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Design of Experiments (Doe) on Suspension Test Equipment of One Part of A Vehicle Wheel Using The Taguchi Method

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Abstract— **Suspension is the most important thing that must be taken into account because it greatly affects driving comfort on the road. The working mechanism of the suspension consisting of spiral springs and shock absorbers is loaded vertically from the weight of the body, driver, and passengers. The uneven shape of the road surface in the form of potholes or bumps will greatly affect the comfort of the driver. This study aims to determine the effect of suspension work and the optimal value of vibration that occurs on one of the wheels of the vehicle against vertical dynamic loads. The method used in this study uses the Taguchi method which is used to determine the optimum dynamic load conditions against vibration in the suspension system. The characteristics used in this method are "Smaller is better". Several variables such as bump height, tire pressure on the wheels, as well as vehicle body weight and passenger weight are necessary factors to calculate optimal dynamic load conditions against vibration in the suspension. Based on the results of the optimum value conditions obtained, namely the height of the mound of 5 cm, tire pressure of 32 Psi, load of 84 kg, and dynamic load of 71 kg. From the results of the contribution rate to the ANOVA obtained, factor A (bump height) and factor D (dynamic load) are significant factors while factor B (tire pressure) and factor C (load load) are insignificant factors. Under optimal conditions, there was a decrease in suspension vibration value by 49.65%.**

Keywords— optimization, simulation, vibration, suspension, pneumatic actuator

I. Introduction

Several types of four-wheeled vehicles or more that pass over the road surface at any time produce some fluctuating dynamic loads. This fluctuating loading is not only obtained from dynamic load variations / can also be caused by more loads (overload, OL) and repetitive loads (Repetition loads, RL) [1]. Fluctuating loading is influenced by variable wheelbase weight and vehicle weight. RL repetitive loading conditions are also strongly influenced by traffic repetition flow, the average volume of traffic flow (Number. kind./hour) produced by each type of vehicle, and the length of time the vehicle passes. In addition, there is a weight of passengers or cargo that occupies space on the vehicle body. The amount of passenger weight or cargo varies greatly depending on the number of passengers or cargo carried. The working direction of the vehicle weight works in a vertical direction that gets direct resistance from spiral springs and *shock absorbers.*

Variations in the weight of light, medium, and heavy vehicles passing over the road surface receive the load. Based on these problems, a study of several influential variables is needed, both direct and indirect. To overcome these problems, an optimization method is needed that can optimize the dynamic load on the suspension that affects directly the road surface.

Taguchi's experimental design is an optimization method used to obtain the optimum value of a response. The optimum value is done using an experimental design

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and involves several factors and levels. The Taguchi method has three stages: system design, parameter design, and tolerance design [2]**.** System design is the first stage in design and is the conceptual stage of creating a new product or innovation. Then, the parameter design is used to identify the parameter *settings* that will provide the average performance of the target. Design tolerances are a stage to improve quality by tightening tolerances in product or process parameters to reduce variability in product performance.

An element of novelty targeted in this study is the use of pneumatic actuators in test equipment/experiments as a substitute for the dynamic load of vehicles weighing on the road surface. The compressed air from the compressor provides a compressive force of compression varying to the springs and shock absorbers contained in the suspension system.

Based on the description above, the author will conduct a dynamic load optimization study on the suspension system or *shock absorber* on one of the wheels of a lightweight vehicle using the Taguchi method which aims to determine the effect of suspension work on one part of the vehicle wheel on vertical dynamic loads, and to determine the optimal value of vibration occurring on one of the wheels of the vehicle against vertical dynamic loads. [3], conducted research on optimization of improving the comfort of car vehicles based on suspension vibration performance on Innova 2000 CC vehicles using the Taguchi method. The parameter or factor used is the weight of the front axle with levels of 820, 870, 920, 970, and 1020 Kg. . [4] conducted research on the Optimization of Shock Absorber Pressure and Coil Spring Pressure Against Car Vibration. This study used the Taguchi method with factors and levels were Pressure Absorber with levels of 6, 8, and 10 bar. Spring pressure with levels of 20, 25, and 30 Kg/cm2. Based on the results, the optimum value is obtained with an absorber pressure factor with a value of 10 bar and a spring pressure of 24 Kg/cm2. Effective style Fef. (N) the cylindrical piston on the forward step is the difference between the theoretical force, Fk (N), and the frictional force Rf(N)[5],[6]. If the frictional force Rf is set at (N), then the overall load transfer mechanism against the asphalt road structure refers to the equilibrium equation of dynamic forces obtained from the Free Body Diagram (FBD) as shown in figure 1 F_k The effective thrust force of the pneumatic cylindrical Piston produced by the P2 air pressure (bar) is expressed as; (N) are:$F_k = \frac{\pi}{4} D^2 P_2$

$$F_{p2} = F_{ef} = F_k - R_f = F_k - 0.1F_k = 0.9F_k \ldots\ldots..(1)$$

which one,style $F_k = 1.1\, k_2 y + c\dot{y}$ and effective style $F_{ef} = F_{p2} = k_2 y + c\dot{y}$

If the dimensions of the cylinder used in the experiment are (0.100 m) then based on equation (2-1) a compressive force is obtained on the suspension mechanism of: so that it is obtained: $D = 100\, mm F_k = 785\, x\, P_2$

$$F_{p2} = 0.9x785\, P_2 = 707\, P_2 = k_2 y + c\dot{y} \text{ (N)} \ldots\ldots..(2)$$

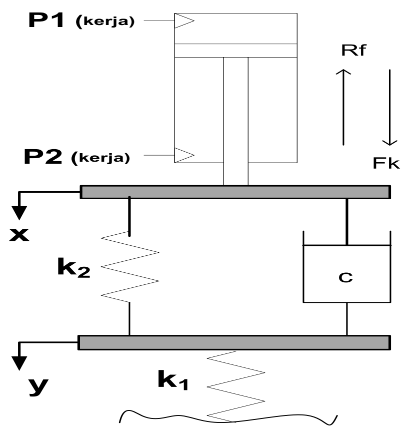

Figure 1. The mechanism of experimental overloading of the system.

If the spring is loaded, it will experience shortening/deflection, based on the law of action-reaction, so that the load exerted on the spring is proportional to the magnitude of the deflection multiplied by the spring constant. The average displacement in the optimized suspension system x = 0.009264 m with maximum vertical acceleration is 15.5707 m/s2. In this condition, the value of the stiffness coefficient of the suspension spring ks = 41821 N/m, and the suspension reducer coefficient **cs** = 68574 N.s/m [7]. The suspension prototype tested by [8]**,** had data on spring constant ks=

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10581.292 N/m, shock damping coefficient, cs= 96.073 Ns/m, and tire elastic constant, to = 98041.246 N/ m. The average displacement in the optimized suspension system has been previously revealed by [7], which is x2=0.009264 m with a maximum vertical acceleration of 15.5707 m/s2.

The test spring used in the suspension system mechanism is a "Helical" type which has specifications/dimensions, inner diameter of the coil, Di = 12.985 cm, outer diameter of the coil, Do = 15.815 cm, diameter of spring wire, d = 1.415 cm, Number of coils, n = 5 pieces, spring material; Crhome Vanadium, ASTM A231, modulus of stiffness, G = 7.929 x 1010 Pa = 7.929 x 106 N/cm2. Type of test spring; *Helical compression* spring, with the calculation of the value of the spring constant, k2 is respectively formulated by [9], and [10] as follows:

$$k_2 = \frac{Gd^4}{8n_a D^3} \quad (3)$$

The modulus value of the stiffness *G* (N/cm2), the diameter of the wire d (cm*), the amount of active coil* n_a *(fruit), and the diameter* of the coil Average D (cm) are derived from the dimensions of the Helical spring. The amount of active coil n_a is usually smaller than the total amount of coil, n (fruit). The compression area of the spring is between the minimum compression of the spring of 20% and the maximum compression of 80%. If the number of active coils, n_a = 80% x n, and the average coil diameter, D = Do – d then the magnitude of the value of the spring constant, k2 can be obtained using the equation (2-3). If equation (2-4) determines the magnitude of the spring constant k2 (N/mm), deviation y (m), and, damping coefficient c (Ns/mm), then the magnitude of the displacement speed in the sprung mass, m2 is:

$$\dot{y} = \frac{707\, P_2 - k_2 y}{c} \quad (4)$$

In general, the suspension system of the vehicle is downgraded [11], consisting of a spring and a shock absorber arranged in parallel. The main function of the suspension system is to support the weight of the vehicle, provide driver comfort to the road conditions traveled, maintain wheel traction against the road surface, and maintain wheel alignment. The passive suspension mechanism and the condition of the vehicle quarter loading structure are shown in Figure 2.

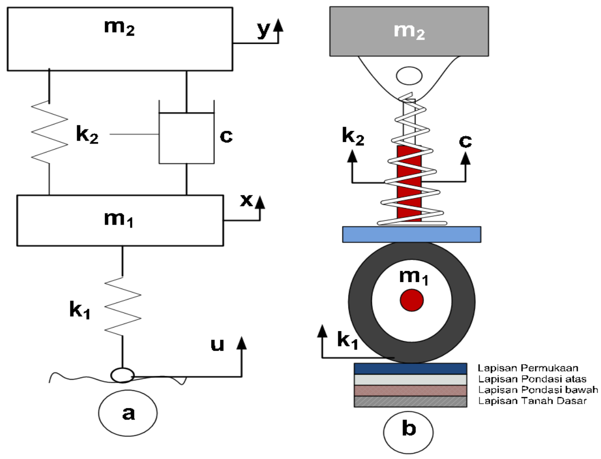

Figure 2. (a) Passive suspension model (b) Suspension unit, shock absorber, axle and wheel on road lining structure. [12]

$$F_{t1} = F_{ro} = 707\, P_2 + (k_1 . x) \quad (5)$$

The Taguchi Method developed in the 1980s by Dr. Genichi Taguchi is a new methodology in engineering that aims to improve the quality of products and processes and keep costs and *resources* to a minimum. The goal of this method is to make *the product robust* against *noise* because it is a *robust design.*

According to [13], there are several advantages or advantages in the Taguchi method, namely that experimental design is more efficient because it allows to carrying out research involving many factors and quantities, allows obtaining a process that produces a consistent and robust product against factors that cannot be controlled, and produces conclusions about the response of factors and the level of control factors that produce optimal values. In the Taguchi method according to [14], the type of matrix used is an orthogonal matrix that can be symbolized in equation (6), namely:

$$La(b^c) \quad (6)$$

Which, *L* is the square design, a is the number of experiments, *b* is the number of levels, and c is the number of factors. The Taguchi Method developed the concept of the S/N *ratio* for experiments involving many factors, called multiple-factor experiments. The S/N *ratio* is

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formulated in such a way that researchers can always choose the largest level factor value to optimize the quality characteristics of the experiment. The purpose of the S/N *ratio* is to minimize the sensitivity of quality characteristics to interference factors [15].

Quality characteristics are the result of processes related to quality. In this study, the S/N *ratio* used is *smaller the better*. S/N *Ratio smaller the better* [16]. $\eta = -10\log_{10}[MSD]$, While

$$MSD\ (\textit{Mean Square Deviation}) = \frac{1}{n}\sum_{i=1}^{n} y_1^2 \quad (7)$$

Which:

η = The number of repetitions of the experiment

Y = sample value (Observation data to-I (i= 1, 2, 3,……..n).

The use of ANOVA in the Taguchi method is useful for processing data statistically to interpret experimental data. As for the type of data, the measurement results can be analyzed using Analysis *of Variance for Variable Data.* The confidence interval (CI) is the value between the maximum and the minimum value where the actual average value will still be covered by some specific confidence percentage. The following confidence interval for variable data on the predicted mean (*predicated mean*) is calculated by the following equation.

$$\mu_{predicted} = \bar{y} + (\text{Selected factors } 1 - \bar{y}) + \ldots + (\text{Selected factors } n - \bar{y}) \ldots (8)$$

$$CI_p = \pm\sqrt{F_{\alpha,v1,v2} \times MS_{pooled} \times \left[\frac{1}{neff}\right]} \ldots (9)$$

$$Nef = \frac{\textit{total nuber of eksperiments}}{\textit{sum of degree of freedom used in estimate of mean}} \quad (10)$$

Where:

$F_{\alpha,v1,v2}$ = F-ratio value of the table

α = 0.05

v_1 = The degrees of freedom for the numerator relate to an average.

v_2 = Degrees of freedom for denominators associated with *pooled variations.*

II. Research Methodology

The Taguchi method is an optimization method used to obtain the optimum value and effect of a response. This method can also be used as a strategy for building products/processes in experimental design. In addition, this method is a new methodology in the field of engineering that aims to improve the quality of products and processes and can reduce costs and resources to a minimum. The implementation of research activities lasted for six months and was located in the Mechatronics and Automation Systems Laboratory of the Mechatronics Engineering Study Program, Department of Mechanical Engineering, Ujung Pandang State Polytechnic.

A. Method Experiment

The main components of the study shown in the research scheme in figure 3 [16], consist of Software Lab view, Arduino Uno, Accelerometer MPU6050, and Suspension Test Equipment. The data retrieval process is carried out using a laptop on the LabVIEW software (1) connected to the Arduino Uno microcontroller (2) Vibrations that occur in the suspension, carried out using the accelerometer MPU6050 (3) connected to the Shock absorber section in the suspension test equipment (4). Data processing is carried out with the Taguchi experimental design as the main instrument, continued until the experiment confirms to determine the factors that have a significant effect and determines the *optimal level* setting.

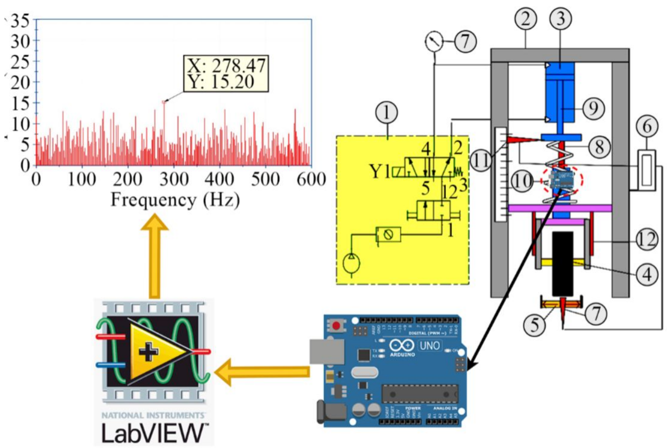

Figure 3. Research Scheme

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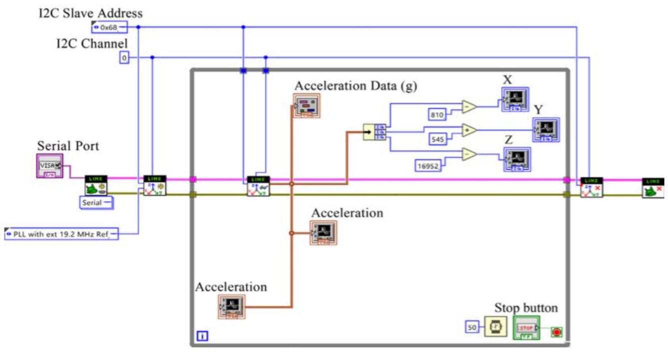


Figure 4. Vibration program using LabVIEW 2019 version student software [17],

The determination of the level setting for each factor can be seen in Table 1.

Table 1. Determination of factors and Number of Level Values

Factor Control		Unit	`Level		
Mound Height	(A)	(cm)	5	10	15
Tyre Pressure	(B)	(psi)	28	30	32
Passenger Load	(C)	(Kg)	56	84	112
Dynamic Load	(D)	(kg)	71	141	212

B. Material

The material in this study uses pneumatic cylinders and 5/2 valve solenoids as vibration triggers in the suspension system. The material used in this study can be seen in Figure 5 [18].

Figure 5. (a) Pneumatic Actuator (b) Memory valve 5/2

III. Results and Discussion

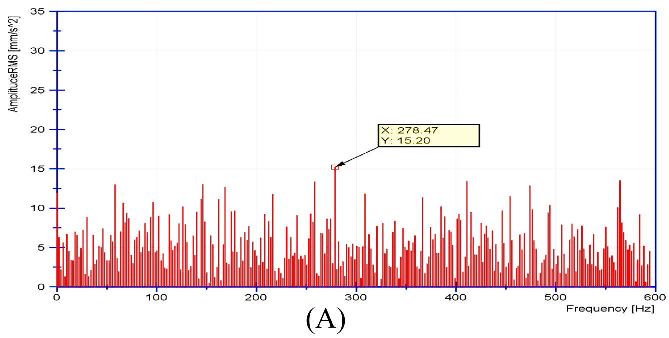
3.1 Research Design Results

The research design used was an L9 orthogonal matrix (34) with three times replication. Suspension vibration data retrieval based on amplitude value in FFT graph.

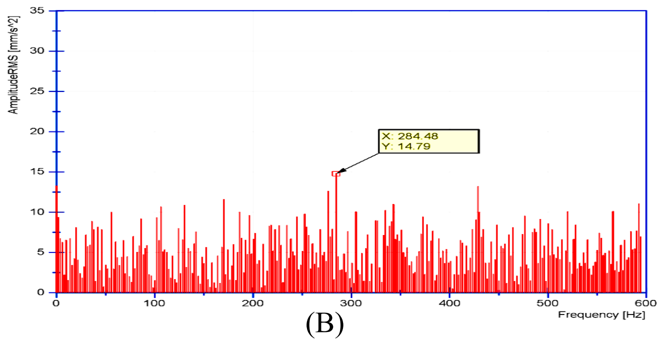
Table 2. Measurement result data retrieval.

Eks	**Factor**				**Suspension Vibration Rating RMS FFT** (mm/s^2)			
	A	B	C	D	I	II	III	**Mean**
1	5	28	56	71	15.20	14.79	15.82	15.27
2	5	30	84	114	25.94	25.44	26.44	25.94
3	5	32	112	212	30.21	30.31	29.33	29.95
4	10	28	84	212	37.67	36.96	38.15	37.59
5	10	30	112	71	21.55	23.94	24.41	23.30
6	10	32	56	114	33.76	34.41	34.69	34.28
7	15	28	112	114	43.96	44.16	42.89	43.67
8	15	30	56	212	58.22	58.48	60.53	59.07
9	15	32	84	71	29.19	31.90	31.23	30.77

In comparison, the average value of suspension vibration under experimental conditions obtained a value of 33.31 mm / s2



(A)



(B)

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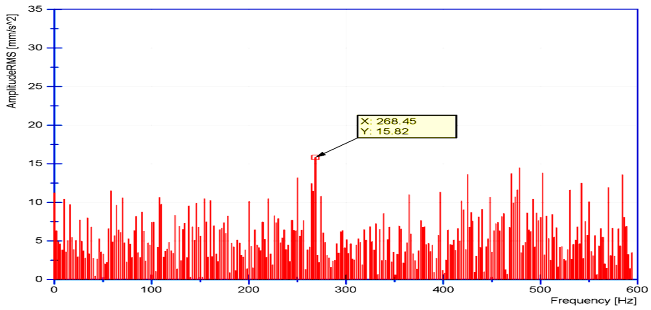

(C)

Figure 6. Suspension vibration data retrieval in the form of FFT signals. (A) Replication I, (B) Replication II, and (C) Replication III.

In Figure 6, it is the result of taking vibration data on the suspension section. The results of the data on the sensor MPU6050, in the form of amplitude acceleration data results, are then converted in the form of FFT signals. The results obtained in experiment 1 replication 1 obtained a value of 15.20 mm / s2, in experiment 1 replication 2 obtained a value of 14.79 mm / s2, and in experiment 1 replication 3 obtained a value of 15.82 mm / s2

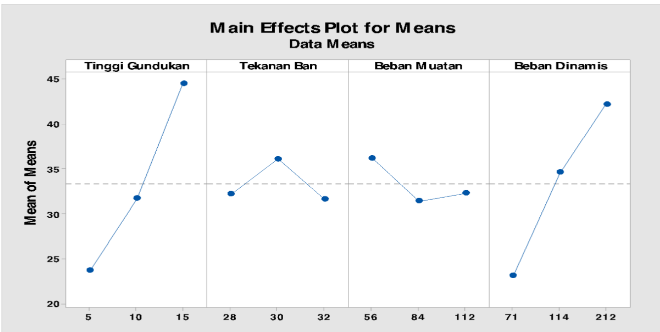

Figure 7. Main Effects Plot of Means on Vibration Acceleration RMS Suspension values

In Figure 7, one level is obtained from each factor that has the lowest value, namely factor A at level 1, factor B at level 3, factor C at level 2, and factor D at level 1.

3.2 Calculation of the S/N ratio of Taguchi's experiment

The S/N ratio value is calculated based on the type of quality characteristics of each response. The vibration response in the suspension test equipment used is the characteristic of the smaller the better or *Smaller the better*.

The results of the calculation of the S/N Ratio vibration value on the suspension test equipment in the second and ninth combinations can be analyzed in Table 3.

Table 3.The result of calculating the value of the Suspension Vibration S/N Ratio

Eks	Factor				**S/N Ratio Suspension vibration**
	A	B	C	D	
1	5	28	56	71	-23.68
2	5	30	84	114	-28.28
3	5	32	112	212	-29.52
4	10	28	84	212	-31.50
5	10	30	112	71	-27.35
6	10	32	56	114	-30.70
7	15	28	112	114	-32.80
8	15	30	56	212	-35.42
9	15	32	84	71	-29.76

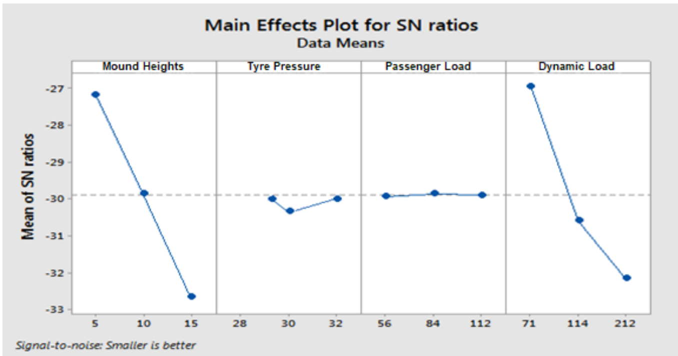

Figure 8. Main Effects Plot of S/N Ratio on Vibration Acceleration RMS Suspension value

In Figure 8, one level is obtained from each factor that has the lowest value, namely factor A at level 1 factor B at level 3, factor C at level 2 with factor D at level 1.

3.3 Analysis of Variance (ANOVA)

Analysis of Variance (ANOVA) shows the relationship between control parameters and quality characteristics. This is the degree of contribution to the quality characteristics of control parameters. Results of ANOVA used be regression, [19] perform statistical results using ANOVA regression using the Taguchi method with

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orthogonal array matrix L9, if the results of ANOVA regression P.<0.05, then the results of ANOVA regression are accepted. Results of calculating the ANOVA Average and S/N Ratio in Table 4 and Table 5

Table 4 Analysis of Variance (ANOVA) Suspension Vibration Average

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	1164.18	291.046	9.38	0.026
Mound Height	1	648.13	648.128	20.90	0.010
Tyre Pressure	1	0.39	0.387	0.01	0.916
Passenger weight	1	22.87	22.867	0.74	0.439
Dynamic Load	1	492.80	492.802	15.89	0.016
Error	4	124.05	31.012		
Total	8	1288.23			

Table 5. Analysis of Variance (ANOVA) S/N Ratio Suspension Vibration

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	81.0277	20.2569	8.89	0.029
Mound Height	1	45.4527	45.4527	19.94	0.011
Tyre Pressure	1	0.6761	0.6761	0.30	0.615
Passenger weight	1	0.0024	0.0024	0.00	0.976
Dynamic Load	1	34.8965	34.8965	15.31	0.017
Error	4	9.1168	2.2792		
Total	8	90.1445			

This study used a control parameter significance test according to a confidence level of 95% and a p-value – 0.05. The calculated F value (F-Test) is the ratio of the *mean squared error to the* residual and is used to determine the significance of the control factor. Test results F calculated from the control factor is F0,05,1,4 = 7.70.

Based on the results of ANOVA calculations for the *means value* and the S/N ratio value. Factors that have an influence and significance on the vibration value of the suspension based on the level of contribution and result in F calculate ≥ F table are factor A and factor D while factor B and factor C are factors that have no effect or are not significant.

3.4 Taguchi Experiment Verification Phase Testing Confirmatory Experiments

Confirmatory testing is the final step in verifying the results of calculations obtained based on Taguchi's experimental design.

In this study, confirmatory experiments were carried out using the optimal level setting, namely factor A (Mound Height) at level 1, factor B (Tyre Pressure) at level 3, factor C (Passenger weight) at level 2, and factor D (Dynamic Load) at level 1.

Table 6 Suspension vibration confirmation experiments

Experiment: Confirm the optimal level setting						
Factors and Levels	**Value**	**Suspension Vibration Acceleration RMS (mm/s^2)**				
		I	II	III	Mean	S/N
A1	5	16.28	17.15	16.92	16.78	-24,49
B3	32					
C2	84					
D1	71					

3.5 *Comparison of results of initial experimental conditions and confirmatory experiments*

At optimal conditions with parameters Mound Height with a value of 5 cm, Tyre Pressure with a value of 30 psi, Passenger weight with a value of 84 kg, and Dynamic Load with a value of 71 kg is the optimal value result in Taguchi's confirmation experiment. This shows that the suspension vibration value on the test equipment decreased by 49.65% as in Table 7. In comparison, the average value of suspension vibration in the initial experimental conditions obtained a value of 33.31, and the optimal value of suspension vibration in the confirmation experiment was obtained of 16.78. For comparison of condition values in the initial experiment and conditions in the confirmation experiment with optimal values can be seen in Table 7.

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Table 7 Comparison of initial conditions with optimal conditions

Responds (Mean)	Condition		Difference	Percentage
	Predictions	confirmation		
Suspension vibration	33.31	16.78	16.54	49.65%

IV. Conclusion

Based on the results of the research that has been done, it can be concluded that:

1. The optimum value condition results obtained are Mound height 5 cm, tire pressure 32 Psi, Passenger weight 84 kg, and dynamic load 71 kg.
2. Factors that have an influence and significance on the vibration value of the suspension based on the level of contribution and the result of F calculate ≥ F table, namely factor A and factor D are very influential or significant factors while factor B and factor C are factors that have no effect or are not significant.
3. Under optimal conditions, there is a decrease in the suspension vibration value by 49.65%

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