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Analysis and Optimization of Cradle of a Multi Barrel Rocket Launcher Using DOE

Joseph C George[1], D N Jadhav[2]
[1]*ME Scholar, Sardar Patel College of Engineering, Mumbai, Maharashtra, India*
[2]*Associate Professor, Sardar Patel College of Engineering, Mumbai, Maharashtra, India*

Abstract:*This document presents the methodology which was adopted to optimize the performance of cradle of a rocket launcher designed for military applications. The cradle was modelled and transient analysis was conductedusing ANSYS with various combinations of design parameters using standard orthogonal arrays as proposed by Taguchi.Design variables like plate thicknesses are optimized so as to reduce the weight while keeping the equivalent stresses and deformation incurred within the limits.*
Keywords*: DOE, finite element analysis, frame,Taguchi, weight optimization*

I. Introduction

A frame or a cradle in general is a load carrying structure which supports the weight above it and acts as a foundation. The cradle here is part of a certain Multi Barrel Rocket Launcher (MBRL) which finds military applications. The whole launcher is mounted on a truck so that it can be transported to any terrain. The launcher consists of Pods which houses the missiles which are in turn supported by the cradle. The cradle sits on an underframe mounted directly to the chassis of the truck.The ultimate aim of the project is to reduce the weight of the cradle by varying the values of some dominant factors while keeping effects like von-mises stresses and deformations within their permissible limits using Design of Experiments (DOE). A standardL9 design array was constructed as proposed by Taguchi and a set of transient analysis experiments under given loads were conducted in an analysis software ANSYS.The data thus obtained can be generalized in a broader sense by calculating S/N ratios [6].The cradle is constructed of box sections with beams of different thicknesses which are welded to each other. The thicknesses of some of these box sections are taken as major design factors whose values are intended to be optimized. The material of the cradle is a military grade Aluminium alloy. This paper will assist in solution of similar problems which involve parametric optimization.

II. Literature Review

DOE has emerged today as an important tool for optimizing processes and products in various kinds of industries. DOE may be combined with classical analysis, to reduce the computational effort without affecting the final solution quality. DOE being a method majorly used for optimization of processes is new to structural analysis and various attempts are now being made in the same. A paper on parametric optimization of an Eicher chassis was referred [1].Based on L18 orthogonal arrays proposed by Taguchi, weight reduction of a chassis of Eicher truck was achieved while keeping other parameters like stresses and deflections within the permissible limit. This method aims at conducting a certain number of experiments while changing the values of several parameters on which the performance of the frame depends and thus collect a raw data, which is then analyzed to come to a most robust design. In another document published on DOE [2], a detailed procedure is provided on how to use the Taguchi method to optimize a particular process. Another paper referred on optimization of a converter housing [3] used various methods to screen a few parameters from a number of parameters for optimization of a process. This can be useful when a lot of parameter are to be considered and it is desired to find only the ones that most affect the performance of the process or the product. In another paper Finite Element analysis (FEA) based Taguchi method was used to investigate the effects of various factors to find the robust design of a vertebral body cage [4]. FEA and DOE techniques were adopted in investigation of welding processin another document [5]. A three dimensional thermal model was developed to simulate the laser transmission contour welding process with a moving heat source. DOE was employed to plan the experiments and to develop mathematical models based on simulation results.

III. Methodology

Fig. 1 shows the steps that were followed while conducting the project.

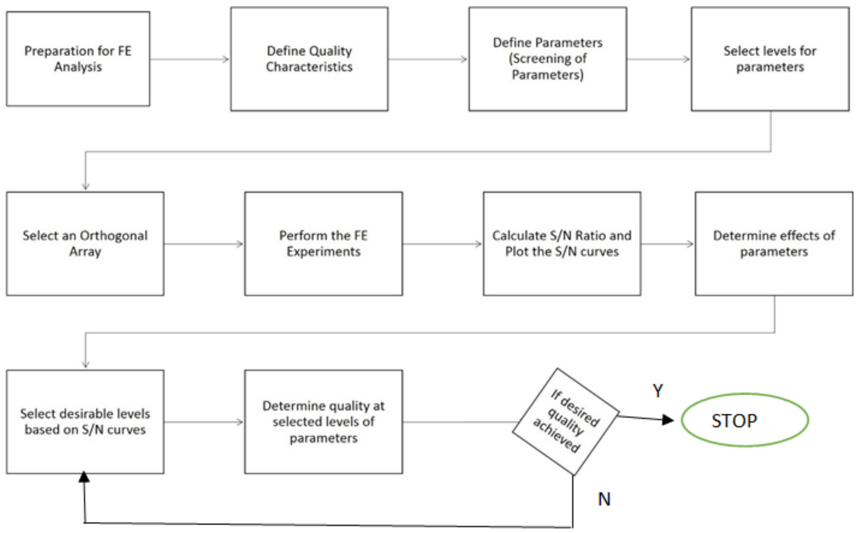


Fig. 1: Flowchart of methodology adopted.

First the 3-D model of the structure or frame in question was modelled and meshed. The model was simplified by removing small holes, blends and structures that didn't contribute towards the stiffness of the cradle. Next loads and constraints are applied to the structure.

Quality Characteristic is a quantity that is a measure of the overall performance of the process or the product. Defining the quality characteristic means defining the objective of DOE or determining the factor that needs to be controlled within a particular value or needs to be brought to a particular target. Quality characteristics selected here are weight, total deformation and von-mises stresses. With the current setting the weight of the frame is found to be 751 kg whose value is required to be reduced as much as possible while keeping the values of stresses and deformation within the limit. There is a requirement of achieving a particular value of factor of safety (FOS) as far as the stress value is concerned. AL 7039 Aluminium alloy is used to manufacture the cradle. It is chiefly used as an Armor material and finds huge application in military field. The maximum yield strength of the alloy is 310 MPa and FOS of 2 is required to be achieved which means the safe limit of stresses is 155 MPa. Also the total deformation is required to be within the limit of 2 mm. Fig. 2 shows the members of the frame whose thicknesses were selected to be optimized. Table 1 shows the current values of these parameters. The values of these parameters were varied in three level settings as shown in Table 2.

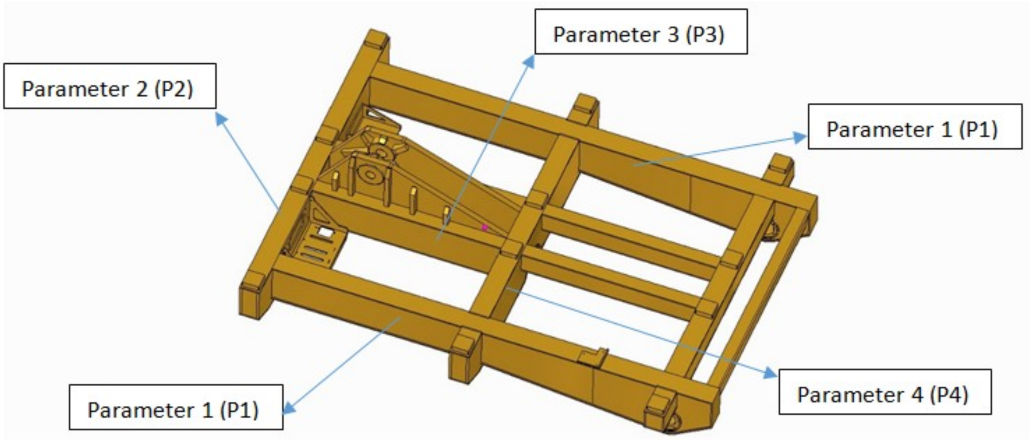
Table 1: Current values of parameters

	PARAMETERS			
	(P1)	**(P2)**	**(P3)**	**(P4)**
Current Value	8	8	6	8

Table 2: Level settings for parameters

PARAMETER	**SETTING 1**	**SETTING 2**	**SETTING 3**
P 1	4	6	8
P 2	4	6	8
P 3	4	6	8
P 4	4	6	8

Fig. 2: Parameters selected for optimization



Based on the number of factors and levels selected the L9 array was selected for the frame in question as it has 4 parameters with 3 levels each. Once the array was formed the experiments were conducted and the results were tabled.

The S/N ratios [6] for each quality characteristics were calculated and plotted. S/N ratio for an experiment is calculated using the following relation.

$$S/N Ratio = \quad -10\log_{10}\left\{\sum_{j=1}^{N} {Y_j^2}/{N}\right\} \quad (1)$$

Where: N = Number of trials for an experiment

Y_{j} =Quality Characteristic

j = Experiment Number

The number of trials for an experiment in this case is only one so the equation can be simplified as:

$$S/N Ratio = \quad -10\log_{10} Y^2 \quad (2)$$

IV. Results and Discussions

Table 3 shows the final array formed including the quality characteristics and the S/N ratio values.

Table 3: Orthogonal array with S/N ratios

L9	PARAMETERS				QUALITY CHARACTERISTICS			S/N RATIO (SMALLER-THE-BETTER)		
Exp No.	(P1)	(P2)	(P3)	(P4)	Mass (Kg)	Deformation (mm)	Stress (MPa)	Mass	Deformation (mm)	Stress
1	4	4	4	4	650.6	1.318	190	-56.2663	-2.3983	-45.5751
2	4	6	6	6	682.8	1.201	174.3	-56.6859	-1.5909	-44.8259
3	4	8	8	8	715	1.076	176.7	-57.0861	-0.6362	-44.9447
4	6	4	6	8	706.1	1.109	164	-56.9773	-0.8986	-44.2969
5	6	6	8	4	711.4	1.097	168.8	-57.0423	-0.8041	-44.5474
6	6	8	4	6	705.2	1.115	169.7	-56.9662	-0.9455	-44.5936
7	8	4	8	6	734.7	0.887	126.4	-57.3222	1.0415	-42.0349
8	8	6	4	8	728.5	0.983	96.4	-57.2486	0.1489	-39.6815
9	8	8	6	4	733.7	0.894	79	-57.3104	0.9732	-37.9525

Based on the calculations above, S/N curves for all the quality characteristics were constructed for each parameter.

Once the curves are plotted, the desired level settings can be selected according to the type of S/N ratios. The type of S/N ratios classified here are smaller-the-better type. It is to be noted that the stress values are required to be within the limit of 155 MPa which corresponds to the S/N ratio value of -43.8, so a value higher than that or having a magnitude smaller than 43.8 is required. Since the total deformation is within the limit of 2 mm any of the above level settings are acceptable.

Fig. 3 shows the S/N ratio plot for mass. It is found from the plot that as the thickness of the plates are increased the mass of the frame increases and thus the S/N ratio decreases.

Fig. 4 shows the S/N ratio plot for deformation at various level settings.

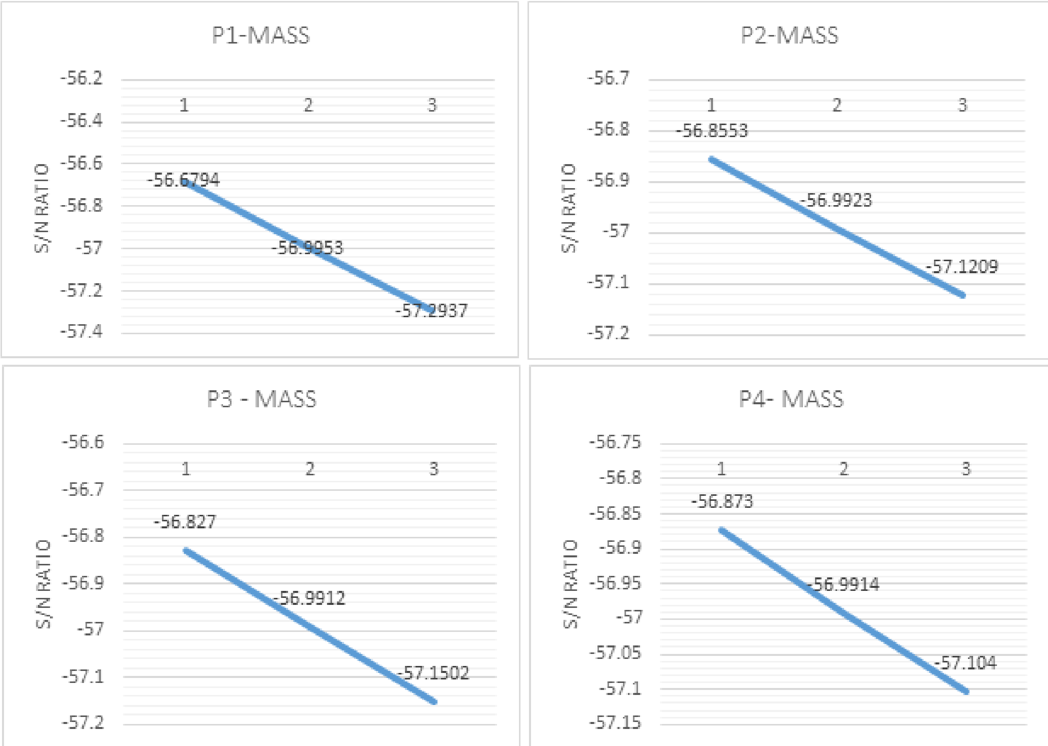


Fig. 3: Plot for S/N ratio: Mass

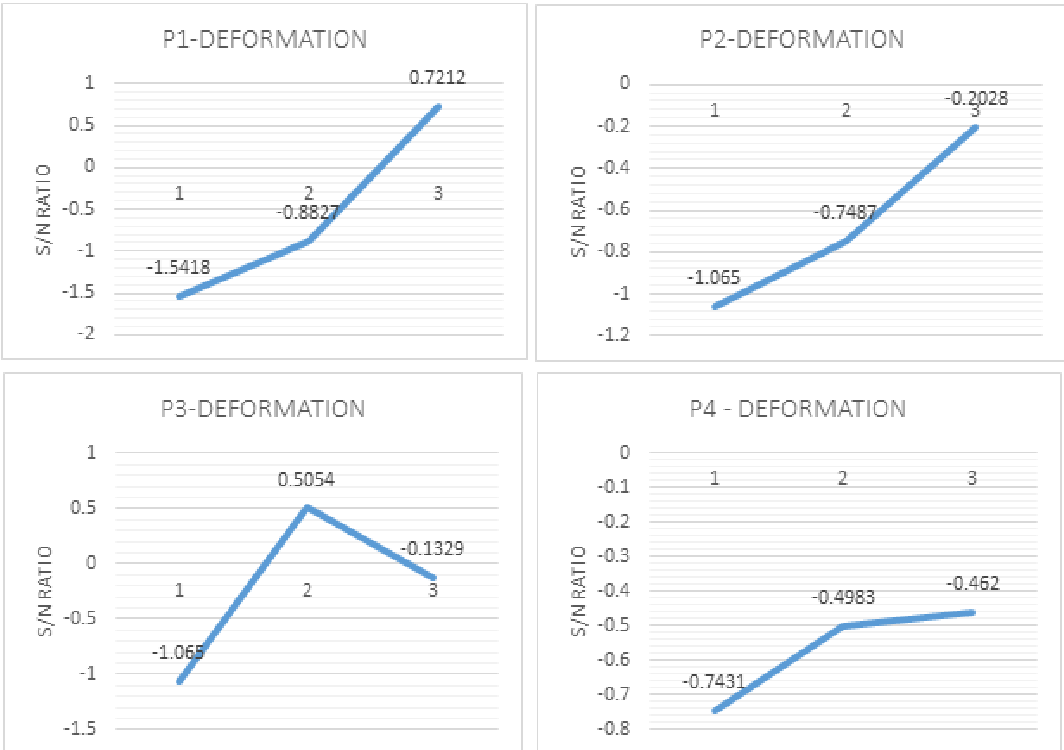


Fig. 4: Plot for S/N ratio: Deformation

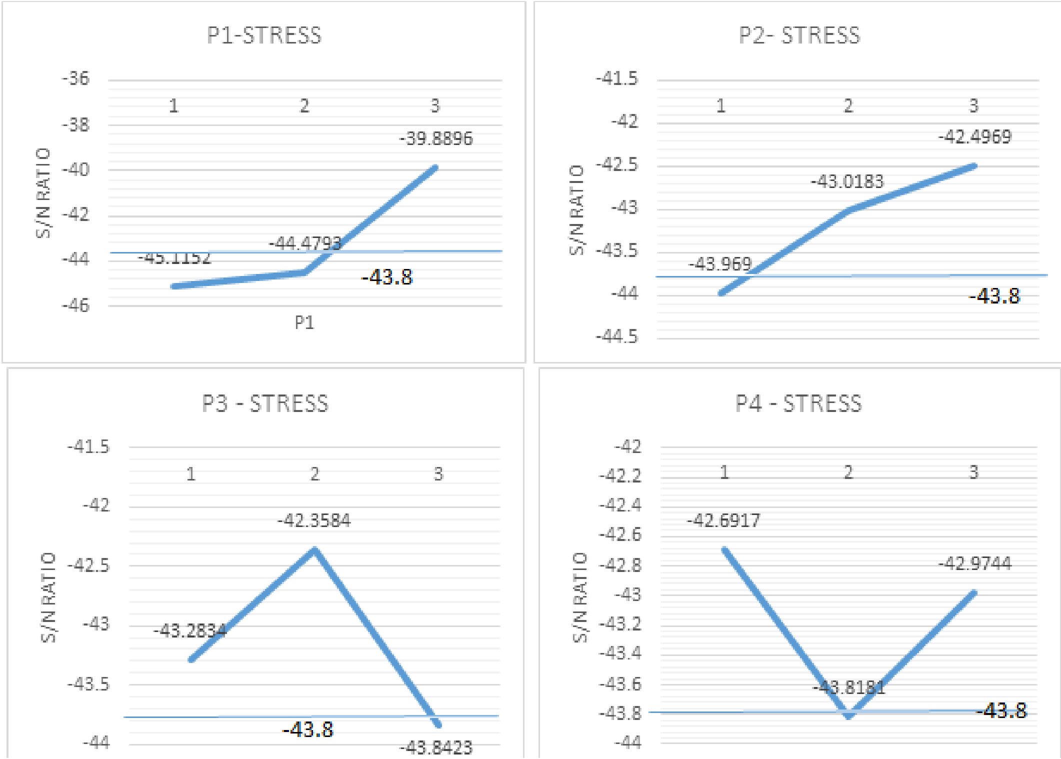


Fig. 5: Plot for S/N ratio: Stress

Fig. 5 shows the S/N ratio plot for the stress values. Considering the first parameter P1 only the third level is safe when it comes to the stress values. For parameter 2 level 1 of 4 mm thickness is not safe so level 2 or level 3 can be selected. Similarly for all other parameters all the levels which are above the -43.8 mark are safe. The table below shows which levels are safe for the particular parameters and the various choices before us.

Table 4: Analysis of shear stress

	P1 (mm)	P2 (mm)	P3 (mm)	P4 (mm)
Stress < 155 MPa (S/N ratio > -43.8)	8	6,8	4,6	4,8
Stress > 155 MPa (S/N ratio <-43.8)	4,6	4	8	6

From the above table it is clear that only 8 mm levels are safe for first parameter P1. Thus the levels 1 and 3 were rejected. So the thickness of side beam of the frame selected is 8mm. For parameter P2 level 2 and level 3 of 6 mm and 8 mm respectively are safe but 4 mm is not. The type of S/N ratios of the other two quality characteristics, i.e. weight and deformation suggest selecting the minimum of the two, i.e. the level 2 of 6 mm be selected. Thus the thickness for front beam is 6 mm. Similarly for parameter P3 level 3 of 8 mm is not safe and 4 mm and 6 mm are safe, of which 4 mm will give minimum weight. Thus for P3 thickness of 4 mm is selected. For parameter P4 6 mm is not safe and only 4mm and 8 mm are safe. Thus the lesser of two which is 4 mm is selected. The thicknesses are selected based on the above discussion and are shown in Table 5.

Table 5: Selected values for parameters

	P1 (mm)	P2 (mm)	P3 (mm)	P4 (mm)
Selected Thicknesses	8	6	4	4

With the selected set of factor levels the problem was again solved and the output quality characteristics thus found were as given in Table 6.

Table 6: quality characteristics at selected settings

	Weight (kg)	**Deformation (mm)**	**Stress (MPa)**
Quality Characteristics at selected settings	710	1.101	153.37

V. Conclusion

The weight of the cradle has clearly reduced from 751 kg in the previous design to 710 kg in the new design which comes to about 5.46% of weight saving. The same was achieved while keeping the deformation values within the limit and still attaining the required factor of safety. Thus using DOE and FEA methods we have saved 41 kg of weight of the cradle. The above procedure for Optimization as done with a L9 array can be done with an L18 or a higher order array with of course the expense of higher amount of resources. It will though yield better accuracy.

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