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Original Research Article

Numerical Analysis and Optimization of Engine Valves

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Abstract

Application of mathematical modelling and numerical methods is a key element of optimum vehicle in this study, the effects of various materials, fillet radius and diameter of an engine valve on stress concentration error were investigated. Multiple regression analysis was employed to derive the predictive equations of the Von Mises Stress and displacement error achieved via experimental design and their results are found in ANSYS software. For this purpose, two materials as cast iron and aluminum, radius condition as with radius and without radius and also diameter with 5 and 6 mm considered as control factors. Optimal control factors for the stress concentration were determined by using Taguchi technique. Minimum von misses stress and displacement were obtained by means of ANSYS software. Confirmation experiments showed that Taguchi method precisely optimized the control parameters on stress concentration.

Key Words: Engine valves, Computer Aided Design, Finite Element Analysis, Taguchi method

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1. Introduction

Presently, the growth of the automobile industry is increasing tremendously. Valve control is also one of the most important parameters for optimizing efficiency and emissions [1-4]. Internal combustion engine valves are precision engine components. They open and close as and when needed. 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. They are also used to seal the working space inside the cylinder against the manifolds. The crucial mechanical properties of the valve steel materials include the tensile strength, yield strength, elongation, hardness, and wear resistance. Primarily there are three areas to be considered for designing the engine valve [2, 5]. 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 Figure 1.

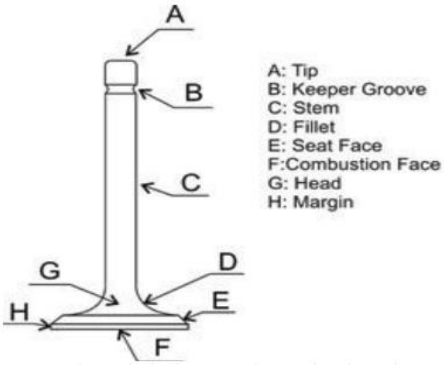


Figure 1. The basic nomenclature of engine valve

Any type of valve failure affects the engine performance, thus making it mandatory to give due importance to failure analysis of internal combustion engine valves. Possible modes of valves failure are wear failure, valve face recession, fatigue failure, thermal fatigue, erosion/corrosion of valves, overheating of valves, carbon deposits on valves etc [2].

Available research literature about valve failures indicates that valve design is a complicated task because the valve is subjected to various loads at any point of time, such as reverse loading at a high temperature, stress concentration at the keeper groove area and under carbon deposits at exhaust valves. The valves generally fail by fatigue. A closed valve is loaded by spring force and pressure inside the cylinder, which varies periodically during engine operation and reaches a peak value of the order of 15 MPa. Such high pressures inside the cylinder cause bending of the valve cone, which results in a sliding motion and improper contact between valve face and seat insert, thus eventually leading to wear failure. The Otto and Diesel engines operate at temperatures of 550 ºC inside the intake valve; the corresponding values inside the exhaust valve being 700°C and 800°C, respectively. The exhaust valve temperature can shoot up to 900°C. Since the exhaust valves operate at high temperatures, they are exposed to thermal load and chemical corrosion. The intake valves, which are not subjected to such extreme thermal loading, are cooled by incoming gases, thermal transmission at the seat, and by other means [3].

Valves are subjected to cyclic loading due to valve train dynamics. The stem of the valve is under axial repeated loading, thus, it can fail by axial fatigue. The keeper groove area is subjected to tensile stresses and becomes a critical section due to geometric stress concentrations. These valves are also subjected to oscillating tensile and compressive loads. Tensile loads on the valve loads are larger in magnitude, this is mainly due to pre-tensions applied to the valve springs and the impact loading on the valve when valve returns back to close position during high engine speed operations. Compressive loads are primarily caused to inertial forces acting on the valve stock during high engine speed operation. Pre-tension is used to create an air-tight hydrostatic seal at the intake [1].

The purpose of this study is to determine the effect of fillet radius of an engine valve on stress concentration. For this purpose, an engine valve is designed and 3D model is created using CATIATM software. The model is also modified by varying material, fillet Radius and diameter of valve.

2. Taguchi Method

In recent years, the Taguchi method has become a powerful tool for improving productivity during research and development, so that high-quality products can be produced quickly and at low cost [2, 6-10].

The Taguchi method developed by Genuchi Taguchi is a statistical method used to improve the product quality. It is commonly used in improving industrial product quality due to the proven success and with the Taguchi method. It is possible to reduce the number of experiments, significantly. The Taguchi method is not only an experimental design technique, but also a beneficial technique for high quality system design [5, 8].

The Taguchi technique includes the following steps:

- Determine the control factors,
- Determine the levels belonging to each control factor and select the appropriate orthogonal array,
- Assign the control factors to the selected orthogonal matrix and conduct the experiments,
- Analyze data and determine the optimal levels of control factors,
- Perform the confirmation experiments and obtain the confidence interval,
- Improve the quality characteristics.

The Taguchi method uses a loss function to determine the quality characteristics. Loss function values are also converted to a signal-to-noise (S/N) ratio (η). In general, there are three different quality characteristics (Eqs. (1) to (3)) in S/N ratio analysis, namely “Nominal is the best”, “Larger is the better” and “Smaller is the better”. For each level of process parameters, signal-to-noise ratio is calculated based on S/N analysis.

"Nominal is the best" quality characteristic;

$$\eta = S/N_T = 10\,log\left(\frac{\bar{y}}{s_y^2}\right) \tag{1}$$

"Larger is the better quality characteristic;

$$\eta = S/N_L = -10\,log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y^2}\right) \tag{2}$$

"Smaller is the better" quality characteristic;

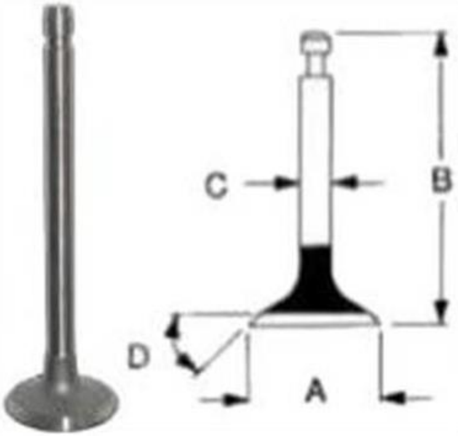
$$\eta = S/N_S = -10\,log\left(\frac{1}{n}\sum_{i=1}^{n}y_i^2\right) \tag{3}$$

where $\bar{y}$ is the mean of observed data s_y^2 is the variance of y, n is the number of observations and y is the observed data.

3. Material and Methods

3.1. Design steps

The engine valve geometry used in this study is shown in Figure 2.



Engine valve dimensions	
A	32 mm
B	110 mm
C	5 or 6 mm
D	45°

Figure 2. Engine valve geometry

3.2. Selection of control parameters and orthogonal array

Material properties of used materials are given in Table 1. Material, radius condition and diameter were selected as control factors and their level is presented in Table 2.

Table 1. Material properties

Material	Young Modulus	Poisson Ratio
Cast Iron	170 GPa	0.29
Aluminum	70 GPa	0.33

Table 2. Control Parameters and their levels.

Symbol	Control Parameters	Level	
		1	2
A	Material	Cast Iron	Aluminum
B	Radius Case	With Radius	Without Radius
C	Diameter (mm)	5	6

A Tensile Force of 900 N was applied on the upper surface of valve as presented in Figure 3

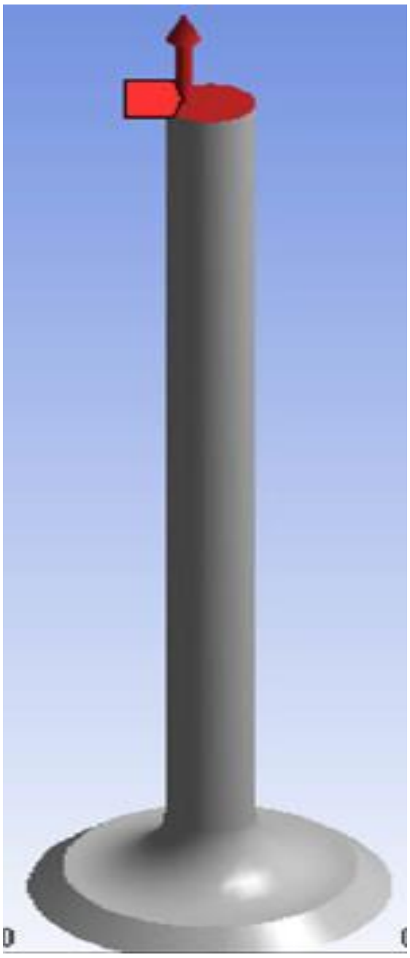


Figure 3. A Tensile Force of 900 N on valve

3.3. Taguchi-based experimental design

The taguchi parameter design stage presents towards the aim of determining the optimal engine valves parameters so as to achieve the lowest Von Mises Stresses. The relationship between the control factors (material, radius and diameter) and output response factors (stress) and the optimal conditions of the parameters taken into consideration in this study.

The first step of the Taguchi method is to select an appropriate orthogonal array. The most appropriate orthogonal array was selected to determine the optimal stress concentration parameters and to analyze the effects of these parameters as shown in Table 3.

Table 3. Orthogonal array of Taguchi L8

Trial no. L8	A	B	C
1	1	1	1
2	1	1	2
3	1	2	1
4	1	2	2
5	2	1	1
6	2	1	2
7	2	2	1
8	2	2	2

In the Taguchi method, orthogonal array can provide an effective experimental performance with a minimum number of experimental trials. The configuration of orthogonal arrays is determined with respect to total degrees of freedom of the targeted function. The degree of freedom (degree of freedom 8–1 = 7) for L8 orthogonal array can be more than or at least equal to the determined process parameters. The Von Mises Stress and displacement values were measured via the experimental design for each combination of the control factors. The determination of the quality characteristics of the measured control factors was provided by signal-to-noise (S/N) ratios.

3.4. Analysis of the signal-to-noise (S/N) ratio

The Taguchi method uses S/N ratio to measure the variations of the experimental design. The equation of “larger is the better” (Eq. (3)) was selected for the calculation of S/N ratio since the lowest values of Von Mises Stress and displacement were the desired results in terms of good product quality. S/N ratios of von misses stress and displacement are shown in Table 3. As shown in Table 4, the control parameters were discriminated by considering different levels and possible effects according to the selected orthogonal array.

Table 4. S/N ratios of experimental results for Von Mises Stress and displacement

Trial No.	**Control Parameters**			**Measured Von Mises Stress (MPa)**	**Measured Displacement (mm)**	**S/N Ratio**	**Mean Value**
	Material	**Radius Case**	**Diameter (mm)**				
1	Cast Iron	With Radius	5	759.5	0.560e-6	62.0259	379.75
2	Cast Iron	With Radius	6	906.7	0.598e-6	61.4557	453.35
3	Cast Iron	Without Radius	5	6015.2	0.805e-6	58.8738	3007.6
4	Cast Iron	Without Radius	6	9232.4	0.917e-6	52.7423	4616.2
5	Aluminum	With Radius	5	692.44	0.167e-5	52.5354	346.22
6	Aluminum	With Radius	6	861.57	0.177e-5	52.5382	430.79
7	Aluminum	Without Radius	5	5688.54	0.238e-5	49,4582	2844.27
8	Aluminum	Without Radius	6	9061.56	0.271e-5	48.3303	4530.78

4. Results and Discussion

The optimum solutions obtained for Engine Valve Von Mises Stress and displacement (Trial 5) are illustrated in Figures 4-5.

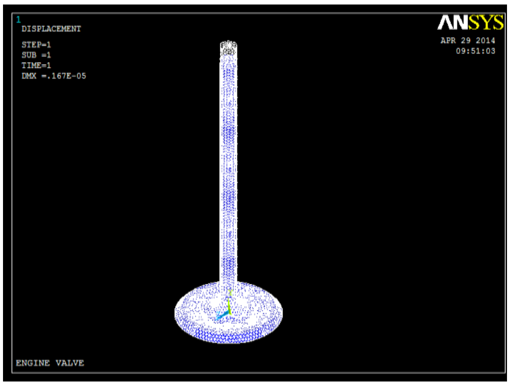


Figure 4. Engine valve displacement

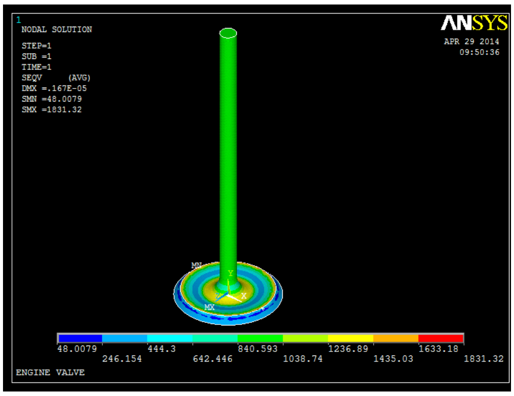


Figure 5. Engine Valve Von Mises Stress

The results obtained from the eight experimental trials, the mean value of Von Mises Stress was calculated as 4152.24 MPa and mean S/N ratio for Von Mises Stress and displacement value were found to be –54.25 dB. Mean S/N ratios for each level of control parameters and level differences of parameters are shown in Table 4. The effects of the level of each factor on the quality characteristics can be analyzed using S/N ratios. These effects are defined and evaluated according to total mean values of experimental trial results or S/N ratios. The optimum Von Mises Stress and displacement error values can be calculated by means of total mean values of experimental trial results. Another requirement in the calculation of optimum values is to determine the optimum levels. The optimum levels can be determined by evaluating two different levels of the control factors according to the results from the combinations generated by the orthogonal array. The levels of control factors were also determined for both Von Mises Stress and displacement error as represented in Table 4, and S/N and mean value graphics of these levels were used for the evaluation in Figures 6 and 7.

Since the minimum values for Von Mises Stress and displacement is suitable in optimization, the optimum combination of Von Mises Stress and displacement were determined as; cast iron as material, with radius and valve diameter of 5 mm.

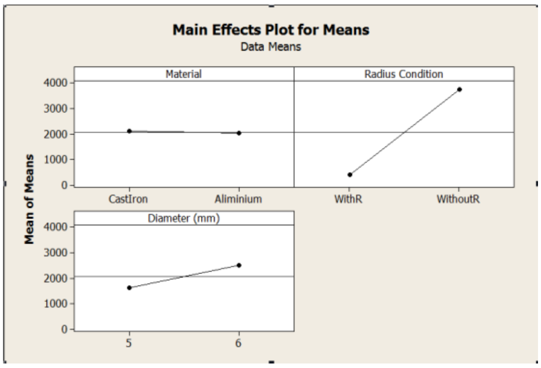


Figure 6. Main Effect Plot for Means

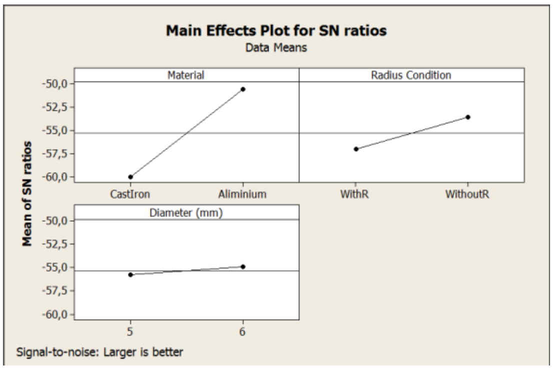


Figure 7. Main Effect for S/N Ratios

5. Conclusion

In this present study, design and analysis of the engine valves have been conduct in order to determine optimal design parameters. The engine valve design by using 3D CAD parametric software CATIA and CAD model of engine valve imported into ANSYS for Finite Element Analysis. Analysis have been performed by varying the material, fillet radius and diameter of engine valve.

Of these design parameters, the sequences of *211* presents the best solution in view of Von Mises Stress which is 692.44 MPa and displacement which has $0.167.10^{-5}$ mm corresponding the lowest S/N ratios. As a result, cast iron as material, with fillet radius and valve diameter of 5 mm presented the best solution.

6. References

[1] Atashkari, K., Nariman-Zadeh, N., Golcu, M. (2007). Khalkhali, A. and Jamali, A., Modelling and multi-objective optimization of a variable valve-timing spark-ignition engine using polynomial neural networks and evolutionary algorithms. Energy Conversion and Management, Volume 48, Issue 3, pp. 1029–1041.

[2] Jaswin, M. A. and Mohan Lal, D. (2010). Optimization of the Cryogenic Treatment Process for En 52 Valve Steel Using the Grey-Taguchi Method. Materials and Manufacturing Processes, vol. 25, pp. 842–850.

[3] Da Silva, F.J., Franco, S.D., Machado, A.R., Ezugwu, E.O. and Souza, Jr. A.M. (2006). Performance of cryogenically treated HSS tools. Wear, vol. 261, no. 5-6, pp. 674-685.

[4] Young, A.Y.L., Seah, K.H.W. and Rahman, M. (2006). Performance evaluation of cryogenically treated tungsten carbide tools in turning. International Journal of Machine Tools & Manufacture, vol. 46, no. 15, pp. 2051-56.

[5] Nalbant, M., Gokkaya, H., Sur, G. (2007). Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning. Materials and Design, vol. 28, no. 4, p. 1379-1385.

[6] Korkut, I., Kucuk, Y. (2010). Experimental Analysis of the Deviation from Circularity of Bored Hole Based on the Taguchi Method. Strojniški vestnik - Journal of Mechanical Engineering, vol. 56, no. 5, p. 340-346.

[7] Lin, Y.C., Chen, Y.F., Wang, D.A., Lee, H.S. (2009). Optimization of machining parameters in magnetic force assisted EDM based on Taguchi method. Journal of Materials Processing Technology, vol. 209, no. 7, p. 3374-3383.

[8] Šibalija, T., Majstorović, V., Soković, M. (2011). Taguchi-Based and Intelligent Optimisation of a Multi-Response Process Using Historical Data. Strojniški vestnik - Journal of Mechanical Engineering, vol. 57, no. 4, p. 357-365.

[9] Yang, J.L., Chen, J.C. (2001). A systematic approach for identifying optimum surface roughness performance in end-milling operations. Journal of Industrial Technology, vol. 17, no. 2, p. 1-8.

[10] Furness, R.J., Wu, C.L., Ulsoy, A.G. (1996). Statistical analysis of the effects of feed, speed, and wear of hole quality in drilling. Journal of Manufacturing Science and Engineering, vol. 118, no. 3, p. 367-375.