CFD ANALYSIS OF VARIOUS DESIGNS OF HOLLOW EXHAUST VALVES FOR INTERNAL COMBUSTION ENGINES

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Abstract— Various designs of hollow exhaust valves are modelled using ProE. The modelled hollow valve designs are 1) Straight hollow portion from top of the stem to the bottom of it. 2) Two hollow portions which are collinear to each other. 3) Two parallel hollow portion with a beam at the center. The hollow portion of the designs are filled with sodium. As per standard designed model is then meshed using Hypermesh. Each of the modelled design is analyzed by CFD software Fluent. It was found that the design 3 had better heat dissipation than other designs. The volume of sodium content affected the heat dissipation property and material surface affected the strength of the exhaust valve. The alternate simple fabrication method is proposed to reduce the complexity of the fabrication method.

Keywords—CFD, Hollow valve

I. INTRODUCTION

An engine valve is a mechanical device that regulates the supply of fuel to an engine. It is an important part of any engine system and comprised of a stem and a head. Exhaust valve is precision engine components used to open to permit the burned gases to exhaust from cylinders [1]. The heads of the valves are subjected to the high temperature of the burning gases. The Exhaust valves may reach a temperature of 800^{o} cherry red. It is essential that they should not warp under the influence of the heat, and that their seats should not scale or corrode, as in either case they would become leaky. Therefore exhaust valve are exposed to serve thermal loads and chemical corrosion. Exhaust valve opens and closes as many as 2000 times per mile.

On account of high temperature operating conditions, the material for exhaust valve should have 1. High strength and hardness to resist tensile loads and stem wear, 2. High hot strength and hardness to combat head cupping and wear of seats, 3. High fatigue and creep resistance, 4. Adequate corrosion resistance, 5. Least coefficient of thermal expansion to avoid excessive thermal stresses in the head, 6. High thermal conductivity for better heat dissipation. Process involved for the exhaust valve basically need high dimensional accuracy and heat treatment to ensure complete sealing of the combustion chamber.

Since the exhaust valve temperatures in modern engines reach very high values of the order of 800°C, cooling of exhaust valves becomes very important. To do this cooling water jackets are arranged as near the valve as possible. Earlier, to carry away the heat effectively, the valves are drilled out to sufficient depth and filled with mixture of potassium nitrate and lithium nitrate salts. Generally two designs are hollow valves are fabricated. The large valves of heavy-duty engines could be kept at a reasonably low temperature by sodium cooling, which is employed extensively for aircraft-engine valves. The main reason they are not widely used in automotive engines is that they are rather expensive to produce.

The aim of the present paper is to perform thermal analysis of various designs of hollow valves and to propose a possible manufacturing process of the designs which would be cost effective at mass production of the valves to be employed in automotive engines.

II. MODELLING AND MESHING OF VARIOUS DESIGNS OF HOLLOW VALVES:

The various designs of hollow valves are designed using ProE modelling software. The dimensions of the each design are as per the standard. The material selected for this high temperature application was stainless steel which has got high strength and hardness to resist tensile loads and stem wear, high hot strength and hardness to combat head cupping and wear of seats, high fatigue and creep resistance, adequate corrosion resistance, least coefficient of thermal expansion to avoid excessive thermal stresses in the head, and high thermal conductivity for better heat dissipation. Hence stainless steel material was chosen as the exhaust material.

Stainless Steels are iron-base alloys containing Chromium. Stainless steels contain less than 30% Cr and more than 50% Fe. They attain their stainless characteristics because of the formation of an invisible and adherent chromium-rich oxide surface film. This oxide establishes on the surface and heals itself in the presence of oxygen. Since sodium has got low specific gravity, a high specific heat, a low melting point, and a high boiling point, it is filled into the hollow spaces of the valves in order to carry away the heat effectively [2].

A. Conventional Design:

The design is a conventional solid valve which is used in regular engines for regulating the supply of air fuel inside the engine. Initially the conventional valve is modelled using ProE. The valve is modelled as per the dimension obtained from Rane Engine valve private limited. The mesh of the modelled design is then created using Hypermesh. The output of the Hypermesh is then fed into Fluent for studying the thermal results of the solid valves. The material selected for the valve is stainless steel. The figure 1 shows the dimension of the valve used whereas the figure 2 shows the ProE design views and meshing of the conventional valve.

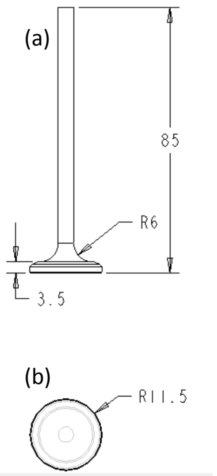


Fig.1. (a) Front view; (b) Top view of conventional exhaust valve

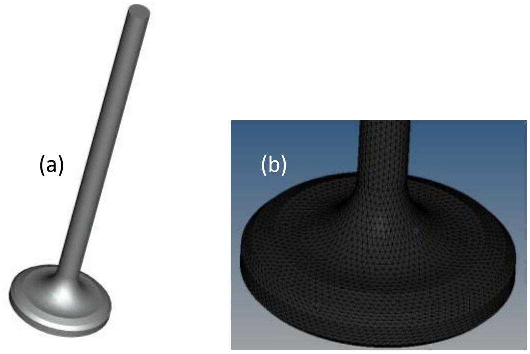


Fig.2. (a) ProE design views; (b) Meshing of conventional exhaust valve

B. Novel Designs:

The design 1 comprises a hollow section through which metallic sodium is filled. The straight hollow section extends from top of the stem to the bottom of it. The length and diameter of the hollow portion is 7cm and 0.5cm respectively. The volume of the hollow portion is 1.375cm^3. The volume of sodium filled is half of it i.e. 0.7cm^3. The figure 3 shows the ProE design views and meshing of through stem one straight hole valve.

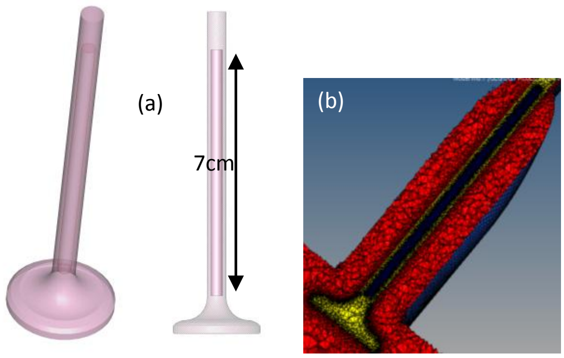


Fig.3. (a) ProE design views; (b) Meshing of through stem one straight hole valve

The design 2 comprises two hollow sections in the valve where the sodium is filled. The hollow portion is split into two sections where the sodium is stored as shown in the figure 4. The diameter of the hollow portion is 0.5cm. The volume of each hollow portion is 0.6cm^3. The volume of metallic sodium is half in each hollow portions. Hence the volume of sodium filled is 1.2 cm^3. The figure 4 shows the ProE design views and meshing of through stem two collinear holes valve.

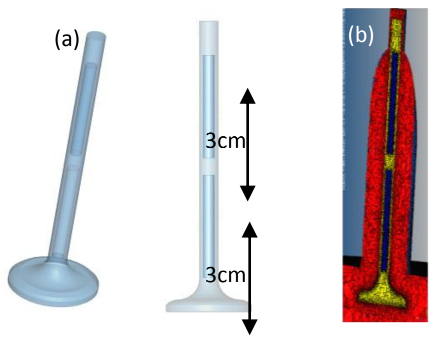
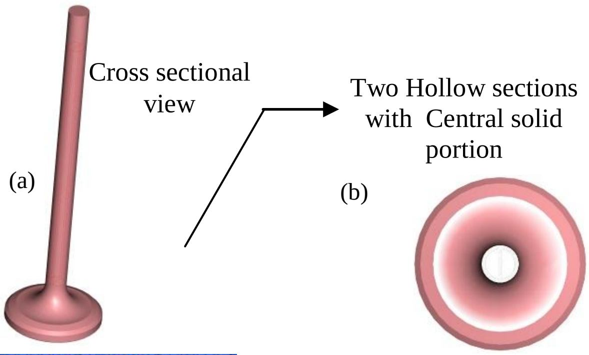


Fig.4. (a) ProE design views; (b) Meshing of through stem two collinear holes valve

The design 3 has two parallel hollow sections along the stem of the valve. The two parallel hollow portions extends from top of the stem to the bottom of the stem as in design 1. The difference in design 3 from that of design 1 is that central beam passes at the center of the hole making two distinct parallel holes. Although the design may be complex, the possibility of conduction and convection might improve the heat carrying capacity of the exhaust valve. The volume of the hollow portion is found to be $0.5cm^3$ calculated leaving the central portion. The figure 5 shows the ProE design views and meshing of through stem two parallel holes valve.



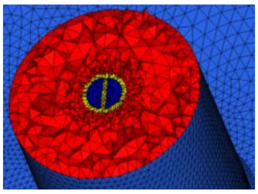
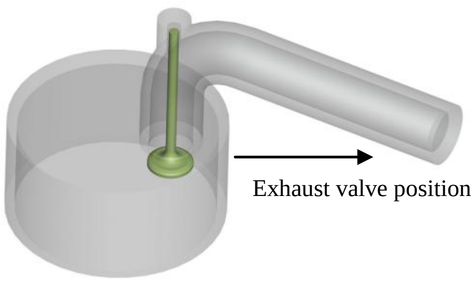


Fig.5. (a) ProE design; (b) Meshing of through stem two parallel holes valve

After the designs are meshed using Hypermesh, each design is studied for thermal analysis. The temperature at the bottom of the head is 800°C. In order to carry out the analysis, a cylinder with exhaust valve setup is designed and the study of each design of exhaust valve is conducted. Finally the temperature distribution of the each design of exhaust valve is determined. The figure 6 shows the arrangement of exhaust valve in the cylinder and meshing of the design using Hypermesh.

(a)



(b)

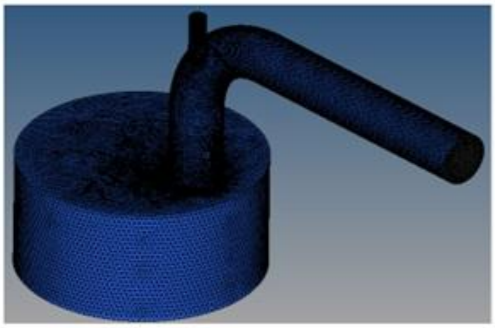


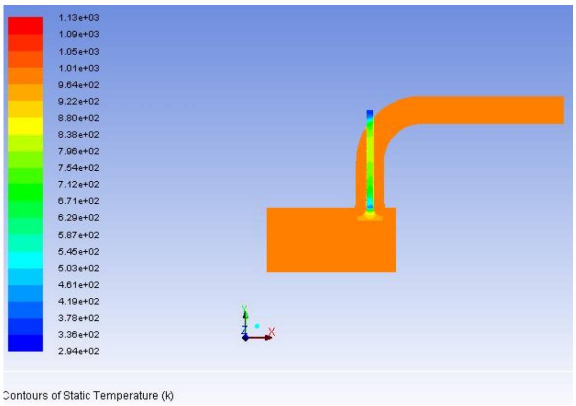
Fig.6. (a) ProE design; (b) Meshing of exhaust valve setup in the cylinder

III. RESULT AND DISCUSSION:

The easier flow of heat was obtained in all the hollow valve designs filled with sodium than that of conventional valve since sodium has higher thermal conductivity. It helped in efficient flow of heat in the hollow valves compared with the conventional solid valve. It is seen that in normal operation the valve is alternately accelerated and decelerated at rates many times that due to gravity, with the result that the sodium is thrown violently from one end of the chamber to the other. When at the top end, it absorbed heat from the hot wall, which it gives up to the cooler, lower end of the stem when next it drops to the bottom of the chamber, whence the heat passes to the valve guide and into the cylinder block.

On comparing the three designs of hollow valves, it was found that design 3, which has two parallel hollow portions helped in even more carrying the heat effectively than other two hollow valve designs. The figure 7 shows the CFD results of design 1 and design 3.

Also the presence of central beam from top of the stem to the bottom of it, the strength of the design 3 is more compared to designs 1 and 2. That helps in providing support to the valve of design 3. In designs 1 and 2, the central beam is absent that prevented providing support to the valve for better strength.



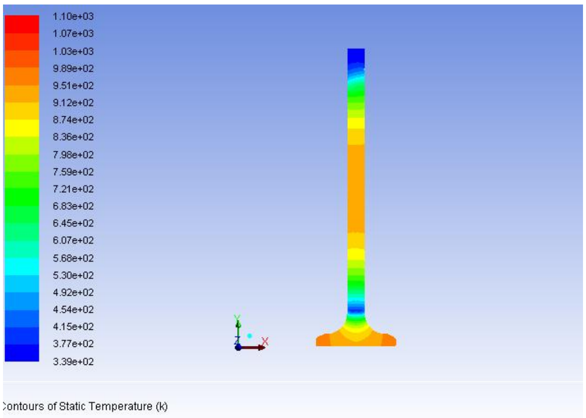


Fig.7. CFD results of design 1 and design 3

Since design 3 had central beam at the center of the valve and two parallel hollow portions on either side of the central beam, the heat is carried away both by conduction through the beam as well as by convection through sodium filled in it. The heat is carried away by conduction through the steel and reaches the bottom of the stem. The heat is also convected to bottom of the stem through sodium as it melts due to higher temperature at the exhaust valve. The conduction and convection are absent in other hollow valve designs. This accounted for less heat carry away by the design 1 and 2.

Also the volume occupied by the sodium in the hollow portion is different in each of the design since the volume of hollow portion and level of sodium filled is different for different designs. The volume of sodium filled decreases in the order of design 1, 2 and 3 as the volume of hollow portion decreases. It was expected that more quantity of sodium in design 1 could have major impact on the heat carrying capacity, but the better heat dissipation of design 3 indicates that even though the volume of sodium filled is less compared to design 1 and 2, the conduction and convection throughout the valve bottom to the top of the stem helped in reducing the temperature increase in the exhaust valve. It also implies that the less quantity of sodium is sufficient to obtain better heat dissipation at the exhaust valve.

The stem is designed larger diameter than usual and could be drilled out from the end and the chamber thus formed, after being nearly closed at the end by swaging process, could be filled about half full with metallic sodium. The sodium will be at the bottom (tip end) of the chamber when the valve is closed.

The method of fabrication of conventional exhaust valves involves 7 stages:

1) Extrusion stage 2) Friction welding stage 3) Upsetting stage 4) Forging stage 5) Heat treatment stage 6) Stellite deposition 7) Turning and Finishing stage. Friction welding is employed for bimetallic valves.

The design 1 could be manufactured by gun drilling. The hole of diameter 0.5cm could be drilled by using gun drilling process. The other process of upsetting, forging could be employed to manufacture single straight one hole valve.

Although the design 2 seems complex than design 1, the screw type fabrication could be employed to manufacture the valve. The stem of the valve is manufactured into two set hollow pieces. The one with screw runs on the thread on the other piece, which would not significantly affect the cost of manufacturing of the valve.

Also the method of fabrication of the design 3 is complex and it may seem expensive, another simple alternate method of fabrication could be adopted to reduce the cost involved in fabricating the complex design of the valve. The valve could be manufactured into two pieces. One piece has a long beam and other beam with three hollow portions. The pieces could be fixed in such a way that the beam of one piece rests on the central hole of the other piece so that two parallel hollow portion with a central beam could be obtained in a simple way. Further research is expected to study the reliability of such a fabricated valve. In this way, the cost of fabrication would not increase significantly if produced in a larger scale.

IV. CONCLUSION:

Hence three novel designs of the exhaust valve is designed using ProE. Thermal analysis of the designs are performed by Fluent. Significantly varied thermal distribution of through stem one straight hole valve and through stem two parallel holes valve are presented. It was found that the design with two hollow portion extending from top of the stem to the bottom of it was better compared with the other designs. The fabrication method of the each of the design are proposed and further research is recommended for the proposed fabrication method in reliability of the hollow exhaust valve.

REFERENCE

[1] V Ganeshan, "Internal Combustion Engines", 3rd edition, Tata Mc-graw Hill

[2] S.D heron, US patent 1,670,965, May 1928