International Journal of Applied Engineering Research ISSN 0973-4562 Volume 11, Number 1 (2016) pp 692-697
© Research India Publications. http://www.ripublication.com

Design of Valve System using Up-gradation Approach

S. M. Muzakkir
Department of Mechanical Engineering
Jamia Millia Islamia, New Delhi, India.
E-mail: smmuzakkir@jmi.ac.in; mez108659@iitd.mech.ac.in

Abstract

The goal of a designer is to design systems that can perform the desired functions efficiently and satisfactorily under the variable operating conditions. In order to enhance the system performance or maintain a particular desired performance level under varying operating conditions, the existing system components that cumulatively achieve the desired functions may be replaced by altogether new components with improved functional features. This results into an increase in the ideality by increase in the useful functions. In the present paper the upgradation method for functional improvement that enhances ideality is demonstrated by considering the example of a valve system.

Keywords: Design, tribology, optimization, variable valve timing.

Introduction

The objective of achieving an optimum design of a mechanical system is very essential for the efficient utilization of the scare natural resources. Many optimization methods (mathematical optimization, experimental optimization, optimization approach using ideality concepts) are currently used to design optimum systems. The proper design may also be achieved by the application of innovative-tribo-design concepts [Muzakkir and Hirani, 2015]. The innovative–tribo-design concept can be applied for the design of bearings [Hirani, 2009, Hirani et al, 2000, Hirani et al, 1999, Hirani et al, 1998, Muzakkir et al, 2011, Hirani, 2005, Hirani et al, 2001, Muzakkir et al, 2013, Hirani 2004, Muzakkir et al, 2015, Hirani, Verma, 2009, Hirani, Suh, 2005, Hirani et al, 2001, Rao et al, 2000, Hirani et al, 2000, Hirani et al, 2002, Burla et al, 2004, Hirani, Samanta, 2007, Lijesh, Hirani, 2015, Lijesh, Hirani, 2014, Shankar et al, 2006, Lijesh, Hirani, 2015, Muzakkir et al, 2014, Lijesh, Hirani, 2015], seals [Hirani and Goilkar, 2011, Goilkar and Hirani, 2010, Hirani and Goilkar, 2009, Goilkar and Hirani, 2009, Goilkar and Hirani, 2009], brakes [Sarkar and Hirani, 2015, Sarkar and Hirani, 2015, Sarkar and Hirani, 2013, Sarkar and Hirani, 2013, Sarkar and Hirani, 2013, Sukhwani et al, 2009, Sukhwan and Hirani, 2008, Sukhwani et al, 2008, Sukhwani et al, 2008, Hirani and Manjunath, 2007, Sukhwani et al, 2007] and gears [Shah and Hirani, 2014, Hirani, 2009].

Even though these methods are in current use but they have one or the other drawbacks that makes the design inferior. However, other convenient approach, that requires lesser effort, is to identify and reduce the harmful functions. But increasing the useful functions of the existing systems by upgrading to better components, even though difficult, is considered beneficial. The concept of ideality [Muzakkir and Hirani, 2015] has been successfully employed for optimum design of mechanical systems. The functional approach for the design of a product is expressed by Eq. 1. The ideality is defined as:

$$\text{Ideality} = \frac{\sum \text{Useful Functions}}{\sum \text{Harmful Functions} + \sum \text{cost}} \qquad (1)$$

Where the useful functions are the desired functions from a product and the harmful functions include undesirable functions such as weight, friction, misalignment, noise, vibration, wear, etc. The ideality may be increased by the increase in the useful functions.

This paper presents an upgradation method for enhancing the ideality of the system. This method is intended to augment the system functionality. The existing components are replaced by new components with improved functionality. As a case study, the method is applied for the functional upgradation of the valve system to a variable valve timing system.

Upgradation approach

The upgradation method replaces an existing component enhances the ideality of the system. The domain knowledge is essential to consider all the parameters that influences the system performance. The contradiction in many objectives makes the design challenging. The concept of reducing the harmful effects is one of the best option to enhance the ideality of the system and to obtain an optimum system. As a case study, that demonstrates the characteristics features of this method, consider a valve system that is required for the opening and closing the valves of a 2-valves/cylinder engine. Due to changes in the operating conditions there is a need to include additional control function to introduce variable valve lift, timing, and duration. There are four cases of variable timings need to examined: Inlet valve opening (IVO), Inlet valve closing (IVC), Exhaust valve opening (EVO) and Exhaust valve closing (EVC).

(a) Intake Valve Opening (IVO)

In conventional engine, generally opening of the intake valve takes place at around 10 degrees before TDC. This valve timing or any other early inlet valve opening (EIVO) is preferred at high speed and high load to refill the engine cylinder with fresh charge to its maximum capacity. However, at part load, volume of engine cylinders is much larger than required for air-intake. Therefore, late intake valve opening (LIVO) will be a good strategy. LIVO timing reduces HC emissions under cold start situation, by lowering the chances of cylinder wall wetting and increasing in-cylinder gas motion that helps ignition and combustion.

(b) Intake Valve Closing (IVC)

Generally closing of the inlet valve represents the end of the intake stroke and the start of the compression stroke. For a conventional engine with fixed intake cam timing, intake valve closing (IVC) timing is a trade-off between low speed torque and high speed power. In variable valve actuated engine, IVC helps to eliminate this trade off. Modulation of IVC timings controls the cylinder filling, so there is no need of throttling operation. The strategies such as early intake valve closing, late intake valve closing and variable valve lift are used to limit the pumping loss.

(c) Early intake valve closing (EIVC)

In EIVC, the intake valve is closed early during the suction stroke of the engine, when the desired fresh air mass has been introduced into the cylinder. During warmed up (part load) conditions, a limited fraction of the intake stroke is used to introduce air fuel charge. As a result, required pumping is much lesser than the traditional throttled engine, which increases engine efficiency at partial loads. To understand this, let us consider pressure (P_{intake}) at which fresh charge is taken in to the cylinder, and pressure ($P_{exhaust}$) at which combustion products are exhausted. Based on intake and exhaust pressures, pumping work is given as:

$$W_{pump} = (P_{exhaust} - P_{intake}) * V_s \qquad (2)$$

where V_s is swept volume. As is apparent from the Eq. (2), the decreasing difference between intake and exhaust pressure reduces the pumping work. At full load conditions, $P_{intake} \approx P_{exhaust} \approx P_{atm}$. In a throttled engine at part load, $P_{intake} \approx 0.25 P_{atm}$. For variable inlet closing timing, P_{intake} remains atmospheric pressure. Once inlet valve is closed, adiabatic expansion process occurs and pressure and temperature are reduced. This contributes to lower heat losses, lesser NOx emissions and reduced pumping losses. However, this strategy has two disadvantages:The manifold pressure remains high, which reduces pressure difference required for liquid fuel to get evaporated. Liquid droplets cause poor combustion. EIVC engines can overcome this penalty by reducing intake valve lift to a reasonable value (too low valve height eats away all the benefits of unthrottled engine operation). Low valve height causes higher intake air-fuel mixture velocity. This higher velocity creates turbulence for good fuel vaporization.

The intake valve closing before bottom dead center results in a nearly adiabatic expansion inside the cylinder. Because of this the fresh charge cools down, resulting in air fuel mixture cooler than that in a conventional engine. Cooler charge is detrimental to the fuel atomization. Therefore this strategy cannot be used in cold-start engine case.

(d) Late intake valve closing (LIVC)

The late intake valve closing is characterized by the intake valve remaining open during the complete suction stroke. It can not be closed before the excess charge is pushed back into the intake manifold during the compression stroke of the piston. In throttled and un-throttled engine LIVC plays different roles. In throttled engine with LIVC timing, some of the charge is expelled back into the intake manifold. The pressure of the entrapped charge is little more than the atmospheric pressure. During the subsequent induction stroke the entrapped charge gets readmitted at a pressure above that of the air-fuel mixture in conventional engines. This means that the suction pressure line deviates very little from the atmospheric line. Thus, the negative area is almost nil, which results in reduced pumping losses. On the other hand, in the absence of the throttle body, LIVC strategy causes very high flow losses because of the air fuel reverse flow. This increases hydrocarbon emissions and fuel consumption.

To summarize, LIVO and EIVC with reduced valve lift are preferred strategies at the engine start, during warm-up period and part load conditions.

(e) Exhaust Valve Opening (EVO)

For a conventional engine with single cam profile, timing of exhaust valve opening (EVO) is a trade-off between high speed exhaust stroke and low speed expansion work. In conventional engines, EVO takes place at around 60 degrees before BDC. Early opening of exhaust valve (EEVO) generally results in losses in the expansion stroke, while late exhaust valve opening (LEVO) causes increase in temperature of exhaust gases and more chances of NOx emission. Variable exhaust valve actuation tries to improve such tradeoff and allows EEVO for high speed and load conditions, while LEVO for partial load situations.

(f) Exhaust Valve Closing (EVC)

Generally, closing of the exhaust valve in conventional engine takes place at around 10 degrees after TDC during the intake stroke. This late closing requires expelling out all the residual gases from the cylinder and bring-in new fresh charge for full load conditions. However, late exhaust valve closing (LEVC) allows an engine torque reduction, under partial load operation. Early exhaust valve closing (EEVC) seems a better strategy for part load circumstances.

To execute the desirable variable valve timings in DOHC valve train (discussed in section 4), a number of valve-extension strategies are available in open literature, which can be grouped as:

- Control at camshaft level
    - Camshaft phasing
    - Two steps valve lift
    - Full flexible variable valve actuation
- Control at the valve train (excluding poppet valves and camshaft)

(g) Camshaft Phasing

Camshaft phasing (rotation of camshaft relative to crankshaft) is adjusted using electrical or electric-hydraulic actuators [Bosch, 2004]. Retarding the intake/exhaust camshaft leads to intake/exhaust valve opening later so that valve overlap is reduced or minimized to zero. At low engine speeds, the low valve overlap results in very little residual gas content in A/F mixture, leading to a more efficient combustion process. This reduces idle engine speed, which is in favor of fuel consumption. Variable valve lift is impossible to handle with this strategy; further variable valve event is very difficult to exercise. Therefore this strategy only partly fulfills the requirements of VVS.

(h) Two Steps Valve Lift

Two steps valve lift involves switching of the cam contour from one to another. Contours can be optimized for low speed and high speed operations. Two-steps cam [Sellnau & Rask, 2003] utilizes two discrete valve-lift profiles. The first cam contour defines, the optimum valve timing and lift, for the intake and exhaust valves in the low to medium power ranges [Bosch, 2004]. The second cam contour controls the longer valve open duration and the increased valve lift needed at higher speed [Bosch, 2004]. This improves the classic tradeoff between low-speed low-load operation, and high-speed full-load operation. By combining two step cam profiles with cam phasing (such as shown in Fig. 1), Sellnau and Rask [2003] demonstrated improvement in the fuel economy and emissions.

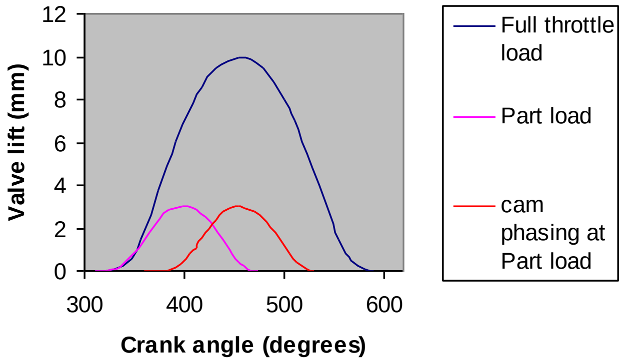

Figure 1: Two step VVA

However, this type of mechanism cannot replace engine throttle valve and thus cannot reduce pumping loss. Further, cam-phasing and axial movement of camshaft consumes the extra-power, reduces upper speed-limit of engine, and costs additional capital bucks. Moreover, these mechanisms do not provide full optimization over the whole load and speed ranges.

(i) Full Flexible Variable Valve Actuation

A camshaft utilizing three-dimensional cams (such as in Ferrari engines) provides a continuously variable valve lift and timing. However the restriction in such design occurs, with the increase of camshaft rotation that causes interference of three-dimensional cam with valve lifter. Moreover, movement of the shaft in the axial direction is limited by the design of cylinder head. Further restriction arises due to growing trends towards higher engine speed. To overcome problems related to 3-D camshaft valve actuation, Ogura & Sasaki [2003] developed a continuous variable valve timing mechanism by combining three-dimensional cam and the rocker arm movement. This mechanism makes the continuous variance of the valve timing possible by moving rocker arm parallel to the three-dimensional cam. These mechanisms require additional movements in valve-systems and causes increase in weight and higher frictional losses.

(j) Control on Intermediate Linkage (Valve Train)

Control at the valve train level is exercised by discarding the cam-lift if it is not desired, using “lost motion” concept. Basic aim of “lost motion” concept is to design cam for high speed operation and regulate valve timing and lift as per cylinder requirements that develop power efficiently with minimum emissions. Kreuter et al. [1999] described various mechanical valve mechanisms to continuously control intake valve lift from zero to maximum. Such mechanisms allow an un-throttled load control of spark ignition engines. Leslie et al. [2003] utilized magnetorheological (MR) fluid to control the timing and/or the lift of valve motion.

In recent modern world there is a drive for quieter and longer service engines. This provides a push for hydraulic device to be used between valve and direct acting cam [Gecim, 1993]. By varying the area of fluid passage opening and closing valve timings, and maximum lift can be controlled. Further such hydraulic devices can also work as a lash adjusters, so periodic adjustment (which require for mechanical last adjusters) of lash can be avoided. This saves maintenance costs. In addition, these devices reduce noise of impact, wear and so improve the durability of engine valve. However, hydraulic based devices reduce overall valve stiffness, and there are problem of pressure loss, leakage and aeration. In such case use of MR fluid in place of hydraulic fluids overcome drawback of aeration and low stiffness. Therefore a number of devices based on MR fluid between cam and valve can be recommended to provide an additional function of variable valve system.

In summary additional function of variable valve actuation can be achieved by replacing mechanical lash adjuster by magnetorheological based lash adjuster. Further, this lash adjuster can be designed to lose the cam motion as per requirements.

Conclusion

The upgradation method that enhances the ideality of the system is presented. This approach was applied to the valve system. The ideality is shown to have enhanced by the use of following:

- The effect of valve timing on the engine performance has been described
- MR fluid between cam and valve is recommended to provide an additional function of variable valve system
- A camshaft utilizing three-dimensional cams is recommended
- Combination of two step cam profiles with cam phasing

References

[1] Muzakkir SM. Studies on Heavily Loaded Slow Speed Journal Bearing. Ph.D. Thesis, IIT Delhi, 2015.

[2] Muzakkir S, Lijesh K, Hirani H, Thakre G. Effect of cylindricity on the tribological performance of heavily loaded slow-speed journal bearing. Proc Inst Mech Eng Part J J Eng Tribol 2014;229:178–95.

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

[4] Muzakkir SM, Hirani H, Thakre GD. Lubricant for Heavily Loaded Slow-Speed Journal Bearing. Tribol Trans 2013;56:1060–8.

[5] Muzakkir SM, Hirani H, Thakre GD. Experimental Investigations on Effectiveness of Axial and Circumferential Grooves in Minimizing Wear of Journal Bearing Operating in Mixed Lubrication Regime. Int J Curr Eng Technol 2015;5:486–9.

[6] H Hirani, and C S Manjunatha, “Performance Evaluation of Magnetorheological Fluid Variable Valve”, Proc. of the Institution of Mechanical Engineers, Part D, Journal of Automobile Engineering, vol. 221, no.1, pp. 83-93, 2007.

[7] C Sarkar and H Hirani, “Theoretical and experimental studies on a magnetorheological brake operating under compression plus shear mode”, Smart Materials and Structures, vol.22. no.11, 2013.

[8] C Sarkar and H Hirani, Development of magnetorheological brake with slotted disc, Proc. IMechE, Part D: Journal of Automobile Engineering, Vol. 229, No. 14 1907-1924, 2015.

[9] V K Sukhwani and H Hirani, A Comparative Study of Magnetorheological Fluid-Brake and Magnetorheological-Grease-Brake, Tribology Online, vol 3, no.1, pp. 31-35, 2008.

[10] C Sarkar and H Hirani, “Synthesis and Characterization of Antifriction Magnetorheological Fluids for Brake”, Defense Science Journal, vol. 63, no.4, pp.408- 412, 2013.

[11] K. P. Lijesh, and H. Hirani, “Development of Analytical Equations for Design and Optimization of Axially Polarized Radial Passive Magnetic Bearing”, ASME, Journal of Tribology, Vol. 137, No. 1, (9 pages), 2015.

[12] Lijesh, K. P., and Hirani, H., 2015, “Magnetic Bearing Using RMD Configuration”, ASME, journal of tribology, Vol. 137, No. 4, 042201-1-042201-9, 2015

[13] Muzakkir, S. M., Lijesh, K. P., and Hirani, H., 2014, “Tribological Failure Analysis of a Heavily-Loaded Slow Speed Hybrid Journal Bearing,” Engineering Failure Analysis, 40, pp. 97–113.

[14] Muzakkir S.M., Lijesh K.P., Hirani H. Fail-safe design of journal bearing hybrized with passive magnetic levitation (2015) International Journal of Applied Engineering Research, 10 (14), pp. 34707-34711.

[15] Muzakkir S.M., Lijesh K.P., Hirani H. Failure mode and effect analysis of journal bearing (2015) International Journal of Applied Engineering Research, 10 (16), pp. 37752-37759.

[16] Lijesh, K. P., and Hirani, H., 2015, “Optimization of Eight Pole Radial Active Magnetic Bearing”, ASME, Journal of Tribology, Vol 37, No.2.

[17] Muzakkir S.M., Talreja V. Design of flywheel for maximization of storage energy using ANSYS (2015) International Journal of Applied Engineering Research, 10 (19), pp. 40291-40300.

[18] Muzakkir S.M., Hirani H., Thakre G.D. Performance evaluation of journal bearings used in sugar mills using Taguchi method (2012) Society of Tribologists and Lubrication Engineers Annual Meeting and Exhibition 2012, pp. 121-123.

[19] Shankar S., Sandeep and Hirani H., 2006, “Active Magnetic Bearing,” Indian Journal of Tribology, pp 15-25.

[20] Samanta, P. and Hirani H., 2008, “Magnetic Bearing Configurations: Theoretical and Experimental Studies,” IEEE Transactions on Magnetics, Vol. 44, No.2, pp. 292-300.

[21] Hirani, H., and Samanta, P., “Hybrid (Hydrodynamic + Permanent Magnetic) Journal Bearings,” Proc. Institute Mech. Engineers., Part J, Journal of Engineering Tribology, Vol. 221(J8), pp. 881-891, 2007.

[22] Lijesh, K. P., and Hirani, H, “Design of eight pole radial active magnetic bearing using monotonicity”, In Industrial and Information Systems (ICIIS), 2014 9th International Conference on IEEE, pp. 1-6, 2014.

[23] Muzakkir S.M., Kumar S. Design of mechanical oil seal and gasket (2015) International Journal of Applied Engineering Research, 10 (12), pp. 30911-30926.

[24] Lijesh, K. P., and Hirani, H “Modelling and Development of RMD Configuration Magnetic Bearing”, Tribology in Industry, 37(2), pp. 225-235, 2015.

[25] Lijesh K. P. and Hirani H, “Design and Development of Halbach Electromagnet for Active Magnetic Bearing”, Progress In Electromagnetics Research C, vol. 56, pp. 173– 181, 2015.

[26] Lijesh K.P. and Hirani H., “Stiffness and damping coefficients for rubber mounted hybrid bearing”, Lubrication Science, Vol.26, No.5, pp. 301-314, 2014.

[27] Lijesh K.P., Muzakkir S.M., Hirani H. Failure mode and effect analysis of passive magnetic bearing (2016) Engineering Failure Analysis, 62, pp. 1-20.

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

[29] Hirani H., Athre K., Biswas S., “Dynamic Analysis of Engine Bearings”, International Journal of Rotating Machinery, Vol.5 No.4, pp. 283-293, 1999.

[30] Hirani H., Athre K., and Biswas S., “A Hybrid Solution Scheme for Performance Evaluation of Crankshaft Bearings,” Trans. ASME, Journal of Tribology, Vol.122, No.4, pp. 733-740, 2000.

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

[32] Hirani, H., Athre, K., Biswas, S. “Lubricant Shear Thinning Analysis of Engine Journal Bearings”, STLE, Journal of Tribology Transaction, Vol. 44, No.1, pp 125-131, 2001.

[33] Muzakkir, S.M., Hirani, H., Thakre, G.D., Tyagi, M.R., Tribological Failure Analysis of Journal Bearings used in Sugar Mill, Engineering Failure Analysis, vol. 18, no. 8, pp. 2093-2103, 2011.

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

[35] Hirani, H, “Multi-objective Optimization of a journal bearing using the Pareto optimal concept”, Proc. Institute Mech. Engineers., Part J, Journal of Engineering Tribology, Vol. 218, No. 4, pp. 323-336, 2004.

[36] Hirani, H., Multiobjective optimization of journal bearing using mass conserving and genetic algorithms, Proc. Institute Mech. Engineers., Part J, Journal of Engineering Tribology, Vol. 219, No. 3, pp. 235-248, 2005.

[37] Hirani, H., Suh, N. P., Journal Bearing Design using Multi-objective Genetic Algorithm and Axiomatic Design Approaches, Tribology International, Vol. 38, No. 5, pp. 481-491, 2005.

[38] Hirani, H., Verma, M., Tribological study of elastomeric bearings of marine shaft system, Tribology International, Vol. 42, No. 2, pp. 378-390, 2009.

[39] Rao, T. V. V. L. N., Hirani, H., Athre, K., Biswas, S. "An Analytical Approach to Evaluate Dynamic Coefficients and Non-linear Transient Analysis of a Hydrodynamic Journal Bearing", STLE Tribology Transactions, vol. 23, no.1, pp. 109-115, 2000.

[40] S. S. Goilkar and H Hirani, "Parametric Study on Balance Ratio of Mechanical Face Seal in Steam Environment", Tribology International, Vol. 43, No. 5-6, pp. 1180-1185, 2010.

[41] Hirani H and Goilkar S S, "Formation of Transfer Layer and its Effect on Friction and Wear of Carbon-Graphite Face Seal under Dry", Water and Steam Environments, Wear, Vol. 226, No. 11-12, pp.1141-1154, 2009.

[42] Goilkar S S, and Hirani H., "Design and development of test setup for online wear monitoring of mechanical face seals using torque sensor", Tribology Transactions, Vol. 52, No.1, pp. 47-58, 2009.

[43] S. S. Goilkar and H Hirani, "Tribological Characterization of Carbon Graphite Secondary Seal", Indian Journal of Tribology, Vol. 4, No. 2, pp. 1-6, 2009.

[44] C Sarkar and H Hirani, Design of a Squeeze Film Magnetorheological Brake Considering Compression Enhanced Shear Yield Stress of Magnetorheological Fluid, Journal of Physics: Conference Series, Vol.412, No.1, 012045. 2013

[45] V K Sukhwani, and H Hirani, Design, Development and Performance Evaluation of High Speed MR Brake, Proc. Institute Mech. Engineers.,Part L, Journal of Materials: Design and Applications, vol. 222, no.1, pp. 73-82, 2008.

[46] S. M. Muzakkir and H. Hirani, "A Magnetorheological Fluid Based Design of Variable Valve Timing System for Internal Combustion Engine using Axiomatic Design," Int. J. Curr. Eng. Technol., vol. 5, no. 2, pp. 603–612, 2015.

[47] S. M. Muzakkir, K. P. Lijesh, and H. Hirani, "Carbon Nanotubes as Solid Lubricant Additives for Anti- wear Performance Enhancement under Mixed Lubrication Conditions," Int. J. Mod. Eng. Res., vol. 5, no. 2, pp. 25–28, 2015.

[48] S. M. Muzakkir, "Design and Development of Experimental setup for Direct Acting Overhead Camshaft (DOHC) Valve System," Int. J. Curr. Eng. Technol., vol. 5, no. 3, pp. 2027–2031, 2015.

[49] S. M. Muzakkir and V. Talreja, "Design of Flywheel for Maximization of Storage Energy using ANSYS," Int. J. Appl. Eng. Res., vol. 10, no. 19, pp. 40291–40300, 2015.

[50] S. M. Muzakkir, M. G. Patil, and H. Hirani, "Design of Innovative Engine Valve," Int. J. Sci. Eng. Technol., vol. 4, no. 3, pp. 212–217, 2015.

[51] S. M. Muzakkir, M. G. Patil, and H. Hirani, "Design of Innovative Engine Valve : Background and Need," Int. J. Sci. Eng. Technol., vol. 181, no. 4, pp. 178–181, 2015.

[52] S. M. Muzakkir and S. Kumar, "Design of Mechanical Oil Seal and Gasket," Int. J. Appl. Eng. Res., vol. 10, no. 12, pp. 30911–30926, 2015.

[53] S. M. Muzakkir and H. Hirani, "Design of Valve System using Optimization Approach," Int. J. Curr. Eng. Technol., vol. 5, no. 2, pp. 1217–1223, 2015.

[54] S. M. Muzakkir, K. P. Lijesh, and H. Hirani, "Effect of Base Oil on the Anti-Wear Performance of Multi-Walled Carbon Nano-tubes (MWCNT)," Int. J. Curr. Eng. Technol., vol. 5, no. 2, pp. 681–684, 2015.

[55] S. M. Muzakkir and H. Hirani, "Effect of Molybdenum Disulfide Particle Sizes on Wear Performance of Commercial Lubricant," Int. J. Sci. Eng. Technol., vol. 4, no. 3, pp. 162–164, 2015.

[56] S. M. Muzakkir, "Effectiveness of Carbon Nanotubes (CNT) as Lubricant Additive in Mixed Lubrication Conditions," Int. J. Emerg. Trends Eng. Dev., vol. 3, no. 5, pp. 261–266, 2015.

[57] S. M. Muzakkir, "Enhancement of Wear Performance of Commercial Lubricant using Zinc (Zn) Nano-Particles as Anti-Wear Additive under Mixed Lubrication Conditions," Int. J. Eng. Res., vol. 5, no. 2, pp. 2014–2016, 2015.

[58] S. M. Muzakkir and H. Hirani, "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," Int. J. Eng. Res., vol. 5013, no. 4, pp. 102–104, 2015.

[59] S. M. Muzakkir and H. Hirani, "Experimental Investigation on Effect of Particle Sizes of Molybdenum Disulphide on Wear Under Heavy Load and Slow Speed Conditions," Int. J. Mod. Eng. Res., vol. 4, no. 12, pp. 46–49, 2014.

[60] S. M. Muzakkir, "Experimental Investigations on Effect of Tungsten Disulphide (WS2) on Wear Performance of Commercial Lubricant under Mixed Lubrication Conditions," Int. J. Curr. Eng. Technol., vol. 5, no. 2, pp. 2014–2016, 2015.

[61] S. M. Muzakkir, H. Hirani, and G. D. Thakre, "Experimental Investigations on Effectiveness of Axial and Circumferential Grooves in Minimizing Wear of Journal Bearing Operating in Mixed Lubrication Regime," Int. J. Curr. Eng. Technol., vol. 5, no. 1, pp. 486–489, 2015.

[62] K. P. Lijesh, S. M. Muzakkir, and H. Hirani, "Experimental Study of the Parameters Affecting the Tribological Performance of Nano Lubricant Containing Multi-Walled Carbon Nano-tubes (MWCNT) using Design of Experiments (DOE)," Int. J. Mod. Eng. Res., vol. 5, no. 3, pp. 66–70, 2015.

[63] K. P. Lijesh, S. M. Muzakkir, and H. Hirani, "Experimental tribological performance evaluation of nano lubricant using multi-walled carbon nano-tubes (MWCNT)," Int. J. Appl. Eng. Res., vol. 10, no. 6, pp. 14543–14550, 2015.

[64] S. M. Muzakkir, K. P. Lijesh, and H. Hirani, "Fail-safe design of journal bearing hybrized with passive magnetic levitation," Int. J. Appl. Eng. Res., vol. 10, no. 14, pp. 34707–34711, 2015.

[65] K. P. Lijesh, S. M. Muzakkir, and H. Hirani, “Failure Analysis of Rolling Contact Bearing for Flywheel Energy Storage Systems,” Int. J. Curr. Eng. Technol., vol. 5, no. 1, pp. 439–443, 2015.
[66] S. M. . Muzakkir, K. P. Lijesh, and H. Hirani, “Failure Mode and Effect Analysis of Journal Bearing,” Int. J. Appl. Eng. Res., vol. 10, no. 16, pp. 37752–37759, 2015.
[67] K. P. Lijesh, S. M. Muzakkir, and H. Hirani, “Failure mode and effect analysis of passive magnetic bearing,” Eng. Fail. Anal., vol. 62, pp. 1–20, 2016.
[68] S. M. Muzakkir and H. Hirani, “Innovative-Tribo-Design of Variable Valve Timing Mechanism: Need and Concept,” Int. J. Curr. Eng. Technol., vol. 5, no. 2, pp. 1115–1125, 2015.
[69] S. M. Muzakkir, “Kinematic , Dynamic and Tribological Analysis of Push Rod Type Valve System,” Int. J. Adv. Ind. Eng., vol. 3, no. 2, pp. 54–59, 2015.
[70] S. M. Muzakkir and H. Hirani, “Maintenance Free Bearings,” Int. J. Eng. Res., vol. 4, no. 3, pp. 133–136, 2015.
[71] S. M. Muzakkir, “Modelling of Push Rod Type Valve System for Minimization of Frictional Losses,” Int. J. Emerg. Trends Eng. Dev., vol. 3, no. 5, pp. 102–109, 2015.
[72] S. M. Muzakkir and K. P. Lijesh, “Studies on Control Aspects of Active Magnetic Bearings,” Int. J. Curr. Eng. Technol., vol. 5, no. 4, pp. 2465–2471, 2015.