Effect of variance of geometric parameters and materials on poppet engine valve

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Abstract: Poppet engine valve is a precision engine component whose functionality is to seal the working space inside the cylinder against manifolds by continuously opening and closing of valve according to valve timing diagram due to which it is subjected to fluctuating stress and as a result of which it tends to fail due to fatigue. Thus this research paper explores the effect of variance of geometric and materials on poppet engine valve to improve its mechanical properties particularly fatigue life using Ansys software.

Keywords: Poppet engine valve, Geometric parameters, Fatigue life, Mechanical properties, Materials.

Introduction

Design of poppet engine valve intrinsically affects the performance of internal combustion engine. With this view this research paper aims to explore the effect of variation of geometric parameters and materials on the mechanical properties of poppet engine valve with mainly to improve its fatigue life.Both exhaust and inlet valve are vital components of an IC engine and which are controlling the flow of fresh air and burnt gases in and out of engine cylinders. In four stroke engine during suction stroke inlet valve remains in open condition which allows the flow of fresh air insidethe combustion chamber and exhaust valve is kept closed. In power stroke both valves remain closed. At the end of power stroke exhaust valve gets opened to remove burnt gases from combustion chamber.

Basic terminology of Poppet engine valve,[1]

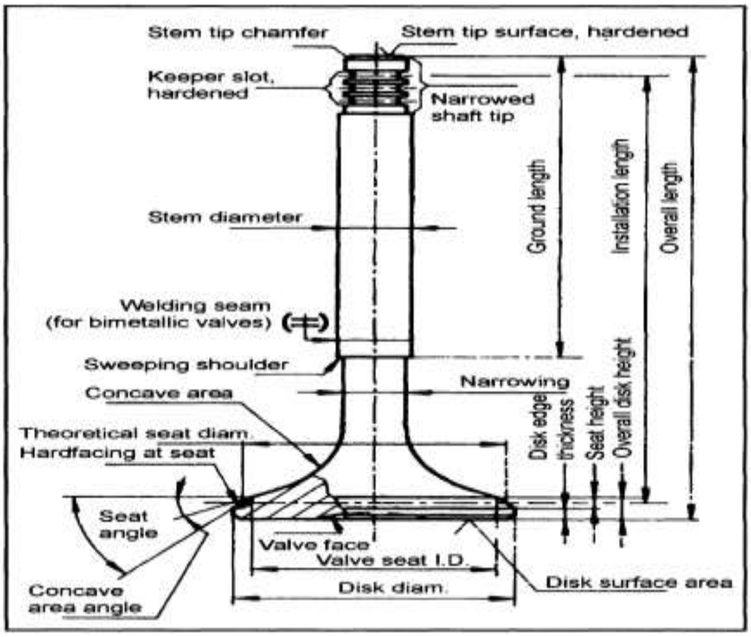

Figure1: Basic terminology of popet valve.

2. Design of poppet engine valve

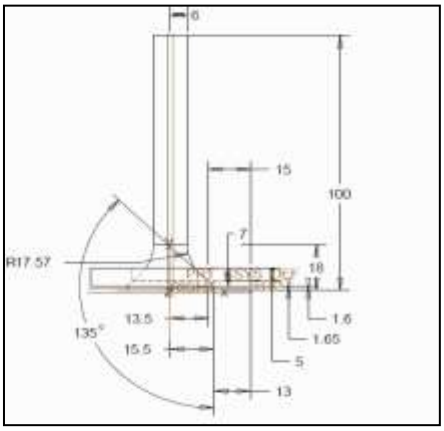

Figure2: Dimensions of poppet valve and valve seat

Above figure shows poppet engine valve where all dimension are in mm.

Specification of Engine for which the poppet valve is designed,

Bore Diameter D = 73.5 mm

Length of stroke L = 73.5 mm

Engine Speed N = 5500 rpm

Break horse power (bhp) @ 5500 rpm =37

Specification of Poppet engine valve

Diameter of valve port (D_p) = 27 mm

Width of valve (W) = 2mm

Valve angle (θ) = 45

Diameter of valve head (D_v) = 31 mm

Thickness of valve disk (t) = 2 mm

Margin (M) = 1.6 mm

Diameter of valve stem (D_s) = 12 mm

Maximum valve lift (h_{max}) = 10 mm

Kinematic motion of poppet engine valve is governed by valve actuating mechanism generally push rod mechanism. This mechanism is driven by motion of crankshaft of engine and as a result of which poppet engine valve continuously opens and closes the ports which control the flow of gas through ports.

Poppet engine valve is opened by valve actuating mechanism just before the beginning of exhaust stroke so that exhaust gases are blown out and it is closed by compressed spring just after the beginning of suction stroke. Thus poppet engine valve is continuously under tension and compression alternatively which lead to fatigue failure

2.1 Calculation for forces acting on poppet engine valve,

a) Force required to open the valve

$F_{open} = F_i + F_l + F_g$ --------------(1)

Where,

F_i = Initial spring force

F_l = Force required to lift the valve

F_g = Gas force

Mathematically,

$F_i = \frac{\pi}{4} D_v^2 * P_s$ ------------------(2)

Where,

P_s = Suction pressure

= 0.002 to 0.004 N/mm^2

$F_l = k * h_{max}$ -----------------(3)

Where K= spring stiffness

= 10 N/ mm

$F_g = \frac{\pi}{4} D_v^2 * P_g$ ------------------(4)

Where P_g = gas pressure

= 0.35 to 0.45 N/mm^2

Substituting equation (2),(3) and (4) in equation (1),

F_{open} = 379.11 N

F_l = 15.08 N

2.2 Calculation for valve timing of poppet engine valve [4]

Engine under consideration is high speed engine and as a result of which the exhaust valve will open 55 before Bottom dead center and will close 20 after top dead center[3]. This being true theoretically but will deviate from it under practical situation whose consideration is beyond the scope of this research paper.

Total angle of rotation of crank shaft when exhaust valve is open is,

$\Theta_1 = 55 + 180 + 20$

$= 255$

Total angle of rotation of camshaft when exhaust valve is open

$\Theta_1 = \frac{255}{2}$

$= 127.5$

$= 2.224$ radians

Speed of camshaft is given by,

$N_{cs} = \frac{5500}{2}$

$= 2750$ rpm

Number of rotation of camshaft per second,

$N_{ps} = \frac{Ncs}{60}$

$= \frac{2750}{60}$

= 45.83 seconds

Time required by camshaft to complete one rotation,

$T_{1r} = \frac{1}{Nps}$

$= \frac{1}{45.83}$

= 0.0218 sec

Time required by camshaft to complete rotation of one degree,

$T_{1d} = \frac{T\,1r}{360}$

$= \frac{0.0218}{360}$

$= 6.06*10^{-5}$ seconds

Time for which the exhaust valve is open is given by,

$T_{open} = \Theta_1 * T_{1d} = 255 * 6.06*10^{-5}$

$= 15.453*10^{-3}$ seconds

Cycle time for poppet engine valve to once open and close is given by,

$T_{total} = 360 * T_{1d}$

$= 360 * 6.06*10^{-5}$ seconds

$= 21.86*10^{-3}$ seconds

Where ,

$T_{total} = T_{open} + T_{idle}$

Where,

T_{idle} = Time for which valve is closed and is in idle state which means that it neither opens nor close during this time.

Therefore,

$T_{idle} = T_{total} - T_{open}$

Substituting values in above equation we get,

$T_{idle} = 21.86*10^{-3} - 15.453*10^{-3}$

$= 6.416*10^{-3}$ seconds.

Based on above calculation the condition of poppet engine valve with change in time for 360 rotation of camshaft is given as follows,

Table1: Poppet valve condition with time.

Sr.no	Span of time (seconds)	Poppet Engine valve condition
1.	0 to $6.41*10^{-3}$	Valve is Idle
2.	$6.41*10^{-3}$ to $9.918*10^{-3}$	Valve opens
3.	$9.918*10^{-3}$ to $18.398*10^{-3}$	Valve is open and Idle
4.	$18.398*10^{-3}$ to $21.86*10^{-3}$	Valve closes

Based on calculation of various forces acting on poppet engine valve, its condition with time and magnitude of forces acting on it is given as follows,

Table2:Forces on Poppet valve with time.

Sr no	Span of time (seconds)	Poppet Engine valve condition	Magnitude of force acting on valve stem head (Newton)
1.	0 to $6.41*10^{-3}$	Valve is Idle	0
2.	$6.41*10^{-3}$ to $9.918*10^{-3}$	Valve opens	379.11
3.	$9.918*10^{-3}$ to $18.398*10^{-3}$	Valve is open and Idle	379.11
4.	$18.398*10^{-3}$ to $21.86*10^{-3}$	Valve closes	15.08

When poppet engine valve opens nature of force acting on its valve stem is compressive in nature and time during which it closes nature of force is tensile in nature, which leads to fatigue loading of poppet engine valve. This loading of poppet engine valve is unidirectional in nature.

Maximum valve lift is calculated to be 10 mm which corresponds to unidirectional displacement of poppet engine valve during lift to be 10mm so that it opens the port in one direction and displacement to be 10mm during fall so that it closes the port in opposite direction.

Consider the unidirectional displacement of poppet engine valve in following table.

Table1: Displacement of Poppet valve with time.

Sr.no	Span of time (seconds)	Poppet Engine valve condition	Magnitude of Displacement of poppet engine valve (mm)
1.	0 to $6.41*10^{-3}$	Valve is Idle	0
2.	$6.41*10^{-3}$ to $9.918*10^{-3}$	Valve opens	10
3.	$9.918*10^{-3}$ to $18.398*10^{-3}$	Valve is open and Idle	0
4.	$18.398*10^{-3}$ to $21.86*10^{-3}$	Valve closes	10

With a view to analyze the effect of Geometric parameters and materials on mechanical properties of poppet engine valve, specially to improve fatigue strength following geometric parameters and materials are considered for purpose of analysis which form the scope of this research paper.

Geometric parameters under consideration,

a) Valve stem diameter
b) Internal diameter of Hollow valve
c) Margin

Materials selected under consideration,

a) Inconel 625
b) Ti-4.5Al-3V-2Fe-2Moz
c) Ni - Cr - Mo Steel SAE8640_361_QT

Range of magnitude of geometric parameters selected is such that they lie on higher side and some on lower side of designed value.

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Range of magnitude of geometric parameters is as follows,

Table 4: Range of geometric parameters.

Sr. no	Geometric parameter	Range of magnitude
1.	Valve stem diameter	8mm,10mm,11mm,12mm,13mm,14mm,17mm
2.	Internal diameter of Hollow valve	6mm, 7mm, 8mm, 9mm, 10mm.
3.	Margin	0.8mm, 1.1mm, 1.4mm, 1.7mm.

Transient structural analysis was performed on Ansys Workbench 14.5 on poppet engine valve with above mentioned variation of geometric parameters and materials. In order to analyze the effect of these variation on mechanical properties of poppet engine valve other geometric parameters other than one under consideration is held same for purpose of comparison.

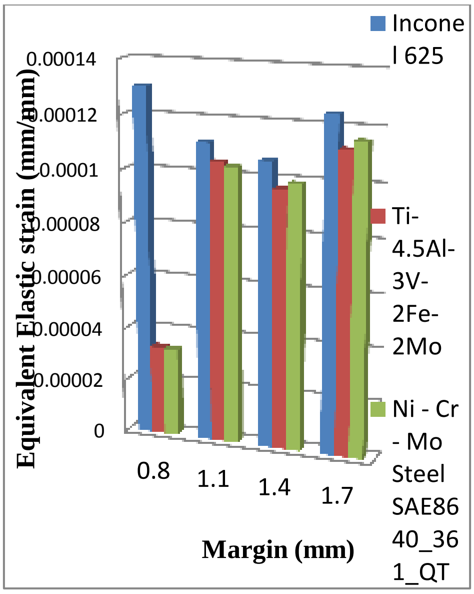
Results and discussion:

Transient structural analysis was used in Ansys workbench 14.5 to obtain following results,

Table5: variation of Equivalent elastic stain and Equivalent stress with variation of margin for material under consideration.

Material	Margin (mm)	Equivalent Elastic strain(mm/mm)	Equivalent stress (Mpa)
Inconel 625	0.8	0.0001303	24.81
	1.1	0.0001115	22.014
	1.4	0.00010647	20.51
	1.7	0.00012436	24.505
Ti-4.5Al-3V-2Fe-2Mo	0.8	3.34E-05	3.9102
	1.1	0.0001048	11.331
	1.4	9.67E-05	10.688
	1.7	0.0001124	12.692
Ni - Cr - Mo Steel SAE8640_361_QT	**0.8**	**3.30E-05**	**6.8256**
	1.1	0.00010335	20.486
	1.4	9.90E-05	19.088
	1.7	0.00011564	22.803

Consider graphical representation of above results,



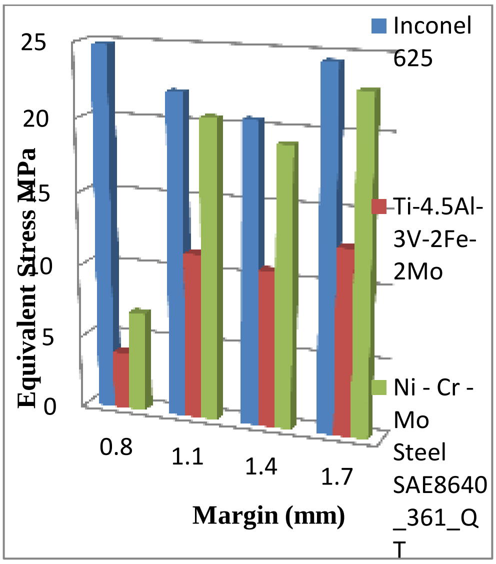


Figure 3: Equivalent elastic strain for poppet valve with 0.8mm margin made of Ni - Cr - Mo Steel SAE8640_361_QT.

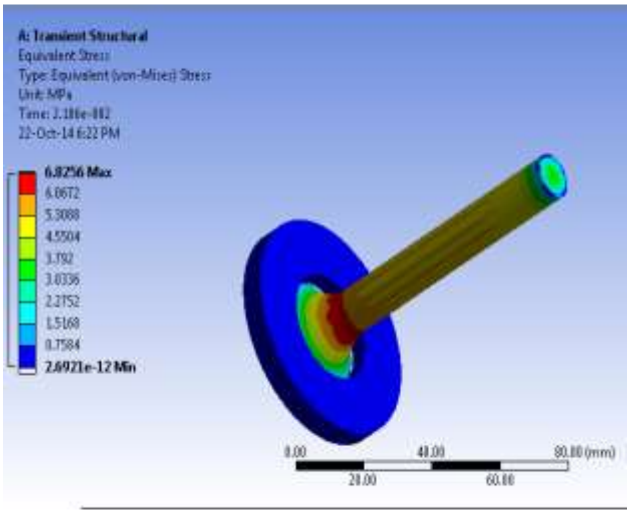


Figure 4: Equivalent stress for poppet valve with 0.8mm margin made of Ni - Cr - Mo Steel SAE8640_361_QT.

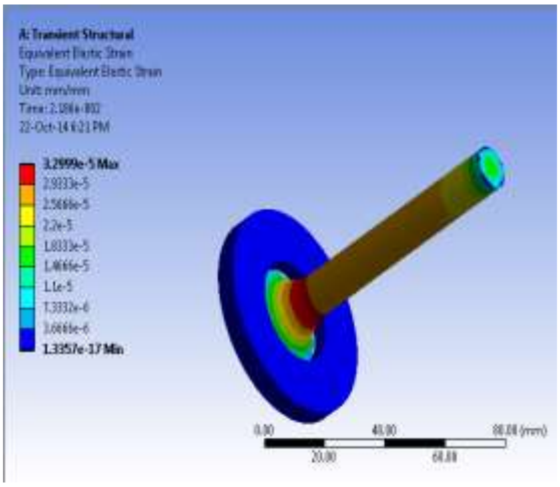
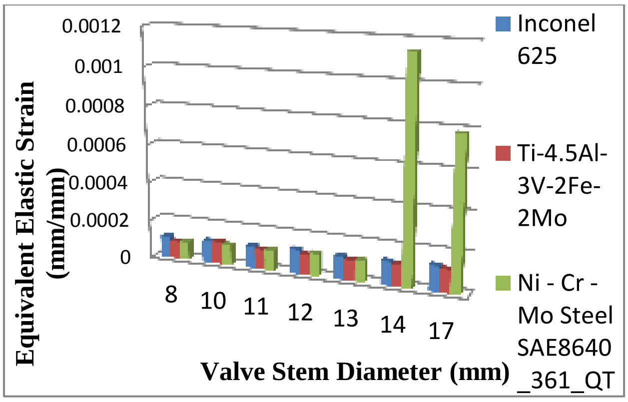


Table 6: the variation of Equivalent elastic stain and Equivalent stress with variation of valve stem diameter for material under consideration.

Material	valve stem diameter (mm)	Equivalent Elastic strain (mm/mm)	Equivalent stress (Mpa)
Inconel 625	8	0.00011286	20.864
	10	0.00011286	20.864
	11	0.00011349	22.114
	12	0.00012526	23.337
	13	0.00011801	23.309
	14	0.00012325	23.946
	17	0.00013192	25.846
Ti-4.5Al-3V-2Fe-2Mo	**8**	**8.98E-05**	**10.147**
	10	0.00011465	12.22
	11	1.03E-04	11.425
	12	0.00010339	1.09E+01
	13	0.00010706	12.029
	14	0.00011169	12.416
	17	0.00011949	13.354
Ni - Cr - Mo Steel SAE8640_361_QT	8	9.29E-05	18.43
	10	0.0001049	19.416
	11	1.06E-04	20.58
	12	0.00011647	21.717
	13	0.00010973	21.691
	14	0.001146	22.283
	17	0.00078303	159.15

Consider graphical representation of above results,



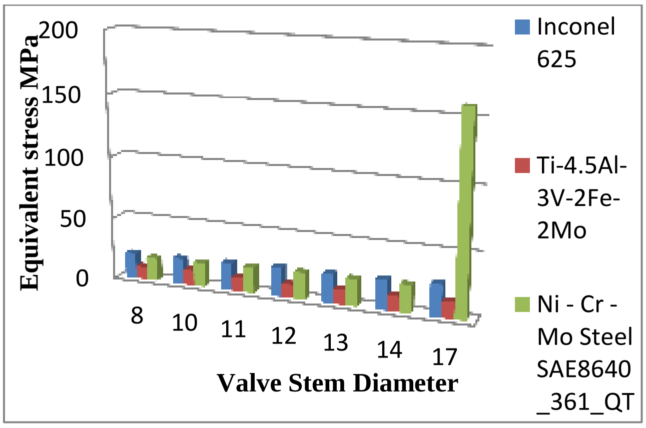


Figure 5: Equivalent elastic strain for poppet valve with 8mm valve stem diameter made of Ti-4.5Al-3V-2Fe-2Mo.

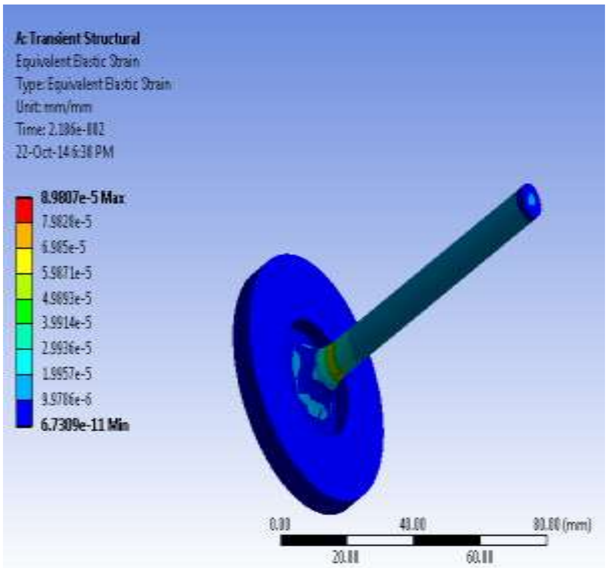


Figure 6: Equivalent stress for poppet valve with 8mm valve stem diameter made of Ti-4.5Al-3V-2Fe-2Mo.

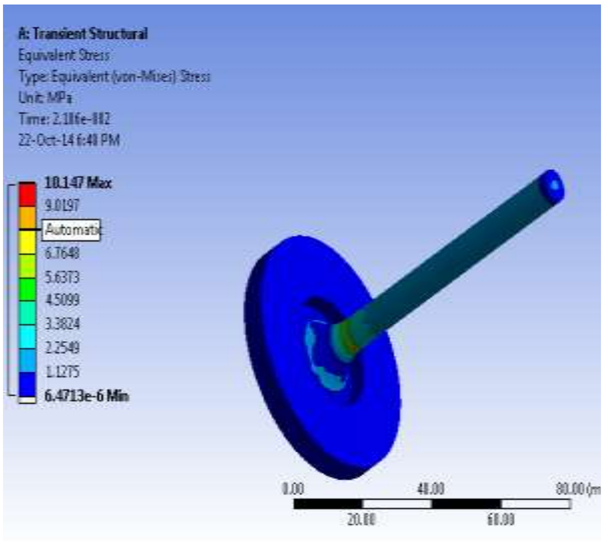
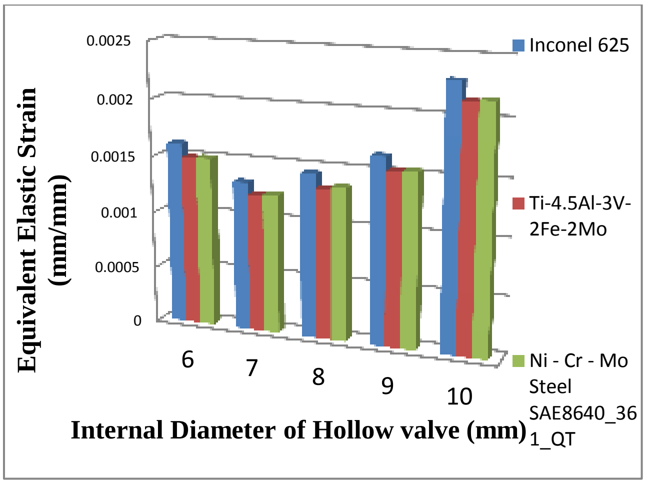


Table 6: the variation of Equivalent elastic stain and Equivalent stress with variation of valve stem diameter for material under consideration

Material	Internal Diameter of hollow valve (mm)	Equivalent Elastic strain (mm/mm)	Equivalent stress (Mpa)
Inconel 625	6	0.0016096	205.87
	7	0.001319	108.43
	8	0.0014459	179.83
	9	0.0016447	213.05
	10	0.0023054	279.49
Ti-4.5Al-3V-2Fe-2Mo	6	1.49E-03	107.9
	7	**0.001217**	**87.799**
	8	1.33E-03	93.512
	9	0.0015272	111.2
	10	0.0021427	146.21
Ni - Cr - Mo Steel SAE8640_361_QT	6	1.50E-03	192.02
	7	0.0012303	157.18
	8	1.35E-03	167.92
	9	0.0015374	199.25
	10	0.0021565	261.58

Consider graphical representation of above results,



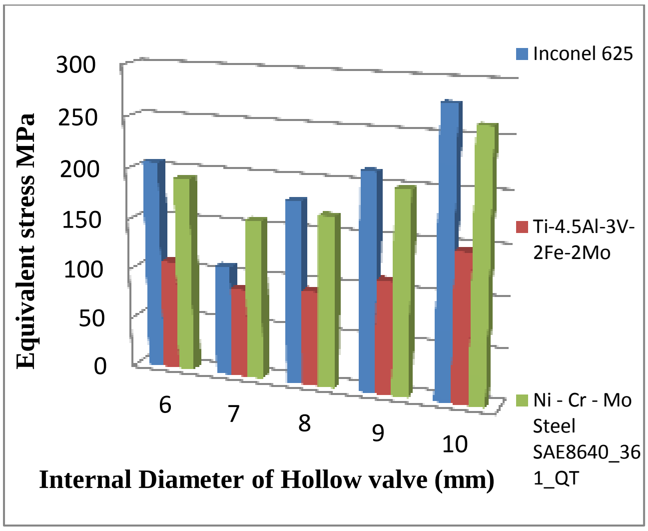


Figure 7: Equivalent elastic strain for poppet valve with 7 mm internal diameter of hollow valve made of Ti-4.5Al-3V-2Fe-2Mo.

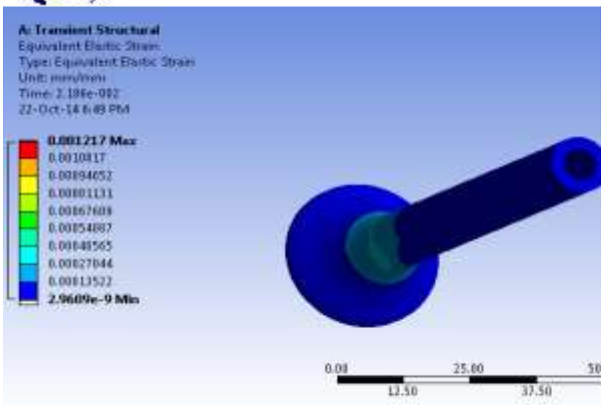


Figure 8: Equivalent stress for poppet valve with 7 mm internal diameter of hollow valve made of Ti-4.5Al-3V-2Fe-2Mo.

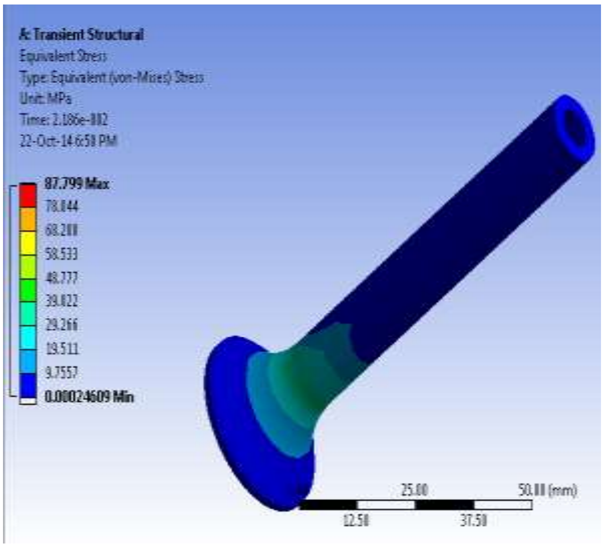


Table 8: the variation of fatigue life with variation of geometric parameter and materials,

Material	Fatigue life
Inconel 625	1.00E+06
Ti-4.5Al-3V-2Fe-2Mo	1.00E+07
Ni - Cr - Mo Steel SAE8640_361_QT	1.00E+11

Conclusion:

Based on results obtained by transient structural analysis following conclusions are deduced,

a. From poppet engine valve's functionality point of view it is desirable that equivalent elastic strain and equivalent stress should be least in magnitude. From the result obtained it can be concluded that Equivalent elastic strain and equivalent stress for poppet valve is least with 0.8mm margin made of Ni - Cr - Mo Steel SAE8640_361_QT.

b. In case of valve stem diameter Equivalent elastic strain and equivalent stress for poppet valve is least with 8mm valve stem diameter made of Ti-4.5Al-3V-2Fe-2Mo.

c. Similarly in case of internal diameter of hollow valve Equivalent elastic strain and equivalent stress for poppet valve is least with 7 mm internal diameter of hollow valve made of Ti-4.5Al-3V-2Fe-2Mo.

d. In case of Fatigue life variation with geometric parameter under consideration show no impact on fatigue life, but shows significantly with change in material, where Ni - Cr - Mo Steel SAE8640_361_QT has highest fatigue life for material under consideration.

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