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FAILURE ANALYSIS OF INTERNAL COMBUSTION ENGINE EXHAUST VALVES USING FEM

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ABSTRACT

Intake and exhaust valves are very important engine components that are used to control the flow of intake and exhaust 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. These valves are loaded by spring forces and subjected to thermal loading due to high temperature and pressure inside the cylinder. The present study is based on different failure modes of internal combustion engine exhaust valve, Failures due to fatigue, high temperature effects, and Failures due to impact load that depends on load and time. For the study of fatigue life, a combined S-N (max. stress v/s number of cycles) curve is prepared. Such a curve helps in comparing the fatigue failure for different materials at different high temperatures and may also assist the researchers in developing the valve materials with a prolonged life. For achieving above sad goals couple –field, fatigue and transient analysis will be done on valves to determine structural and thermal behavior in working condition.

Keywords: *Internal Combustion Engine, Valves, Fatigue.*

1. INTRODUCTION

Exhaust valve is termed as essential component of an IC engine as it provides path to expel out the exhaust gases generated after combustion of the fuel in the combustion chamber. If there is improper design of exhaust valve then it indirectly affects its reliability i.e. exhaust valve fails before performing its intended function and thus the following stroke will begin to mix with exhaust fumes rather than clean air. This may be inadequate for proper combustion and it leads to poor running conditions. Exhaust valve fail at higher rate than intake valve. Because intake valves are virtually cooled by fresh air, however exhaust valves are subjected to a very high temperature burnt gases. Because of that it can be exposed to very high thermal stresses more than intake valves and hence there are more chances of failure of exhaust valves rather than intake valves. The detailed literature is available relevant to the proposed study.

2. LITERATURE REVIEW

Sagar. S Deshpande et al. [1] conducted Experimental Investigation and Analysis of Engine Valve Designs for Enhanced Fatigue Life. B.E. Gajbhiye et al. [2] proposed the Vibration Testing and Performance Analysis of IC Exhaust Valve Using Finite Element Technique. Aim of this paper is to find out effects of vibration on exhaust valve. Yuvraj K Lavhale et al. [3] proposed the Overview of Failure Trend of Inlet & Exhaust Valve. In this workDifferent modes of failure of valves, Methods of fracture analysis were used for valve failure analysis. Kum-Chul et al. [4] proposed the study of durability analysis methodology for engine valve considering head thermal deformation and dynamic behavior. In this paper durability analysis is based on thermal deformation and dynamic behavior. Rohit T. Londhe et al. [5] proposed the Valve and Valve Seats Wear analysis experimentally in CNG Fuelled Engine. This paper gives material for valve and valve seat in gas fuel engine. Ajay Pandey et al. [6] studied the failures of automobile valves as a part of analysis. The valve microstructure change were analyzed with the aid of SEM. Bo Wong et al. [7] studied the thermal deformation field of exhaust valve used in steam booster pump based on ANSYS. Simulation results show that the thermal deformation value of the new type of exhaust valve is less than the traditional exhaust valve. Grzegorz Maciejewski et al. [8] proposed robust and simple optimization method of functionally graded material (FGM) for combined loading with application to valve design. S. M. Jafari et al. [9] proposed the Valve Fault

Diagnosis in Internal Combustion Engines using Acoustic Emission and Artificial Neural Network. Goli Udaya Kumar et al. [10] proposed the Failure Analysis of Internal Combustion Engine Valves by using ANSYS. The present study is focused on different failure modes of IC engine valves. M. Azadi et al. [11] conducted a failure analysis of failed intake valve of gasoline engine. Material examination by a light microscope and also a scanning electron microscope were conducted on the fracture surface.

A. S. More et al. [12] proposed the analysis of Valve Mechanism – A Review. In this proposed work dynamic and kinematic analysis of IC engine is done. Sanoj. T et al. [13] proposed the Thermo Mechanical Analysis of Engine Valve. In this thermal and structural analysis of valve with different materials (Nimonic 80A and Nimonic 105A) were used for valve analysis. Naresh Kr. Raghuwanshi et.al [14] had given a review on the failure analysis of IC engine valves. From the study, it is quite evident that a common cause of valve fracture is fatigue. Jae Soo Hong et al. [15] studied the exhaust valve and valve seat wear depending on fuel type. He concluded that the abrasive wear was observed only in the specimen for the test performed with LPG fuel. J.-G. IH et al. [16] presented an optimal design of the exhaust system layout to suppress the discharge noise from an idling engine. Jerzy Jaskólski et al. [17] focused on the temperature and Stress Fields of valves of IC Engine and performed structural and thermal analysis to notice the temperature computed in the middle are too low. P. Forsberg et al. [18] proposed the Wear mechanism study of exhaust valve system in modern heavy duty combustion engines. Nurten Vardar et al. [19] investigated the failure of Exhaust Valve in Heavy duty Diesel Engine. Oh Geon Kwon et al. [20] investigated the valve stem failure of exhaust valve from a waukesha P9390 GSI gas engine. He concluded that the valve failed as a result of overheating.

From the literature review it is seen that most of the studies on exhaust valve design had focused on fatigue behavior, wear behavior, deformation mechanisms in metallic materials. However, very less research is done in design of exhaust valve based on optimization of its parameter i.e. fillet radius, valve stem diameter, valve head diameter. Therefore this study is conducted to design the exhaust valve by optimizing the fillet radius and recommending the best alternative material for valve through experimentation and validation in order to increase the working life of exhaust valve.

3. PROBLEM DEFINITION

3.1 Specification of the problem

In exhaust valve, there is sudden change in cross section due to presence of valve stem as a small shaft and valve head as a small disc, which is a functional requirement of exhaust valve. Such a discontinuities in cross of exhaust valve generates maximum stress concentration at the junction where there is abrupt change in cross section. It is impossible to eliminate presence of stress concentration totally but its reduction is possible to some extent. Change in cross sectional area should be gradual to the possible extent, hence fillet is provided at the junction. Thus stress concentration level can be reduced by selecting suitable fillet radius. Thus problem statement is "to design the valve with modeling & structural analysis by selecting suitable fillet radius for which stresses are less and recommending the best alternative material by finite element analysis, so that valve can withstand to given operating conditions and to verify it experimentally on UTM."

3.2 Objectives

a) Study the valve mechanism basics and failure modes in exhaust valve.

b) Design the valve as per the specification and model it in CATIA and analyze it in ANSYS software.

c) Find the cause of failure in existing valve.

d) Take necessary corrections in design and modify it in order to eliminate the cause of failure.

e) Study the different valve materials and recommend the best alternative material for valve with stress and weight as a selection criterion

f) Conduct test on Universal Testing Machine to find stress and strain for experimental validation

3.3 Specification of the existing valve

Stroke CI engine-

a) Bore x Stroke (D X L) = 120 x 125 (mm),

b) Valve seat angle, □ □ 45^0,

c) Gas Velocity, v_g = 2100m/min

d) Length of stem = 10.5 cm, e) Engine speed, N_s = 1150 rpm, f) Max. Gas Pressure, P_{max} = 6.0 N/mm^2

g) Mean Piston Speed, N = 275 m/min, h) Exhaust valve Temperature, T= 750^0C

3.4 Material properties of existing valve

Table 1: Material Properties of the existing valve

Material properties	Symbol	Values for Martensitic steels VV45
Density	D	7627-6611 kg/m^3
Young's Modulus	Y	210 GPa
Ultimate Tensile Strength	U	776 MPa
Yield Strength	YT	314-387 MPa
Composition	C	Mn=0.4 %, C = 0.45%, Si=3.30 %, S=8.6 %

Design of Exhaust Valve

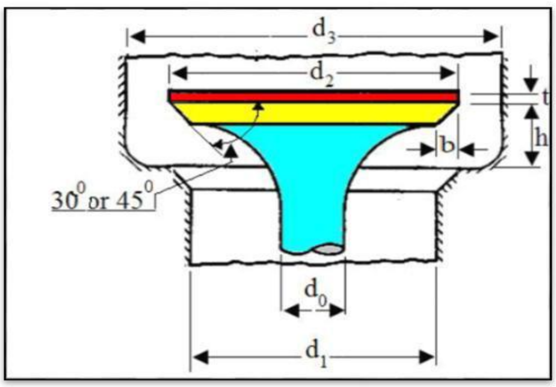

Fig.1: Geometry of exhaust valve

Composite materials

A composite material (also called a composition is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. In the present study we are using composite material 21-4A, Nimonic 80A, Nimonic 105A. The chemical composition and mechanical properties of the above materials are given below:

Table 2: Chemical composition of 21-4A

Elements	**Content (%)**
Chromium, Cr	**21**
Manganese, Mn	**9**
Nickel, Ni	**3.88**
Carbon, C	**0.53**
Silicon, Si	**0.25 max**

Table 3: Chemical composition of Nimonic 80 A

Element	Content (%)
Nickel, Ni	69
Chromium, Cr	18-21
Iron, Fe	≤3
Cobalt, Co	≤2
Titanium, Ti	1.8-2.7
Aluminum, Al	1.0-1.8

Table 4: Chemical composition of Nimonic 105 A

Element	Content (%)
Nickel, Ni	51
Cobalt, Co	18-22
Chromium, Cr	14-15.7
Molybdenum, Mo	4.50-5.50
Aluminum, Al	4.50-4.90
Iron, Fe	1
Manganese, Mn	1
Silicon, Si	1
Titanium, Ti	0.90-1.50
Copper, Cu	0.20
Zirconium, Zr	0.15
Carbon, C	0.12
Sulfur, S	0.010
Boron, B	0.0030-0.010

Objectives

1. To study the valve mechanism basics and failure modes in exhaust valve.

2. To study the valve as per the specification and model it and analyze it in ANSYS software. Composite materials will be used as valve material in order to eliminate the cause of failure.

3. To find the cause of failure in existing valve.

4. Study the different valve materials 21-4A, Nimonic 80A, Nimonic 105A and recommend the best alternative material for valve with stress and displacement values as a selection criterion

4. RESULTS & DISCUSSIONS

The static structural analysis of the exhaust valve for different materials such as 21 4N, Nimonic 80A and Nimonic105A is carried out. The properties of different exhaust valve materials such as thermal expansion, young s modulus are given as input for the structural analysis. The outer surface is constrained which has been given the mechanical load in to the FEA model. The results for the three different valve materials are given above. It has been concluded from the results that among the three materials chosen for the structural analysis, the Nimonic105A are best as far as stiffness are concerned compared to the other two materials as the maximum displacement in the Nimonic105A is greater than the other two materials which is evident in the figure below.

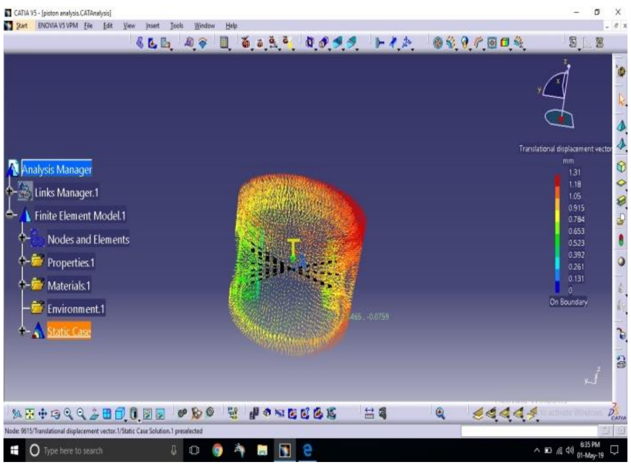

Fig.2: Analysis of piston valve

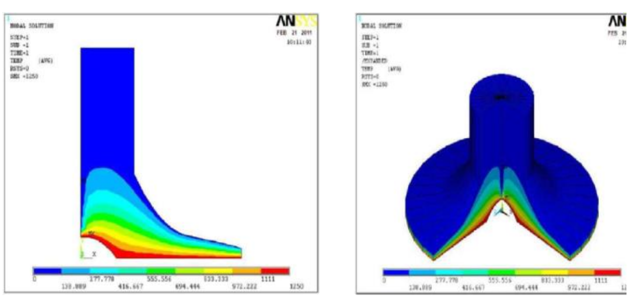

Fig.3: Thermal Analysis of Temperature distribution Nimonic 80A

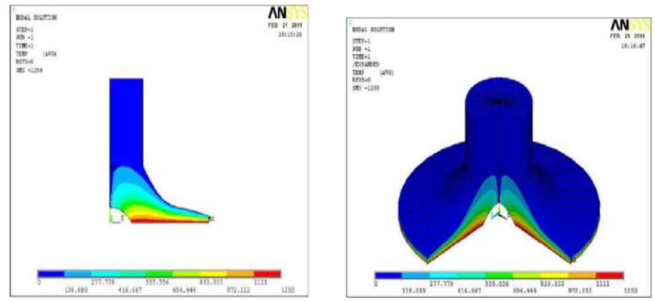

Fig.4: Thermal Analysis of Temperature distribution Nimonic 105A

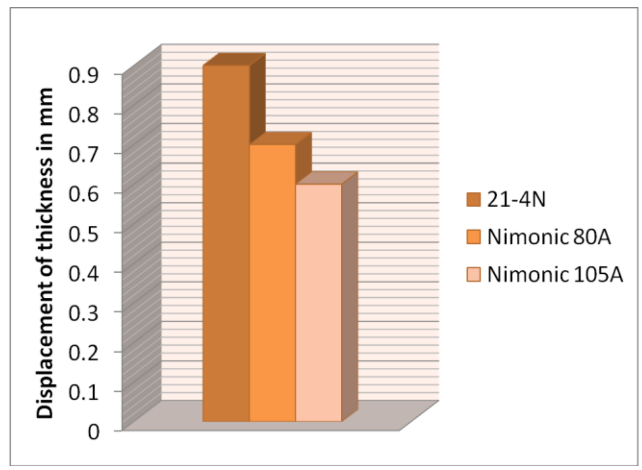

Fig.5: Displacement thickness graph

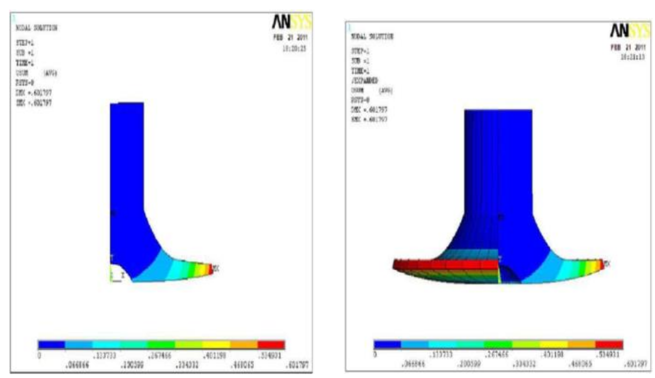

Fig.6: Displacement Analysis of Nimonic 105 A

CONCLUSION

Improper selection of fillet radius leads to exhaust valve and piston failure. Thus, fillet radius plays important role in exhaust valve failure and should be carefully selected. Valve with fillet radius 14.0 mm shows safe results and is selected for further work. Overall reduction in stress is 14.35 % and weight is on greater side by 1.29 % (For 21-2N material) and is not a big issue considering stress reduction.

FUTURE SCOPE

a) Valve shape optimization with new shapes of valve than existing can be studied.

b) Instead of static analysis, dynamic Analysis can be done.

c) Thermal analysis for temperature effect study can be included for further improvement.

d) Vibration analysis can be performed on valve by using FFT.

e) Modal analysis can be added to study natural frequencies and their behavior for various frequencies

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