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Design Analysis of Valve Gear Train Mechanism for an Innovative Pendulum Type Combustion Engine

Mr. Sunil R. Kewate
Asst. Prof. Mech. Dept
Govt. College of Engg. & Research, Awasari(Kh)
Sunilkewate@rediffmail.com

Mr Vivek R. Gandhewar
Asso. Prof . Mech Dept
J.D.I.E. T. Yavatmal(M.S.)
Vivek.gandhewar@rediffmail.com

Miss. Jayshree A. Suryawanshi
Student, Mech. Dept.
Govt. College of Engg. & Research, Awasari(Kh)

Abstract**—** Energy efficiency is one of the essential needs of designing any component. Therefore, both the industry and governments are eagerly searching for new energy efficient solutions, which will both address this rowing supply in industry's point of view, turn a profit. The internal combustion engines are of a great concern as entire world works on locomotive industry. Hence efficient performance of IC engine is of great concern. Pendulum type combustion engine is a type of combustion engine and is newly innovated concept engine. Currently there are no steps taken in development of pendulum engine and also there is no valve gear train mechanism designed yet. So the concept of valve gear train mechanism for this type of engine comes in mind for research work. As the power of engine increases the size of engine also increases. Hence, the engine becomes bulky. But for a pendulum type combustion engine which is under developing stage in R and D section, the size of cam remains same for existing increased power and also the conventional valve gear train cannot be suitable for this type of engine. In this paper, it introduces the detailed design, development and analysis of valve gear train mechanism for pendulum type engine. The valve gear train mechanism design includes following components: timing mechanism, cam shaft, bearing, cam, follower, pushrod rocker arm, valve stem, valve guide, spring, guide valve. In this paper work, the forces which acts on the system are calculated and also the thermal analysis of valve and structural analysis of follower, camshaft is studied using software and then results shown in tabular form.

Keywords*- Efficiency, performance, valve gear train mechanism, cam, thermal and structural analysis etc*

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I. INTRODUCTION

There is scope for a lot of research in the field of energy generation, because none of the machines made yet is perfect, both in performance and in design. Also the engines used have very low efficiencies, so efforts can be made to improve the terms. Even modern internal combustion engines convert only one third of the energy of fuel into useful work. All of the steps at which energy is wasted are opportunities for advanced technologies to in-crease fuel economy. The world is becoming compact and there is problem of space, so everything we need should accommodate in small space and it should be light in weight. The essence of the invention is that the design, development and analysis of valve gear train mechanism for the conceptual type pendulum engine. The main role of the valve train mechanism is to ensure the gases exchange process for all the engine speeds and that influences the engine good functioning. Internal combustion engine valves are precision engine components. The valve train system is one of the major parts of internal combustion engine, which controls the amount of air-fuel mixture to be drawn into the cylinder and exhaust gas to be discharged. The fresh charge (air - fuel mixture in Spark Ignition Engines and air alone in Compression Ignition Engines) is induced through inlet valves and the products of combustion get discharged to atmosphere through exhaust valves. This seals the working space inside the cylinder against the manifolds. So design of valve lifts profiles and valve train components are most important for the engine performance, valve train durability, and NVH. Therefore valve train system should be optimally designed so as to avoid an abnormal valve movement, such as valve jumping or bounce up to the maximum engine speed. There are different types of valves used by the manufactures; some common types of valves being poppet valves, slide valves, rotary valves and sleeve valve. Cam has direct influence on efficiency and performance of engine. If the lifting of valve is not on appropriate timing then the time for which the fuel inlet is allowed and also the time for which exhaust gases are retained in the combustion chamber affects the efficiency. The valve timing diagram is so designed such that there is maximum duration of lift for intake of fuel. We have designed entire valve gear train for pendulum type engine. Detailed forces which acts on the system are calculated and the results are given in the end.

II. DESIGN OF VALVE GEAR TRAIN

The essence of the invention is that the pendulum engine with a combustion chamber in which the energy of combustion is being converted into a swinging motion of a blade fixed to a shaft, which is adequate to a piston role in piston combustion engine, and the engine principle of operation is to use the same combustion chamber space by both the sides of the blade placed inside the combustion chamber on the engine as shown in fig.4(b).Now Pendulum engine is new developed concept, so valve gear train is not designed yet because of the following issues-i) For the same power generation, size of conventional and pendulum engine does not match, So valve gear train cannot be directly, i.e. For the same size say 150 cc, normally power generated by conventional IC engine is about 6 kW while by pendulum engine is 8 kW. ii) For the same power generation, pendulum engine is small in size, compact and less weight.iii) As the engine is spherical shaped, we get ratio of volume to surface area maximum as compare to the cylinder shape. Hence, it enhances power to weight ratio.

1) Timing mechanism-To transfer the motion from crankshaft to camshaft, Timing mechanism is needed. As in case of four stroke engine, drive transmitted to camshaft is half as compared to crankshaft. We can use chain or sprocket

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mechanism but here direct gear drive is used. If crankshaft rotates with N speed then camshaft rotates with N/2 speed.

2) Gear drive-As distance between camshaft and crankshaft is less, so direct gear drive is used. Material Selected-Plain Carbon Steel 40C8 (Case hardened) for gear and pinion,
S_{ut}= 580 N/mm^2, Hardness= 400 BHN.

3) Camshaft-it is supported in bearing. Maximum force is exerted simultaneously on both valves. Hence, maximum bending moment may occur. Camshaft is considered as a simply supported beam and equivalent bending moment & equivalent tensional moment is acting on the shaft.

4) Design of Bearing-In order to select a most suitable ball bearing, first of all, the basic dynamic radial load is calculated. It is then multiplied by the service factor (Ka =1.5) to get the design basic dynamic radial load capacity. So now we calculate the Reaction force at the supports i.e. radial load on each bearing.

5) Cam and follower Design-Considering cam as circular arc cam and flat follower and by considering valve timing diagram, arc radius is calculated. Nose radius and base radius is assumed as shown in fig.1

-Input parameters of inlet cam -Valve lift= 7mm, Base circle radius, Rb =10mm Nose circle radius, Rn = 2mm Distance between = 7 + 10 - 2 centre of circles = 15mm, angle of ascent = 60^o,Arc length is the flank circle radius. Its formula is given by

R= R_b^2 R_n^2 + d^2 (2 R_b d cos) 2(R_b R_n d cos)
= 171mm

-Input parameters of exhaust cam

Valve lift= 7mm Base circle radius, Rb =11.5mm Nose circle radius, Rn = 1.5mm Distance between = 7 + 11.5 - 1.5 centre of circles = 17mm, angle of ascent = 55^o

Arc length is the flank circle radius. Its formula is given by

R= R_b^2 R_n^2 + d^2 (2 R_b d cos) 2(R_b R_n d cos) = 389.46mm

Unless we assume some mass of each component, force cannot be evaluated. Hence we assume mass as 0.4kg.

Angle between the Cams-As inlet valve and exhaust valve opens at different time i.e. inlet valve during suction stroke and exhaust valve during exhaust stroke. So there should be angle between suction cam and exhaust cam, angle of orientation (lobe separation angle) which is shown in fig. 1

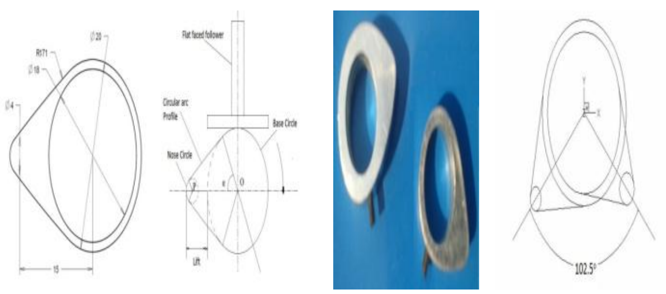


Fig.1 Inlet circular arc cam front view with Flat follower and Angle between cam

Inlet valve opens before B by 15^0 , Inlet valve closes after A at 45^0 , Exhaust valve open before A at 30^0 , Exhaust valve closes after B at 10^0

Where, A = Top Dead Centre, B = Bottom Dead Centre

Now, we find total action angle of both the cams.

For Suction cam: 15 + 180 + 45 = 240^0, For Exhaust cam: 30 + 180 + 10 = 220^0

The Kinematics on Cam -Maximum acceleration during outward stroke, a_{max} = I^2 (R r_b)

But,I = 157:07rad=sec, Then, a_{max} = 3972:51m/s^2

Maximum retardation, = I^2 d = 370.11m/s^2 , Assumed masses, Valve mass = 20 gm ,
Flat follower = 20 gm ,Therefore, Total mass = 0.04 kg

Forces on cam -Inertia force: F_a = m $_{max,}$ F_a = 158:9,Retardation force = 14:80N

F_r = 2 Fretard =30N ,Gas pressure force on valve: As per adiabatic expansion,

but,P_1 = 3:039MPa,P_2 = 2:36MPa,So P1:P2 =7:6,d = 20mm

Force on valve disc diameter, F_g = 123N,Total force = F_a + F_r + F_g = 313N

Design of Camshaft – Power-1.61 kW Shear stress: 42 MPa, Bending stress: 56 MPa

Taking moment at point A, as per vertical loading diagram shown in fig. 3

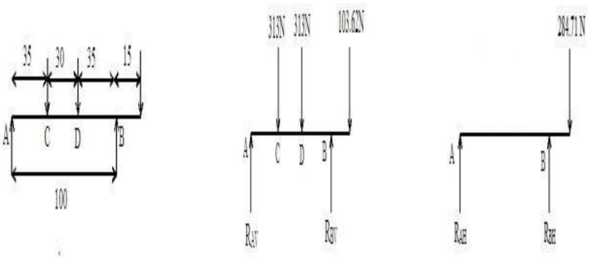


Fig 2.Vertical loading and horizontal loading diagram of camshaft

Therefore, R_{bv} = 437:344N, R_{av} = 292:276N

Bending moments at various points, At B = -2.0724 Nm,At C = 10.229 Nm,At D = 9.608 Nm,Taking moment at A,as per horizontal loading diagram shown in figure 4(b).

Therefore, R_{bh} = 341:652N,R_{ah} = 56:942N and
R_{bh} = 341:652N,R_{ah} = 56:942N

Bending moments at various points, at B = -5.694 Nm.at C = 1.993 Nm. At D = 3.701 Nm,We obtained maximum bending moment at C which is 10.42 Nm.

M=10.42 N, Torque due to power, T= 10:249Nm

Equivalent torque,

T_e = [(K_mM)^2 + (K_tT)^2] = 18:690 Nm, :::::::::: (K_m = 1:5;
K_t = 1)

Equivalent bending moment,

M_e = 1=2(K_mM) + [(K_mM)^2 + (K_tT)^2] = 13:13 Nm

To Calculate Diameter of Camshaft

By considering shear stress,d = 13:135mm and bending moment,d= 14.61 mm,

Selected standard diameter, d= 15 mm.

A. Valve stem-Valve stem is designed by considering the buckling or crushing stress.
B. Spring-Spring is designed on the basis of modified Soderberg equation, because fluctuating load is acting on spring.

Design of valve -The valves used in internal combustion engines are of the following three types1) Poppet or mushroom valve 2) Sleeve valve 3) Rotary valve . In designing a valve, it is required to determine the following dimensions-

Size of the valve port- Let,a_p = Area of the port, v_p = Mean velocity of gas flowing through the port, a = Area of the plate, and v =Mean velocity of the plate.

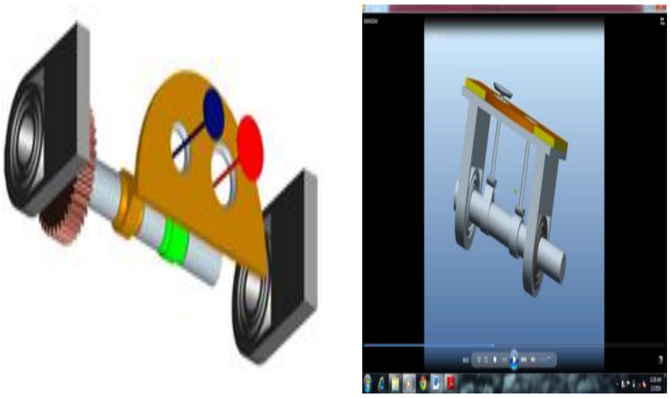
We know that, $a_p \; v_p = a \; v$,$_{ap\,=}$ =2 r^2 r ! v_p,

d_p = 22:86mm,Valve port diameter=23 mm

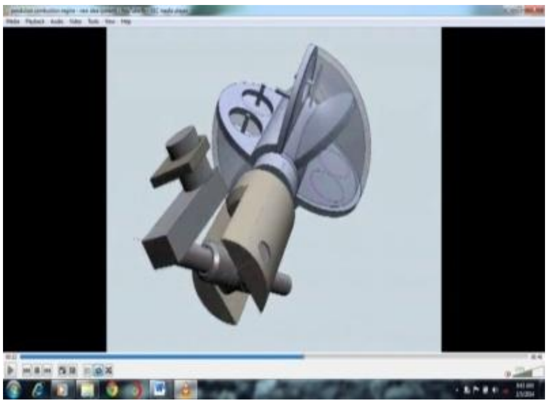
Inlet port is made 20 to 40 per cent larger than exhaust port for better cylinder charging.

Thickness of the valve disc -The thickness of the valve disc (t) may be determined empirically t = 2:38mm

Simulation of Valve gear Train-The development of simulation tools helps in valve train design. The dynamic simulation of a valve train can be done using different software available in the market like, CATIA, PRO/E, Mat Lab, etc. Fig.4(a) shows the simulation window dialog box. A computer model is developed to study the dynamic behavior of a pushrod, tappet. For accurate simulation, the model had many degrees of freedom and will be decided based on requirements accuracy of simulation and convergence. The model is used to investigate following



a) Valve gear train and its simulation



b) Pendulum type combustion engine

Fig.3 Valve gear train and its simulation for Pendulum type combustion engine

i) The dynamic behavior of a valve train over operating speed range ii) The harmful consequences of strongly exciting valve train resonances iii)The minimization of valve train resonances. In general, valve train resonances are excited by camshaft's lift profile. The aggressive motions will excite valve train resonances. Valve train resonances can either increase or decrease component loads, depending upon the resonance phase relationship with the valve train's non-resonant loadings. When resonant and non-resonant loadings are additive, higher contact stresses occur. When these two loads are out of phase with each other, the component separation can occur. During severe separation, each component acquires a different velocity leading to high impact loads.

III. DESIGN AND ANALYSIS

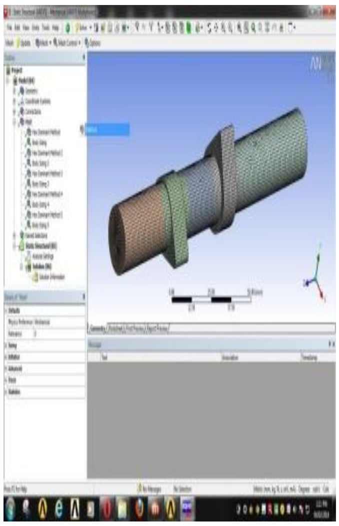
Valve train analysis procedures are carried out in two stages structural and thermal analysis. Structural analysis is used for design of a camshaft and find out static forces on follower. Thermal analysis is used to determine the temperature analysis of valve train component considering the effect of heat generated in combustion chamber.

Analysis is done is ANSY's and ProE software i.e. Structural analysis of follower is done in ANSY's software and Thermal analysis of valve is done in ProE software. We analyzed valve gear train for its valve lift. The conclusion of that can be understood from the graph given below in fig, According to the graph, for the given period of crank angle the maximum lift of exhaust valve is 6.253351 mm and maximum lift of suction valve is 6.105573 mm.

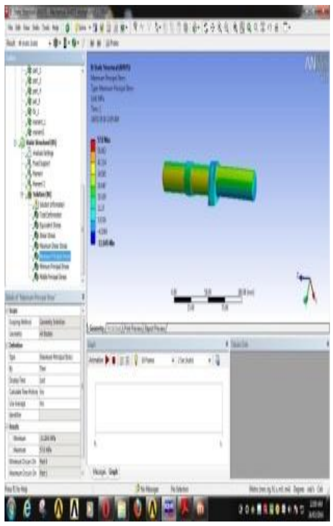
Structural Analysis of Camshaft-The results found after analysis are mentioned below,

Maximum principle stress: 57.8 MPa ,Middle Principle Stress : 17.502 MPa

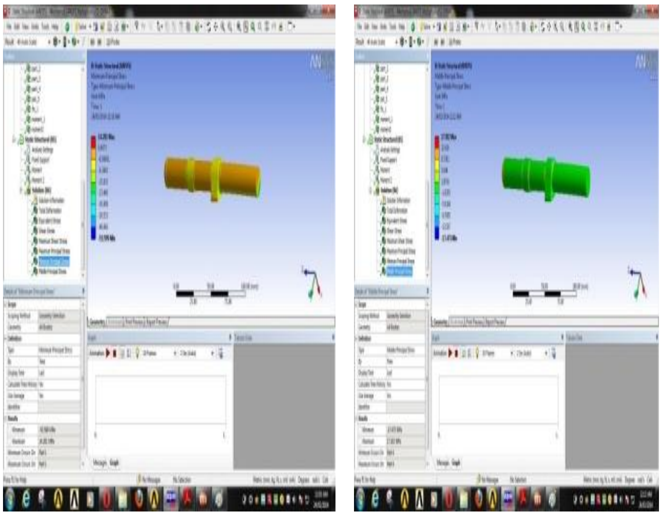
Minimum Principle Stress: 14.701 MPa,Total Deformation : 0.19063 mm



a) Meshed component



b) Max. and Mini. Principle stress



c) Middle Principle stress

Fig.4 Thermal stress analysis

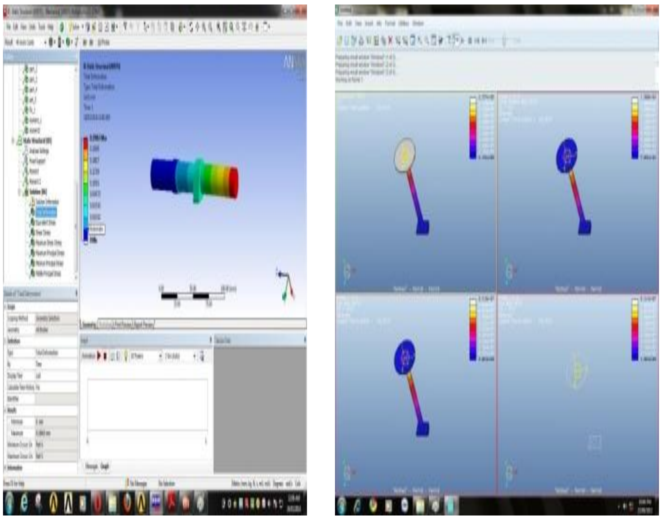


Fig.5 Thermal analysis of valve

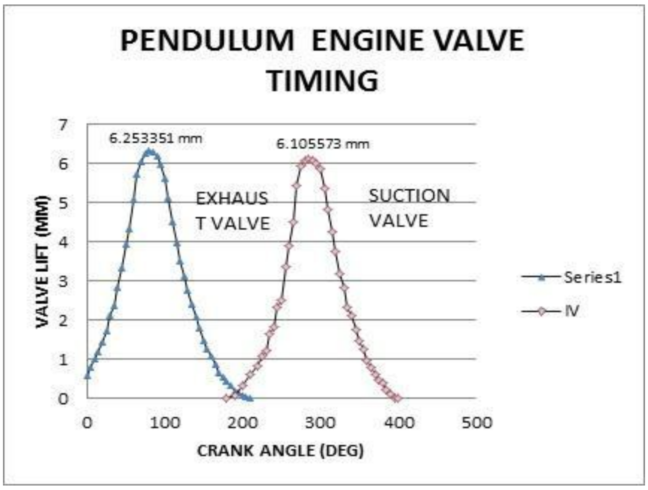


Fig.6 Graph of valve lift vs Crank angle

IV. CONCLUSION

The valve design and the valve timing directly affect the engine performance. As per thermal analysis of valve and structural analysis of follower and camshaft, all are safe for this engine. Valves are rocking as per the valve timings considered. According to analysis, the design is safe for pendulum type combustion engine generating power of 6.24 KW for 4 chambers in work (of which we have considered only one generating 1.61 KW). So, this valve gear train is suitable for the newly developed "Pendulum Type Combustion Engine".

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