Design and Optimization of Vehicle Crush Box using DFSS,Taguchi Techniques

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Abstract— **The Indian automotive buyer is very cost-conscious and the hence auto manufacturers are striving to bring in low cost of ownership with high fuel economy. Other than Initial cost and fuel consumption of the vehicle, damaged parts replacement and reparability of the vehicle is one of the major concerns of thecustomers. In cities, as the traffic density increases, low speed accidents are commonplace. In a low speed impact, the vehicle must withstand the crash with minimal damage so that repaircosts remain low. So the purpose of the project is to make optimum vehicle crush box using dfss techniques.**

***Keywords*— Crush Box, Orthogonal Array, DFSS, Taguchi Method.**

I. INTRODUCTION

Multiple cost effective crush box design will be generated for the model, and a iterative study to find the optimal crush or reactive force that a crush box can and should take to achieve lowest possible reparability cost in case of low speed impacts.
Using the application of Taguchi's Method to improve energy absorption of the crush box .Energy absorption is a measure of absorbing the external force and it is a factor that has a high influence on the manufacturing cost and weight.

Taguchi Method involves identification of proper control factors to obtain the optimum results of the process. Orthogonal Arrays (OA) are used to conduct a set of experiments. Results of these experiments are used to analyze the data and predict the quality of components produced.

II. APPROACH TO PRODUCT/PROCESS DEVELOPMENT

2.1 DFSS

Design for Six Sigma (DFSS) is used by businesses to design a quality product from scratch. Design for Six Sigma is fundamentally different from Six Sigma itself. The focus of Six Sigma is on improving the existing designs whereas the focus of DFSS is on creating new and better products. IDDOV in DFSS provides the necessary framework for product development and emphasizes the step-by-step phases to achieve Six Sigma, including Identify, Define, Develop, Optimize and Verify. It is described in detail here.

2.1.1 Identify the Opportunity -This is the phase where you identify the customer requirements, prioritize their needs, and translate those needs into design requirements. It is the most important phase of DFSS since all of the future activities of the projects depends on this phase. Once the requirements are identified, the complete project plan can be made. Ideally, the project plan consists of the scope of the project, project objectives, project milestones and the budget. Here the requirement is, a low speed impact take place, the vehicle must withstand the crash with minimal damage.

2.1.2 Define the Requirements - This is the phase where you clearly define the product requirements. In this phase, the customer needs and wants are translated into verifiable requirements. The primary tool used for this purpose is Quality Function Deployment (QFD). QFD is a method by which the customer needs or wants are converted into specific corporate goals so that product designers are aware of what exactly they should do.

2.1.3. Develop the Concept - This is the phase where you develop a feasible concept which will meet the customer requirements. If the concept developed is found to be unreasonable, then assess other alternatives. In this phase, any potential product failure is identified and thus, eliminated. The usual tools used during this phase are TRIZ (the theory for inventive problem solving), Pugh (a technique for evaluating and developing concepts), and FMEA.

2.1.4 Taguchi Method The Full Factorial Design requires a large number of experiments to be carried out as stated above. It becomes laborious and complex, if the number of factors increase. To overcome this problem Taguchi suggested a specially designed method called the use of orthogonal array to study the entire parameter space with lesser number of experiments to be conducted. Taguchi thus, recommends the use of the loss function to measure the performance characteristics that are deviating from the desired target value. The value of this loss function is further transformed into signal-to-noise (S/N) ratio. Usually, there are three categories of the performance characteristics to analyze the S/N ratio. They are: nominal-the-best, larger-the-better, and smaller-the-better.

III. STEPS INVOLVED IN TAGUCHI METHOD

Use of Taguchi's parameter design involve the following steps
a. Identify the main function and its side effects.
b. Identify the noise factors, testing condition and quality characteristics.
c. Identify the objective function to be optimized.
d. Identify the control factors and their levels.
e. Select a suitable Orthogonal Array and construct the Matrix

f. Conduct the Matrix experiment.

g. Examine the data; predict the optimum control factor levels and its performance.

h. Conduct the verification experiment.

3.1 Identifying the Control Factors and their levels

The factors and their levels were decided for conducting the experiment, based on a "brain storming session".

Table 3.1 Selected Factors and their Levels.

FACTORS	LEVELS		
	1	2	3
Shape	Box	Tube	Hexagon
Steel Material	Low	Medium	High
Rib	No	One	Two
Crush Initiator	No	Two	Four

3.2 Selection of Orthogonal Array

To select an appropriate orthogonal array for conducting the experiments, the degrees of freedom are to be computed. The same is given below:

Degrees of Freedom: 1 for Mean Value, and

8= (2x4), two each for the remaining factors

Total Degrees of Freedom: 9

The most suitable orthogonal array for experimentation is L9 array as shown in Table 3.2

Table 3.2: Orthogonal Array (OA) L9

Experiment No.	Control Factors			
	1	2	3	4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

3.3 Conducting The Matrix Experiment

In accordance with the above OA, experiments were conducted with their factors and their levels as mentioned in table 3.3.

Table3.3.1: OA with Control Factors & Measured Value

Ex. No.	Parameters				Mean	
	Shape	Steel Material	Rib	Crush Initiator	Max Displacement	Max Acceleration
1	Box	Low	No	No	90.402	0.2368
2	Box	Medium	One	Two	58.657	0.3175
3	Box	High	Two	Four	34.447	0.4389
4	Tube	Low	One	Four	52.568	0.2595
5	Tube	Medium	Two	No	23.094	0.6701
6	Tube	High	No	Two	22.507	0.8256
7	Hexagon	Low	Two	Two	65.317	0.1945
8	Hexagon	Medium	No	Four	84.071	0.1812
9	Hexagon	High	One	No	29.737	0.4755

The S/N ratio for the individual control factors are calculated as given below:

$S_{s1}=(\eta_1+\eta_2+\eta_3)$, $S_{s2}=(\eta_4+\eta_5+\eta_6)$ & $S_{s3}=(\eta_7+\eta_8+\eta_9)$

$S_{m1}=(\eta_1+\eta_4+\eta_7)$, $S_{m2}=(\eta_2+\eta_5+\eta_8)$ & $S_{m3}=(\eta_3+\eta_6+\eta_9)$

$S_{r1}=(\grave{\eta}_1+\grave{\eta}_6+\grave{\eta}_8)$, $S_{r2}=(\grave{\eta}_2+\grave{\eta}_4+\grave{\eta}_9)$, & $S_{r3}=\grave{\eta}_3+\grave{\eta}_5+\grave{\eta}_7)$

$S_{i1}=(\eta_1+\eta_5+\eta_9)$, $S_{i2}=(\eta_2+\eta_6+\eta_7)$ & $S_{i3}=(\eta_3+\eta_4+\eta_8)$

For selecting the values of η_1, η_2, η_3 etc. and to calculate S_{s1}, S_{s2} & S_{s3} see table 4.3.

η_k is the S/N ratio corresponding to Experiment k.

Average S/N ratio corresponding to Cutting Speed at level1= $S_{s1}/3$

Average S/N ratio corresponding to Cutting Speed at level2= $S_{s2}/3$

Average S/N ratio corresponding to Cutting Speed at level3= $S_{s3}/3$

j is the corresponding level each factor. Similarly S_{fj} and S_{tj} are calculated for feed and depth of cut.

The average of the signal to noise ratios is shown in table 4.7. Similarly S/N ratios can be calculated for other factors.

Table 3.3.2: Average S/N Ratios for each factor

Level	Shape		Steel Material		Rib		Crush Initiator	
	Sum (S_{sj})	Avg S/N Ratio	Sum (S_{mj})	Avg S/N Ratio	Sum (S_{rj})	Avg S/N Ratio	Sum (S_{ij})	Avg S/N Ratio
1	183.5	61.16	208.28	69.42	196.57	65.52	116.49	38.83
2	97.76	32.58	165.82	55.27	140.96	46.98	146.07	48.69
3	179.12	59.70	86.31	28.77	122.85	40.95	171.06	57.02

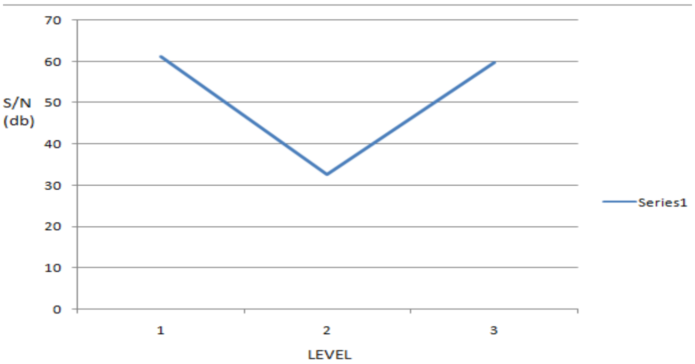

Fig3.3.1: Parameter Level v/s S/N Ratio for shape

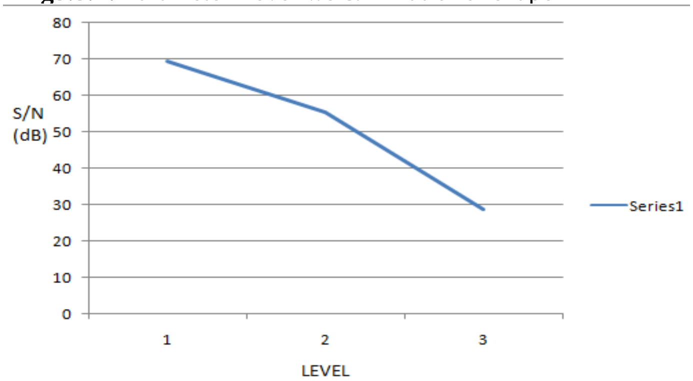

Fig3.3.2: Parameter Level v/s S/N Ratio for steel material

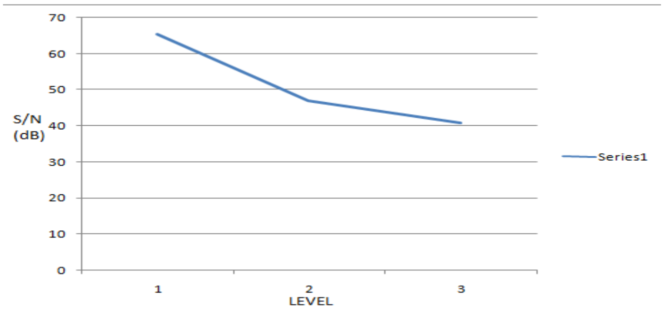

Fig3.3.3: Parameter Level v/s S/N Ratio for rib

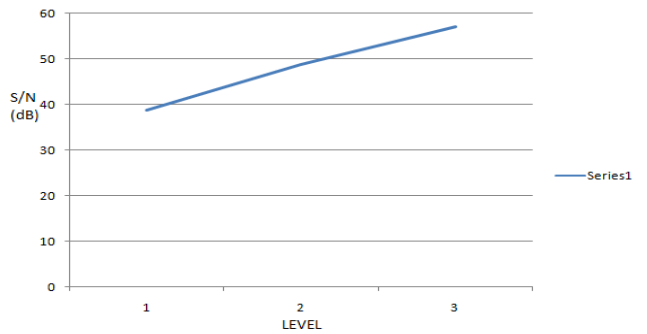

Fig3.3.1: Parameter Level v/s S/N Ratio crush initiator

For calculating the Surface Roughness the objective function, "smaller-the-better" type was used as shown.

$$\grave{\eta} = -10 \log_{10} (1/n \{\textstyle\sum^{n}_{i=1} y^2_i\})$$

The factor levels corresponding to the highest S/N ratio were chosen to optimize the condition.

IV. OPTIMIZE THE DESIGN

This is the phase where you optimize the design in such a way that the maximum output is obtained from the developed concept. In this phase, the critical design variables and functional parameters are determined to ensure utmost customer satisfaction.

From these linear graphs it is clear that the optimum values of the factors and their levels are as given in table 4.1

Table 4.1: Optimum design of factors and their levels

Parameter	**Optimum Design**
Shape	Tube
Steel Material	High Strength
Rib	Two Rib
Crush Initiator	No Initiator

V. VERIFY CONFORMANCE

Once optimization of the design is done, it is validated against established process controls and a complete cost-benefit analysis is done. In this phase, testing is done to verify that the product meets all the legal and environmental norms. Also, it is seen to it that there are no unexpected side effects.

VI. CONCLUSION

This paper illustrates the application of the parameter design (Taguchi method) in the optimization of vehicle crush box . The following conclusions can be drawn based on the above experimental results of this study:

- The optimum design obtained above is absorbing more energy than the other.
- Using the design we can reduce the damageability of car from low speed impact (15km/hr).

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