International Journal of Scientific Engineering and Technology (ISSN : 2277-1581)
Volume No.4 Issue No.3, pp: 212-217 01 March. 2015

Design of Innovative Engine Valve

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Abstract: This is part two of the paper on conceptual design of an engine valve. The previous paper describes the background and the need of an engine valve for an internal combustion engine. The present state of the engine valve technology and the innovations incorporated in its design has been described. This paper presents the conceptualization of an innovative valve train aiming at lesser number of components, reduction in friction and wear, proper sealing, and trimming down pumping losses. Various geometric designs of valve trains have been detailed and compared. Finally a convolution based poppet valve mechanism, which is free from numerous mechanical elements like camshaft, cam, push rod, rocker arm and rocker bearing has been recommended. Finite element analysis of convoluted spring has been carried out to ascertain safe limits in terms of stresses and achieving desirable valve lift. Magnetorheological fluid and electromagnet are used to vary the valve-lift.

Keywords: Innovative Design, Variable valve actuation mechanism, cam-less engine valve, Magnetorheological fluid.

I. Conceptual Design of Engine valve

A review of literature has indicated a definitive trend of replacement of cam-pushrod valve train with direct-overhead-cam valve train. Another trend observed is in the reduction of reciprocating masses to minimize friction and wear losses. There is also an observable trend to eliminate mechanical cam drive with hydraulic, electromechanical or electromagnetic drive system. Such trend analysis indicates the possibility of a new valve mechanism as shown in Fig. 4. In the present work three valve train designs have been conceptualized, which are described below.

Concept 1: Rotary valve with magnetorheological fluid:

Rotary valves [14], used for internal combustion engines 1976 [14] proved to be theoretically to reduce losses, but could not take off due to limited sealing characteristics. Recently Paul [15] presented rotary valve assembly with a variable timing control to make rotary valve suitable variable valve actuation. A schematic of such a rotary valve is shown in Fig. 1.The amount of overlap between core and throttle body subassembly reduces or increase the area available for fresh charge.

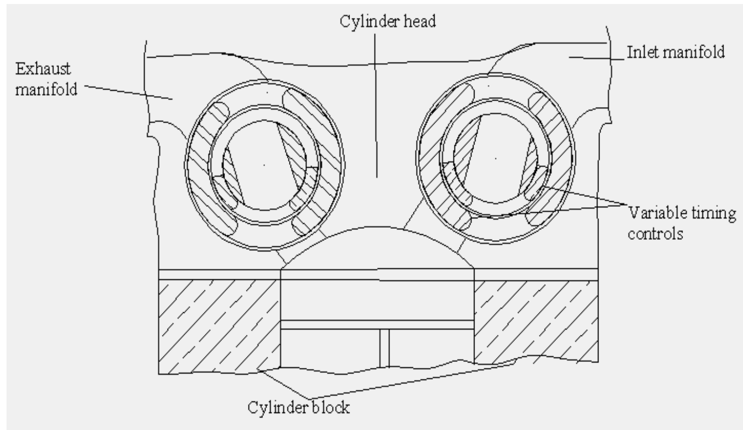

Figure 1: Rotary valve [17]

To overcome the drawback of sealing, rotary valve with magnetorheological fluids, shown in Fig. 2, has been hypothesized in the present study.

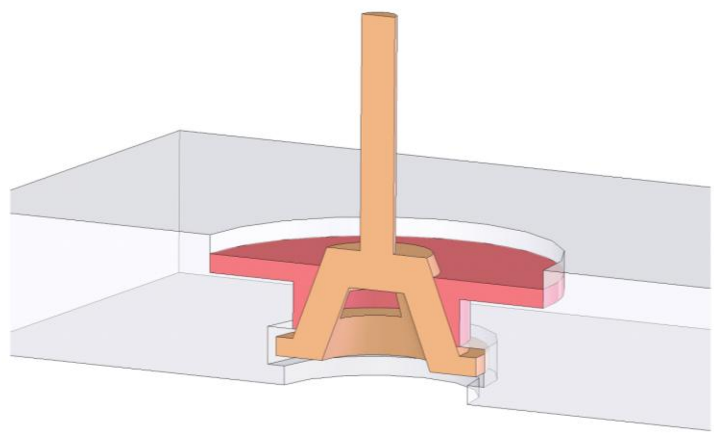
Figure 2: Sketch showing MR fluid, cylinder head and valve

A Magneto-Rheological fluid (MR fluid) is a suspension of micrometer-sized magnetic particles in a carrier fluid, and acts as a smart fluid. On subject to magnetic field, the fluid greatly increases its viscosity. Importantly, the yield stress [16] of the fluid when in its active state can be controlled very accurately by varying the current supplied to electromagnetic coils.

As shown in Fig. 2, the hypothesized rotary valve has a slot to pass fresh charge to the cylinder. When this slot coincides with the opening in the cylinder head, fluid flow (charge) takes place. MR fluid filled in the space between the rotary valve and cylinder head provides tight sealing and does not allow rotary valve and seat to wear out.

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Concept 2: Hollow expandable valve with magnetorheological fluid

While working on new concepts to achieve variable shape valve attempts were made to make the valve analogous to balloon, in the sense that in expanded position valve should occupy about 2 to 3 times the area occupied in the collapsed condition. If this could be achieved, then it could be placed in the cylinder head and in collapsed condition it would allow fluid flow through the annular space between itself and the cylinder head. In the expanded condition, it would touch the cylinder head surface and block the fluid flow, forming a seal. To design a variable stiffness valve, a hollow poppet valve filled with MR fluid, as shown in Fig. 3, was conceptualized.

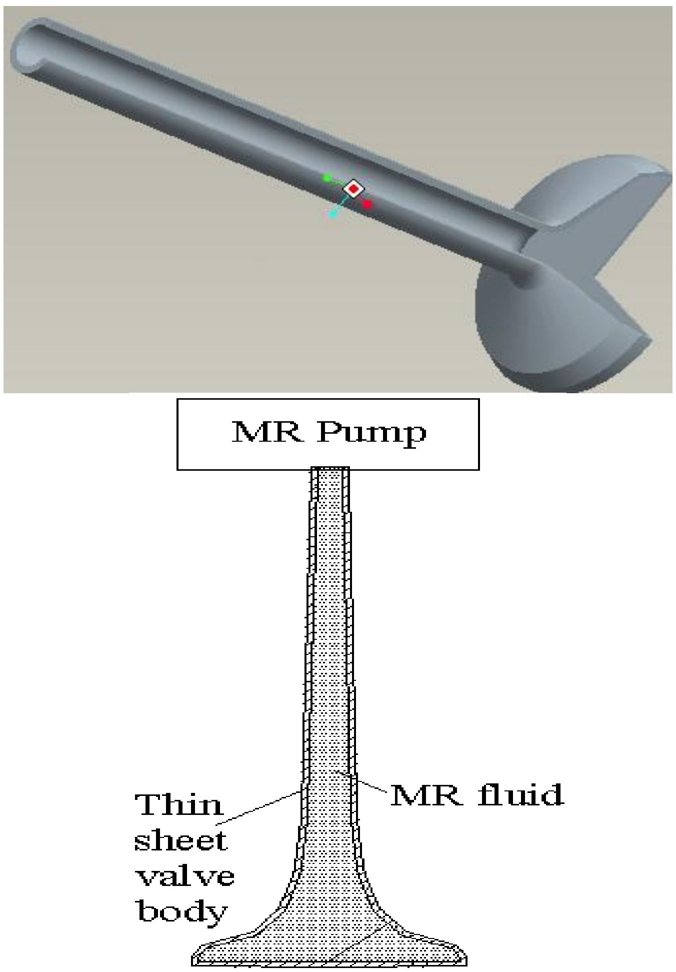

Figure 3: Hollow valve filled with MR fluid

High stiffness of valve could be achieved by magnetizing the MR fluid. In addition magnetic coupling between valve and valve seat would provide excellent sealing capability. However FEM simulation (shown in Fig. 4) indicated that on pressurizing hollow valve, bottom of the valve facing combustion chamber develops a bulge. Therefore there was a need to rethink on this concept of hollow valve.

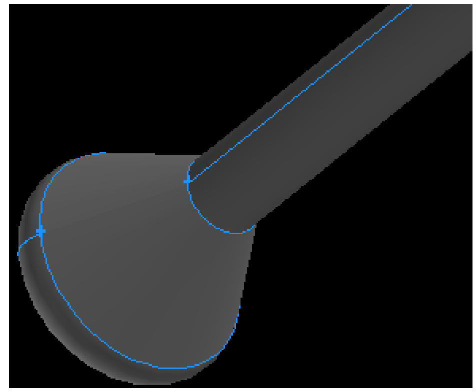

Figure 4: Bulging of hollow valve under fluid pressure

Concept was modified to tubular conical geometry as shown in Fig. 5 and 6

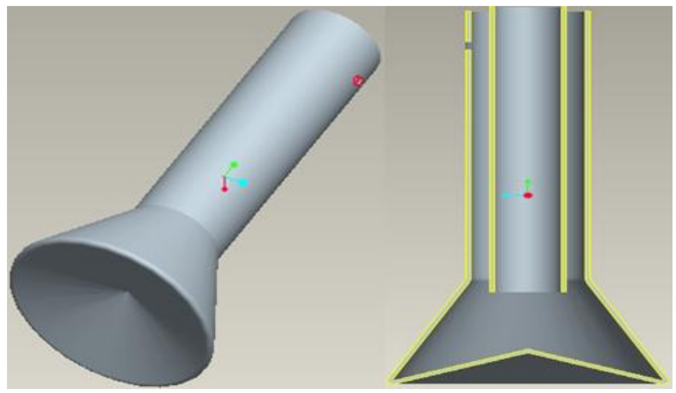

Figure 5 Hollow expandable valve (3-D & x-sectional view)

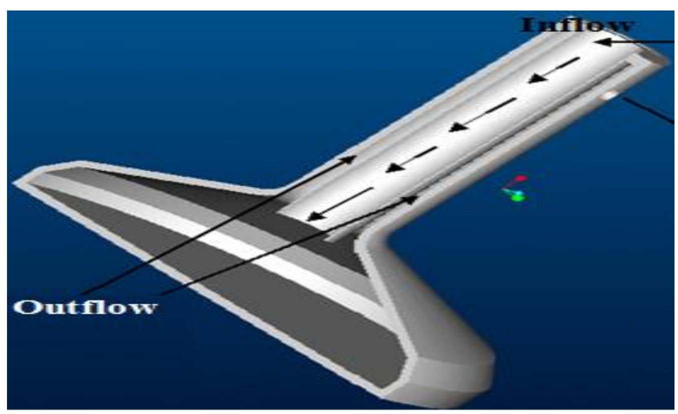

Figure 6 Tubular Conical hollow valve mechanism

This valve has one inlet passage and one outlet hole. On closing outlet valve pressure develops inside the poppet valve which deflects the conical shape to full poppet valve shape (as shown in Fig. 6). Finite element analysis using ANSYS was carried out to get an estimate of the deflection in radial and axial (along the valve stem) direction. The deflection was found to be about 0.3mm in radial direction, which was very low to go ahead with this proposal. To increase the radial deflection, the spherical valve with higher thickness at bottom to achieve more radial expansion and the triangular cross-section of valve (shown in Fig. 7) were attempted.

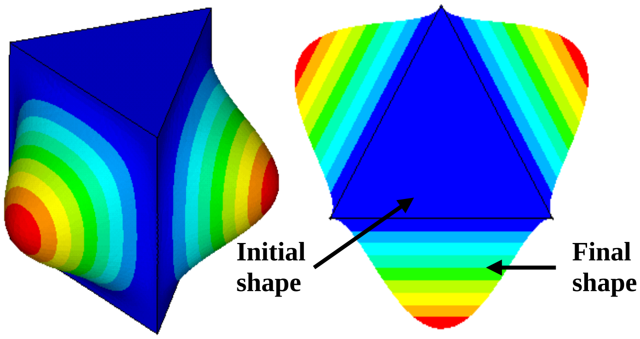

Figure 7 Triangular cross section hollow valve

Fig 7 shows triangular geometry of valve when outlet of valve (shown in Fig. 6) remains open and allow easy passage of MR fluid. However, on closure of outlet of valve, pressure develops within the valve and the valve faces bulge out and take the final shape (valve in closed condition). The simulation results indicated an initial cross-sectional area (when outlet area remained open) was 171 mm^2 and in the final position (closure of outlet area) its cross-sectional area turned out to 445mm^2. Such variation in area (274mm^2) was good enough to allow fresh charge to fill the cylinder, however high values (approximately 5000 MPa) of stresses forced to think an alternative concept. In addition MR fluid takes approximately thirty milliseconds to change its liquid state to solid state completely. If such a liquid to solid cycle is required for every two rotation of crankshaft, then maximum achievable speed would be restricted to 3000 rpm. Due to these limitations, a need to alternative concept was realised.

Concept 3: Convoluted spring and solid poppet valve

Working on two previous concepts it was learnt that getting radial deflection of valve body compared to axial deflection was difficult. So instead of using the radial expansion of valve for blocking & allowing the fluid flow, the axial deflection was emphasized in the present concept.

The functional requirements such as free fluid flow during suction stroke, complete sealing during the compression, power and exhaust strokes, and minimal consumption of energy can be achieve by deflecting/displacing valve geometry axially. To achieve this, an assembly of convoluted spring and poppet valve, as shown in Fig. 8, is proposed.

In the present concept, the poppet valve is fixed to the convoluted spring configuration and both move integrally. In the expanded position, convoluted spring pushes the valve inside the cylinder, which is generally achieved in contemporary vehicles by cams. In other words, the convoluted spring acts as an actuator for the conventional (solid or hollow) poppet valve. By using this concept, the camshaft, its accessories, springs, etc. can be eliminated.

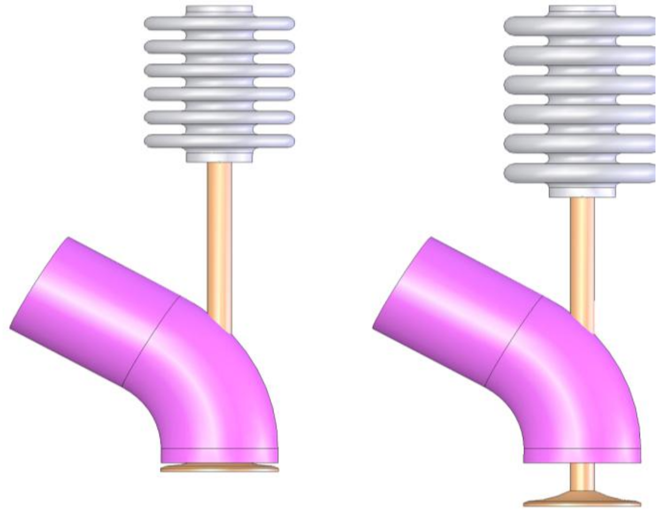

Figure 8 Closed and opened positions of valve actuated using convolution spring

The convoluted spring under internal pressure greater than atmospheric pressure elongates in axial direction, there-by acting as an actuator for the valve. For return motion of poppet valve, two options are proposed. One option is to release the pressure as elaborated in option ‘A’ below and the other option is to utilize the pressure build-up inside the cylinder to move the valve in the upward direction as explained in option ‘B’.

Option A: It is proposed to release the pressure in the convolutions to return back to its un-stretched position. In the present study MR fluid is used as the pressurizing media. Figure 9 shows the circuit of the MR fluid flow.

The MR fluid is pumped into the convolution spring. The MR fluid exit from the bellow is connected to a sump, through a controllable magnetic field. When the magnetic filled is switched on, the MR fluid will solidify across the magnetic field, thus builds up pressure in the bellow required for its functioning.

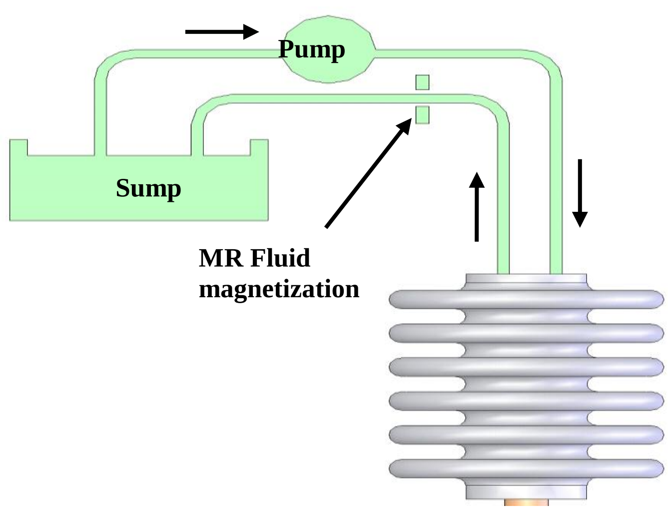

Figure 9 MR fluid circuit diagram for convoluted spring poppet valve assembly

Sequence of operations

The bellow is pressurized internally, so that it expands axially and opens the valve. The pump operates continuously and pressurization is achieved by blocking the MR fluid flow as shown in the circuit diagram. The MR fluid flow is blocked by applying a magnetic field across the flow.

When the valve is to be closed, the magnetic field is switched off and because of the continuous pumping, the solidified MR fluid is broken up and the built-up pressure vanishes. So the bellow is no more pressurized internally, hence by virtue of its shape, it acts like a spring and comes back to its original position.

Hence, the valve is opened and closed by controlling the time at which MR fluid is magnetized and de-magnetized.

Option B: It is proposed to use the pressure in the cylinder side to close the inlet port with poppet valve. When the pressure on the cylinder side increases beyond the internal pressure of the convolutions, the return reciprocating motion of the valve starts. On solidification of MR fluid wall thickness of convolute spring increases and valve remains open for longer duration. To understand the operation of proposed inlet valve, let us consider the process of suction stroke. During the suction stroke, pressure in the cylinder would be lesser than atmospheric pressure, and this sub-atmospheric condition would allow “internally pressurized convoluted spring” to expand completely and open the inlet port of cylinder. During the start of the compression stroke too, the inlet valve would remain for a few degrees of the crank rotation to enhance the engine performance. This way inlet valve would work satisfactorily.

At higher engine speeds, better breathing of cylinder is essential and for that purpose inlet valve need to remain open for longer duration in terms of crank-angle. This can be achieved by hardening the MR fluid, which in turn increases the wall thickness of convoluted spring. Increased thickness of convolute springs requires higher pressure to get compressed. Higher cylinder pressure during compression stroke means longer duration in terms of crank-angle. Therefore on hardening MR fluid, the inlet valve remain would remain open for longer duration in terms of crank-angle. Thus, inlet valve meets its functional requirements at low as well as at high speeds. As this option does not require any pump and pipe fitting, therefore this option of valve train is cost effective solution and can be named as “Innovative Engine Valve train”.

III. FINITE ELEMENT ANALYSIS OF INNOVATIVE ENGINE VALVE

Finite element analysis of the convolution concept has been carried out basically to decide the dimensions of convolute spring for a typical 10 mm lift of conventional (solid) poppet valve. The stresses and deflections have been determined to ensure that they are as per requirements. Theoretical results of FEM study carried out on geometric model shown in Fig. 10, are tabulated below:

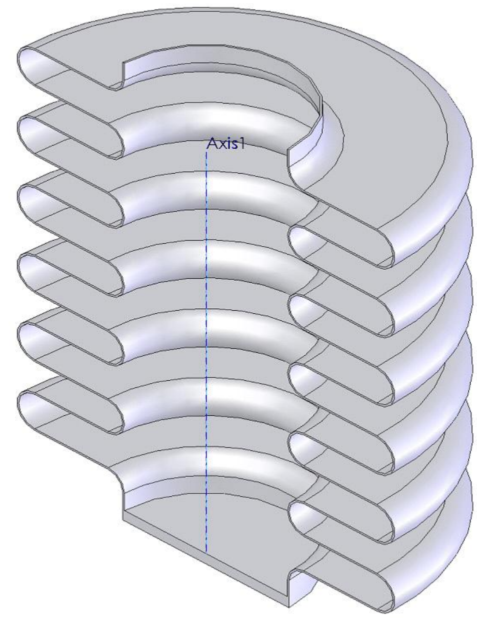

Figure 10: Model of convolution configuration valve

Table 1: Theoretical study on number of convolutions and wall thickness

No. of convolution	Thickness (mm)	Pressure (MPa)	Convolution depth (mm)	Stress (MPa)	Deflection (mm)
3	0.1	0.2	Only radius of 2mm	285	0.22
3	0.1	0.2	8mm with 2mm radius	4275	94
5	0.2	0.2	8mm with 2mm radius	1160	14.9
6	0.2	0.06	9mm with 2mm radius	357	11.07

Based on the results, six convolutions with thickness of 0.2 mm and depth of 9 mm were considered for detail analysis. Detailed geometry is shown in Fig. 11.

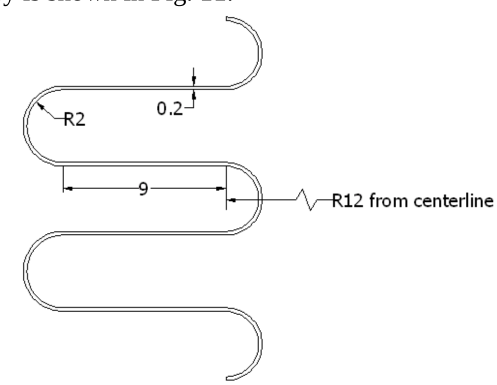

Figure 11: Convolution dimensions

Three dimensional 10-node tetrahedral structural solid elements (size: 0.4mm), which can take up large deflection, were used for finite element analysis. Titanium material, having Young's modulus equal to 105 GPa and Poisson's ratio equal to 0.37, was used for the present FEM analysis. The meshed model of convoluted spring is shown in Fig. 12.

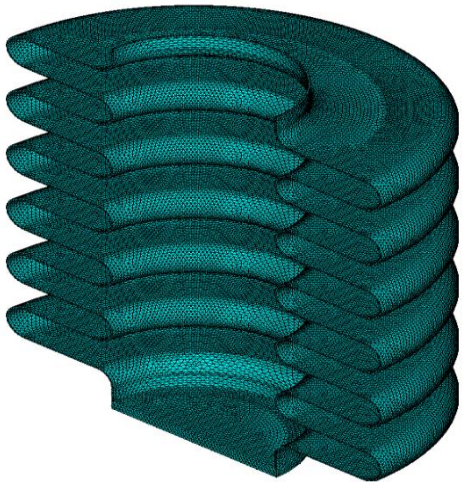

Figure 12: Meshed model

This model contains 430457 elements and 850687 nodes. To apply boundary conditions, the top surface of bellow was constrained. Gauge hydrostatic pressure equivalent of 0.06 MPa was kept as internal pressure within the convoluted spring. Overall axial displacement and Von-Mises stress distribution are shown in Fig. 13 and Fig. 14 respectively.

These results demonstrate the feasibility of assembling convoluted spring and poppet valve as “innovative valve train”. However, detailed experimental and theoretical analyses are required to establish the feasibility of this concept.

IV CONCLUSION

The paper presents three conceptual designs of the valve train for an internal combustion engine. The proposed concept of assembling convoluted spring with poppet valve as “innovative valve train” is feasible. This innovative valve train provides 11 mm as valve lift with six convolutions in spring.

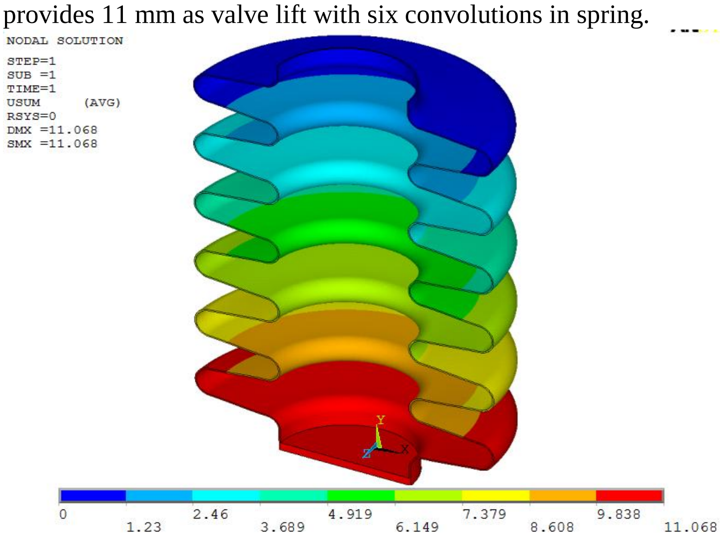

Figure 13: Overall axial deformation analysis

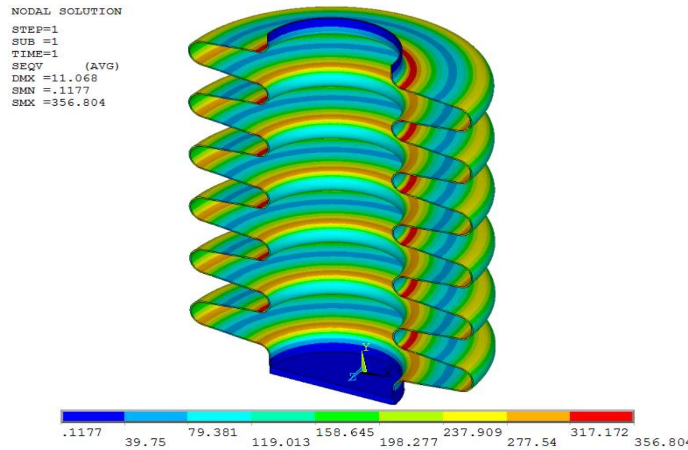

Figure 14: Von-Mises Stresses

The proposed valve train eliminates the cam, camshaft, pushrod, etc. which is required in conventional engine valves. With this innovative valve train the engines frictional losses can be reduced substantially. However for adoption of this concept a detailed fatigue analysis and experimental study is required.

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