Design Optimization of IC Engine Rocker-arm Using Taguchi Based Design of Experiments

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Abstract — **During the past decades, rocker arms have been optimized for delivering better performance. Fatigue life, durability, toughness, high dimension stability, wear resistance, strength as well as economic factors influenced the selection of criteria for optimization. Rocker arms are mainly subjected to cyclic loads and their fatigue life plays a vital role in their design. Therefore, this work aims at designing the rocker arm for higher fatigue life by changing material and arm ratio. Three different materials and three different arm ratios are chosen as inputs.**

The rocker arm is modeled using CATIA V5 software and the fatigue analysis is carried out using ANSYS 14.5 APDL finite element software. The total deformation, Vonmises equivalent stresses, factor safety are evaluated for each combination. Taguchi based design of experiments is applied and the trials are conducted using L9 orthogonal array. From the design of experiments, it is observed that structural steel having arm ratio of 1:1 provides the best combination for higher fatigue life.

Keywords: Rocker arm, Arm ratio, Fatigue life, Orthogonal array.

I. INTRODUCTION

ROCKER arm is an important part of the valve train in fuel injection system providing not only the means of actuating the valves through a fulcrum utilizing the lifter and the push rod but also provide a means of multiplying the lift ratio. Cam shaft design advanced in leaps and bounds over last three decades but overhead valve engines with centrally located camshafts still use lifters and push rod and rocker arms as a means of opening and closing the intake and exhaust valves in fuel injection pumps. Advancements in materials used in construction of rocker arm for reducing noise, weight and improving strength for efficient operation are going on throughout the globe since long. The usual materials used for such purpose are Steel, Aluminum, and Forged steel to Stainless steel, aluminum alloys and composites. The success lies in investigating the possibility of creating a light weight rocker arm which provides higher fatigue life, reduced friction between the rocker and the valve stem but still remain economical. Structural and mechanical components subjected to fluctuating service stress (or more appropriately, strain) are susceptible to failure due to fatigue.

A. Nagaraja and G. Suresh Babu [1] made an effort to design a rocker arm for a four wheeler using theoretical formulas. In this theoretical calculation is done for design for fulcrum pin, Design for forked end, Design for rocker arm cross-section, Design for Tappet, and Design for valve spring. Syed Mujahid Husain and Siraj Sheikh [2] reviewed the various types of rocker arms, based on published sources from the last 40 years in order to understand rocker arm for its problem identification and further optimization. Mohd Moesli *et al.* [3] presented the failure analysis of a diesel engine rocker arm, used in shipsand boats, which failed in service. The fracture occurred at the threaded part of the rocker arm. A detailed metallurgical investigation was conducted to indentify themode of failure and the point at which the crack was initiated. Lenin Rakesh N. and A. Thirugnanam [4] carried out finite element analysis to find out the stress analysis of rocker arm and the hand crank and compared results with experimental test procedures to validate the magnitude, position and frequency of occurrence of various failure modes.

Antaryami Mishra [5] made an attempt to find out various stresses under extreme load condition for a polymer matrix composite rocker arm. Glass fibre reinforced (10% volume fraction) High Density Polyethylene (HDPE) composite rocker arm of fuel injection pump has been considered for analysis owing to its light weight, higher strength and good frictional characteristics. Christer Spiegelberg and Soren Andersson [6] presented that the surface velocities obtained from a rigid body model are used to simulate friction and wear in the contact between the rocker arm pad and valve bridge in the cam mechanism of a diesel engine.

The friction is simulated with two different friction models, a 3D brush model capable of handling transient conditions such as an varying normal load and varying surface velocities and a Columbian friction model. Chin-Sung Chung and Ho-Kyung Kim [7] presented a paper on rocker arm in 2005.In order to evaluate the fatigue endurance for the rocker arm of a diesel engine, stress measurements were performed using strain gages attached near the neck, which is one of the most critical regions

in the rocker arm, while varying the engine speed. Fatigue life experiments were carried out on miniature specimens taken from rocker arms. To evaluate the fatigue endurance of the rocker arm, the S–N data were compared with the stress analysis results obtained through a Finite Element Modeling (FEM) analysis of the rocker arm. Dong Woo Lee, Seok Swoo Cho and Won Sik Joo [8] presented the failure analysis of a rocker arm shaft for a 4-cylinder SOHC engine.

Fractures occurred at the interface between the rocker arm shaft and the engine block. These fractures were found to be responsible for bolt tightening. Srinivasa Athreya [9] applied the Taguchi based optimization technique for lathe process parameter optimization in order to improve the surface finish. Messias Borges Silva *et al.* [10] Presented the Taguchi Method, a statistical design modeling for experiments applied in Environmental engineering. This method was applied to optimize the treatment conditions of polyester-resin effluent by means of Advanced Oxidative Processes (AOPs) using chemical oxygen demand (COD) as response parameter. The influence of each independent parameter including respective interactions was evaluated by Taguchi Method, which allowed determining the most statistically significant variables and conditions to best fit the process. Balla Yuvaraj *et al.* [11] Presented the Taguchi design of experiments and orthogonal array to find a specific range and combinations of turning parameters like cutting speed ,feed rate and depth of cut to achieve optimal values of response variables like surface finish, tool wear, material removal rate in turning of Brake drum of FG 260 gray cast iron Material. In this work, the rocker arm is modeled using three different materials namely Aluminum composite, AL6061 alloy and structural steel. Three different arm ratios *i.e.* 1:1, 1:1.15 and 1:3 were chosen for analysis based on available literature. The finite element model was made using structural solid 187 element. A completely reversed bending load of magnitude 1900 N chosen from TAPEQRS-Truck rocker arm is applied on the finite element model of rocker arm. Structural steel with arm ratio of 1:1 showed to have highest fatigue life of 17983 cycles.

II. MODELING AND FINITE ELEMENT ANALYSIS

Figure 1 shows the CATIA V5 models of rocker arm and its pin assembly. The finite element model
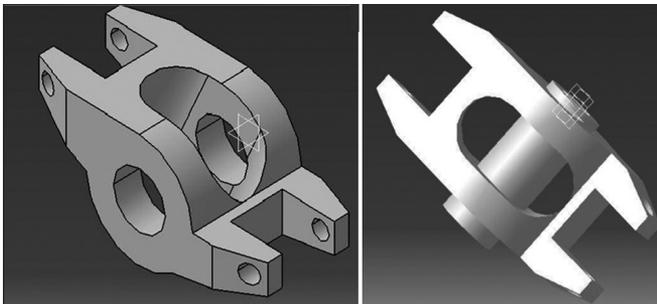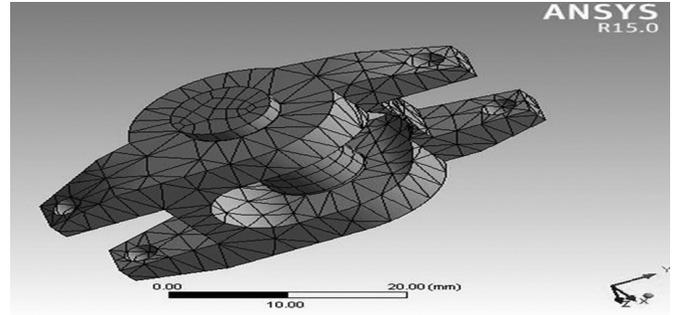

Figure 1. Rocker arm and pin assembly.

Figure 2. FEM Model of rocker arm.

Of the rocker arm using structural solid 187 is shown in fig2. A medium mesh (Neither too coarse nor too fine) is used for the analysis. Tables 1 to 3 display the properties of Aluminum composite, structural steel and AL6061 alloy. Ansys uses Good Man's mean stress theory to determine the fatigue life.

TABLE 1 -- PROPERTIES OF ALUMINUM COMPOSITE

S. No.	Mechanical Properties	Value	Units
1	Density	2.77	g/cm^3
2	Ultimate tensile strength	331.24	MPa
3	Modulus of elasticity	90.67	GPa
4	Poisons ratio	0.33	----
5	Tensile yield strength	284.49	MPa
6	Shear strength	215	MPa

TABLE 2 -- PROPERTIES OF STRUCTURAL STEEL

S. No.	Mechanical Properties	Value	Units
1	Density	7.85	g/cm^3
2	Ultimate tensile strength	460	MPa
3	Modulus of elasticity	200	GPa
4	Poisons ratio	0.30	----
5	Tensile yield strength	250	MPa
6	Shear strength	345	MPa

TABLE 3 - PROPERTIES OF Al-6061

S. No.	Mechanical properties	Value	Units
1	Density	2.7	g/cm^3
2	Ultimate tensile strength	310	MPa
3	Modulus of elasticity	68.9	GPa
4	Poisons ratio	0.33	-----
5	Tensile yield strength	276	MPa
6	Shear strength	207	MPa

III. FINITE ELEMENT ANALYSIS RESULTS

Out of the three material combinations chosen for different arm ratios, rocker arm made of structural steel with arm ratio 1:1 displayed highest fatigue life, least total deformation was shown by AL 6061 alloy with arm ratio 1:1.3, and least Vonmises
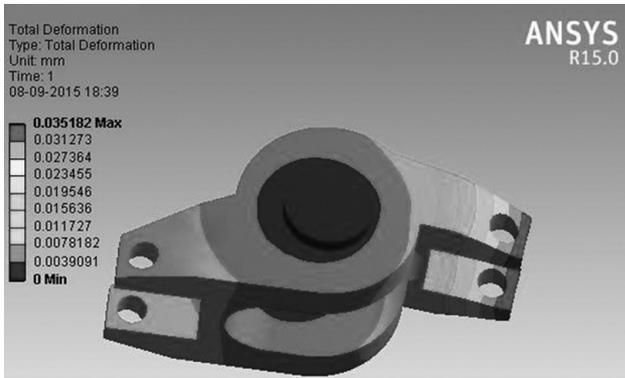
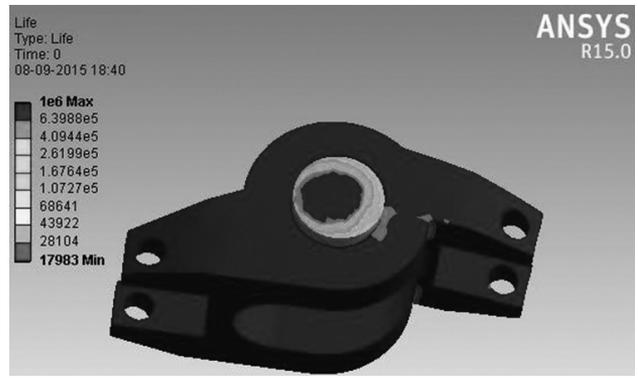Figure 3. Total deformation (steel)

Figure 5. Minimum finite Fatigue life of structural steel in cycles.

Figure 4. Vonmises stress (steel)

equivalent stress was shown by AL composite with arm ratio 1:1.3. The results are shown in figures 3 to 5.

Table 4 displays the overall structural analysis results for different materials and arm ratios.

IV. DESIGN OF EXPERIMENTS
Results from the trials conducted using ANSYS are taken

and used in determination of optimal combinations of input parameters *i.e.*, material as well as arm ratio for each of the output parameters using Taguchi methods. Minitab 17 is used for Taguchi experimental design with L9 orthogonal array. The plots for signal to noise ratio for fatigue life, total deformation, and Vonmises stresses are plotted. The criteria for each output parameter are shown in Table 5.

Figure 6 shows the signal-to-noise ratio for minimum life. Since the minimum life has to be maximum the larger the better criteria is considered. It can be concluded that the material at level 1 and Arm Ratio at level 1 *i.e.* structural steel with 1:1 Arm Ratio will give maximum life than the remaining combinations. Figure 7 shows the signal-to-noise ratio for equivalent stresses .Since the equivalent stresses has to be minimum the smaller the better criteria is considered. It can be concluded that the material at level 3 and Arm Ratio at level 3, *i.e.* Aluminum composite with 1:1.3 Arm Ratio will give minimum than the remaining combinations.

Figure 8 shows the signal-to-noise ratio for minimum deformation .Since the minimum deformation has to be

TABLE 4 -- STRUCTURAL FATIGUE ANALYSIS RESULTS

Material	Arm ratio	Total deformation (mm)	Equivalent Stress(MPa)	Fatigue Life (cycles)	Safety Factor
Structural Steel	1:1	0.035	220.74	17983	2.96
Structural Steel	1:1.15	0.044	240.06	13492	2.72
Structural Steel	1:1.3	0.057	253.5	11197	2.58
Al composite	1:1	0.10017	221.55	14977	2.83
Al composite	1:1.15	0.125	242.72	5151.6	2.61
Al composite	1:1.3	0.16222	253.87	3374.9	2.47
Al 6061/	1:1	0.0784	221.55	13775	4.8
Al 6061/	1:1.15	0.09823	242.72	12857	4.42
Al 6061/	1:1.3	0.127	253.87	8236.3	4.19

TABLE 5 -- CRITERIA OF SELECTION

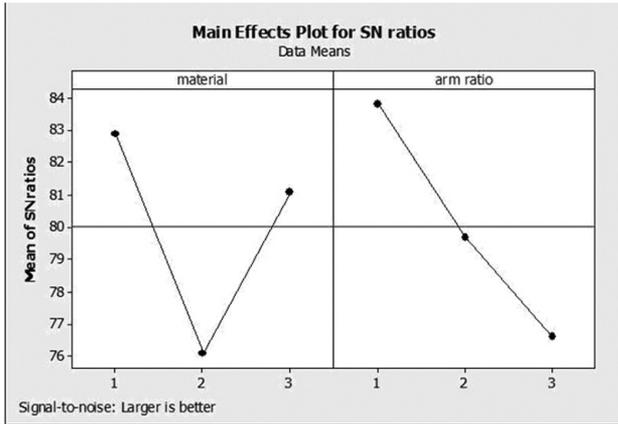| S. No.	Out-parameter	Criterion
1	fatigue Life	Larger the best
2	Total deformation	Smaller the best
3	Vonmises stress	Smaller the best

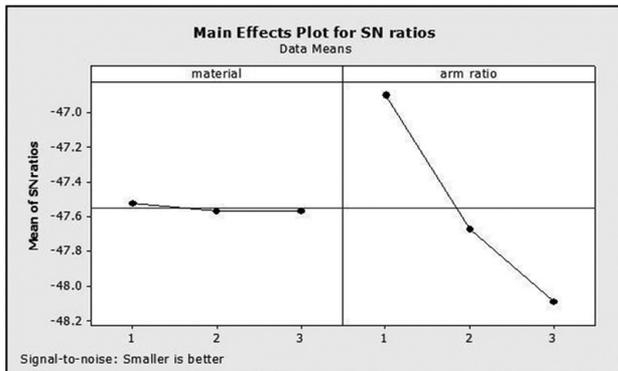Figure 6: Main effects plot for fatigue life.

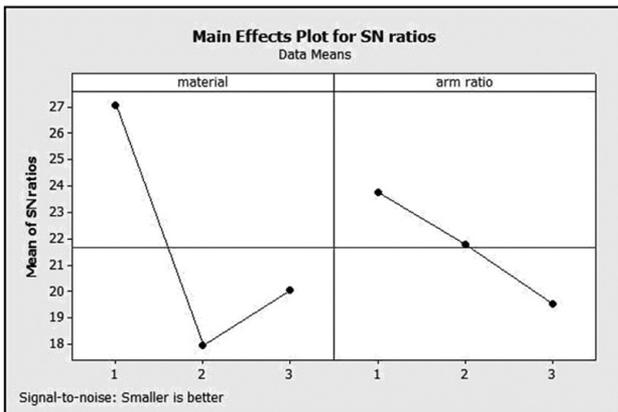Figure 7: Main Effects plot for Equivalent Vonmises stress.

Figure 8: Main Effects plot for total deformation.

minimum the smaller the better criteria is considered. It can be concluded that the material at level 2 and Arm Ratio at level 3,

i.e. Aluminum alloy with 1:1.3 Arm Ratio will give minimum deformation than the remaining combinations.

V. CONCLUSION

The following important conclusions are drawn out of the work carried out.

- It can be concluded that the fatigue life of the rocker arm is influenced by the arm ratio and material of rocker arm with it is made .Using Taguchi method, the optimal combination for maximum fatigue life is for rocker made with structural steel and arm ratio 1:1.
- The total deformation is minimum in the case of material AL 6061 with arm ratio 1:1.3.
- The Vonmises stresses are minimum for Al composite with arm ratio 1:1.3.

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Dr. G. Chaitanya received his M E degree from Satyabhama University, Chennai and PhD degree from JNTU, Hyderabad. He has published over 10 articles in international journals and presented over 2 articles at different national conferences. Currently Dr. G.Chaitanya is an associate professor in the department of Mechanical Engineering, R.V.R & J.C College of Engineering (Autonomous) Guntur, Andhra Pradesh, India. He is life member of ISTE and IAENG.