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INVESTIGATION OF EXHAUST VALVE OF C.I. ENGINE FOR PERFORMANCE AND ITS ANALYSIS

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Abstract: In I.C engines valves are essential components for better working of engine. The Intake and exhaust valves are used to control the flow and exchange of gases. These valves seal the working space inside the cylinder against the manifolds and are opened and closed with the valve train mechanism. These valves are loaded by spring forces and subjected to pressure inside the cylinder and thermal loading due to high temperature. Due to these different conditions faced by the valves the premature failure of valve takes place. In this paper, design of exhaust valve was done based on given specifications with study of valves and Suitable valve radius was selected. To analyze the valve ANSYS is used. Transient structural and modal analysis of valve was done and optimization of valve radius along with recommendation of better material for life improvement of exhaust valve and further experimentation was done on universal testing machine.

Index Terms: Diesel engine, Exhaust valve, Modal analysis, Transient structural analysis, Valve radius

I. INTRODUCTION

A valve system is the main component of diesel engine. A valve system controls the amount of air to be drawn into the cylinder and exhaust gas to be discharged from the exhaust manifold. The purpose of the valve in the cylinder of the engine is to admit the air in C.I. engine and to force out the exhaust gases. Also the valve opens and closes the connection between the cylinder and the exhaust manifolds during the work of engine. The exhaust valve is subjected to the complex thermo-mechanical loading. The mechanical load is acted by the spring force during the closing of valve and the valve had contact with hot exhaust gases which are at High temperature due to which the non-uniform temperature causes the thermal loading on the valve. This reduces the fatigue and static Properties of valve material. In diesel engine the intake valve is less failed than the exhaust valve as exhaust valves are subjected to high temperature burnt gases. In order to proper working of diesel engine the valve must work properly .There are different types of valve are used likely poppet valve is used as exhaust valve. Failure of any valve causes the performance of engine due to which it is necessary to make the failure analysis of the valve of internal combustion engines. The possible failure of valve are fatigue failure, thermal failure, wear, corrosion, overheating of valves or the carbon deposit on the valve.

II. LITERATURE REVIEW

The different works are performed on the exhaust valve for different parameters in recent years. Lucjan Witek [1] work on ―Failure and thermo-mechanical stress analysis of the exhaust valve of diesel engine‖ In this work the failure analysis of the exhaust valve of diesel engine was performed. In order to explain the reason of premature valve damage, the non-linear finite element analysis was utilized. The results of stress analysis performed for the valve with the carbon deposit showed, that in the valve stem a high bending stresses were occurred. S. M. Jafari et al. [2] worked on―Valve Fault Diagnosis in Internal Combustion Engines using Acoustic Emission and Artificial Neural Network‖It was shown that using time and frequency domain analysis only detects the difference between faulty and healthy valves..In order to distinguish between the faults in valves, an ANN was used based on AE features. Leakage rate increased as pressure increased for all faults. Kum-Chul, et al. [3] presented ―A Study of Durability Analysis Methodology for Engine Valve Considering Head Thermal Deformation and Dynamic Behavior‖ the authors describe the problem of exhaust valve fracture of gasoline engines. From the results, it was found that the maximum stress occurred at the stem region and that stem region is the same region at which higher temperature occurred. The stress at the valve head is similar to the stress under the combustion pressure condition, but the stress on the valve neck goes up to high level where the failure occurred. Yuvraj K Lavhale et al. [4] had studied the overview of failure trends of inlet and exhaust valve. There are different causes for the failure of the exhaust valve such as fatigue failure, wear, thermal loading, failure due to corrosion-erosion which leads to degradation of mechanical properties of valve material and its performance. B.E. Gajbhiye et al. [5] ―Vibration Testing and Performance Analysis of IC Engine Exhaust Valve Using Finite Element Technique‖ Author had performed the Modal analysis of valve using FEA software. It was found that Stem of valve is most affected zone. The deformation is observed at the bottom side of the valve. The reason for exhaust valve damage may be high vibrations at resonance frequency value which are slightly greater than natural frequency of exhaust valve. Naresh Kr. Raghuwanshi et al. [6] had studied the failure analysis of internal combustion engine valves. According to authors the main reasons of valve failure are overheating, decrease the strength of material at high temperature, oxidation and impact load. Sanoj. T et al. [7] had studied ―Thermo Mechanical Analysis of Engine Valve‖ in their work deals with the stress induced in a valve due to high thermal gradient and high pressure inside the combustion chamber. To analyse the valve

ANSYS was used as the tool. Thermal and structural analyses are performed on the valve and finally the best material is suggested for the valve based on its strength and thermal properties. A.S.More et al. [8] presented the analysis of valve mechanism and in that they performed the kinematic and dynamic analysis of engine valve. H. J. C. Voorwald et al. [9] presented ¯Fatigue Strength of X45CrSi93 stainless steel applied as internal combustion engine valves‖. Authors studied the influence on the axial fatigue strength of the resulting microstructure after heat treatment at X45CrSi93 steel, combined with different surface treatments as hard chrome-plating, nitride and grinding. It was found that significant increase in the fatigue strength of the steel after nitriding, and slight increase in the tensile strength was also noticed on nitrided parts. P. Forsberg, et al. [10] had presented ¯Wear mechanism study of exhaust valve system in modern heavy duty combustion engines.‖ studied on the wear and Wear mechanism of engine valve and put some remarks as, the dominant wear mechanism of the VSI material is oxidation and formation of a tribo film. There are no signs of abrasive wear on any part of the studied systems. The valves did not wear for the samples where the tribo film was found. For the cleaner engine – Sample Engine Cell – the combustion residues have not been sufficient to build up a protective layer, which lead to material transfer and rougher surfaces. Nurten Vardar et al. [11] had investigated the exhaust valve failure in heavy-duty diesel engine and concluded that valve was broken down before its expected life. Jerzy Jaskólski, et al. [12] presented their work on ¯The Temperature - and Stress Fields of Valves of IC Engine‖ has performed Structural and thermal analysis using ANSYS.In that the temperature computed in the middle are too low.

III. PROBLEM STATEMENT

A. Statement

In I .C. Engines either Automobile or Stationary engines the failure of valve takes place at the cross section variation region i. e. fillet zone and there is need to strengthen that zone along with overall improvement in strength of valve thus ¯To design the exhaust valve for the fillet zone with modelling and transient structural analysis of the valve for different optimization parameter like valve radius, valve material and further it is validate by experimentation. In addition to this modal analysis is done.

B. Objectives

- To investigate stress and deformation of existing valve.
- Design of Valve its modelling, transient structural analysis & optimization based on fillet radius & material
- Modal analysis is performed to study the natural Frequencies and their behavior with frequencies
- Experimentation is done to find the Deformation.

IV. DESIGN OF EXHAUST VALVE

A. Valve specification

4-Stroke CI engine- 450 cc Valve Seat Angle -300, Gas Velocity -2320m/min Mean Piston Speed -210m/min, Max. Gas Pressure -6.25 N/mm2, Cylinder Bore Diameter -140mm, Stroke- 175 mm
Engine speed- 1220 rpm
Exhaust valve Temperature - 8200C. Length of stem - 11.2 cm

B. Material properties of existing valve

TABLE 1: MATERIAL PROPERTIES OF EXISTING VALVE

Material properties	Symbol	Values for ferritic AISI 409 Steel
Density	ñ	7800 kg/m^3
Young's Modulus	*E*	220 Gpa
Ultimate Tensile Strength	Sut	450 Mpa
Yield Strength	Syt	250 Mpa
Composition		Mn=1.0%,C=0.08%, Si=1.0% ,Ti=0.75% S=0.030%

C) Design

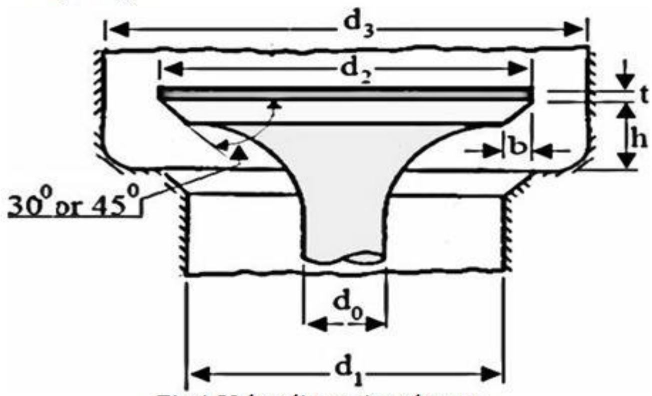

Fig.1 Valve dimensions layout

The different parameter for the valve are calculated by using the following

a) Port diameter = $d_1 = D$ Port diameter = $d_1 = \sqrt{\frac{N}{Vg}}$
b) Valve lift =h= $\frac{0.25d1}{cos\alpha}$
c) Port area= $\frac{1}{4}$ ð d_1^2
d) Thickness of valve disc = t = $k_1 d_1$
e) Valve head diameter = $d_2 = d_1 + 2(t \times \sin(90 - á))$
f) Diameter of valve head opening area=
$d_3 = \sqrt{d1^2 + d2^2}$
g) Width of seating =b =0.5($d_2 - d_1$)
h) Diameter of valve stem = $d_0 = \frac{d1}{o} + 4$
i) Diameter check=

$0.7854\ (d_3^2 – d_2^2) \geq 0.7854\ d_1^2$

$0.7854\ (66.25^2 – 51.14^2) \geq 0.7854\ (42.12)^2$

1393.11 ≥1393.11 Design is safe.

D) Dimension of exhaust valve

TABLE 2: DIMENSION OF EXHAUST VALVE

Design parameter	Symbol	Dimension(mm)
Port Diameter	d1	42.12
Valve lift	h	12.16
Thickness of valve disc	t	5.21
Diameter of valve head	d2	51.14
Diameter of valve head opening area	d3	66.25
Width of seating area	b	4.51
Diameter of valve stem	do	9.265

E) Forces on the valve

Forces on the valve are due to gas pressure on the valve when it opens , the inertia force when the valve moves up and the initial spring force to hold the valve in its seat against the suction or negative pressure inside the cylinder

a) force due to gas pressure on the valve when it opens F_G = ð/4 d_2^2 p_c

Where,

F_G = Gas Force when the valve opens d_2 = Valve head diameter, mm

p_c = Cylinder pressure when intake valve opens = 0.5 Mpa

The inertia force, when the valve moves up. F_A = mass x acceleration

Where,

Mass = Valve mass, kg

Acceleration = Valve acceleration, m/s^2

Acceleration = ð^2 ù^2 h / 2 Θ_L^2

= Cam Shaft Speed, rad/sec Θ_L = Angle of lift, rad

Cam Shaft Speed = ½ Crank Shaft speed (4stroke engine)

½ * 1220*2 ð/60

60.21 rad/sec

Θ_L = ½ Θ_{cam} = 1.272 rad

Valve lift = 12.16 mm

Acceleration = ð^2 ù^2 h / 2 Θ_L^2

ð^2 * $60.21^{2\,*}$ 12.16 $x10^{-3}$ / 2 $(1.272)^2$

134.45 m/s^2

The initial spring force to hold the valve in its seat against the suction or negative pressure inside the cylinder. $\mathbf{F_I}$ = ð/4 d_2^2 p_s

Where,

F_I = Initial Spring force

p_s = Maximum Suction pressure, MPa = 0.03 MPa below atmosphere

F_T = Total Force on valve face, N

$\mathbf{F_T} = F_G + F_A + F_I$

TABLE 3: VALUES OF FORCE ACTING ON THE VALVE

Force acting on exhaust valve	Values
Force due to gas pressure (F_G)	1027.03 N
Inertia force (F_A)	34.82 N
Initial spring force (F_I)	61.62 N
Total force (F_T)	1000.23 N

From the above table the inertia force is nothing but the tensile force whereas the compression force is nothing but the addition of initial spring force and force due to gas pressure which is1088.65 N

V. ANALYSIS OF EXISTING VALVE

A. Transient structural analysis of existing valve with 9.25 mm valve radius

Transient dynamic analysis is a technique used to determine the dynamic response of a structure under the action of any general time dependent load. To determine the time-varying displacement ,forces and strain in a structure as the time scale of the loading such that the damping effect or inertia is considered to be important , this type of analysis is used. For the analysis of valve firstly the valve drawing is made with the evaluated dimensions, after that CATIA model is made, then in the engineering data material properties of existing material are added. Meshing of valve is done using tetrahedral element and further ANSYS is used for the required solutions. Following figures shows the different results obtained during analysis. Following figures include the CATIA model of valve with 9.25 mm valve radius, meshing of valve using tetrahedral element, deformation elastic and von-Mises stress of the valve.

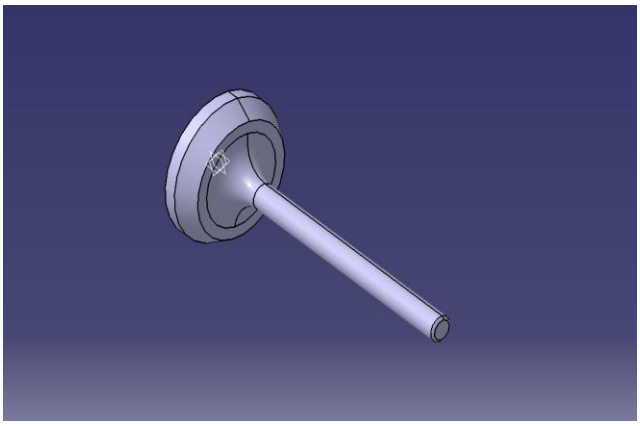

Fig.2 CATIA model of Valve

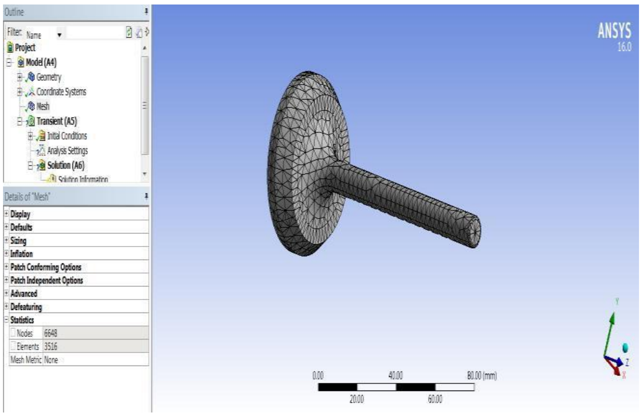

Fig.3 meshing of valve using tetrahedral element

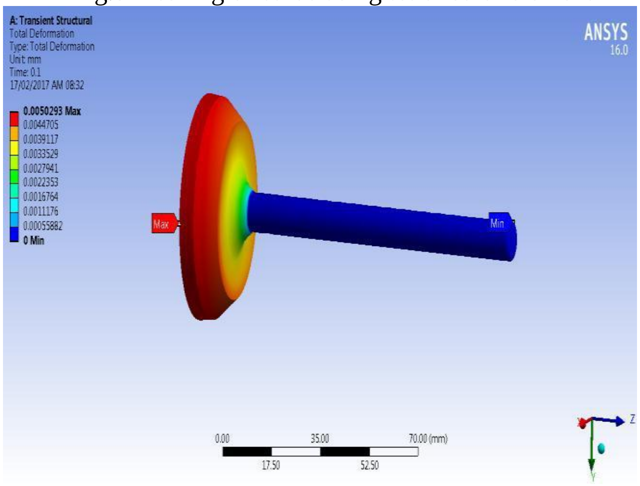

Fig.4 Deformation in the valve

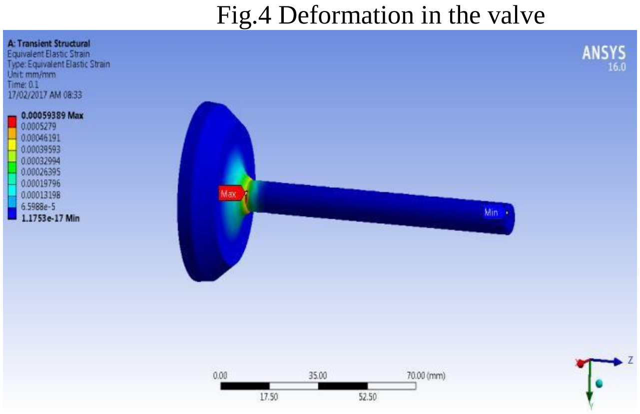

Fig.5 Elastic strain in the valve

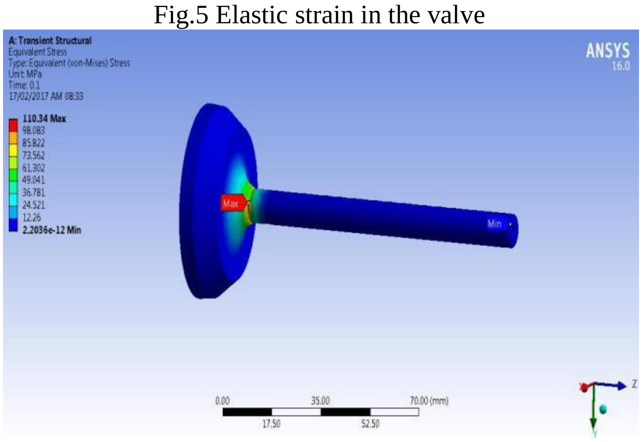

Fig.6 Von-Mises stress in the valve

B. Modal analysis of existing valve with 9.25 mm valve radius

Modal analysis studies the dynamic properties of structures under vibration excitation .The modal analysis is obtained with different mode sets and their respective deformation. Each mode gives the vibration range in the form of frequency and maximum deformation at that frequency level. The maximum frequency is 12644Hz and this is the natural frequency of the valve, above which the resonance occurred And structure experience the structural damage.

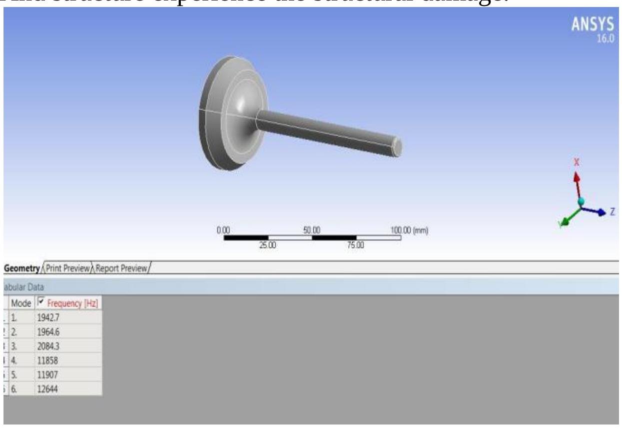

Fig.7 Natural frequency of valve

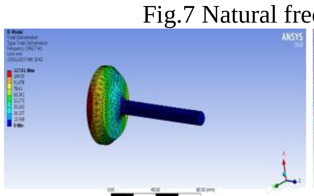

Fig.7(a): 1st Mode shape

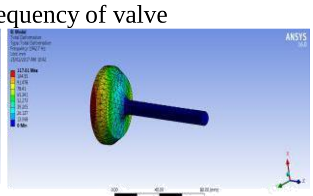

Fig.7(b): 2st Mode shape

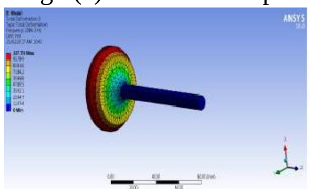

Fig.7(c): 3rd Mode shape

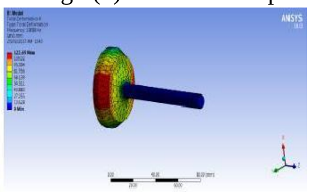

Fig.7(d): 4th Mode shape

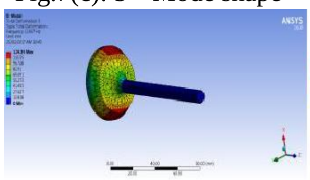

Fig.7(e): 5th Mode shape

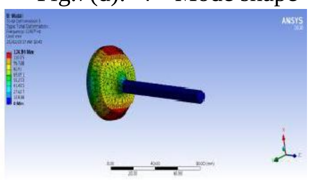

Fig.7(f): 6th Mode shape

From the modal analysis Frequency values and deformation for each mode of vibration are obtained which are listed in following table

TABLE 4: FREQUENCY VALUES AND THEIR DEFORMATION

Mode	Frequency (Hz)	Deformation(mm)
1	1942.7	117.61
2	1964.6	117.8
3	2084.3	107.76
4	11858	122.65
5	11907	124.36
6	12644	84.306

VI. OPTIMIZATION OF EXHAUST VALVE

A. Based on valve radius

From the analysis of existing valve it is found that stress is concentrated at the valve radius, in order to reduce the stress the number of trials are taken for the valve radius .the following table shows that the von-Mises stress obtained for the existing valve with 9.25 mm fillet radius is 110.34 which is above the allowable stress for the given material due to which failure takes place in order to obtain the less stress at the fillet region further valve radius are checked for stresses. From the following result table we can see that fillet 16.0 mm is giving good results and the stresses generated are also less as compared to existing fillet. Valve radius 16.00 mm will be selected for further analysis work. Stresses are 22.56 % less; deformation is 11.39 % less than existing fillet. 16.0 is maximum possible fillet that we can give to valve.

TABLE 5: VALVE RADIUS TRIALS FOR MODIFIED DESIGN

Trials	Fillet, mm	Stress, Mpa	Deformation, mm	Strain, mm/mm
Trial 1	0	137.31	0.013765	0.0012702
Trial 2	2	133.67	0.0050015	0.00077069
Trial 3	4	124.50	0.0059952	0.0006869
Trial 4	6	120.63	0.0049696	0.00064063
Trial 5	8	115.79	0.0052576	0.00061465
Trial 6	9.25 (Existing)	110.34	0.0050293	0.00059389
Trial 7	12	98.751	0.0043375	0.00052021
Trial 8	14	88.489	0.0035392	0.00050017
Trial 9	16 (Selected)	85.449	0.0044562	0.00047561

Following figures shows the results obtained for Deformation, strain, and von-Mises stress for the valve with 16.00 mm valve radius.

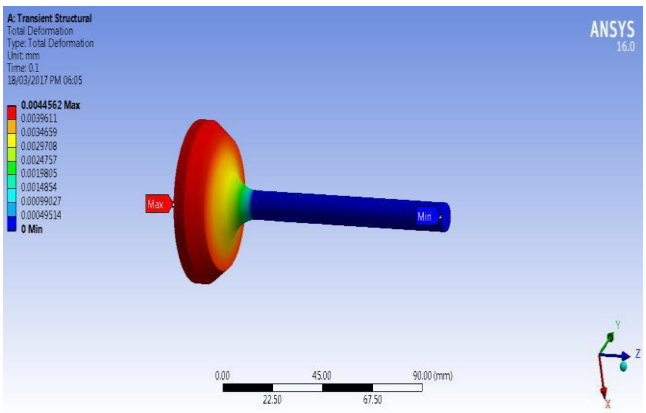

Fig.8 Deformation in the valve

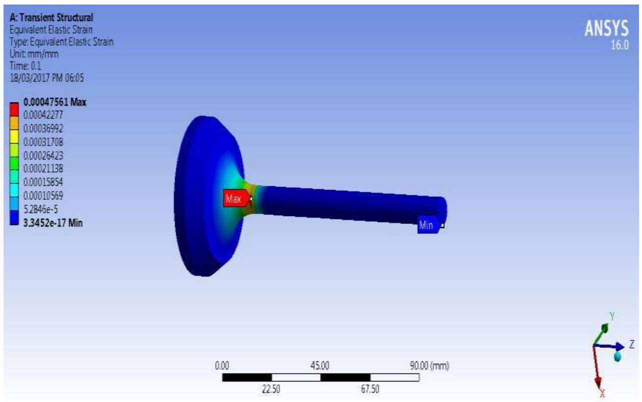

Fig.9 Elastic strain in the valve

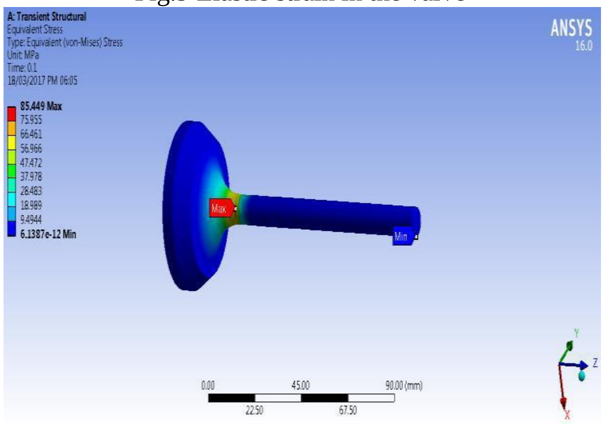

Fig.10 Von-Mises stress in the valve

B. *Based on Material*

For providing the alternate material for the valve different materials are available in order to provide the alternate material the material properties of different material are edited in the engineering data of ANSYS and further analysis is done in order to obtain the deformation, strain and von-Mises stresses. Following table shows the different material used for valve as alternative material with their Properties.

TABLE 6: VALVE RADIUS TRIALS FOR DIFFERENT MATERIALS

Material properties	Density (ñ) kg/m^3	Young's Modulus (*E*)Gpa	Yield Strength **(Syt)** Mpa	Composition
ASTM A890	7800	230	520	Fe=58.1-65.9%, Cr=24-26%,Ni=6-8% , Mo=4-5%, Mn=0-1.5%, Si=0-1 %
AISI 1541 carbon steel	7900	190-210	380-650	Fe=97.82-98.29%, Mn=1.35-1.65% , C=0.360-0.440%

				S=0.05%,P=0.04%
Super Alloy 21-2 N valve Steel	7600	215	440	Cr=20.35%, Mn8.5%, Ni=2.13%,C =0.55%, Mo=0.50%, Si=0.25%

The results obtained for different materials with valve radius 16.00 mm are listed in below table which is useful for selecting the material for exhaust valve with less stress concentration and improved working life of valve.

TABLE 7: RESULTS BASED ON MATERIALS FOR VALVE RADIUS 16.00 MM

Material	AISI 409	ASTM A890	AISI 1541	21-2N
Deformation (mm)	0.00445	0.00368	0.00319	0.00398
Elastic Strain (mm/mm)	0.00047	0.00052	0.00045	0.00056
Von-Mises Stress,(Mpa)	85.449	92.227	79.765	99.705
Allowable Stress,(Mpa)	83.33	173	133.33	146.67
Volume, (mm^3)	33675	33675	33675	33675
Density, (kg/ m^3)	7500	7790	7600	7850
Weight,(g)	252.56	262.33	255.93	264.35

From the above result it can be seen that Material AISI 1541 gives us better result without failure, hence can be used as alternative material to existing material. AISI 409 steel i.e. existing material is having low allowable stress; else this material also shows good results. ASTM A890 having stress under allowable stress but the stress values are over safe. Hence for further experimentation Material AISI 1541.

C. Modal analysis of optimized valve

The modal analysis obtained with the optimized valve .From the modal analysis the maximum frequency is 11922 Hz. From the modal analysis Frequency values and deformation for each mode of vibration are obtained which are listed in following table

TABLE 8: FREQUENCY VALUES AND THEIR DEFORMATION FOR OPTIMIZED VALVE

Mode	Frequency (Hz)	Deformation(mm)
1	1600	109.62
2	1603	109.62
3	1925.5	105.78
4	11551	123.58
5	11568	123.42
6	11922	76.83

The first and second mode of vibration shows the same deformation and their respective frequency values are also same. The maximum frequency of the optimized valve gives the comparatively less deformation.

VII. EXPERIMENTAL TESTING

For the testing of exhaust valve of selected material AISI 1541 with valve radius 16.00 mm, a valve is tested on universal testing machine.

TABLE 9: SPECIFICATION OF UNIVERSAL TESTING MACHINE

Max Load Capacity	100 KN
Load Accuracy	Within +/- 1%
Test Space Tensile Compression	 550 mm 500 mm
Piston Stroke	200 mm
Dimensions	750*600*2100 mm
Power Supply	Three-Phase, 240V-50HZ

The set up for testing is shown in below fig.

Fig. 11 Set up for testing

The valve with the selected material is tested in order to validate the result which are obtained with ANSYS. For testing purpose the optimized valve is tested on the set up as shown in figure. From experimental testing observations are obtained which are below

TABLE 10: OBSERVATION TABLE

Weight (gm)	Material	Deformation, mm (Experimental)			
		Trial 1	Trial 2	Trial 3	Avg.
224.4	AISI 1541	0.0034	0.0033	0.0034	0.0034

VIII. RESULTS AND DISCUSSION

From the FEA results we can found that the Von-Mises stress obtained from existing valve is 110.34 Mpa which is above the allowable stress 83.33 Mpa whereas the final design gives the stress 79.76 Mpa which is below the allowable stress133.33Mpa for that material. The deformation obtained from existing valve with FEA is 0.00502 mm whereas the deformation of new valve with AISI 1541 material is 0.00319mm. The deformation obtained from the FEA of new valve is 0.00319 and the deformation obtained by the Experimentation of new valve is 0.0034 which is good match. From the Modal analysis of optimized valve it is found that the deformation of the first two mode of frequency are same whereas for the last mode of vibration the deformation is comparatively reduced.

IX. CONCLUSION

Based on the present study the valve radius is the vital parameter to avoid the failure of the valve Valve with the fillet radius 16.00 mm and AISI 1541 material shows the safe result. The exhaust valve with AISI 1541 material shows 36.56 % less deformation and 27.71% less stress. than the existing valve. The deformation obtained from the FEA of new valve and the deformation obtained by the Experimentation there is error of only 6.17 %. Based on the modal analysis of valve with AISI 1541 material, the maximum frequency of valve provides better stability and the deformation obtained with this frequency is 9.43% less.

X. FUTURE SCOPE

- Microscopic analysis of valve can be done
- Thermal analysis can be done for studying thermal stresses in valve

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