Journal of Mines, Metals and Fuels, *71(12D): 65-70; 2023. DOI: 10.18311/jmmf/2023/47992*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.com/index.php/jmmf*

Optimisation of Permanent Magnet Eddy Current Braking System using Aluminum Discs by Taguchi Technique

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Abstract

In this work, an attempt has been made to understand the suitability of various positions of permanent magnets, the optimum thickness and speed of Aluminum discs, and Taguchi parameter optimisation. L9 orthogonal array was chosen for the analysis. From Signal to Noise (S/N) ratio calculations it was observed that 3000 rpm, 4mm thick disc and solo magnet with swift application situation were optimum values. SS% from ANOVA indicated that the position of magnets has the greatest influence on brake parameters. The permanent magnet used is a Neodymium – Iron – Boron (NdFeB) magnet. The brake parameters recorded are speed reduction percentage, time consumed and negative acceleration. In solo magnet condition and solo magnet with swift application, better brake parameters were observed in a 4mm thick disc. Solo magnet condition with a 4mm thick disc may be suitable for elevated-speed train applications. Solo magnet with swift application situation may be suitable for high-speed automotive applications.

Keywords: *Aluminum, Eddy Current, Induced Magnetisation, NdFeB Magnets, Negative Acceleration; Speed Reduction, Time Taken*

1.0 Introduction

Taguchi technique is a statistical technique for the selection of optimum process parameters. It involves the selection of process parameters and separating them into control and noise factors. Orthogonal arrays are used for the conduction of a set of experiments. Results from these experiments can be used for analysis and predict the quality of components. The signal factor is controlled by the user of the product to make use of its intended function. Noise factor influences the performance of the product but they cannot be controlled during usage of the product. Signal-to-noise ratios (S/N) determine the optimal parameter settings. Widely used S/N ratios are nominal is best, larger is better and smaller is better.

2.0 Literature Survey

Catarina Vidal *et al.*,[1] carried out an improvement of welded joints of aerospace aluminium alloy AA 2024 – T 351 using the Taguchi method. It was observed that the parameter design of the Taguchi method gives an efficient and methodical method for the optimisation of parameters.

Mostafa M. Makrashy *et al.*,[2] worked on modelling and optimisation of parameters on wedge disc brake performance using the Taguchi design method. An L9 orthogonal array was chosen and S/N ratio and ANOVA were carried out. It was observed that the Taguchi design method exhibited a better performance in optimisation.

There are abundant inconveniences related to friction brakes such as squealing, thermal distortion, judder, fade

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etc. To overcome these problems, contactless braking systems using eddy current principles are perceived to be alternative[3–6].

Eddy current brakes produce the braking force required to decelerate the motion of a moving object. In such a braking system there is no friction at all[7–8]. Eddy current brakes work on the theory of induced eddy current. The electromagnetic forces could interfere which creates irreparable damage to the signalling systems[9]. In the present work, Aluminum is chosen as the conducting material as it has better properties like conductivity and permeability.

To find the optimum values of the speed of the disc, thickness of the disc and position of magnets, Taguchi's statistical technique is adopted. One–way ANOVA is employed to find out the percentage contributions of the above parameters on response factors such as speed reduction percentage, time consumed and negative acceleration.

3.0 Methodology

Experimental investigations were carried out to learn the influence of parameters like speed and thickness of discs and position of magnets on braking parameters. Taguchi technique is applied to optimise the parameters and to understand the influence of control factors on response factors.

The experiments are conducted on special-purpose test equipment. The base is made of Aluminum. A DC motor that can run at 10,000 rpm is mounted. The stainless steel shaft is fastened to the motor to which Aluminum discs of thickness 4mm, 6mm and 8mm are mounted. The diameter of the discs selected is 200mm. The speeds at which experiments were conducted are to simulate speeds of 20.8m/s, 31.4m/s, 41.9m/s and 52.4m/s respectively. The Neodymium – Iron – Boron (NdFeB) magnets of 12.5 mm thickness and 50mm diameter are preferred for investigations.

4.0 Results and Discussions

In the current work, full factorial design is considered. For interpreting the results, the one-way analysis of variance (ANOVA) method is used. L9 orthogonal array is chosen in the present work.

- The control factors are
- Speed of disc.
- Thickness of disc.
- Position of magnets from the rotating disc.

The response factors are

- speed reduction percentage.
- Time consumed for speed reduction.
- Negative acceleration.

Table 1 indicates control factors and their levels.

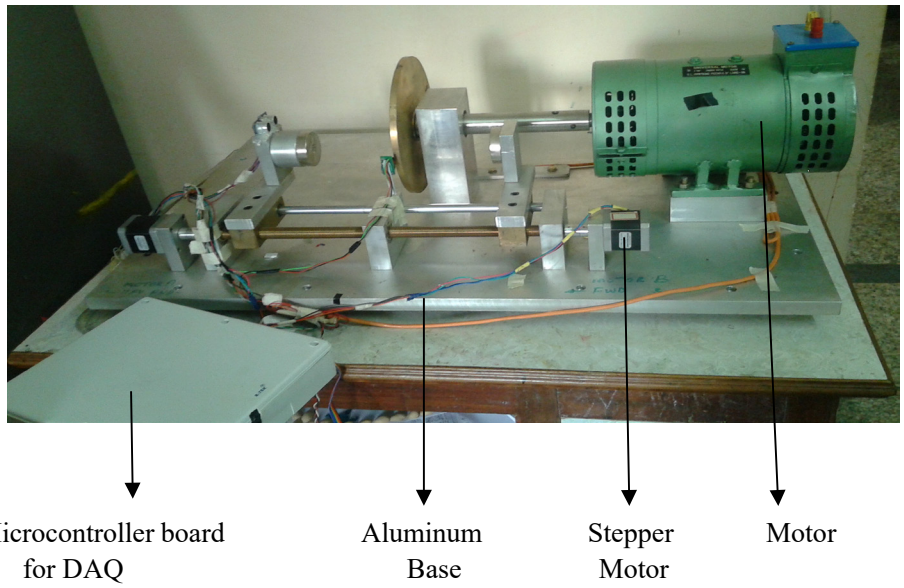


Figure 1. Developed test equipment.

Table 1. Levels of control factors

Control Factors	Levels		
	1	2	3
Speed of disc, rpm	3000	4000	5000
Thickness of disc, mm	4	6	8
Position of magnets	Solo magnet with swift application situation	Solo magnet condition	Two coaxial magnets condition

Table 2. L9 Orthogonal array and experimental description

Exp no.	Speed, rpm	Thickness, mm	Position of Magnets
1	3000	4	Solo magnet with swift application
2	3000	6	Solo magnet
3	3000	8	Two coaxial magnets
4	4000	4	Solo magnet
5	4000	6	Two coaxial magnets
6	4000	8	Solo magnet with swift application
7	5000	4	Two coaxial magnets
8	5000	6	Solo magnet with swift application
9	5000	8	Solo magnet

Table 3. Tabulated S/N ratios of brake parameters of Aluminum discs

Exp no	% Speed Reduction	S/N Ratio	Time in Seconds	S/N Ratio	Negative acceleration in m/s^2	S/N Ratio
1	98	39.82	1.03	-0.26	3.03	9.63
2	96.1	39.65	0.53	5.51	0.59	-4.58
3	86	38.69	3.14	-9.94	0.56	-5.04
4	97.1	39.74	1.2	-1.58	0.68	-3.35
5	66.7	36.48	3.55	-11.00	0.62	-4.15
6	95.6	39.61	1.47	-3.35	2.77	8.85
7	60.2	35.59	4.3	-12.67	0.73	-2.73
8	86.9	38.78	1.56	-3.86	2.94	9.37
9	96.7	39.71	3.95	-11.93	0.78	-2.16

Table 4. Average S/N ratios for each factor

	Speed Reduction Percentage			Time Taken			Negative Acceleration		
Levels	1	2	3	1	2	3	1	2	3
Speed of disc	39.89	38.61	38.03	5.23	5.31	9.49	6.42	5.45	4.75
Thickness of disc	38.38	38.30	39.34	4.84	6.79	8.41	5.24	5.22	5.19
Position of magnets	39.40	39.70	36.92	2.49	6.34	11.20	9.28	3.36	3.97

Table 5. ANOVA table for speed reduction percentage, negative acceleration and time taken

Factors	DF	SS	F	P	%SS
	Speed Reduction Percentage				
Speed	2	221	0.48	0.641	15.02
Thickness	2	153	0.32	0.74	20.62
Position of magnets	2	1176	8.23	0.019	64.36
Error	2	55			0.0
Total	8	1605			100
	Negative Acceleration				
Speed	2	0.03	0.01	0.993	0.033
Thickness	2	0.02	0.01	0.994	0.033
Position of magnets	2	10.16	449.48	0.000	99.08
Error	2	0.0217			0.854
Total	8	10.23			100
	Time Taken				
Speed	2	4.59	1.19	0.368	4.51
Thickness	2	1.49	0.3	0.748	21.08
Position of magnets	2	8.76	3.54	0.096	38.81
Error	2	1.34			35.6
Total	8	16.18			100

Based on levels for control factors from Table 1, the description of experiments of the L9 orthogonal array is as in Table 2.

For computing the S/N ratio for speed reduction percentage and negative acceleration, the larger the better concept of parameter design is used since higher speed reduction percentage and negative acceleration is a desirable parameter. For computing the S/N ratio for the time taken, the smaller the better concept of parameter design is used since the lesser value of time consumed is

a desirable parameter. Table 3 indicates the tabulated S/N ratios for Aluminum discs for speed reduction percentage, time consumed and negative acceleration results.

The mean of the S/N ratio at different levels of the brake parameters is summarized in Table 4. From the mean of the S/N ratio, the optimum values of parameters can be determined.

From Table 4, it can be observed that the optimum values of parameters for speed reduction percentage are 3000rpm, 8mm thick disc and solo magnet condition. Optimum values of parameters for time consumed are 3000rpm, 4mm thick disc and solo magnet with swift application situation. Optimum values of parameters for negative acceleration are 3000rpm, 4mm thick disc and solo magnet with swift application situation.

In full factorial experimentation, it is confirmed that the optimum parameters obtained are in agreement with the parameters obtained from the design of experiments. High repulsion was experienced using optimum values for speed reduction percentage. This may be attributed to the presence of unknown noise in the system.

Also, it may be concluded that the optimum values are 3000rpm of disc, 4mm thickness of disc and solo magnet with swift application situation for effective response factors. It may also be concluded that the position of magnets has a greater influence on the brake parameters.

These observations are in line with full factorial experimental results. Hence, a 4mm thick Aluminum disc is the most suitable candidate material for use in a permanent magnet eddy current braking system.

The purpose of ANOVA is to explore which factor significantly affects the brake parameters. One–way ANOVA was carried out using Minitab 16 software and results are tabulated. Table 5, indicates the degrees of freedom (DF), sums of squares of deviations (SS), Fisher's value (F) and probability (p) value for response factors such as speed reduction percentage, time consumed and negative acceleration respectively for Aluminum discs.

From Table 5, it can be observed that the F factor is highest at 8.23 for the position of magnets and p – the value is 0.019 which is less than 0.05 for the position of magnets. The higher value of the F factor and lower value of the p-value for the position of magnets indicate that the position of magnets has the greatest influence on the speed reduction percentage parameter.

Also, it can be observed that the percentage contribution for the position of magnets condition i.e. SS% is 64.36%. Hence, it may be concluded that for better speed reduction percentage, the position of magnets has a significant influence.

From Table 5, it can be observed that the F factor is very large at 449.48 and the p-value is 0.00. This indicates that the position of magnets has the greatest influence on the negative acceleration parameter. Also, SS% is 99.08% which indicates that the position of magnets solely influences the negative acceleration.

From Table 5, it can be observed that the F factor is highest at 3.54 for the position of magnets. The SS% for the position of magnets is highest at 38.81%. Hence, it may be concluded that the position of magnets has a greater influence on the time consumed parameter.

From ANOVA it is confirmed that the position of magnets has the greatest influence on response parameters. The observations from full factorial experiments and the Taguchi technique are in agreement.

5.0 Conclusions

Taguchi technique is adopted to optimise the process parameters by studying the effect of control factors on response factors. In the present work, the control factors are the speed of the disc, the thickness of the disc and the position of the magnets. The response factors are speed reduction percentage, time consumed and negative acceleration. L9 orthogonal array is chosen. The S/N ratio was calculated considering the larger the better concept for speed reduction percentage and negative acceleration. The lesser the better concept is adopted for the time taken. One–way ANOVA is applied to understand the intensity of significance of control factors on response factors. From an average of S/N ratio calculations, it is observed that a 4mm thick disc at 3000rpm in a solo magnet with a swift application situation are optimum parameter for better response factors. From ANOVA it may be observed that the position of magnets has the greatest influence on response factors. Full factorial experimentation was carried out to understand the influence of all parameters. Aluminium is chosen as a conducting material because of its good conductivity and permeability properties.

NdFeB magnets were chosen for investigations because of their superior properties over other rare earth magnets. From experimental investigations, it is observed that the highest negative acceleration and lowest time consumed were observed in a 4mm thick disc in a solo magnet with a swift application situation. The optimum parameters obtained experimentally are in agreement with those obtained from the Taguchi method.

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