International Engineering Research Journal Page No 1103-1108

Performance optimization of disc brake by Taguchi's method of Design of experiments

Vilas G. Pawar[1], N. K. Kharate[2]

***Abstract*— The aim of this Project is to find the optimal performance parameters of the disc brake system using experimental and statistical approach. A standard energy (DOE) design of experiments by taguchi method is applied to study three performance parameters each with four levels. A total of sixteen experimental tests are run using the brake setup to evaluate the main and interaction effect of these variables namely; braking pressure, Rotational speed in rpm, Load. The variability in dependent variables is explained by SN Ratio graphs The experimental results indicate that the proposed mathematical model successfully describes the performance of disc brakes within the limits of the performance parameters that are being investigated.**

***Index Terms*— DOE design of experiments, SN signal to noise ratio , performance parameters**

I. Introduction

The most significant safety aspect of an automobile is its brake system, which must slow the vehicle quickly and reliably under varying conditions. There are many types of brake systems that have been used since the inception of the motor car, but in principle they are all similar. Brakes are energy-converting machine elements belonging to the class of couplings which consist of rotating parts (rotor) and stationary parts including; calliper housing with its piston and anchor bracket. The main function of brake system is to retard the vehicle by transforming the kinetic energy of the vehicle into heat by the process of friction, and this heat must be effectively and efficiently dissipating to the surroundings by the brake components.

Corresponding author.
Vilas G Pawar.[1] Tel.: +91 9595203612
P.G Student (Mechanical Design Engineering)
[1]Department of Mechanical Engineering
[1]NDMVP'S KBT COE, Nasik, Maharashtra, India.
Savitribai Phule Pune University, Pune, Maharashtra, India.
E-mail address: vilaspawar.pawar@gmail.com

Nilesh. K. Kharate.[2] Tel.: +91 9822767671 FAX:.+91-253 2317016
Associate Professor
[2]Department of Mechanical Engineering
[2]NDMVP'S KBT COE, Nasik, Maharashtra, India.
Savitribai Phule Pune University, Pune, Maharashtra, India.
E-mail address:. kharate_1234@yahoo.co.in

The primary requirements of the brake system are performance, robustness and durability.

A disc brake is a type of brake that uses calipers to squeeze pairs of pads against a disc in order to create friction that retards the rotation of a shaft, such as a vehicle axle, either to reduce its rotational speed or to hold it stationary. The energy of motion is converted into waste heat which must be dispersed. Hydraulic disc brakes are the most commonly used form of brake for motor vehicles but the principles of a disc brake are applicable to almost any rotating shaft.

Many researchers define brake system requirements as being: (1) function (braking distance, load stability); (2) comfort (vibration & noise); (3) ergonomics (actuation force & feedback); (4) brake design (low corrosion & appearance); and (5) low maintenance and wear. During the earlier years, researches were oriented towards understanding, identifying critical factors and possibly in improving the brake system performance.

Much progress has been made using different numerical and experimental approaches. However, brake performance still needs much work to carry out. This is due to the fact that disc brake performance strong dependence on many parameters including materials and geometry of brake components, component interaction, many operating and environmental conditions. The need of a new method to find out the contributions of the operating, environmental conditions structural modifications and their interactions is required. One of the earliest researchers who attempted to integrate experimental or numerical approaches with design of experiments (DOE) to assess effectively the contributions of different parameters and their interaction.

II. Literature Review

In the past, several researchers have studied the Optimisation of performance of disc brake by Taguchi's method of Design of experiments (DOE) . Khomdram Herojit Singh, etal [1]. In this research 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. Nouby M. Ghazaly, K. R. M, et al[2]. In this research paper work is done to find the optimal geometric parameters of the wedge disc brake performance using experimental and statistical studies. A standard response surface methodology called central composite design is applied to study four geometric parameters each with three levels. Mostafa M. Makrahy, Nouby M. Ghazaly, et al[3] In this study, a new wedge disc brake performance is assessed using brake dynamometer and Taguchi approach. Three control factors were considered as applied pressure, vehicle speed and wedge angle inclination, each at three levels is selected. The most affects parameters on brake performance were performed using the analysis of signal-to-noise (S/N) ratio and ANOVA analysis, respectively. It can be concluded that Taguchi method is reliable and reduce the time and experimental costs. In addition, the results indicated that the applied pressure and wedge angle are the most significant parameters for evaluation the wedge disc brake. Mostafa M. Makrahy, Nouby M. Ghazaly et al[4] In this paper, a novel wedge disc brake is evaluated experimentally using brake dynamometer and Taguchi approach. The main purpose of Taguchi method is to assess the significant of different operation parameters that effect of wedge brake performance. This approach facilitated the study factors and their settings with a small number of experimental runs leading to considerable economy in time and cost for the process optimization. Four control factors are defined as applied pressure, vehicle speed, wedge angle inclination and water spraying, each at four levels are selected and an orthogonal array layout of L16 (44) are performed. From the signal-to-noise (S/N) ratio of the test results, the significant parameters to improve wedge disc brake behavior are suggested.The wedge brake performance based on the experimental results is compared with the predicted results using Taguchi approach and they are found to be in good agreement. Nouby M. Ghazaly, et al [5] The main objective of their study was to optimize the geometric parameters of wedge disc brake for improving brake performance by applying the Taguchi method with orthogonal array robust design. The experimental tests using brake dynamometers are integrated with Taguchi method to find out the significant contributions of different types of geometric parameters for effective increasing of the brake performance. From Taguchi method results, the effective geometric parameters to improve the performance of wedge brake are obtained. Results of this work show that the most significant geometric parameters on wedge brake performance can be achieved through combination of the friction material thickness and friction material length.

III. Problem Statement and Objective

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.

The primary requirements of the brake system are Good performance, robustness and durability .So it becomes utmost important to improve the braking performance by optimizing the process parameters of disc brake..

The main objective of this Project is to optimize the performance parameters of disc brake and to find the optimal performance parameters of the disc brake performance using experimental and statistical studies. Optimization of performance parameters thus enhances the efficiency and also increases reliability on the braking system.

The primary objective of current project is to improve performance of disc brake.

IV. Methodology

A standard energy DOE design of experiments by taguchi method is applied to study three performance parameters each with four levels. A total of sixteen experimental tests are run using the brake setup to evaluate the main and interaction effect of these variables namely; braking pressure, RPM rotor vehical speed and Load . The variability in dependent variables is explained by SN Ratio graphs The experimental results indicate that the proposed mathematical model successfully describes the performance of disc brakes within the limits of the performance parameters that are being investigated And final validation to be done by running the test setup on the optimized parameters

V. Use of Taguchi Method in This Project

In the present work, Taguchi method is integrated to find out the significant contributions of the different operation variables with other design parameters. According to Taguchi, all machines or set-up are classified as engineering systems (if it produces a set of responses for a given set of inputs). Those systems can be classified in to two categories. They are: i) Static and ii) Dynamic. The dynamic system has signal factors (input from the end user) in addition to control and noise factors, whereas in static system signal factors are not present. Optimization of performance of disc brake is a static system.

The parameter design of the 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. Analyse 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.

VI. SELECTION OF VARIABLES AND THEIR LEVELS

Based on the detailed literature survey, the disc brake performance influences by applied brake pressure, rotational speed, load that are important and their design have effects on the performance. To select the optimum values for the each parameter for effective increasing brake performance, the following parameters are considered for the experiments, as listed in Table 1.

Table1. Selection of variables and their level

Factors (Parameters)	Level			
	1	2	3	4
A: Applied braking pressure (Kg/cm^2)	4	5	6	7
B: Rotational speed (rpm)	1100	920	730	550
C:Load(Kg)	2	6	10	14

VII. TAGUCHIS ORTHOGONAL ARRAY

While there are many standard orthogonal arrays available, each of the arrays is meant for a specific number of independent design variables and levels. In this research, if there is an experiment having 3 factors which have four values, then total number of experiment is 81. Then results of all experiments will give 100 accurate results. In comparison to above method the Taguchi orthogonal array make list of sixteen experiments in a particular order which cover all factors. Those sixteen experiments will give 99.96% accurate result. By using this method number of experiments reduced to 16 instead of 81 with almost same accuracy. The present set of experimental tests is conducted as per the Taguchi L16 orthogonal design array to identify the "most significant" variables by ranking with respect to their relative impact on the brake performance. The L16 orthogonal array consists of three control parameters at four levels, as shown in Table 2. The experimental tests are carried out for sixteen row and the results are recorded in the Table 2.

Table2 Taguchi L16 Orthagonal array

Sr no	A: Applied braking pressure (Kg/cm^2)	B: Rotational speed (rpm)	Load(Kg)
1	4	1100	2
2	4	920	6
3	4	730	10
4	4	550	14
5	5	1100	6
6	5	920	2
7	5	730	14
8	5	550	10
9	6	1100	10
10	6	920	14
11	6	730	2
12	6	550	6
13	7	1100	14
14	7	920	10
15	7	730	6
16	7	550	2

.

In the Taguchi method, the S/N ratio is computed to analyze the deviation between the simulated value and the desired value. Usually, there are three types of quality characteristic in the analysis of the signal-to-noise ratio, (i.e. the lower-the-better, the larger-the-better, and nominal-the-better). Since, the requirement is to maximize the brake performance through selection a proper parameters; larger-the-better quality characteristic is employed.

The S/N ratio η is given by:

$$\eta=10 \log (MSD) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where, MSD is the mean-square deviation for the output characteristic. MSD for the larger-the-better quality characteristic is calculated by the following equation,

$$MSD=\frac{1}{N}\left[\sum_{i=1}^{n}\frac{1}{y^{2}}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

1Where, Yi is the response time for the ith test, n denotes the number of tests and N is the total number of data points. The function '-log' is a monotonically decreasing one, it means that we should maximize the S/N value. The S/N values are calculated using "equation 1"

VIII. EXPERIMENTAL SETUP

The primary goal in the development of the Experimental setup is to generate accurate braking performance data for use in evaluating the performance of disc brake system. The setup is designed to study the effect of many operation and design parameters on the performance of the air ventilated disc brake. The operating parameters such as applied brake pressure, rotational speed, torque, contact brake surface area. In addition, design parameters namely; friction material slots, different brake pad thickness and length, and different types of brake rotor. It can be divided into three main subsystems: the driving system, the braking system and the measurement facilities. Fig. shows a photo of the test rig with its different systems. The driving system consists of an D.C. motor of 2 HP and 2800 rpm, that rotates the driving shaft at different rotating speeds. This is achieved with the help of Electronic speed controller system. The braking system contains the new air ventilated disc brake assembly which used in this study to increase the braking force, as shown in Fig. 1. Brake master cylinder is used to apply required pressure. The measurement facilities including suitable instruments to measure the following: Rotating speed (using position sensor and electronic counter), Actuating pressure (a pressure gauge), Load (spring balance) and Transmission system (V-belt). Brake performances are recorded at different vehicle speeds ranged from 550 to 1100 rpm. Different brake pressure in the range of 4to 7 kg/cm^2 is used.

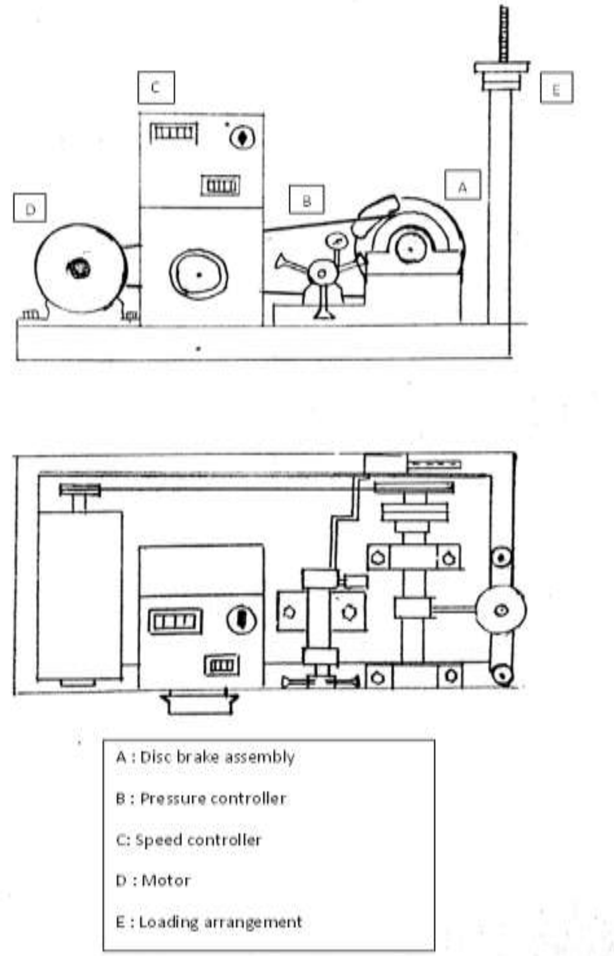

Fig 1 Experimental setup

IX. RESULTS AND DISCUSSIONS

Table3 Taguchi L16 Experimental results

Sr no	A: Applied braking pressure (Kg/cm^2	B: Rotational speed (rpm)	C:Load (Kg)	Average braking time(s)	SN ratio
1	4	1100	2	3.1	9.83
2	4	920	6	5.68	15.09
3	4	730	10	4.86	13.73
4	4	550	14	4.2	12.46

5	5	1100	6	4.14	12.34
6	5	920	2	6.02	15.59
7	5	730	14	5.44	14.71
8	5	550	10	6.04	15.62
9	6	1100	10	5.56	14.90
10	6	920	14	5.16	14.25
11	6	730	2	6.44	16.18
12	6	550	6	8.44	18.53
13	7	1100	14	5.32	14.52
14	7	920	10	6.76	16.60
15	7	730	6	6.72	16.55
16	7	550	2	7.66	17.68

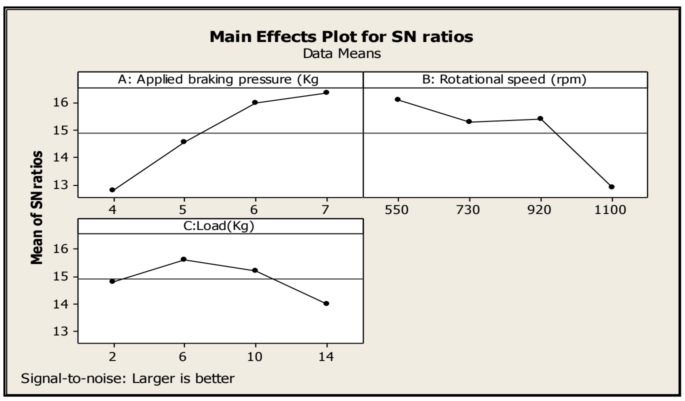

Fig:2 Graphs of Experimental results

Table 4 Analysis of variance for SN-ratio

Source of variation	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
A: Applied braking pressure (Kg/cm^2)	3	31.3	31.3	10.4	6.850	0.023	52%
B: Rotational speed (rpm)	3	23.1	23.1	7.7	5.060	0.044	38%
C:Load(Kg)	3	5.9	5.9	2.0	1.280	0.363	10%
Residual Error	6	9.1	9.1	1.5			
Total	15	69.4					

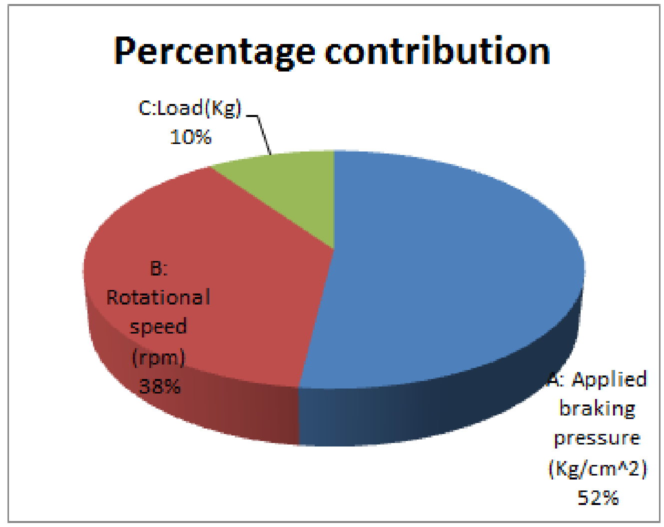

Fig 3 Percentage contribution of parameters in consideration

1. From fig:2 using taguchis approach of higher the better it is observed that the value of optimal braking pressure is 7 kg/cm^2 since this value has maximum SN ratio and also SN ratio increases with increase in braking pressure
2. For rotational speed of shaft the value of SN ratio is maximum for 550 rpm .thus this value can be stated as optimal value of rotational speed
3. It is observed that for the value of Load the SN ratio changes very slowly so it can be concluded from above result that Load has very less impact on optimal performance of disc brake moreover from the SN ratio graph we can say 6 kg is optimal value
4. The proposed project will help re-designing the tolerance value of performance parameters for braking system
5. It will help researchers to further investigate and re-optimize the already optimized parameters
6. It will help design engineers to understand the behaviour of braking system on change in contact area
7. Researchers willing to optimize further performance parameter can refer the work for studying the significance of these performance parameters on Braking system

X. Multiple Linear Regression Model Analysis

A multiple linear regression analysis attempts to model the relationship between two or more predictor variables and a response variable by fitting a linear equation to the observed data. Based on the experimental results, a multiple linear regression model was developed using MINITAB15. A regression equation thus generated establishes correlation between the significant terms obtained from ANOVA such as Applied braking pressure, rotational speed and load. The regression equation developed for average time is

The regression equation is:
Average braking time = 4.91 + 0.745 A: Applied braking pressure (Kg/cm^2) - 0.00332 B: Rotational speed (rpm) - 0.0691 C: Load(Kg)

The above equation can be used to predict the avg braking time of the disc brake. The constant in the equation is the residue. The regression coefficient obtained for the model was 0.964.From the regression equations for avg braking time, we can conclude that avg braking time is directly proportional to applied braking pressure and inversely proportional to rotating speed and load.

XI. Conclusion

By Taguchi's method of DOE optimal values of performance parameters of disc brakes are found using Taguchi's approach of higher the better and optimal values of three performance parameters i.e. applied braking pressure, Rotational speed in RPM and Load are found successfully.

Acknowledgement

I take this opportunity to thank the people who helped me through this project. I am grateful Prof. A. B. Kakade, HOD of Mech. Dept., Prof. D. V. Kushare, PG Coordinator and Prof. N. K. Kharate my project guide for his continuous help and guidance.

References

[1] Khomdram Herojit Singh, Abhishek Kumar, Rajender Kumar: Optimization of Quality and Performance of Brake Pads Using Taguchi's Approach, International Journal of Scientific & Engineering Research, Volume 5, Issue 7, July-2014

[2]. Nouby M. Ghazaly, K. R. M. Mahmoud, Mostafa M. Makrahy, optimal geometric parameters of the wedge disc brake performance using experimental and statistical studies ijmer , June 2014

[3] Mostafa M. Makrahy, Nouby M. Ghazaly, [3] : Optimization of a New Wedge Disc Brake Using Taguchi Approach International Journal of Modern Engineering Research (IJMER) Vol. 3, Issue. 6, Nov - Dec. 2013 pp-3461-3465

[4] Mostafa M. Makrahy ; Optimization of Operation Parameters on a Novel Wedge Disc Brake by Taguchi Method, American Journal of Vehicle Design, 2013, Vol. 1, No. 2, 30-35

[5]Nouby M. Ghazaly*, Mostafa M. Makrahy : Optimization of Geometric Parameters of a New Wedge Brake Using Taguchi Approach International Journal of Mechanical Engineering ISSN : 2277-7059 Volume 3 Issue 11 (November 2013)

[6] A.K. Matta*: Optimization of operation parameters on a Novel internally ventilated cross drilled Disc Brake by using Taguchi Method , international journal of engineering studies and technical approaches

[7] Taguchi's Quality Engineering Handbook: Genichi Taguchi , Subir Chowdhury and Yuin Wu (2005 Edition)

Biographies

Mr. Vilas G Pawar received the degree in B.E. Mechanical from D Y Patil College of Engineering, Akurdi Pune, Maharashtra, In 2013 and pursuing master degree in (Mechanical Design Engineering) in NDMVP'S KBT College of Engineering, Nasik, Maharashtra, India under Savitribai Phule Pune University, Pune, Maharashtra, India.

Prof. Kharate N.K. is Associate. Professor in NDMVP'S KBT College of Engineering, Nasik, Maharashtra, India. He .received the degree in B.E. Mechanical and Specialization in M.Tech (CAD/CAM). Pursuing PhD in CAD/CAM. He has 12 Years' experience.