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# Optimization of Design Parameters for Leaf Spring by Taguchi Technique

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## ABSTRACT

Spring design in vehicles is one of the basic requirements in the system of suspension as by ensuring the proper design, the necessary comfort for passengers can be obtained. Thus, the car's stability on the road and in different places (the flat roads, winding roads and mountain roads) will be achieved. Given this importance, there are many factors that affect the design of springs (leaf springs). This research includes the study of three factors considered namely :( thickness, length and step) of springs. Taguchi experiment is used in determining the best among the tests performed. Then each factor was taken individually in control to get the design parameters for the leaf spring.

Taguchi technique is applied in the design process of the three factors and mix levels to choose the optimal level for each factor that gives nominal of suitable displacement, stress and load. Optimal levels that have been achieved for case study of leaf spring of a total thickness of (12) mm were:

- Spring work in regions with high bumps.
- Spring work in flat areas and highways.
- Spring work in the middle regions (winding roads within cities).
- Applied cases studied were NISSAN, SCANIA and MAN automobiles to apply this rule and compare the actual design specifications of these automobiles. The output results showed a complete compatibility between these cases.

**Keywords:** Leaf spring, laminated spring, Taguchi Method, S/N.

| Nomenclature | | |
|---|---|---|
| 1 | ANOVA | Analysis of variance. |
| 2 | F.E.M | Finite element method. |
| 3 | MSD | Mean squared deviation |

## تحقيق امثلية تصميم العوامل لنابض ورقي باستخدام تقنية تاجوشي

**الخلاصة**

يعتبر تصميم النوابض في المركبات ،احدى المتطلبات الاساسية في منظومة التعليق اذ من خلال ضمان التصميم الملائم يمكن الحصول على الراحة اللازمة للراكب وبالتالي الحصول على استقرار السيارة على الطريق وفي اماكن مختلفة (الطرق المستوية ،الطرق المتعرجة ،الطرق الجبلية). ونظرا لهذه الاهمية، هنالك العديد من العوامل المؤثرة على تصميم النوابض (النابض الورقي) ،تم في هذا البحث دراسة ثلاثة عوامل من هذه العوامل (السمك ،الطول والتدرج). كما تم في هذا البحث استخدام تقنيات التمثيل الاحصائي المتمثلة بطريقة تاجوشي في تحديد التجربة الافضل من بين التجارب التي اجريت، ثم فصل كل عامل سيطرة بمفرده وذلك للحصول على عوامل التصميم للنابض الورقي.

تم تطبيق نظرية تاجوشي في عملية التصميم لثلاثة عوامل (عاملين بأربعة مستويات والعامل الثالث بمستويين) لاختيار المستوى المثالي لكل عامل يعطي معدل ازاحة مناسب. المستويات المثالية التي تم تحقيقها لدراسة حالة النابض الورقي ذو سمك كلي (12) ملم هي:

- ❖ نابض يعمل في المناطق ذات المطبات العالية (قوة قليلة وازاحة عالية).
- ❖ نابض يعمل في المناطق المستوية والطرق السريعة.
- ❖ نابض يعمل في المناطق المتوسطة (الطرق المتعرجة داخل المدن) .
- ❖ تم تطبيق الدراسة على العجلات نيسان، سكانيا و مان لغرض مقارنة نتائج الحسابات مع الخواص التصميمية الحقيقية لهذه العجلات. النتائج اظهرت تطابق تام بين هاتين الحالتين.

## 1. Introduction:

One of the basic systems in all types of heavy vehicles and transport automobiles is the suspension system. It is the system which contains springs to minimize the sudden impact on the vehicles body structure and passenger group. Therefore, in this study has been done the best model study for the leaf springs used in heavy vehicles and various kinds of automobiles. The basic element in valuation of this model is considered as the force quantity which can be endured in all kinds of work conditions. The second element is the bend quantity given by these springs, in order to minimize the impact on

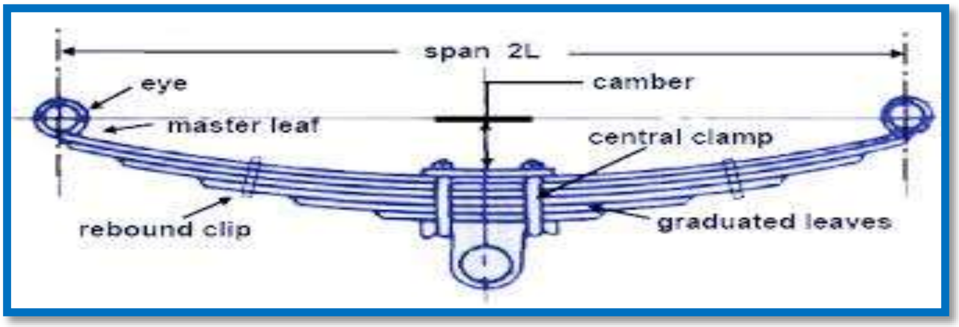


Figure (1). Leaf spring

the passenger, goods and vehicles structure. There are two elements work together. It is not allowed to leave one of them or disvalue its importance. Thus a detailed study has been carried out on two parameters to reach to the complied state between the basic elements that have to be applied in these models. . The leaf spring consists of a number of flat plates (known as leaves) of varying lengths, as shown in Figure (1). These are mostly used in automobiles. [1].

## 2. Literature survey

**Achamyeleh A Kassie.et al (2014)[2]** Reduced the weight and increased strength of products that are high research demands in the world, composite materials are getting to be up to the mark of satisfying these demands. In this paper reducing weight of vehicles by 68.14% and increasing the strength of their spare parts is considered. A mono composite leaf spring for the vehicular suspension system was designed using E-Glass/Epoxy with the objective of minimizing weight of the leaf spring. And it is shown that the resulting design stresses are much below the strength properties of the material satisfying the maximum stress failure criterion. The deflection of the leaf spring along its transverse direction, which is very small compared to the considered maximum deflection.

**Mouleeswaran et. al. (2007)[3]** carried out design and experimental fatigue analysis of composite multi leaf spring using glass fibre reinforced polymer using life data analysis. Compared to steel spring, the composite leaf spring was found to have 67.35 % lesser stress, 64.95 % higher stiffness and 126.98 % higher natural frequency than that of existing steel leaf

spring.The conventional multi leaf spring weight was about 13.5 kg whereas the E-glass/Epoxy multi leaf spring weight was only 4.3 kg. Thus a weight reduction of 68.15 % was achieved. Besides the reduction in weight, the fatigue life of composite leaf spring was predicted to be higher than that of steel leaf spring. Life data analysis was found to be a tool to predict the fatigue life of composite multi leaf spring. It was found that the life of composite leaf spring was much higher than that of a steel leaf spring.

## 3. Taguchi method

Taguchi method is a record method developed by Taguchi and Konishi.. Taguchi Method involves identification of proper control factors to obtain the optimum results of the process. Orthogonal Arrays (OA) are being used to conduct group of experiments. Outcomes of these experiments are being used to analyze the data and predict the quality of components produced[4].

## 4. Experimental work:

The framework of proposed methodology of research as shown in Figure (2) the details of the experiment work can be explained in the following which contain all the steps of Taguchi method that used in the research.

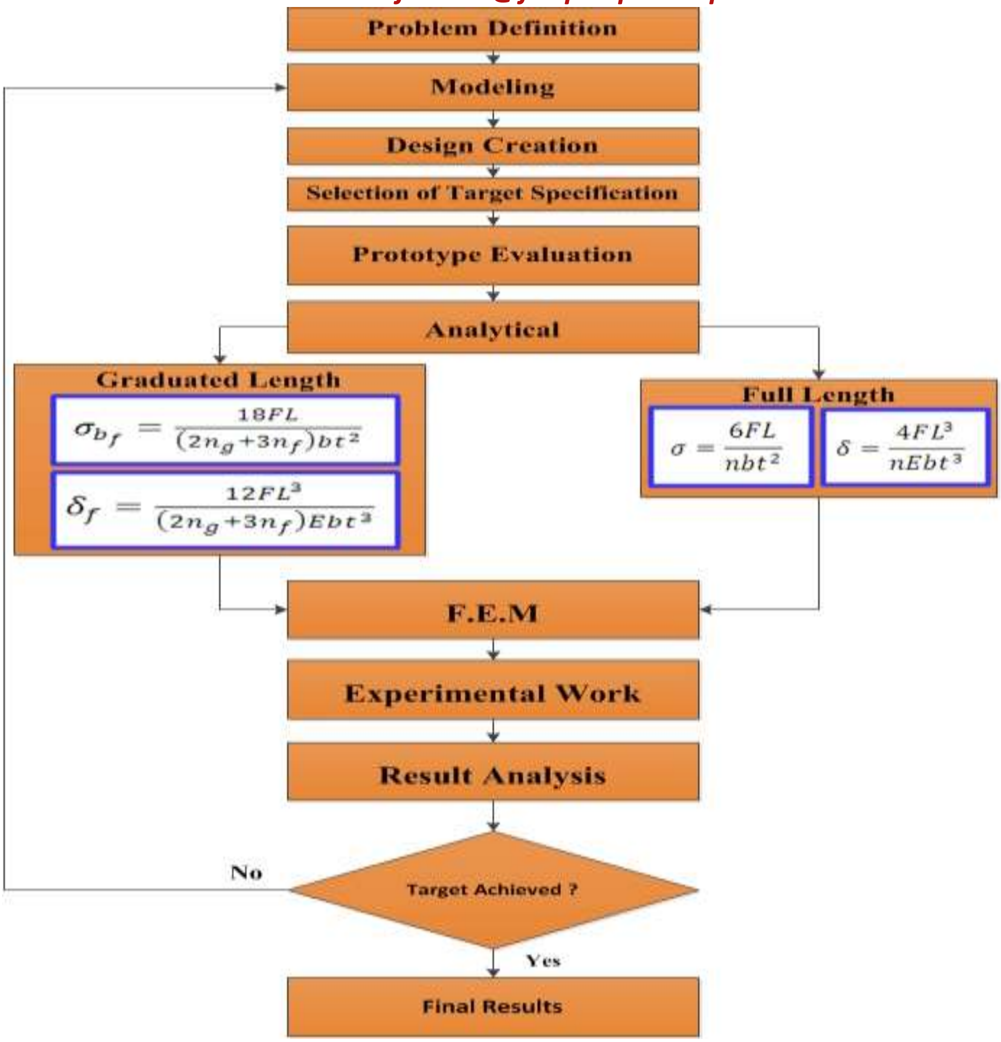


Figure (2) the research methodology

**4.1 Materials:** The total thickness of strips to be studied was (12 mm) with different layers. This thickness was chosen because of the availability of the required thickness of all the needed strips.

- **Chemical composition:** The chemical composition of the material used is shown in table I the commercial code of materials was found by using (key to steel) software. The strips examined steel in several thickness (4, 6, and 12) mm.

Table Ⅰ Chemical composition of used strips

| | Thickness of strips | | |
|---|---|---|---|
| Component | 4 mm | 6 mm | 12 mm |
| **% C** | 0.177 | 0.176 | 0.114 |
| **% Si** | 0.167 | 0.279 | 0.260 |
| **% Mn** | 0.554 | 0.490 | 1.08 |
| **% P** | 0.012 | 0.022 | 0.012 |
| **% S** | 0.02 | 0.018 | 0.006 |
| **% Cr** | 0.078 | 0.047 | 0.028 |

- **Mechanical_properties**: The mechanical properties for the material used are shown in table Ⅱ.

Table Ⅱ Mechanical properties of used strips

| | Thickness of strips | | |
|---|---|---|---|
| Mechanical properties | 4 mm | 6 mm | 12 mm |
| Yield stress N/mm$^2$ | 325 | 310 | 329 |
| Tensile strength N/mm$^2$ | 458 | 431.6 | 460 |
| Elongation % | 35 | 38.2 | 39.2 |
| Reduction in area % | 39.8 | 41.4 | 42.3 |

**4.2 Design_of experiments:**

Taguchi method is applied in the design of leaf spring to select the optimal parameters for the resilience. This uses an orthogonal array to study the entire parametric space with a limited number of experiments. The four parameters (control factors) considered in this study are: thickness, length, radius of

curvature and step. All of them were set at four different levels (see Table Ⅲ ). Therefore, an L16 orthogonal array is used (see Table Ⅳ)

**Table Ⅲ Control factors**

| a. Array 1 | | | |
|---|---|---|---|
| **Levels of factors** | Experimental factors | | |
| | Thickness | Length of strips | Step |
| **1** | 12 | 300 | Full length |
| **2** | 6 | 280 | Step |
| **3** | 3 | 260 | |
| **4** | 1 | 240 | |

| b. Array 2 | | | |
|---|---|---|---|
| **Levels of factors** | Experimental factors | | |
| | Thickness | Length of strips | Step |
| **1** | 12 | 300 | Full length |
| **2** | 4 | 280 | Step |
| **3** | 2 | 260 | |
| **4** | 1 | 240 | |

The response variables chosen for the present investigation is deflection. The nominal the best quality characteristic has been used for calculating the signal to noise (S/N) ratio for these responses, see Eq. 1. [16]

QC: Nominal is best (S/N based on MSD)

S/N = - 10 Log (MSD) ………………….. (1)

Where Y = Results, N = Number of results in a trial, and MSD = Sum of all [(Y - Target) ^2] / N

Table Ⅳ Trial conditions

| a. Array 1 | | | |
|---|---|---|---|
| **Trial Condition 1** | | | |
| | T/ thickness of strips (mm) | 12 mm | 1 |
| | L/length of layer | 300 | 1 |

| | | | |
|---|---|---|---|
| | S/step | step | 1 |
| **Trial Condition 2** | | | |
| | T/ thickness of strips (mm) | 12 mm | 1 |
| | L/length of layer | 280 | 2 |
| | S/step | Step | 2 |
| **Trial Condition 3** | | | |
| | T/ thickness of strips (mm) | 12 mm | 1 |
| | L/length of layer | 260 | 3 |
| | S/step | Full length | 3 |
| **Trial Condition 4** | | | |
| | T/ thickness of strips (mm) | 12 mm | 1 |
| | L/length of layer | 260 | 4 |
| | S/step | full | 4 |
| **Trial Condition 5** | | | |
| | T/ thickness of strips (mm) | 6 mm | 2 |
| | L/length of layer | 300 | 1 |
| | S/step | Step | 3 |
| **Trial Condition 6** | | | |
| | T/ thickness of strips (mm) | 6 mm | 2 |
| | L/length of layer | 280 | 2 |
| | S/step | Step | 4 |
| **Trial Condition 7** | | | |
| | T/ thickness of strips (mm) | 6 mm | 2 |
| | L/length of layer | 260 | 3 |
| | S/step | Full length | 1 |
| **Trial Condition 8** | | | |
| | T/ thickness of strips (mm) | 6 mm | 2 |
| | L/length of layer | 260 | 4 |
| | S/step | Full length | 2 |
| **Trial Condition 9** | | | |
| | T/ thickness of strips (mm) | 3 mm | 3 |
| | L/length of layer | 300 | 1 |
| | S/step | Full length | 4 |
| **Trial Condition 10** | | | |
| | T/ thickness of strips (mm) | 3 mm | 3 |
| | L/length of layer | 280 | 2 |
| | S/step | Full length | 3 |
| **Trial Condition 11** | | | |
| | T/ thickness of strips (mm) | 3 mm | 3 |
| | L/length of layer | 260 | 3 |
| | S/step | Step | 2 |
| **Trial Condition 12** | | | |
| | T/ thickness of strips (mm) | 3 mm | 3 |

| | | | |
|---|---|---|---|
| | L/length of layer | 260 | 4 |
| | S/step | step | 1 |
| **Trial Condition 13** | | | |
| | T/ thickness of strips (mm) | 1 mm | 4 |
| | L/length of layer | 300 | 1 |
| | S/step | Full length | 2 |
| **Trial Condition 14** | | | |
| | T/ thickness of strips (mm) | 1 mm | 4 |
| | L/length of layer | 280 | 2 |
| | S/step | Full length | 1 |
| **Trial Condition 15** | | | |
| | T/ thickness of strips (mm) | 1 mm | 4 |
| | L/length of layer | 260 | 3 |
| | S/step | step | 4 |
| **Trial Condition 16** | | | |
| | T/ thickness of strips (mm) | 1 mm | 4 |
| | L/length of layer | 260 | 4 |
| | S/step | Step | 3 |
| **b. Array 2** | | | |
| **Trial Condition 1** | | | |
| | T/ thickness of strips (mm) | 12 mm | 1 |
| | L/length of layer | 300 | 1 |
| | S/step | step | 1 |
| **Trial Condition 2** | | | |
| | T/ thickness of strips (mm) | 12 mm | 1 |
| | L/length of layer | 280 | 2 |
| | S/step | Step | 2 |
| **Trial Condition 3** | | | |
| | T/ thickness of strips (mm) | 12 mm | 1 |
| | L/length of layer | 260 | 3 |
| | S/step | Full | 3 |
| **Trial Condition 4** | | | |
| | T/ thickness of strips (mm) | 12 mm | 1 |
| | L/length of layer | 260 | 4 |
| | S/step | Full | 4 |
| **Trial Condition 5** | | | |
| | T/ thickness of strips (mm) | 4 mm | 2 |
| | L/length of layer | 300 | 1 |
| | S/step | Step | 3 |
| **Trial Condition 6** | | | |
| | T/ thickness of strips (mm) | 4 mm | 2 |
| | L/length of layer | 280 | 2 |
| | S/step | Step | 4 |

| | | | |
|---|---|---|---|
| **Trial Condition 7** | | | |
| | T/ thickness of strips (mm) | 4 mm | 2 |
| | L/length of layer | 260 | 3 |
| | S/step | Full length | 1 |
| **Trial Condition 8** | | | |
| | T/ thickness of strips (mm) | 4 mm | 2 |
| | L/length of layer | 260 | 4 |
| | S/step | Full | 2 |
| **Trial Condition 9** | | | |
| | T/ thickness of strips (mm) | 2 mm | 3 |
| | L/length of layer | 300 | 1 |
| | S/step | Full | 4 |
| **Trial Condition 10** | | | |
| | T/ thickness of strips (mm) | 2 mm | 3 |
| | L/length of layer | 280 | 2 |
| | S/step | Full | 3 |
| **Trial Condition 11** | | | |
| | T/ thickness of strips (mm) | 2 mm | 3 |
| | L/length of layer | 260 | 3 |
| | S/step | Step | 2 |
| **Trial Condition 12** | | | |
| | T/ thickness of strips (mm) | 2 mm | 3 |
| | L/length of layer | 260 | 4 |
| | S/step | Step | 1 |
| **Trial Condition 13** | | | |
| | T/ thickness of strips (mm) | 1 mm | 4 |
| | L/length of layer | 300 | 1 |
| | S/step | Full | 2 |
| **Trial Condition 14** | | | |
| | T/ thickness of strips (mm) | 1 mm | 4 |
| | L/length of layer | 280 | 2 |
| | S/step | Full | 1 |
| **Trial Condition 15** | | | |
| | T/ thickness of strips (mm) | 1 mm | 4 |
| | L/length of layer | 260 | 3 |
| | S/step | Step | 4 |
| **Trial Condition 16** | | | |
| | T/ thickness of strips (mm) | 1 mm | 4 |
| | L/length of layer | 260 | 4 |
| | S/step | Step | 3 |

## 5. Results and Discussions:

Q4W software used to analysis the results. Depending on the results in table ( V ) the S/N ratio can be determined. The S/N ratio for the nominal is the best quality characteristic used in this study and is calculated by equation (1): The results illustrated in table (VI)

Table ( V ) a. The Response of experiment for Array 1.

| Trail | Inner array L16 | | | Load | Stress | Response | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 280 | 140 | 4.024 | 5.027 | 4.481 | 4.894 | 4.606 |
| 2 | 1 | 2 | 1 | 300 | 140 | 3.572 | 4.578 | 3.932 | 4.072 | 4.038 |
| 3 | 1 | 3 | 2 | 320 | 140 | 3.089 | 4.135 | 3.579 | 3.899 | 3.675 |
| 4 | 1 | 4 | 2 | 350 | 140 | 2.767 | 3.773 | 3.027 | 3.567 | 3.283 |
| 5 | 2 | 1 | 1 | 130 | 140 | 6.968 | 7.974 | 7.428 | 7.888 | 7.564 |
| 6 | 2 | 2 | 1 | 140 | 140 | 6.167 | 7.173 | 6.547 | 7.037 | 6.73 |
| 7 | 2 | 3 | 2 | 152 | 140 | 5.555 | 6.501 | 5.835 | 6.215 | 6.026 |
| 8 | 2 | 4 | 2 | 166 | 140 | 4.799 | 5.745 | 4.999 | 5.669 | 5.303 |
| 9 | 3 | 1 | 2 | 63 | 140 | 14.176 | 15.282 | 14.736 | 14.946 | 14.78 |
| 10 | 3 | 2 | 2 | 68 | 140 | 12.582 | 13.585 | 13.039 | 13.382 | 13.14 |
| 11 | 3 | 3 | 1 | 74 | 140 | 10.136 | 11.032 | 10.406 | 10.806 | 10.59 |
| 12 | 3 | 4 | 1 | 80 | 140 | 8.714 | 9.61 | 8.944 | 9.484 | 9.188 |
| 13 | 4 | 1 | 2 | 23 | 140 | 51.084 | 51.93 | 51.184 | 51.754 | 51.48 |
| 14 | 4 | 2 | 2 | 24 | 140 | 43.861 | 44.417 | 43.871 | 44.421 | 44.14 |
| 15 | 4 | 3 | 1 | 25 | 140 | 28.716 | 29.272 | 28.646 | 29.516 | 29.03 |
| 16 | 4 | 4 | 1 | 26 | 140 | 23.305 | 24.421 | 23.755 | 24.115 | 23.899 |

Table ( V ) b. The Response of experiment for Array 2.

| Trail | Inner array L16 | | | Load | Stress | Response | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 280 | 140 | 4.024 | 5.027 | 4.481 | 4.894 | 4.606 |
| 2 | 1 | 2 | 1 | 300 | 140 | 3.572 | 4.578 | 3.932 | 4.072 | 4.038 |
| 3 | 1 | 3 | 2 | 320 | 140 | 3.089 | 4.135 | 3.579 | 3.899 | 3.675 |
| 4 | 1 | 4 | 2 | 350 | 140 | 2.767 | 3.773 | 3.027 | 3.567 | 3.283 |
| 5 | 2 | 1 | 1 | 85 | 140 | 10.499 | 11.505 | 10.959 | 11.419 | 11.09 |
| 6 | 2 | 2 | 1 | 92 | 140 | 9.298 | 10.304 | 9.678 | 10.168 | 9.862 |
| 7 | 2 | 3 | 2 | 100 | 140 | 7.827 | 8.773 | 8.107 | 8.487 | 8.298 |
| 8 | 2 | 4 | 2 | 109 | 140 | 6.791 | 7.737 | 6.991 | 7.661 | 7.295 |
| 9 | 3 | 1 | 2 | 42 | 140 | 18.886 | 19.992 | 19.446 | 19.656 | 19.495 |
| 10 | 3 | 2 | 2 | 45 | 140 | 16.64 | 17.643 | 17.097 | 17.44 | 17.205 |
| 11 | 3 | 3 | 1 | 50 | 140 | 17.5 | 18.396 | 17.77 | 18.17 | 17.959 |
| 12 | 3 | 4 | 1 | 54 | 140 | 14.927 | 15.823 | 15.157 | 15.697 | 15.401 |
| 13 | 4 | 1 | 2 | 22 | 140 | 51.084 | 51.93 | 51.184 | 51.754 | 51.48 |
| 14 | 4 | 2 | 2 | 24 | 140 | 43.861 | 44.417 | 43.871 | 44.421 | 44.14 |
| 15 | 4 | 3 | 1 | 25 | 140 | 28.716 | 29.272 | 28.646 | 29.516 | 29.03 |
| 16 | 4 | 4 | 1 | 26 | 140 | 23.305 | 24.421 | 23.755 | 24.115 | 23.899 |

➢ **Apply Q4W program to obtain the following objectives:**

Software for Taguchi design of experiments "Qualitek-4, automatically designs experiments based on user-indicated factors and levels. The program selects the array and assigns the factors to the appropriate column. For more complex experiments, there is a manual design option. The program also performs the three basic steps in analysis: main effect, analysis-of-variance, and optimum studies. Analysis can be performed using standard or signal-to-noise ratios of results for

smaller, bigger, nominal, or dynamic characteristics. The results can be displayed using pie charts, bar graphs, or trial-data-range graphs.

### 5.1 Design leaf spring with high load and small deflection:

**The target is :( load = 160 N)**

#### 5.1.1 Results Analysis of Leaf Spring:

The result analysis of leaf spring includes two stages as follows:

- Stage (1) calculates the S/N ratio for each experimental design point. Depending on the results in table (V) the S/N ratio can be determined. The S/N ratio for the nominal is the best quality characteristic used in this study which calculated by equation 1.

For all rows in table (V) a the S/N ratio can compute by using equation 1.

S/N = - 10 Log (MSD) = -41.656

The same calculation procedure is repeated for unit 1 to unit 16 above. The results illustrated in table VI

Table VI S/N ratio for experimental trials-case160 N

| Trial no. | S/N |
|---|---|
| 1 | -41.656 |
| 2 | -42.985 |
| 3 | -44.137 |
| 4 | -45.621 |
| 5 | -29.252 |
| 6 | -25.584 |
| 7 | -16.961 |
| 8 | -16.961 |
| 9 | -39.646 |
| 10 | -39.182 |
| 11 | -38.589 |
| 12 | -37.954 |
| 13 | -42.671 |

| | |
|---|---|
| 14 | -42.607 |
| 15 | -42.543 |
| 16 | -42.478 |

After obtaining the S/N values the average performance of each factor at each level was calculated. The results are tabulated below against the symbols T to S representing Factor 1 to 3 respectively. Table Ⅶ represents the average at each level. The average S/N value of each factor is plotted; Graphical representations can make data easy to interpret by just looking at graphs. The main-effects of chart are a plot of average responses at different levels of a factor versus the factor levels. The main-effect plots are shown in Fig.3. In the plots, the x-axis indicates the value of each process parameter at two levels and y-axis indicates the response value. Horizontal line indicates the mean value of the response.

Table Ⅶ Average S/N table for factors-case 160 N

| Level | Thickness | Length | Step |
|---|---|---|---|
| 1 | -43.6 | -38.306 | -37.077 |
| 2 | -22.189 | -37.589 | -38.183 |
| 3 | -38.843 | -35.558 | |
| 4 | -42.575 | -35.838 | |

Then analysis of variance is calculated for factors.

Using Q4W software ANOVA is computed for S/N for all factors. Table Ⅷ explains it.

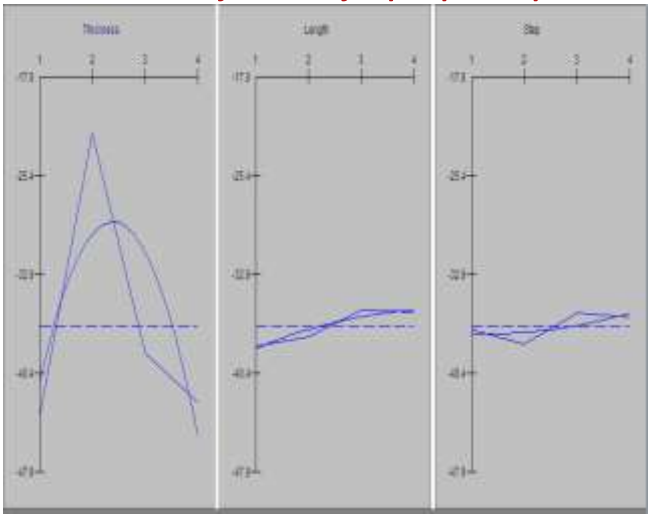

Fig .3. Main effects plot for S/N ratios-case 160 N

Table Ⅷ ANOVA for S/N

| Source | DF | Seq SS | Adj MS | F | P |
|---|---|---|---|---|---|
| Thickness | 3 | 1188.9 | 396. | 26.2 | 86.959 |
| Length | 3 | 22.126 | 7.375 | 0.488 | 0 |
| Step | 1 | 13.571 | 4.523 | 0.299 | 0 |
| Residual Error | 6 | 90.536 | 15.089 | | 13.041 |
| Total | 15 | 1315.148 | | | 100% |

In Taguchi experimental analysis, percentage contributions are often used to evaluate the relative importance of each effect. The latest column in table Ⅷ represents the percentage contribution of factors calculated by using the equation below. The percentage contribution of X $= SS_x/SS_T$

The percentage contribution of control factor is represented in Fig.4.

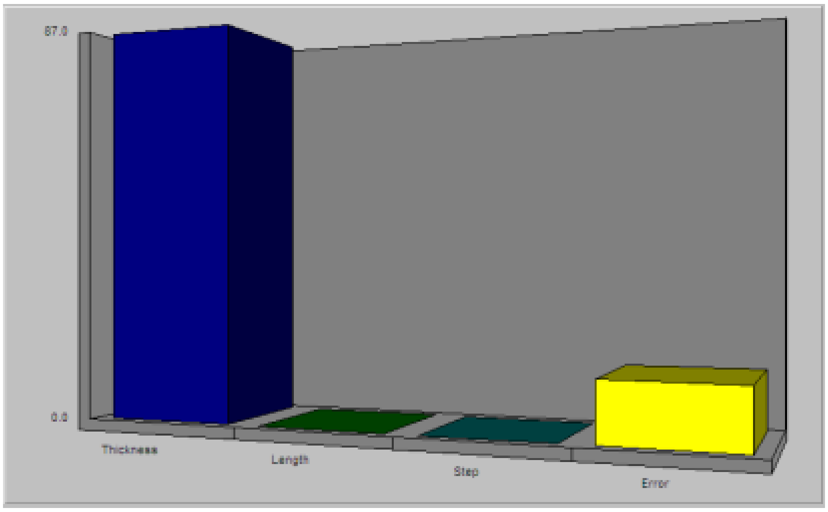


Fig.4. Percentage contribution of S/N.- case 160 N

The results data of ANOVA in table Ⅷ are represented as shown in Fig.3 the most significant factor is T (thickness).

The optimum conditions for this target:

- Thickness (T): 6 mm
- Length (L): 260 mm
- Step (S): step

## 5.2 Design leaf spring with small load and high deflection:

**The target is :( load = 40 N)**

The optimum conditions for this target:

- Thickness (T): 2 mm
- Length (L): 260 mm
- Step (S): step

## 5.3 Design leaf spring with medium load and medium deflection:

**The target is :( load = 100 N)**

The optimum conditions for this target:

a. **Three layers :**

- Thickness (T): 4 mm

- Length (L): 240 mm
- Step (S): step

b. **Four layers** :

- Thickness (T): 3 mm
- Length (L): 280 mm
- Step (S): step

## 6. Conclusions:

1- The results of force, stress and bend obtained from the mathematical model equations show that there is a limitation of these equations to cover all the cases of study in this research compared with results obtained by F.E.M.

2- There is a good compatibility between experimental results and results obtained by (F.E.M) for the graduated leaf spring.

3- All results show an increase in deflection amount with plate number increase in total group equal to major beam thickness and decrease in the amount of load which can be applied at constant bending stress.

| No. | Thickness (mm) | No. of layers | Stress (Mpa) | Load (N) | Deflection (mm) |
|---|---|---|---|---|---|
| 1 | 12 | 1 | 140 | 280 | 4.60 |
| 2 | 6 | 2 | 140 | 130 | 7.56 |
| 3 | 3 | 4 | 140 | 63 | 14.78 |
| 4 | 1 | 12 | 140 | 23 | 51.48 |

4- The results show possibility of increasing deflection with decreasing applied load which is convenient for the vehicle and transporting automobiles when they use herringbone ways.

| No. | Thickness(mm) | Length(mm) | Step | Deflection(mm) | Load(N) |
|---|---|---|---|---|---|
| 1 | 3 | 260 | step | 9.18 | 80 |
| 2 | 4 | 260 | Step | 7.29 | 109 |

5- There is a possibility of lowering deflection amount accompanied by increase in the carrying load for a heavy vehicle which works on high ways.

| No. | Thickness(mm) | Length(mm) | Step | Deflection(mm) | Load(N) |
|---|---|---|---|---|---|
| 1 | 6 | 260 | step | 6.02 | 152 |

**6-** The thickness of leave is the dominant parameter in design of leaf spring followed by the length and step.

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