.

S M Muzakkir, H Hirani and G D Thakre, 2013, Lubricant for Heavily-Loaded Slow Speed Journal Bearing, Tribology Transactions, 56 (6), 2013, 1060-1068.

S M Muzakkir, H Hirani, G D Thakre and M R Tyagi, 2011, Tribological Failure Analysis of Journal Bearings used in Sugar Mill, Engineering Failure Analysis, 18(8), 2093-2103.

H. Hirani, K. Athre, S. Biswas, 1999, Dynamic Analysis of Engine Bearings, International Journal of Rotating Machinery. 5(4), 283-293.

H. Hirani, K. Athre, S. Biswas, 1998, Rapid and Globally Convergent Method for Dynamically Loaded Journal Bearing Design, Proc. IMechE (UK), Journal of Engineering Tribology. 212, 207-214

H. Hirani, K. Athre, S. Biswas, 2000, A Hybrid Solution Scheme for Performance Evaluation of Crankshaft Bearings, Trans. ASME, Journal of Tribology. 122(4), 733-740.

H. Hirani, K. Athre, S. Biswas, 2000,Transient Trajectory of Journal in Hydrodynamic Bearing, Applied Mechanics and Engineering. 5(2).

H. Hirani, K. Athre, S. Biswas, 2001, A Simplified Mass Conserving Algorithm for Journal Bearing under Dynamic Loads, International Journal of Rotating Machinery. 1, 41-51.

H. Hirani, K. Athre, S. Biswas, Lubricant 2001, Shear Thinning Analysis of Engine Journal Bearings, STLE, Journal of Tribology Transaction, 44 (1), 125-131.

H. Hirani, K. Athre, S. Biswas, 2002, Comprehensive Design Methodology for Engine Journal Bearing, IMechE (UK), Part J, Journal of Engineering Tribology. 214, , 401-412.

H. Hirani, 2004, Multi-objective Optimization of a journal bearing using the Pareto optimal concept, Proc. Institute Mech. Engineers., Part J, Journal of Engineering Tribology. 218 (4), 323-336.

H. Hirani, Multiobjective optimization of journal bearing using mass conserving and genetic algorithms, Proc. Institute Mech. 2005, Engineers., Part J, Journal of Engineering Tribology. 219(3), 235-248.

H. Hirani, N.P. Suh, 2005, Journal Bearing Design using Multi-objective Genetic Algorithm and Axiomatic Design Approaches, Tribology International, 38(5), 481-491.

H. Hirani, M. Verma, 2009, Tribological study of elastomeric bearings of marine shaft system, Tribology International, 42(2), 378-390.

S M Muzakkir, H. Hirani, 2015, A Magnetorheological Fluid Based Design Of Variable Valve Timing System For Internal Combustion Engine Using Axiomatic Design, International Journal of Current Engineering Research, 5(2), 603-612.

T. V. V. L. N Rao, H. Hirani, K. Athre, S. Biswas, 2000, An Analytical Approach to Evaluate Dynamic Coefficients and Non-linear Transient Analysis of a Hydrodynamic Journal Bearing, STLE Tribology Transactions, 23(1), 109-115.

S M Muzakkir, H. Hirani, 2015, Maintenance Free Bearings, International Journal of Engineering Research, 4(3), 133-136.

S M Muzakkir, H. Hirani, G. D. Thakre, 2015, Experimental Investigations on Effectiveness of Axial and Circumferential Grooves in Minimizing Wear of Journal Bearing Operating in Mixed Lubrication Regime. International Journal of Current Engineering and Technology, 5(1), 486-489.

S M Muzakkir, K. P. Lijesh, H. Hirani, 2015, Effect of Base Oil on the Anti-Wear Performance of Multi-Walled Carbon Nano-tubes (MWCNT), International Journal of Current Engineering and Technology, 5(2), 681-684.

H Hirani, T Rao, K Athre and S Biswas, Rapid performance evaluation of journal bearings, Tribology international, 30(11), 1997, 825-834.

H Hirani, K Athre, S Biswas, 1999, Dynamically loaded finite length journal bearings: analytical method of solution. Journal of tribology, 121(4), 844-852.

K. P. Lijesh, H. Hirani, Stiffness and Damping Coefficients for Rubber mounted Hybrid Bearing, Lubrication Science, 26(5), 2014, 301-314.

K. P. Lijesh, H. Hirani, 2015, Development of Analytical Equations for Design and Optimization of Axially Polarized Radial Passive Magnetic Bearing, ASME, Journal of Tribology, 137(1), (9 pages).

K. P. Lijesh, H. Hirani, 2015, Optimization of Eight Pole Radial Active Magnetic Bearing, ASME, Journal of Tribology, 137(2),

K.P. Lijesh, H. Hirani, 2015, Design and Development of Halbach Electromagnet for Active Magnetic Bearing, Progress In Electromagnetics Research C, 56, 173–181.

P. Samanta, H.Hirani, 2007, A Simplified Optimization Approach for Permanent Magnetic Journal Bearing, Indian Journal of Tribology

P. Samanta, H. Hirani, 2008, Magnetic bearing configurations: Theoretical and experimental studies Magnetics, IEEE Transactions on 44(2), 292-300.

S. Shankar, Sandeep, H. Hirani, Active Magnetic Bearing, Indian Journal of Tribology, 15-25, 2006.

P. Samanta, H. Hirani, 2007, Hybrid (Hydrodynamic + Permanent Magnetic) Journal Bearings, Proc. Institute Mech. Engineers., Part J, Journal of Engineering Tribology, 221(J8), 881-891. K. P. Lijesh, H. Hirani, 2014, Design of eight pole radial active magnetic bearing using monotonicity. In Industrial and Information Systems (ICIIS), 2014 9th International Conference on IEEE, 1-6.

K. P. Lijesh, H. Hirani,, 2015, Magnetic Bearing Using RMD Configuration, Journal of Tribology.

H. Hirani, 2009, Root cause failure analysis of outer ring fracture of four row cylindrical roller bearing, Tribology Transactions, 52(2), 180-190.

K.P. Lijesh, S. M. Muzakkir, H. Hirani. 2015, Failure Analysis of Rolling Contact Bearing for Flywheel Energy Storage System, 5(1), 439-443.

K. P. Lijesh, H. Hirani, 2015, Shaft Alignment Systems: A Comparative Study, 5(2), 1009-1014.

H. Hirani, H. S.S.Goilkar, 2011, Rotordynamic Analysis of Carbon Graphite Seals of a Steam Rotary Joint , Book on IUTAM Symposium on Emerging Trends in Rotor Dynamics, Springer Netherlands, 253-262.

H. Hirani, H. S.S.Goilkar, 2009, Design and development of test setup for online wear monitoring of mechanical face seals using torque sensor, Tribology Transactions, . 52(1), 47-58.

H. Hirani, H. S.S.Goilkar, 2009, Tribological Characterization of Carbon Graphite Secondary Seal Indian Journal of Tribology, 4(2), 1-6.

H. Hirani, S.S.Goilkar, 2010, Parametric Study on Balance Ratio of Mechanical Face Seal in Steam Environment, Tribology International, 43(5-6), 1180-1185.

H. Hirani, S.S.Goilkar, 2009,Formation of Transfer Layer and its Effect on Friction and Wear of Carbon-Graphite Face Seal under Dry, Water and Steam Environments, Wear, 226(11-12), 1141-1154.

S M Muzakkir, Hirani H, Thakre G D., 2012, Performance evaluation of journal bearings used in sugar mills using Taguchi method. Soc. Tribol. Lubr. Eng. Annu. Meet. Exhib. 2012, p. 121–3.

Lijesh KP, S M Muzakkir, Hirani H. 2015, Experimental Tribological Performance Evaluation of Nano Lubricant using Multi-Walled Carbon Nano-tubes (MWCNT). Int J Adv Eng Res:1–8.

S M Muzakkir, Lijesh K P, Hirani H. 2014, Carbon Nanotubes as Solid Lubricant Additives for Anti-wear Performance Enhancement under Mixed Lubrication Conditions. Int J Mod Eng Res;2:1–4.

Burla RK, Seshu P, Hirani H, Sajanpawar PR, Suresh HS. 2003, Three Dimensional Finite Element Analysis of Crankshaft Torsional Vibrations using Parametric Modeling Techniques..

Gupta S, Hirani H. 2011, Optimization of Magnetorheological Brake. ASME/STLE 2011 Jt. Tribol. Conf., ASME; p. 405–6.

Hirani H. 2009, Online wear monitoring of spur gears. Soc. Tribol. Lubr. Eng. Annu. Meet. Exhib. 2009, p. 350–2.

Hirani H. 2009, Magnetorheological smart automotive engine mount. Soc. Tribol. Lubr. Eng. Annu. Meet. Exhib. 2009, p. 353–5.

Hirani H, Dani S. 2005, Variable valve actuation mechanism using magnetorheological fluid. Proc. World Tribol. Congr. III - 2005, p. 569–70.

Hirani H, Samanta P. 2005, Performance evaluation of magnetohydrodynamic bearing. Proc. World Tribol. Congr. III - 2005, p. 97–8.

Hirani H, Suh NP. 2005, Journal bearing design using multiobjective genetic algorithm and axiomatic design approaches. Tribol Int;38:481–91.

Hirani H, Sukhwani VK. Theoretical and experimental studies on magnetorheological brake. Inst. Mech. Eng. - Braking 2009, 2009, p. 75–84.

Hirani H, Manjunatha CS. 2007Performance evaluation of a magnetorheological fluid variable valve. Proc Inst Mech Eng Part D J Automob Eng; 221:83–93.

S M Muzakkir, Lijesh KP, Hirani H. 2014, Tribological failure analysis of a heavily-loaded slow speed hybrid journal bearing. Eng Fail Anal;40:97–113.

Rao TVVLN, Biswas S, Hirani H, Athre K. 2000, An analytical approach to evaluate dynamic coefficients and nonlinear transient analysis of a hydrodynamic journal bearing. Tribol Trans;43:109–15.

Samanta F, Hirani H, Mitra A, Kulkarni AM, Femandes BG, 2005, Test setup for magnetohydrodynamic journal bearing, Proc. 12th Natl. Conf. Mach. Mech. NaCoMM 2005, National Conference on Machines and Mechanisms, NaCoMM 2005; p. 298–303.

Samanta P, Hirani H. 2009, An overview of passive magnetic bearings. 2008 Proc. STLE/ASME Int. Jt. Tribol. Conf. IJTC 2008, p. 465–7.

Sukhwani VK, Hirani H, 2008, Design, development, and performance evaluation of high-speed magnetorheological brakes, Proc Inst Mech Eng Part L J Mater Des Appl;222:73–82.

Sukhwani VK, Hirani H, Singh T, 2007, Synthesis and performance evaluation of magnetorheological (MR) grease, NLGI Spokesm; 71:25.

S M Muzakkir, Lijesh KP, Hirani H. 2014, Tribological failure analysis of a heavily-loaded slow speed hybrid journal bearing. Eng Fail Anal;40:97–113.

S M Muzakkir, K. P. Lijesh and Harish Hirani. 2015, Effect of Base Oil on the Anti-Wear Performance of Multi-Walled Carbon Nano-tubes (MWCNT), *International Journal of Current Engineering and Technology*, vol.5, no.2, pp.681-684.

S M Muzakkir and Hirani, H., 2015, Design of Innovative Engine Valve: Background and Need, *International Journal of Scientific Engineering and Technology*, Volume No.4 Issue No.3, pp : 178-181.

S M Muzakkir and Hirani, H., 2015, Design of Innovative Engine Valve*, International Journal of Scientific Engineering and Technology*, Volume No.4 Issue No.3, pp: 212-217.

S M Muzakkir, & Hirani, H., 2015, Modelling of Push Rod Type Valve System for Minimization of Frictional Losses, *International Journal of Emerging Trends in Engineering and Development*, Issue 5, Vol. 3 (April.-May. 2015), pp. 102-109.

S M Muzakkir, & Hirani, H., 2015, Design of Valve System using Optimization Approach*, International Journal of Current Engineering and Technology,* Vol.5, No.2, pp. 1211-1217.

S M Muzakkir, 2015, Experimental Investigations on Effect of Tungsten Disulphide (WS_2) on Wear Performance of Commercial Lubricant Under Mixed Lubrication Conditions*, International Journal of Current Engineering and Technology*, vol.5, no.2, pp.1112-1114.

S M Muzakkir, 2015, Enhancement of Wear Performance of Commercial Lubricant Using Zinc (Zn) Nano particles Under Mixed Lubrication Conditions, *International Journal of Current Engineering and Technology*, vol.5, no.2, pp.1109-1111.

S M Muzakkir, Hirani, H., 2015, Effect of Molybdenum Disulfide Particle Sizes on Wear Performance of Commercial Lubricant *International Journal of Scientific Engineering and Technology*, Vol. .4, no. 3, pp: 162-164.

S M Muzakkir & Hirani, H., 2015, Innovative-Tribo-Design of Variable Valve Timing Mechanism: Need and Concept, *International Journal of Current Engineering and Technology*, vol.5, no.2, pp.1115-1125.

Lijesh K. P., S M Muzakkir and Harish Hirani., 2015, Experimental Study of the Parameters Affecting the Tribological Performance of Nano Lubricant Containing Multi-Walled Carbon Nano-tubes (MWCNT) using Design of Experiments (DOE), *International Journal of Modern Engineering Research*, Vol. 5, Iss.3, pp.66-70.

S M Muzakkir, 2015, Effectiveness of Carbon Nanotubes (CNT) as Lubricant Additive in Mixed Lubrication Conditions, *International Journal of Emerging Trends in Engineering and Development*, Issue 5, Vol. 3, pp. 261-266.

S M Muzakkir, K. P. Lijesh, and Harish Hirani, 2015, Carbon Nanotubes as Solid Lubricant Additives for Anti-wear Performance Enhancement under Mixed Lubrication Conditions, *International Journal of Modern Engineering Research,* Vol. 5, Iss.2, pp. 1-4.

S M Muzakkir and Harish Hirani, 2015, Experimental Investigation on Effect of Grinding Direction on Wear Under Heavy Load and Slow Speed Conditions with Molybdenum Disulphide (MoS_2) as Additive in Commercial Lubricant, *International Journal of Engineering Research*, Volume No.4, Issue No.3, pp : 102- 104.

S M Muzakkir and Harish Hirani, 2014, Experimental Investigation on Effect of Particle Sizes of Molybdenum Disulphide on Wear Under Heavy Load and Slow Speed Conditions, *International Journal of Modern Engineering Research,* 2014, Vol. 4, Iss. 12, pp. 46-49.