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Redesign of Stationary I.C. Engine Valve using Optimization and FEM

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Abstract: *Intake and exhaust valves are very important engine components that are used to control the flow and exchange of gases in internal combustion engines. They are used to seal the working space inside the cylinder against the manifolds; and are opened and closed by means of what is known as the valve train mechanism. Such valves are loaded by spring forces and subjected to thermal loading due to high temperature and pressure inside the cylinder. This project deals with the stress induced in a valve due to high pressure inside the combustion chamber, spring force and cam force. For modeling CATIA is used and to analyze the valve ANSYS is used as the tool. Structural analyses performed on the valve. Optimization of valve radius is done and radius 9 mm is selected for improved design. In this case 41 % stresses are reduced with 9 mm fillet radius compared to zero radious. Further, Super Alloy 21-2N Valve Steel Material is suggested for new design having better results over other materials.*

Keywords: I.C. Engine, Valve, Stress Analysis, Design of Valve, Valve Stem.

I. INTRODUCTION

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 lift profiles and valve train components is most important for the engine performance. 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. The basic nomenclature used for valves is as shown in Fig.[1]

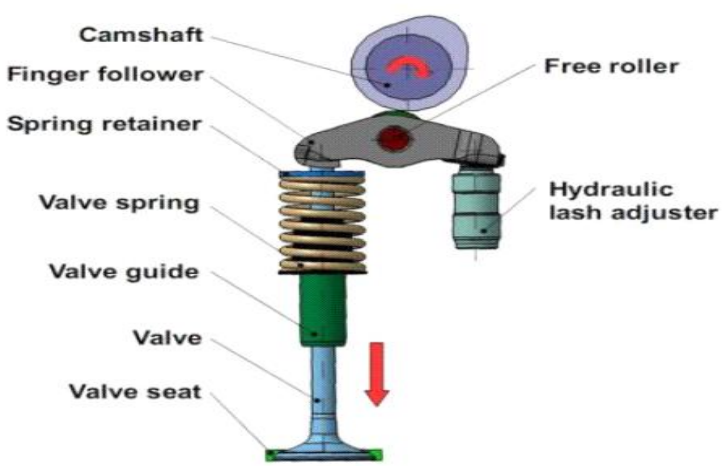

Fig 1 Engine Valve Mechanism

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1.1 Objectives of Valve Train

Valve train design and the valve timing directly affect the engine performance. The important objectives of valve train are;

- **Engine Performance:** The main requirements here are the exact timings (Valve opening and closing), a high volumetric flow (flat valve lift), and fast opening and in some cases a short overlap period. The usual considerations for design optimization are WOT (wide open throttle) performance characteristics for gasoline engines and full load smoke for diesel engines.
- **Durability:** The limits for the design are given by Hertz pressure, the oil film thickness at cam/follower, velocity and force at the valve seat, prevention of contact loss and valve bouncing.
- **Vibration and Noise:** Optimum solutions are achievable with high stiffness and high natural frequencies of the valve train. The impacts and the inertia forces should be minimized.

1.2 Purpose of Valves

The purpose of the valve in the cylinder of the engine is to admit the air-fuel mixture and to force out the exhaust gases. The inlet valve also known as intake valve admits the charge into the cylinder and exhaust valves are used to send the exhaust gases out of the cylinder. In a 4-stroke engine the inlet valve and exhaust valve operate once in two revolution of the crankshaft. Each of the valves must operate once in one turn and this is done by a camshaft, which turns at half speed of the crankshaft. The firing order of cylinder establishes the sequence in which the valves opening and closing. The main components of the mechanism are valves, rocker arm, valve spring, push rod, cam and camshaft. The fuel is admitted to the engine by the inlet valve and the burnt gases are escaped through the exhaust valve.

Jerry Jaskólskiet. al. have stated in his paper that “The Temperature - and Stress Fields of Valves of IC Engine” and concluded that

1. The temperature field is not easy comprehensible in techniques, the temperature computed in the middle are too low.
2. In general, the intake valves have cavity in the centre part of the ‘fire-surface’ of the cone. Hence, the huge compression stress there should vanish.
3. One can attain to the stresses commonly occurring in the common highly forced Diesel engines, i.e. in their valves – about 500 MPa.

B.E. Gajbhiyeet. al.have stated that “Vibration Testing and Performance Analysis of IC Exhaust Valve Using Finite Element Technique” and concluded that

1. Stem of valve is most affected zone.
2. The deformation is observed at the bottom side of the valve. But as this portion is placed on valve sheet, this deformation is reduced.
3. Exhaust valve may damage due to high vibrations at resonance frequency value which slightly greater than natural frequency of exhaust valve.

1.3 Methodology

1. Redesign of intake valve based on actual failures.
2. Modelling using CAD software.
3. Static Analysis using FEM.
4. Selection of optimized design parameters- fillet radius& material.

1.4 Design of Intake Valve

Specifications:

- 4-Stroke CI engine-

Allowable Stress 55N/mm2 (Carbon Steel),
Gas Velocity 2400m/min
Max.Gas Pressure 5.5 N/mm2,
Stroke: 120 mm
Intake valve Temperature is 8000C.
Valve Seat Angle 450,
MeanPiston Speed 250m/min,
Cylinder Bore Diameter 100mm,
Engine speed: 1000 rpm
Length = 10cm

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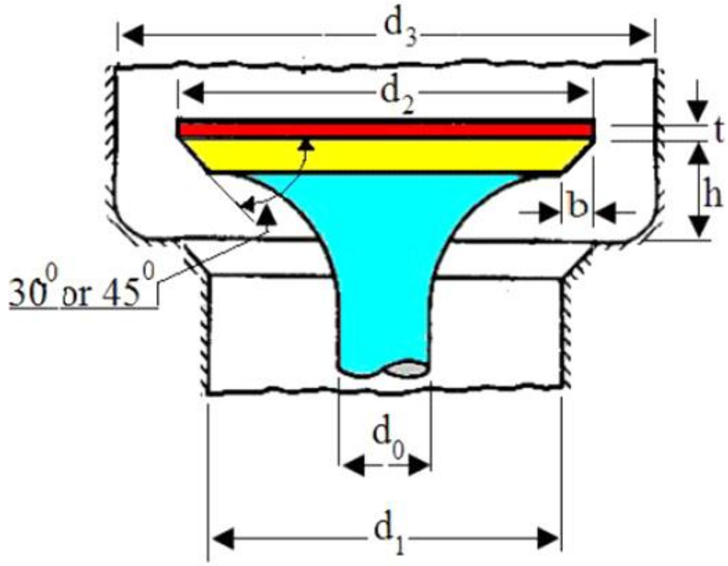

Fig.2 Valve dimensions

d_1= d_{port} = Portal diameter =D= $\sqrt{\frac{\text{Piston speed}}{\text{velocity of gas through valve}}}$

d1 $\sqrt{\frac{250}{2400}}$

= 32.3 mm

Valve lift h $= \frac{0.25d1}{\cos\alpha}$

$= \frac{0.25\ x\ 32.3}{\cos 45}$

= 11.42 mm

α = valve face angle = 45°

Port area = $\frac{1}{4}\pi d_1^2$ = 819.4 mm^2

Thickness of valve disc, t $= k_1\, d_1 \sqrt{\frac{\text{Pmax}}{\sigma}}$

=0.42 x 32.3 $\sqrt{\frac{5.5}{55}}$

= 4.29 mm

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Where

k_1 = 0.54-for cast iron; 0.42-for carbon steel &high grade steel

σ= allowable stress = 55 MPa for plain carbon steel

Diameter of Valve head, d_2 $= d_1 + 2(t \times \sin(90 - \alpha))$

$= 32.3 + 2\,(4.29 \times \sin 45)$

= 38.37 mm

Diameter of valve head opening area, d_3 $= \sqrt{d1^2 + d2^2}$

$= \sqrt{32.3^2 + 38.37^2}$

= 50.16 mm

Width of seating, b $= 0.5\,(d_2 - d_1)$

=0.5 (38.37–32.3)

= 3.035 mm

Diameter of valve stem do $= \frac{d1}{8} + 4$ mm

$= \frac{32.3}{8} + 4$ mm

= 8.04 mm

Diameter check

$0.7854\,(d_3^2 - d_2^2) \geq 0.7854\, d_1^2$

$0.7854\,(50.16^2 - 38.37^2) \geq 0.7854\,(32.3)^2$

$819.77 \geq 819.4$

Size of valve ports Check:

Vg × a = Ap × Cpave.

Where Vg = velocity of gas ≈2300 to 3300 m/min-for stationary/marine engines

= 2400 m/min ≈3300 to 5000 m/min-for automobile engines

Ap = area of piston= $\frac{1}{4}\pi D^2 = 7853.98$ mm^2

Cpave = average piston velocity = 2 L N, m/min

= 2 x 0. 120 x 1000

= 240 m/min

By calculations,

a = port area= $\frac{1}{4}\pi d^2_{port} = 1000$

$\mathbf{d_{port}}$= 31.63 mm

$$V_g' = \frac{14.7\ Vg.\ T.\ \eta ch.180}{520P\ (180+\alpha+\beta)}$$

$$V_g' = \frac{14.7x\ 7874.02\ x\ 528\ x\ 0.85\ x180}{520\ x\ 14.7\ (215)}$$

= 5689.58 ft/min≤12000ft/min.

Where,

Vg = gas velocity – fixed – in ft/min

(180+α+β) = Duration of valve opening = (180+10+25) = 215^0

T=Intake temp. inRankine – T ^oF = 1.8 T^oC+32, and T(R)= T^oF+459.67

Intake temp ≈ 20^oC = 68^oF = 528 Rankine

$_{ch}$= Charging efficiency ≈85%;

P = pr. of gas in psi =14.7 psi - for intake = 1atm.

Inlet valve – α = opening advance = 10^o, & β = closing delay – generally = 20 to 30^o

V'_g- For Stationary engines ≤12000 ft/min – for intake valve &≤18000 ft/min – for exhaust valve

- For Automobile engines ≤18000 ft/min – for intake valve &≤27000 ft/min – for exhaust valve

II. MODELING & ANALYSIS

Modeling

Modeling is the process of producing a model; a model is a representation of the construction and working of some system of interest. A model is similar to but simpler than the system it represents. One purpose of a model is to enable the analyst to predict the effect of changes to the system. On the other hand, a model should be a close approximation to the real system and incorporate most of its salient features, on the other hand, it should not be so complex that it is impossible to understand and experiment with it. A good model is a judicious tradeoff between realism and simplicity.

Geometric Modeling-

The geometric modeling is used to represent the geometry in terms of points, curves. It stores enough information to fully describe the boundaries and the topology of the object. Fig. below shows the geometric modeling of the structure with coordinate system used for Finite Element Analysis. During the present study, the geometry of the conveyor frame is developed using CATIA V5 R20. Geometric modeling is done in parametric way; so that effect of change in dimension on quantities can be obtained by changing the parameter only.

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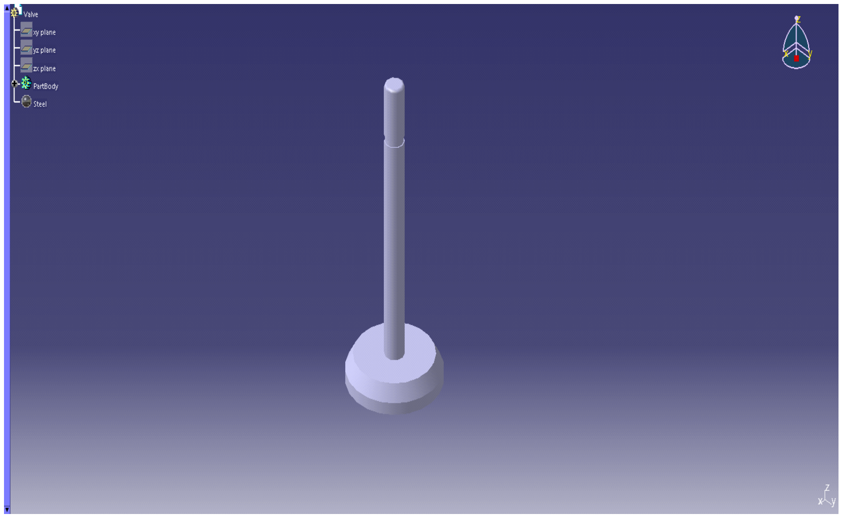

Fig.3 CAD Model of valve – isometric view

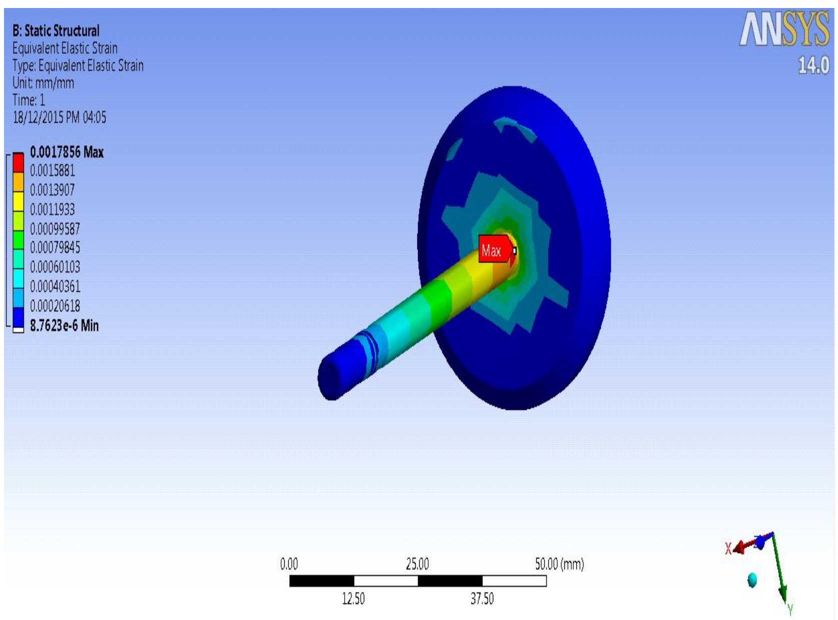

Fig 4 Elastic Strain of Valve in Carbon Steel Material.

III. OPTIMIZED VALVE MODELLING AND ANALYSIS

Fillet Radius used for Optimization

Trial	Fillet Radius, mm
1	1.5
2	3
3	4.5
4	6

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5	7.5
6	9
7	10.5
8	12

Result
From the below results it can be seen that till 6.0 mm fillet radius stresses generated are higher than proposed material allowable stresses and hence can't be consider.
Due to valve seat arrangement and size restriction maximum radius, we can afford to select is 9 mm, and hence fillet radius for further work is 9 mm.

Trial	Radius, mm	Elastic Strain, mm/mm	Von Mises Stress, MPa	Stress Intensity, MPa	Maximum Principal Stress, MPa
0	0	0.00178	346.85	358.18	110.02
1	1.5	0.00166	330.19	354.1	80.418
2	3.0	0.00138	274.96	286.82	68.838
3	4.5	0.00128	255.42	264.25	60.834
4	6.0	0.00122	244.75	251.98	51.775
5	7.5	0.00115	230.14	237.17	42.279
6	9.0	0.00107	214.37	219.37	35.067
7	10.5	0.00098	195.83	199.29	30.747
8	12.0	0.000901	179.93	182.43	29.061

3.1 Material Optimization
Materials Used for Valve:
Super Alloy 21-2N Valve Steel (UNS K63017)

Elements	Content (%)
Chromium, Cr	20.35
Manganese, Mn	8.5
Nickel, Ni	2.13
Carbon, C	0.55
Molybdenum, Mo	0.50 max
Silicon, Si	0.25 max

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AISI 1541 Carbon Steel

Element	Content (%)
Iron, Fe	97.82 - 98.29
Manganese, Mn	1.35 - 1.65
Carbon, C	0.360 - 0.440
Sulfur, S	0.0500
Phosphorous, P	0.0400

Results Based on Material

From the above result it can be seen that Material 21-2N gives us better result without failure.

Material	Elastic Strain, mm/mm	Von Mises Stress, MPa	Stress Intensity, Mpa	Maximum Principal Stress, Mpa	Weight, gm
Plain Carbon Steel	0.00107	214.37	219.37	35.067	150
21-2N	0.00102	204.48	209.25	33.14	155
AISI 1541	0.00105	211.07	216	34.528	180

3.3 Validation:

Validation or Verification, in engineering is, `confirming that a product or service meets the needs of its users.'Software results should be compared with appropriate theoretical results whenever possible. In most cases, one would use theory to obtain order-of-magnitude estimates rather than to make a head-to-head comparison since presumably FEA is being used because a theoretical solution is not available.

Numerical solution method is approximate method.The results obtained from FEA analysis depend on the mesh. An important step in the analysis is to make sure that the mesh resolution is adequate for the desired level of accuracy. This is done by refining the mesh and comparing results obtained with different levels of mesh resolution.So the numerical result has to be compared with either Analytical results or with Experimental results, to ensure as per requirement working and the safety of the component.

IV. CONCLUSION

Valve radius fillet plays important role in valve failure and should be carefully selected.

- The results we got for valve radius are showing good improvement compared to allowable stresses.
- Valve with fillet radius 9.0 mm shows safe results and is selected for further work.
- Material 21-2N shows less stress (3.8 %) and weight (13.89 %) compare to AISI 1541 and hence finally suggested for Valve improvement.
- Overall reduction in stress is 41.05 % and weight is on greater side by 3.22% and is not a big issue considering stress reduction.

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