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Analysis of The Testing Sequence for A 3,000 Watt Electric Motorcycle Using The Taguchi Method

Genia Auberta [1], Muslimin [1*], M. Prasha Risfi Silitonga [1], Daniel Janthinus Kristianto [2], Wan Mansor Bin Wan Muhamad [3], Muhammad Aziz [4]

1 1 Program Studi Manufaktur, Jurusan Teknik Mesin, Politeknik Negeri Jakarta, Jl. Prof. G. A. Siwabessy, Kampus UI, Depok 16425, Indonesia
2 PT. XYZ Kawasan B II E, Jl. Raya Inti Blok C3 No. 12, Cibatu, Cikarang Selatan, Bekasi Regency, West Java 17550, Indonesia
3 Universiti Kuala Lumpur Kampus Cawangan Malaysia France Institute, Malaysia
4 Institute of Industrial Science, The University of Tokyo, Japan
* Correspondence: muslimin@mesin.pnj.ac.id

Abstract: Electric vehicle manufacturers have a significant need for brushless DC (BLDC) motors. This is because of its benefits, including brushless construction, high efficiency and power ratio, huge mass, and ease of control. This study aims to examine the relative importance of the various var-iables on the three motorcycles that the three prototypes are actually mounted on. In order to op-timize the technical testing process and save wasteful time and expense, the Taguchi Method with the characteristic of smaller is better was employed for the research. Two different types of road terrain were used for the tests: flat and uphill with slope angles of 2 and 4. Use. Prototypes 1, 2, and 3 of the electric motors utilized in this study each feature a distinct ratio of magnetic poles: prototype 1 has 48 poles/54 slots, prototypes 2 has 50 poles/45 slots, and prototype 3 has 40 poles/36 slots. According to the test results, the type of electric motor, the type of road, the dis-tance, and ultimately the speed level are the parameters that have the greatest influence.

Keywords: BLDC Electrric Motor 1; Taguchi Method 2; Magnet Pole 3; Types of Road 4; Travel Distance 5; Level Speed 6;

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1. Introduction

Indonesia has proposed to achieve carbon neutrality by 2060, supported by a 45% reduction in carbon dioxide (CO2) emissions by 2030 compared to 2010 levels and an expansion of renewable energy in the electricity, transportation, and industrial sectors [1]. President of Indonesia, Joko Widodo, plans to make Indonesia one of the global centers for electric vehicle manufacturing [2]. As of November 2022, the Ministry of Energy and Mineral Resources (ESDM) recorded approximately 25,782 electric motorcycles in Indonesia, both for personal and conventional use [3].

The government's efforts to support the achievement of carbon neutrality are outlined in the Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia No. 3 of 2023, which states that the government will provide support through conversion workshops covering at least battery costs, Brushless Direct Current (BLDC) motors, and controllers that match the battery power capacity and engine wattage details [4]. There is a significant demand for Brushless Direct Current (BLDC) motors in the electric vehicle industry [5], supported by their advantages in performance, high power-to-weight ratio, ease of handling, and longer lifespan.

In the automotive industry, PT XYZ, a company operating in this sector, needs to enhance its products to accommodate these changes. A study was conducted to support these changes, such as analyzing the electric vehicle market at the Indonesia Electric Motor Show (IEMS) 2022. Observations made during the event revealed that out of 43 electric two-wheeler brands operating in Indonesia, none were using local BLDC motors. This situation encouraged PT XYZ to innovate and establish local production and development of BLDC motors, particularly BLDC motors with a maximum continuous power of 3000W.

PT XYZ designed three prototypes with different magnet poles numbers: prototype 1 with 48 poles/54 slots, prototype 2 with 50 poles/45 slots, and prototype 3 with 40 poles/36 slots. The pole combinations were selected based on the simplest three-phase coil topology to implement [6]. Different pole combinations have the effect of reducing voltage, current, and power values while improving efficiency [7]. These three BLDC prototypes were applied to electric motorcycles, resulting in different power requirements, with power consumption being influenced by road conditions and driving speed [8].

Hence, dynamic testing is needed to assess the performance of electric motorcycles and determine the power consumed on flat roads and steep inclines [9]. This research aims to determine the sequence of factors that most affect dynamic testing, specifically on flat roads and two steep roads with inclinations of 2° and 4° based on The American Association of State Highway and Transportation Officials (AASHTO) standards for urban roads [10]. The distance variations used in this study are 60 meters, 120 meters, and 180 meters, with road inclinations not exceeding 200 meters [11]. This study aims to identify the order of factors that have the most influence on the testing of three prototype electric motors installed on electric motorcycles to determine which product is the most optimal.

2. Materials and Experiment Methods

The flowchart for this research begins with a literature review, followed by the determination of testing using the Taguchi Method, which will result in a summarized testing scheme. Next, there is the preparation of the Brushless Direct Current (BLDC) motor on the electric motorcycle, followed by an initial check of the motorcycle's functionality. Subsequently, tools and materials for testing are prepared, and the BLDC motor is tested on three different road terrains. The data obtained from testing is then analyzed using statistical analysis based on the Taguchi Method, which determines the sequence of the most influential factors in the research. Finally, the research concludes with the selection of the most optimal prototype using statistical analysis based on the Taguchi Signal-to-Noise (S/N) Ratio.

Determination of Testing Using the Taguchi Method

The completion stages to produce a testing scheme in this research consist of the following:

a. In the initial stage of this research, the determination of the testing output is conducted, where the desired output in this study is the average power consumption result for each prototype.
b. Next is the selection of the testing factors to be conducted. In this stage, an analysis of the factors influencing the optimal testing process for two-wheeled electric vehicles is performed. Several factors are used in this research, as shown in Table 1.

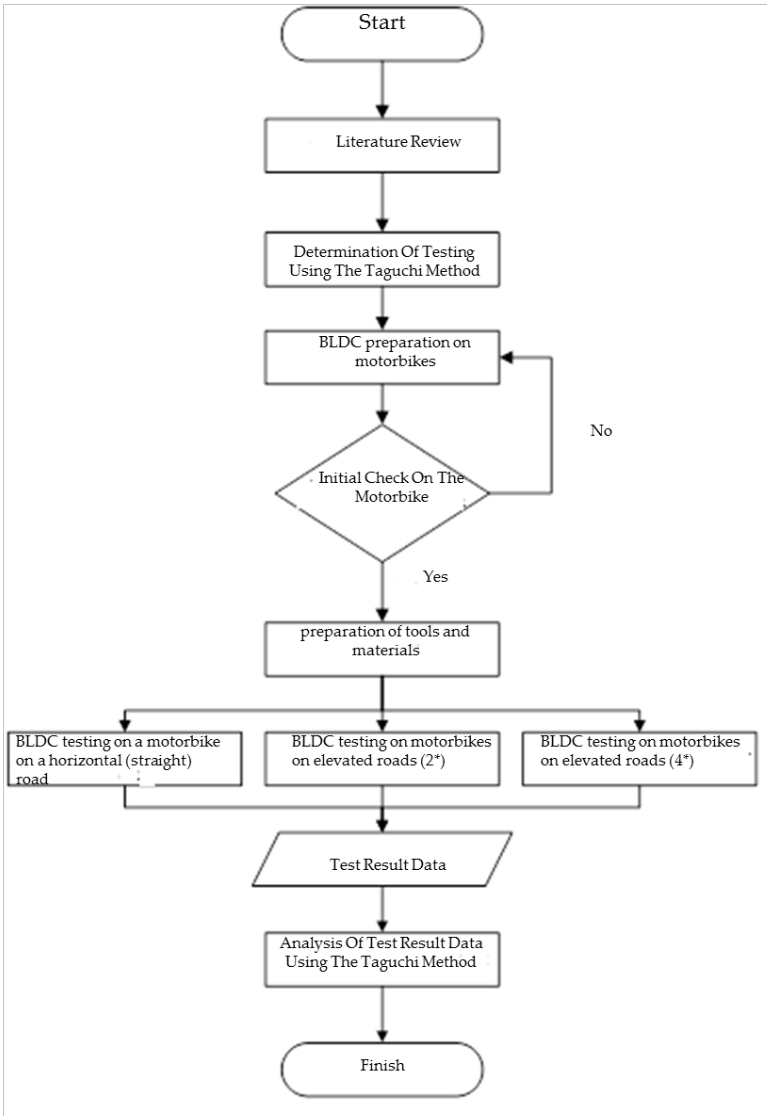


Figure 1. Research Flowchart

Table 1. Testing Factors

Control Factors	**Variation**		
	Level 1	Level 2	Level 3
Types of Electric Motors (A)	40 Poles Magnet	48 Poles Magnet	50 Poles Magnet
Road Terrain (B)	Flat	Elevation 2°	Elevation 4°
Distance (C)	60 m	120 m	180 m
Speed (D)	Speed 1	Speed 2	Speed 3

c. The determination of uncontrollable factors (noise factors) and their variations is then carried out.

d. The selection of an orthogonal array, which helps reduce the number of experiments conducted. For example, in this study, there are 4 controlled variables with 3 variations, which means that using a conservative method would require running 3^4 = 81 simulations. However, with the Taguchi method, the number of tests is reduced to only 9. This reduction is based on the calculation of the degrees of freedom of the observed factors, as follows:
Degrees of Freedom = (Number of Levels) - 1 (1)

In this case, the degrees of freedom for each factor and the total degrees of freedom for the study result in a total value of 8. The selection of the appropriate matrix for the experiment is determined by the calculation of the degrees of freedom, and the L_9 orthogonal matrix (3^4) is suitable and sufficient for use in this research [12].

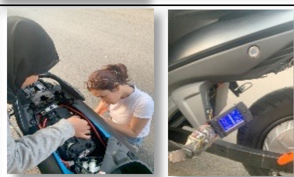
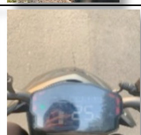
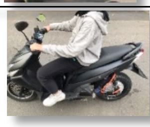
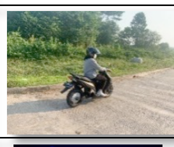
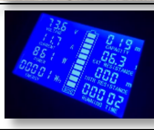
e. The final step is to create a testing scheme using the orthogonal array table [13].

Test Results Data

The real-time testing results of the electric motorcycle with the assistance of testing equipment will display the magnitude of the input power, where power is expressed as [9]. The test sequence is shown in Table 2.

$P = I \times V$ (2)
Where:
P = power (Watt)
I = current strength (A)
V = voltage (V)

Table 2. Electric Motor Testing Scheme for BLDC

Process Flow	Illustration
Start	
Motorcycle Checck	
Installation of Personal Protective Equipment	
Start the Motorcycle	
Run the Motorcycle	
Return the Motorcycle to the Starting Distance	
Check Power Meter	
End	

Analysis of Test Results Data Using the Taguchi Method

The testing results that have been conducted will be analyzed using the Taguchi Method to determine the influencing factors and the optimal factor levels. The analysis takes into account the impact of the factors, and the author develops equations based on the book "A Primer on the Taguchi Method" [13].

3. Results and Discussion

Testing Using the Taguchi Method

After conducting the testing according to the orthogonal array matrix, the average power output values obtained from all experiments are shown in Table 3.

Table 3. Testing Factors

Experiment No.	Column				Power Output (Watt)
	Jenis Motor (A)	Medan Jalan (B)	Jarak (C)	Speed	
1	40 Poles Magnet	Flat	60 m	Speed 1	473,89
2	40 Poles Magnet	Elevation 2°	120 m	Speed 2	690,73
3	40 Poles Magnet	Elevation 4°	180 m	Speed 3	1031,09
4	48 Poles Magnet	Flat	120 m	Speed 3	347,18
5	48 Poles Magnet	Elevation 2°	180 m	Speed 1	334,38
6	48 Poles Magnet	Elevation 4°	60 m	Speed 2	322,24
7	50 Poles Magnet	Flat	180 m	Speed 2	238,00
8	50 Poles Magnet	Elevation 2°	60 m	Speed 3	262,06
9	50 Poles Magnet	Elevation 4°	120 m	Speed 1	469,35

Analysis of Test Results Data Using the Taguchi Method

Calculation of the influence of factor levels on the output power of the electric motor. The calculation results are shown in Table 4, which reveals the optimum factors with the characteristic response of the average output power of the electric motor, where "smaller is better" then the calculation will subsequently be plotted on the curve depicted in Figure 2 using Minitab Statistical Software.

Table 4. Testing Factors

Level	A	B	C	D
1	731,90	353,02	352,73	425,87
2	334,60	429,06	502,42	416,99
3	323,14	607,56	534,49	546,78
Difference	408,77	254,53	181,76	129,79
Ranking	1	2	3	4

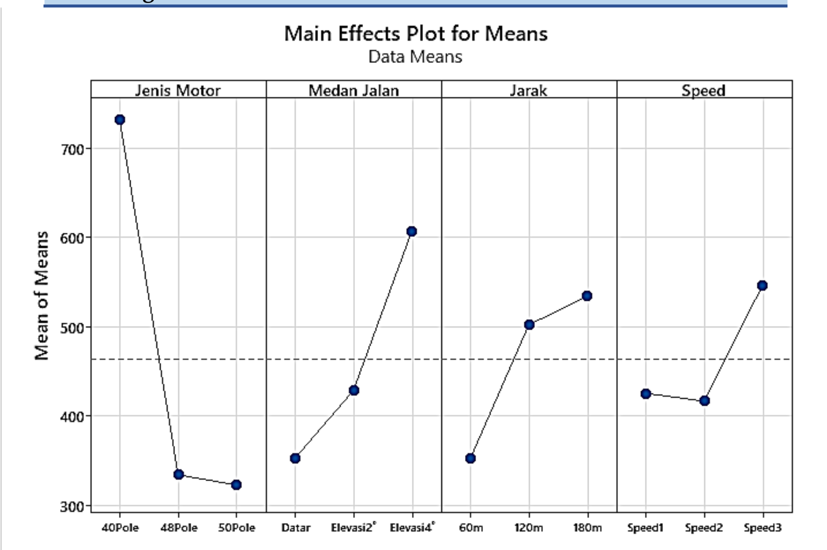


Figure 2. Main Effects Plot for Means

The results of the Taguchi Method analysis conclude that the order of factors influencing the average output power of the electric motor with the "smaller is better" characteristic is factor A (motor type), B (road terrain), C (distance), and D (speed).

4. Conclusions

The application of the Taguchi Method to direct testing on flat and uphill road terrains with elevation angles of 2° and 4° yields the order of the most influential factors, namely the type of electric motor used, road terrain, distance, and speed level. Direct testing with the assistance of the Taguchi Method reveals that the largest average output power, with a value of 1031.09 Watts, occurs with the 40-poles motor type, a 4° uphill terrain, a distance of 180 meters, and a speed level of 3.

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