Optimization of Quality and Performance of Brake Pads Using Taguchi's Approach

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Abstract: Safety aspect in automobile engineering has been considered as a number one priority in development of new vehicle. In view of that data was collected from a servicing center of Thoubal District that the failure of disc brake is frequently happened now a day. After identifying mostly failure part (i.e. Disc Brake) through general observation, the reason of failure of disc brake is found through fish bone analysis and further evaluated by Pareto analysis to priorities and select the major reason of disc brake failure in this study. After finding the major reason it is again evaluated experimentally using Taguchi approach. Three control factors, back plates thickness, slots width and slots angle, for each higher and lower levels are identified and an orthogonal array layout of L8 are performed with the signal to noise (S/N) ratio. Analysis of variance (ANOVA) used to analyze the effect of selected process parameters along with their levels of influence. The optimized process parameter i.e. slot width of 3 mm is obtained and which lead to minimize the defects of disc pads.

Keywords: Taguchi approach, Fish Bone Analysis Pareto Analysis, ANOVA and S/N Ratio.

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1 introduction: Failure of brake leads to many undesired accidents and many lives have gone with many in disfigured. So braking system in a vehicle is more important among the automotive parts. If it is in good functional condition, it cans safe many lives from dangerous accident. Brake pads are a component of disc brakes, which are steel backing plates with friction material bound to the surface that faces the disk brake rotor. They are designed for high friction with brake pad material embedded on the disc. Brake pad friction can be divided into two categories. They are: Adhesive and abrasive.

Brake pads convert the kinetic energy of the vehicle to thermal energy by friction when the brakes are hydraulically applied; the caliper clamps or squeezes the two pads together into the spinning rotor to slow/stop the vehicle. Different types of brake pads mostly used in automotives are semi metallic brake pads, non-asbestos organic, low-metallic nao & ceramic brake pads.

Brakes are crucial system for stopping the vehicle during any moving conditions including braking while high speed, sharp cornering, traffic jam and downhill. All of those braking conditions give different temperature distribution and thermal stress. Performance of disc brake pads depend upon good material with better mechanical and thermal properties [9].

Present study analyzes the disc brake pads and suggests design improvement of pads. **GLOBAL MOTORS SERVICING CENTER**, Thoubal Athokpam Khunou cooperated and provided the one year warranties data of motor bikes. According to which the failure of disc brake is found commonly of

1. Bend of plate, 2. Oil leakage and 3. Damage of pad.

Then through Pareto analysis damage of pad is found as most occurring for finding design parameters influencing damage. Fishbone analysis is used before putting select parameters in Taguchi method to solve the problem and to optimized parameters to reduce damage of pad.
Cause and Effect Analysis was devised by Professor Kaoru Ishikawa, a pioneer of quality management, in the 1960s. The technique was then published in his 1990 book, "Introduction to Quality Control." The diagrams created through Cause and Effect Analysis is known as Ishikawa Diagrams or Fishbone Diagrams [5]. Cause and Effect Analysis can be used in number of ways. Few of them are

- Quality control.
- Discover the root cause of a problem.
- Uncover bottlenecks in your processes.
- Identify where and why a process isn't working.

On the other hand a Pareto analysis technique is useful where possible courses of action many and is competing for attention. In this estimation of the benefit delivered by each action is alone, and then selection of number of the most effective actions to deliver total benefit reasonably close to the maximal possible. Pareto analysis is a creative way of

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looking at causes of problems because it helps stimulate thinking and organize thoughts, but the restriction to use this is combining it with other analytical tools such as failure mode and effects analysis and fault tree analysis [6].

Taguchi methods [7] are statistically developed to improve the quality of manufactured goods, and also applied to other i.e. engineering, biotechnology, marketing and advertising. Researchers, Professional statisticians have welcomed the goals and improvements and development of designs for studying variation brought by Taguchi methods.

Taguchi method is based on specially three phase of design are 1. System design, 2. Parameter design and 3.Tolerance design. In the system design, a basic functional prototype design is produced depending on engineering knowledge but it may be far from optimum in terms of quality and cost. The parameter design is used to optimize and settings of the parameter values to improve quality characteristics and to identify the product parameter values at optimal condition. Finally, the tolerance design is required if the reduced variation obtained by the parameter design does not meet the required product performance (Tarng and Yang 1998) [10] around the optimal settings recommended by the parameter design. All machines or set-up are classified as engineering systems. Those systems can be classified in to two categories. They are: i) Static and ii) Dynamic. For improvement of parameters of disc brake components is a static system. In which parameter design is used to arrive at the optimum levels for types of parameters in order to minimize of the damage occurrence during braking. According to Taguchi, two major tools are employed to achieve any quality goal or any robust design (Phadke 1989) [11] are

1. Orthogonal arrays, which are used to study many parameters simultaneously.
2. Signal -to- Noise ratio (S/N ratio), which measures quality.

Taguchi method includes the following steps:

1. Identify the quality characteristics and parameters to be evaluated.
2. Determine the number of levels for the parameters and possible interactions between the parameters.
3. Select the appropriate orthogonal array and assign the parameters to the orthogonal array.
4. Conduct the experiments based on the arrangement of the orthogonal array.
5. Analyze the experimental results using the signal-to-noise ratio and statistical analysis of variance.
6. Select the optimal levels of parameters.
7. Verify the optimal parameters through the confirmation experiment.

2 Literature review:

Disc-style brakes use and development begin in England during 1890's which is the first ever automobile disc brakes were patented. (F.W. Lanchester, 1890) [1]. It was patented at Birmingham factory in 1902, though it took another half century for the innovation to be widely adopted. The first designs resembling modern-style disc brakes began to appear in Britain in the late 1940 and early 1950. The first appeared on the low-volume Crosley Hotshot in 1949, although it had to be discontinued in 1950 due to design problems. Modern-style disc brakes offered much greater stopping performance than comparable drum brakes, including much greater resistance to "brake fade" which is caused by the overheating of brake components. Meanwhile, from the late 1990 to present, North American automotive industry accelerated the pace on brake research and application to catch up with Japanese quality performance. It has been more tailored towards American vehicle brake designs which often have more challenges to balance between brake performance and quality. Discs have now become the more common form in most passenger vehicles.

The literature review within the scope of research found to be very limited and the most related available investigations are reviewed. The recent investigation by N. Chand, S.A.R. Hashimi, S Lomash and A. Naik [2] was towards development of asbestos free brake pad. In this experiment focuses on physical of new material asbestos-free with wear properties and found that it is said that the asbestos-free friction lining material can be used for brake as well as other friction lining applications. Mikael Eriksson, Filip Bergman, Staffan Jacobson [3] has investigated the surface characterization of brake pads after running under silent and squealing conditions.

Rashid and Asim [4] worked on disc brakes evolution over time to be a reliable method of decelerating and stopping a vehicle. There have been different designs of disc brake systems for different applications. This review gives a detailed description of different geometries of the components and the materials used in a disc brake system. Manuel González, Raúl Díez and Esteban Cañibano (2004-10-10) [12] studied on noises in braking system have been classified according to its typology and frequency range. On the "groan" noises, a few studies have been published in comparison with other noises better known, such as "judder" and "squeal".

3 Methodologies:

ISSN 2229-5518

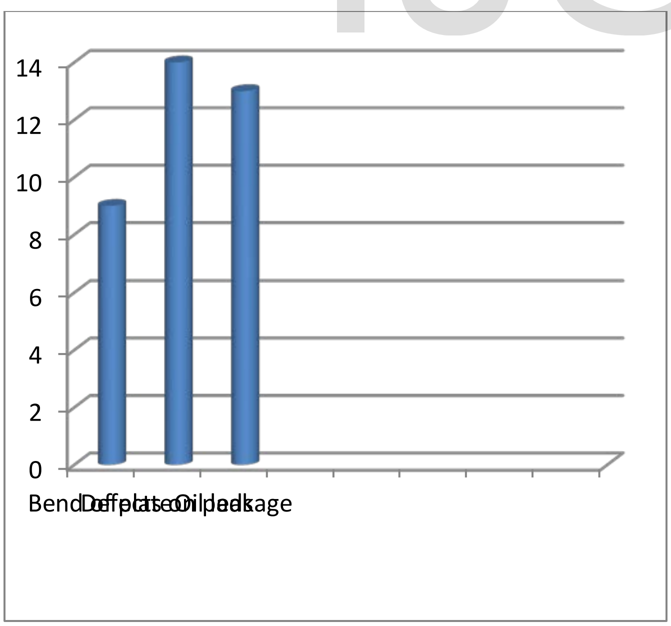
3.1 Pareto Analysis [6]: Pareto analysis is a formal technique useful where many possible courses of action are competing for attention. In essence, the problem-solver estimates the benefit delivered by each action, then selects a number of the most effective actions that deliver a total benefit reasonably close to the maximal possible one.

Steps to identify the important causes using 80/20 rule: From the table 1 we can see the problems on bike i.e. disc brake system. The main causes of disc brake failure are bending of plate, leakage of oil and damage on pads. From the data collected, the score of bending of plate is 9, 14 for pads and 13 for oil leakage. Now we draw the Pareto diagram using the score obtained. From the diagram, we saw the defect on pad is highest among the problems. So if we solved this problem, then 80 % of the brake system will be solved.

Table 1: Analyzing the data's collected

SL/NO.	Problem	Cause	Score
1	Disc Brake	Bend of plate	9
2	Disc Brake	Defects on pad	14
3	Disc Brake	Oil leakage	13

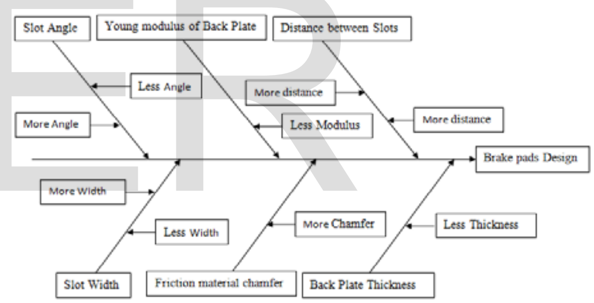
Figure 1: Pareto Analysis of Disc Brake.



3.2 Fishbone Diagrams (Cause and Effect Analysis) [5]: There are four steps to using Cause and Effect Analysis.

1. Identify the problem: Defects on the disc brake system are bending of plate, leakage of oil and damage on pads. Brake pad is the major problem among the problems and it put on the box at right site of the main line.
2. Work out the major factors involved: Major factors involved in the brake pad are put on the upper and lower box of main line. They are Young modulus of back plate, friction material chamfer, slot angle, back plate thickness, slot width and distance between slots.
3. Identify possible causes: Possible causes are shown on the left and right sides of major factor lines as arrow indication. They are as the bones of the diagram.
4. Analyze your diagram: After analyzing the diagram, selecting back plate thickness, slot width and slot angle are the important cause that failure the brake pads. For designing the pads we need to know about the parameters involved in this.

Figure 2: Cause and effect analysis of Brake Pad.



3.3 Application of Taguchi Approach [7]: Taguchi methodology is used to find the optimal solution regarding causes of failure. From factor above given, design of pad is selected for analyzing. The below table show the parameters to be considered on design of pads. The ranges of dimensions of parameters are categorizing into two levels that level 1 and level 2. Level 1 denotes the lower dimension and level 2 denotes the higher dimension.

Table 2: Parameters and their levels for Taguchi method

Factors			Range	
Parameters	Code	Units	1(Low)	2(High)
Back plate thickness	A	mm	3.5	4
Slot width	B	mm	1	3
Slot angle	C	Deg.	5	15

3.3.1 Selection of Orthogonal Array: The present set of simulations is conducted as per the Taguchi L8 orthogonal design array to identify the "most significant" variables by ranking with respect to their relative impact on the occurrence. The L8 orthogonal array consists of six control parameters at two levels.

3.3.2 Experimentation: Once the parameters and interaction of parameter are assigned to a particular column of the selected orthogonal array, the factors at different levels are assigned for each trial. The experiments are conducted twice for the same set of parameters, using a single repetition randomization technique. The defects occurring in each trial conditions are measured. The disc brake pad is made against the trial conditions, as given in Table 3.

Table 3: Experimental L8 Array.

Experiment no.	A	B	C
1	4	1	5
2	3.5	3	5
3	3.5	1	5
4	4	3	15
5	3.5	1	15
6	4	3	5
7	3.5	3	15
8	4	1	15

The average of the pads defects are computed for each trial condition and it is shown in Table 7. A total number of eight trials are conducted and a set of data is collected as per the structure of CCD of experiments. Using the tool CCD, the percentage defects in experiment are calculated for each trial at two levels. The results of percentage defects in experiment are computed in table 4.

Table 4: Percentage defects in Experiments.

Experiment no.	Trials	
	1	2
1	31.21	27.32
2	19.33	13.80
3	18.53	13.76
4	8.00	7.00
5	22.37	20.90
6	17.00	11.78
7	12.10	8.54
8	4.87	4.12

3.3.3 Sample Calculations for Signal to Noise Ratios: The design defects are "Lower the Better" type of quality characteristics. Lower the better S/N ratios are computed for each of the 8 trials and sample calculations are also given as under.

Lower is better: S/N_{LB} ratio = -10 log [(∑y^2i)/n]

For the case of minimizing the performance characteristic, the following values of the S/N ratio is calculated as:

$$SN_i = -10 \log \left(\sum_{u=1}^{N_i} \frac{y_u^2}{N_i} \right)$$

For the case of maximizing the performance characteristic, the S/N ratio is calculated as:

$$SN_i = -10 \log \left[\frac{1}{N_i} \sum_{u=1}^{N_i} \frac{1}{y_u^2} \right]$$

Where, n is the number of observation and yi are the different experimental values for various trials.

Table 5: Design defect values and S/N ratio against trial number

Percentage Defects in Experiment					
Experiment no.	1	2	Sum	Average	S/N Ratio
1	31.21	27.32	58.53	29.27	- 26.90
2	19.33	13.80	33.13	16.57	- 24.50
3	18.53	13.76	32.29	16.16	- 24.26
4	8.00	7.00	15.00	7.50	- 17.52
5	22.37	20.90	43.27	21.64	- 26.71
6	17.00	11.78	28.78	14.39	- 23.30
7	12.10	8.54	20.64	10.32	- 20.40
8	4.87	4.12	8.99	4.495	- 13.09
Total	133.41	107.22			- 176.68

The mean response, referring to the average value of the performance characteristics (the design defects and S/N ratios) for each parameter at different levels is given in Table 6. The Figure shows the graphical representation of the crimping leakage defects at different levels.

Sample calculations

For Example: Trial No.1, Table Number 7;

Sum of defects = percentage defect at level 1 + percentage defect in level 2

= 31.21 + 27.32 = 58.32

Average percentage defect = Sum of defects/ 2 = 29.27

ISSN 2229-5518

Average S/N ratio $= -10\log\{(31.21^2 + 27.32^2)/2\} = -26.90$

Table 7 shows the design defect values and S/N ratios as shown below.

2. Average value for defects and S/N ratio at different levels

Defect at level 1, A_1 = (Sum defects at level 1) / No. of observation = 19.27

Similarly, $A_2 = (20.90 + 11.78 + 8.54 + 4.12) / 4 = 11.3$

S/N ratio at level at 1, A_1 = (Sum of S/N ratio at level 1) / No. of observation = - 23.30

Similarly $A_2 = (-26.71 - 23.30 - 20.40 - 13.09) / 4 = -20.88$

Table 6: Average value for design defects and S/N ratios at different levels

Factors	Average value of design defects and S/N ratio at different levels			
	Level 1		Level 2	
	design Defect	S/N ratio	Design Defect	S/N ratio
A	19.27	- 23.30	15.47	- 20.88
B	22.48	- 25.35	8.36	- 18.82
C	17.9	- 21.89	12.56	- 22.28

Figure 3: Average value of pads Defect on different levels.

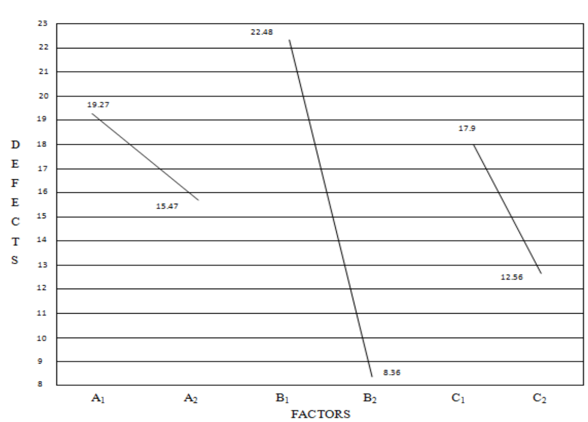
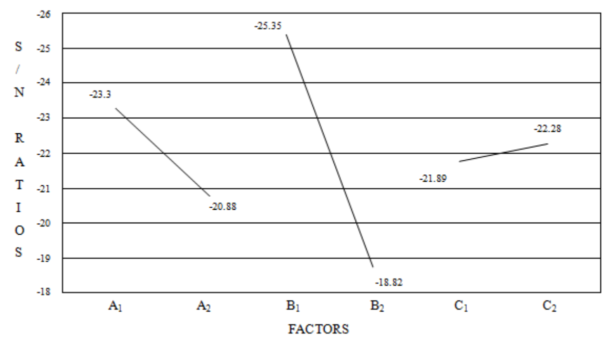


Figure 3 shows the graph of average values of pads defects on different levels. X-axis denotes the values of defects and Y-axis represent the different levels of parameters like A_1 to F_2. From this graph, we can easily identify which parameters are high in defects and which are low.

Figure 4: shows the graphical representation of the average values of S/N ratio at different levels.



Similarly, in figure 4 also shows the average values of S/N ratio at different levels. X-axis denotes the values of S/N ratio and Y-axis denotes the different parameters at different levels.

Table 7: Sum of Squares for various parameters

Sr. No.	Source	Sum of Squares
1	A	11.71
2	B	85.28
3	A×B	40.86
4	C	0.39
5	A×C	2.25
6	B×C	18.85
7	A×B×C	16.59
Total		175.93

4. Calculation of Sum of Squares for different factors.

Sum of Squares of A, SS_A = {No. of trial at A_1 × (S/N ratio at A_1 + Average S/N ratio)^2} +
{No. of trial at A_2 × (S/N ratio at A_2 + Average S/N ratio)^2} =
$\{4 \times (-23.30 + 22.085)^2\} + \{4 \times (-20.88 + 22.085)^2\} = 11.7$
Similarly, the sums of squares for other parameters are calculated, as shown in Table 7.

Analysis of Experimental Results: Run the DOE software, found the following results.

Response: defects
Folio: Experiment
Base Design Type: Taguchi OA Factorial
Analyzed on 6/22/2014 3:27:42PM

ISSN 2229-5518

ANOVA Table

ANOVA Table					
Source of Variation	**Degrees of Freedom**	**Sum of Squares [Partial]**	**Mean Squares [Partial]**	**F Ratio**	**P Value**
Model	6	394.1014	65.6836	1.4188	0.5667
Main Effects	3	152.8503	50.9501	1.1005	0.5892
2-Way Interactions	3	241.2511	80.417	1.737	0.4968
Residual	1	46.2963	46.2963		
Lack of Fit	1	46.2963	46.2963		
Total	7	440.3976			

S = 6.8041
R-sq = 89.49%, R-sq (adi) = 26.41%

Regression Table

ANOVA Table					
Source of Variation	**Degrees of Freedom**	**Sum of Squares [Partial]**	**Mean Squares [Partial]**	**F Ratio**	**P Value**
Model	6	394.1014	65.6836	1.4188	0.5667
Main Effects	3	152.8503	50.9501	1.1005	0.5892
2-Way Interactions	3	241.2511	80.417	1.737	0.4968
Residual	1	46.2963	46.2963		
Lack of Fit	1	46.2963	46.2963		
Total	7	440.3976			

Diagnostics Information

Diagnostics									
Standard Order	**Run Order**	**Actual Value (Y)**	**Fitted Value (YF)**	**Residual**	**Standardized Residual**	**Studentized Residual**	**External Studentized Residual**	**Leverage**	**Cook's Distance**
6	1	29.27	26.86	2.41	0.35	1	0	0.88	1
3	2	16.57	18.98	-2.41	-0.35	-1	0	0.88	1
2	3	16.16	18.57	-2.41	-0.35	-1	0	0.88	1
8	4	7.5	9.91	-2.41	-0.35	-1	0	0.88	1
1	5	21.64	19.23	2.41	0.35	1	0	0.88	1
7	6	14.39	11.98	2.41	0.35	1	0	0.88	1
5	7	10.32	12.73	-2.41	-0.35	-1	0	0.88	1
4	8	4.495	2.1	2.41	0.35	1	0	0.88	1

Least Square Means

Least Squares Means		
Effect	**Level**	**Mean**
A:Back Plate Thickness	[3.5]	14.7162
	[4]	15.37
B:Slot Width	[1]	19.3475
	[3]	10.7388
C:Slot Angle	[5]	15.73
	[15]	14.3562
A • B	[3.5, 1]	18.9
	[3.5, 3]	10.5325
	[4, 1]	19.795
	[4, 3]	10.945
A • C	[3.5, 5]	19.105
	[3.5, 15]	10.3275
	[4, 5]	12.355
	[4, 15]	18.385
B • C	[1, 5]	15.98
	[1, 15]	22.715
	[3, 5]	15.48
	[3, 15]	5.9975

5 Results: From the above ANOVA software run conclude the result and percentage contribution.

Table 8: Result and percentage contribution of disc brake parameters

ANOVA for design defects						
Source	**Sum of Square (SS)**	**Degree of Freedom**	**Variance**	**F ratio**	**Results**	**Percentage Contribution %**
A	11.71	1	11.71	11.38		2.66

ISSN 2229-5518

B	85.28	1	85.28	82.88	Significant	19.36
A×B	40.86	1	40.86	39.71		9.28
C	0.39	1	0.39	0.38		0
A×C	2.25	1	2.25	2.19		0.51
B×C	18.85	1	18.85	18.32		4.28
A×B ×C	16.59	1	16.59	16.12		3.77
Error	264.48	257	1.029			
Total	440.4	264				

It is clear from the ANOVA table that Slots Width has significant effect on the Disc Brake Pads. The optimum levels for this factor can be obtained by examining the level averages of the factor, as shown in Table 9.

Table 9: Affecting Parameter value at the different levels average

Parameter	**Level Average**	
	1	2
Slot width	22.48	8.36

Various experiments are conducted on disc brake. ANOVA, along with interpretation method is used to obtain the percentage contribution of each parameter and optimum levels of each parameter are shown in Table 10.

Table10: Process parameter optimum level with optimal value

Parameter designation	**Process parameter**	**Optimum level**	**Optimum value**	**Percentage Contribution (%)**
D	Slot width	2	3	19.36

6 Conclusion:

The contribution of individual quality influencing factors is the deciding key of the control to be enforced on the product design. A commonly applied statistical treatment - The Analysis of Variance (ANOVA) is used to analyze the results of the Orthogonal Array (OA) experiment in product design and to determine how much variation each quality-influencing factor has contributed. By studying the main effects of each one of the factors, the general trends of the influencing factors towards the product or process can be characterized.

From Table 9 (Affecting Parameters value at the different levels average) clearly shows that the most significant parameter affect both the mean and variation of the design of pad defects and also shows the optimal settings of each parameter to reduce the pad design defects and hence improves the quality of disc brake assembly at lowest cost. Before the application of Taguchi's method, the parameters of the design process were more arbitrary and difficult to control and, of course, the product quality has instability problems. Taguchi's method yielded optimized control factors, resulting in superior product quality and stability. From the analysis, it is found that the improvement in the design at the lowest possible cost can be achieved by Taguchi's method of parameter design. It is also possible to identify the optimum levels of signal factors at which the noise factor's effect on the response parameter is minimized. The optimized process parameters i.e. slots width of 3 mm are obtained by Taguchi methodology, which lead to minimize the failure of disc brake.

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