Suleman Ahmed

Taguchi Quality Design

Taguchi Method Implemented on Tire Wear

One of the most important parts on a car is the tire. It is possibly the only part of a car that actually touches the floor, so its importance is heavily emphasized. Tire wear depends on many different factors and has been researched quite extensively. For the sake of simplicity, our design takes in one tire wear formula that has been derived from previous literature. The formula can be seen in figure 1.

$$\mathrm{A} = \left(\frac{E}{\sigma}\right) \mu^{0.45} \left(\frac{(\theta a^{2.45})}{2.45}\right)$$

(Figure 1)

In this formula, we take in slip angle, tension strength, coefficient of friction of tire to the floor, the length of the contact area of the tire with the floor, and the modulus of elasticity to calculate A, tire wear.

The Taguchi method allows us to test the quality in the design process and made into the final product, not inspected into it. Our process objective in this experiment is tire wear rate and with our formula we can inspect 5 different factors that influence tire wear rate, with 3 levels acting on 3 factors. Of course, there are many other different factors that can affect tire wear rate, such as pressure, but pressure can influence the contact area of the tire to the floor, and that is well included in our design parameters. The following are the values of our design parameters, where the first value is the average of a regular tire:

θ : [0.1, 0.2, 0.3] degrees

σ : [16.5, 16.6, 16.7] MPA

E : [0.9, 1, 1.1] MPA

μ: [0.68, 0.8, 0.15] concrete, asphalt, ice

a: [83.1, 83.2, 83.3] mm

We also want to create a robust design by adding in factors for noise. In our experiment, we add noise for slip angle, tension strength, and length of contact area, each with 2 levels. These values can be seen below:

θ: [-0.02 ; +0.02]

σ: [-0.03 ; +0.03]

a: [-0.03 ; +0.03]

Following the Taguchi method, we created an inner orthogonal array of $L_{27}\ 3^5$ (Figure 2) and also combined our noise orthogonal array $L_4\ 2^3$ (Figure 3) to create our final outer array with our tire wear rate results. Figure 4 shows the tire wear results as well as mean square error and signal to noise ratio. The whole process can also be seen in the excel sheet attachment.

theata	stress	Modulus	friction	area
1	1	1	1	1
1	1	1	1	2
1	1	1	1	3
1	2	2	2	1
1	2	2	2	2
1	2	2	2	3
1	3	3	3	1
1	3	3	3	2
1	3	3	3	3
2	1	2	3	1
2	1	2	3	2
2	1	2	3	3
2	2	3	1	1
2	2	3	1	2
2	2	3	1	3
2	3	1	2	1
2	3	1	2	2
2	3	1	2	3
3	1	3	2	1
3	1	3	2	2
3	1	3	2	3
3	2	1	3	1
3	2	1	3	2
3	2	1	3	3
3	3	2	1	1
3	3	2	1	2
3	3	2	1	3

Figure 2.a; Orthogonal L_{27} 3^5 array

theata	stress	area
1	1	1
1	2	2
2	1	2
2	2	1

Figure 3.a; Orthogonal L_4 2^3 array

theata	stress	Mod	friction	area
0.1	16.5	0.9	0.67	83.1
0.1	16.5	0.9	0.67	83.2
0.1	16.5	0.9	0.67	83.3
0.1	16.6	1	0.8	83.1
0.1	16.6	1	0.8	83.2
0.1	16.6	1	0.8	83.3
0.1	16.7	1.1	0.15	83.1
0.1	16.7	1.1	0.15	83.2
0.1	16.7	1.1	0.15	83.3
0.2	16.5	1	0.15	83.1
0.2	16.5	1	0.15	83.2
0.2	16.5	1	0.15	83.3
0.2	16.6	1.1	0.67	83.1
0.2	16.6	1.1	0.67	83.2
0.2	16.6	1.1	0.67	83.3
0.2	16.7	0.9	0.8	83.1
0.2	16.7	0.9	0.8	83.2
0.2	16.7	0.9	0.8	83.3
0.3	16.5	1.1	0.8	83.1
0.3	16.5	1.1	0.8	83.2
0.3	16.5	1.1	0.8	83.3
0.3	16.6	0.9	0.15	83.1
0.3	16.6	0.9	0.15	83.2
0.3	16.6	0.9	0.15	83.3
0.3	16.7	1	0.67	83.1
0.3	16.7	1	0.67	83.2
0.3	16.7	1	0.67	83.3

Figure 2.b; inner array

theata	stress	area
-0.02	-0.03	-0.03
-0.02	0.03	0.03
0.02	-0.03	0.03
0.02	0.03	-0.03

Figure 3.b; noise array

Trial 1	Trial 2	Trial 3	Trial 4	MSE	SN
1.928969101	1.925370277	5.218156525	5.190026809	15.39837707	-11.8747495
1.934663214	1.931049661	5.233548845	5.20534722	15.48938693	-11.90034229
1.940367262	1.936738948	5.248968003	5.220694364	15.5808244	-11.92590433
2.307335166	2.303080886	6.241694617	6.208183269	22.03206708	-13.43055245
2.314146175	2.309874426	6.26010613	6.22650917	22.1622844	-13.45614524
2.32096907	2.316679812	6.278549747	6.244867048	22.29311354	-13.48170728
1.187793246	1.185628845	3.213162447	3.195980309	5.838817899	-7.663249307
1.191299486	1.189126168	3.222640511	3.205414505	5.87332738	-7.688842092
1.194811844	1.192629589	3.232135102	3.214865163	5.907999004	-7.714404134
7.969614897	7.95474621	13.053396	12.98302856	116.4357316	-20.66086276
7.993140358	7.978210818	13.09190041	13.02135308	117.1239083	-20.68645556
8.01670687	8.00171634	13.13047196	13.05974449	117.8153183	-20.71201761
17.08809724	17.05659009	27.98851676	27.83824781	535.3138611	-27.28608489
17.1385395	17.10690297	28.07107622	27.92042337	538.4777568	-27.31167768
17.18906978	17.15730358	28.15377964	28.00274233	541.656518	-27.33723974
15.05175957	15.02433221	24.65320855	24.52137743	415.3411669	-26.18404979
15.09619078	15.06865042	24.72592965	24.59376194	417.7959812	-26.20964258
15.14069951	15.1130459	24.79877755	24.66627276	420.2623295	-26.23520463
54.96661443	54.86406476	76.37434609	75.96263198	4408.689125	-36.44309476
55.12887007	55.02590069	76.59963223	76.18686564	4434.746054	-36.46868756
55.29140883	55.18801881	76.8253112	76.41149058	4460.925411	-36.49424962
21.04604408	21.00723924	29.24280258	29.08579943	646.3413258	-28.10461925
21.10816978	21.0692056	29.32906189	29.17165764	650.1614341	-28.13021205
21.17040388	21.13128	29.4154716	29.25766566	653.9994911	-28.1557741
45.58347914	45.50041679	63.33678084	62.9980923	3032.112235	-34.81745273
45.71803675	45.63463219	63.52360927	63.18405601	3050.033102	-34.84304553
45.85282916	45.76908162	63.71076346	63.37034422	3068.038171	-34.86860759

Figure 4; outer array, with the addition of mean square error and signal to noise ratio

From Figure 4, we see the 4 trails ran from each experiment number (all the way to 27). The 4 trails stem from the L_4 noise array. The next part of experiment requires us to calculate the signal to noise ratio. In our experiment, we want the tire wear rate to be low as possible, so we use the formula for MSE:

$$\text{MSE} = \frac{1}{n}\sum_{1}^{n} y_i^2$$

And use the MSE to calculate the S/N ratio which is:

$$S/N = -10\log_{10}MSE$$

Figure 4 has all these values already collected for each experiment. The first trail contains the optimal levels and factors for tire wear, 1.9%.

After calculating the S/N ratio for each experiment, we calculate the average S/N value for each factor and level. This is done to observe which parameter has the most effect to the design. We use Minitab software to tabulate our results, and also analyze them graphically, shown below.

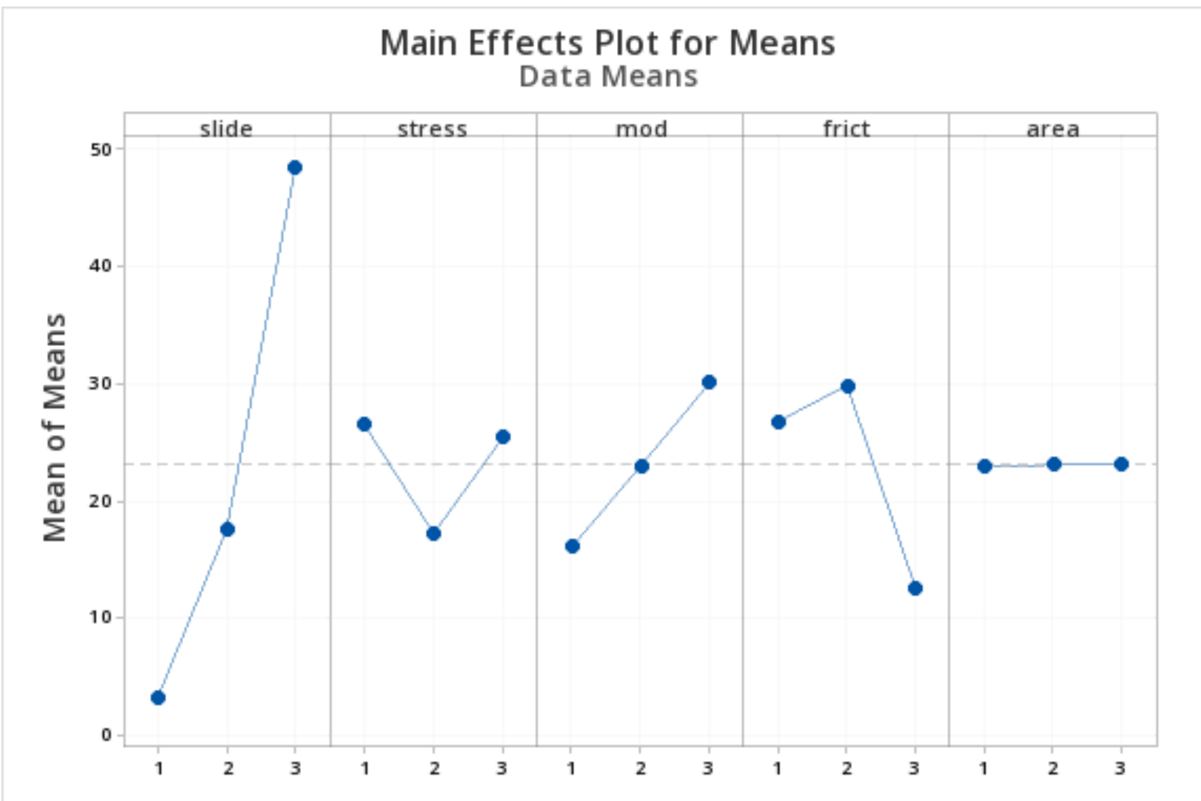
Response Table for Signal to Noise Ratios

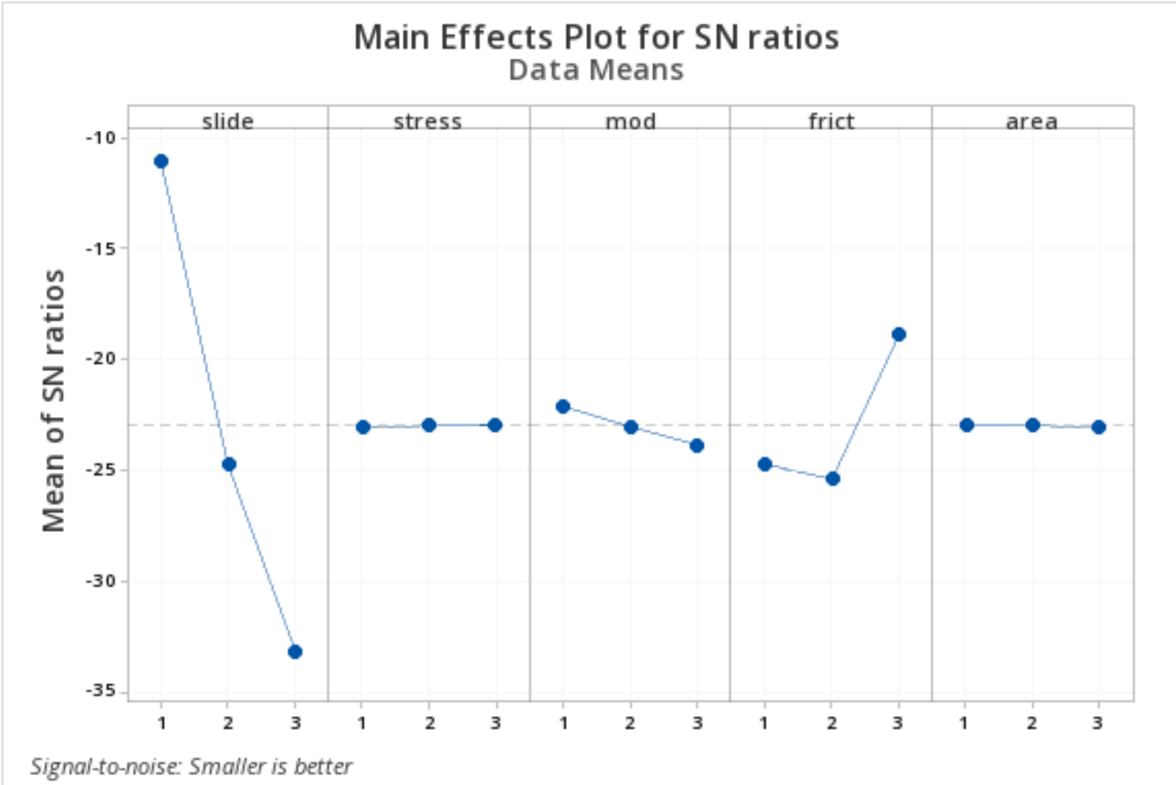
Smaller is better

Level	slide	stress	mod	frict	area
1	-11.02	-23.02	-22.08	-24.69	-22.94
2	-24.74	-22.97	-23.00	-25.38	-22.97
3	-33.15	-22.91	-23.82	-18.84	-22.99
Delta	22.13	0.10	1.74	6.54	0.05
Rank	1	4	3	2	5

Response Table for Means

Level	slide	stress	mod	frict	area
1	3.352	26.611	16.206	26.884	23.090
2	17.651	17.336	23.105	29.961	23.159
3	48.473	25.529	30.166	12.631	23.227
Delta	45.121	9.275	13.960	17.330	0.136
Rank	1	4	3	2	5





We can see from the charts above that slip angle had the biggest effect on tire wear. If we were to rank, it would be slip angle, coefficient of friction, modulus of elasticity, tension stress, and length of contact area, in that order. From our S/N ratio being low, it can be concluded that the noise play a very big role on the overall quality characteristic variable, tire wear. This experiment can further help us create a tire that allocates for these defects.

Reference:

- Saibel and Tsai, “Tire wear Model”, Department of Mechanical Engineering

  Carnegie-Mellon University, 1969

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- Rao, “Reliability Engineering”, Pearson, 2015