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Helical Coil Springs Life Quality Assessment

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Abstract

This paper presents the analysis of life quality assessment of helical coil springs. The types of springs considered are: outer spring, inner spring and stabilizers spring. Statistical process control chart was used as the main tool on the analysis. In order to fully understand problem statement, various parameters were considered, namely: Free height, load at test height, additional deflection, free height, after static test, coil/bar diameter, outer and inner diameter. Measurements were performed using tape measure, dynamic actuators and the Vernier Caliper.

For all the spring types considered, thirty samples were recorded. The lower and upper limits, were obtained from the design specification. The usefulness of process capability, the process capability of six-sigma was used. The normal distribution curve for each parameter considered was constructed using the standard deviation calculated for each parameter. Six sigma tools were also used in this part of the paper. Hence, the standard deviation was used to calculate the Z-value of each parameter or process. According to six-sigma calculation analysis and justification, only the stabilizers and inner springs for coil bar diameter meet the six-sigma requirement. It was concluded that spring must be replaced because they do not meet the six sigma requirements.

Keywords
Quality assessment, six-sigma, process capability, helical coil springs

1. Introduction
Locomotive is a railway vehicle that provides the motive power for a train via the suspension system (bogie), rail road wheels and the rail-line. In railway environment, helical coil springs and stabilizer springs are used in Spoornet locomotives for comfort ride (Reduce forces) for both the locomotives and the wagons and as well used to prolong the lifespan service of other components. In other words, helical coil springs are used in the suspension of rail vehicles to provide active load supporting functions and suitable spring rate to the drivers, conductors, passengers and freight. The helical coil springs that are currently in used have at least 15 years of years.

At the moment many problems are encountered due to spring's arrangement on the suspension. Hence, the three types of springs (in bogie assembly) will be analyzed, namely; inner springs, outer springs and stabilizers springs.
The following varying quality characteristic of interest will be considered:

- Free height
- Load at test height
- Additional deflection
- Free height after static test
- Coil/Bar diameter
- Outer and inner diameter

The data collected will definitely give a clear indication on the quality characteristic of the springs. It must be noted that the minimum and maximum dimensions are given in the spring specification per the Spring Manufacture (design specification). The relativity of the variability is apparently considered has the utmost configured in the actual spring-life service. The actual spring-life service is shortened by the operating conditions. Thus, the SPC run chart will be the most important tool in analyzing and justifying the random selected after-service springs data. Conclusion can then be drawn based on the analysis done on the inner springs, outer springs and stabilizers.

2. Research Objectives

2.1 To assess the lifespan of helical springs

There are factors adversely affecting the service life of the helical and stabilizer springs namely;

- Corrosion influences

During the manufacturing process the springs design and evaluation are considered alongside with the protection coatings against corrosion and friction hardening. Damage to the surface of the spring occurs as a result of friction against surrounding components (Axle), e.g. when the spring bulges, and this will also lead to a considerable reduction in the service of the springs.

- Friction and chafing marks

The hardness values of the spring cater for the friction action upon the Axle. The severe friction action leaves chafing marks to the springs and the spring plank. Hence causes the variability in the springs' characteristics which results to shortening of the spring's lifespan (Service life).

2.2 To establish the root cause of spring fracture in service.

The factors that contribute to the spring fracture in service are as follows: improper positioning of the springs during maintenance action, the stiffness of the spring itself against the exerted force, manufacturers' faulty (for the case of impurities inbuilt to coils) and the service action upon uneven rail-lines(lose position) and overloading.

2.3 To quantify the springs' quality variability after service

The specifications of the helical coil springs are given by the designer/ Manufacturer of the helical coil springs and the stabilizer springs. Hence, the reference of the amount variation is established by comparing the measurement system of the springs' quality variability after service with the precision scale from the designer/ Manufacturer.

2.4 To define the parameters used to clarify the range and standard deviation

The overall standard deviations calculated stipulate the measures for the variability of the whole data set. The data set collection upon the measured values of the different variable of the springing components gives the actual measures after-service of the parameters. The helical coil springs and the stabilizer springs are measured in terms of: coil free height, load at test height, additional deflection, free height after static test, coil/bar diameter, ground edge thickness, outer and inner diameter parameters.

3. Literature Review

For spring design, four main dimensions are required, namely: Coil diameter, bar diameter, free height and solid height. All four dimensions are explained below:

- Coil diameter is the height or length of spring not loaded
- Bar diameter is the measure of the width of the rod
- Solid height is the height when all coils are in contact, all effective axial movement having been exhausted
- Static load is the actual dead load weight supported by spring, no motion being involved

The Springs Manufacturer ascertain the shear strength of the springs to which the material's ability to resist forces that attempt to cause it to become permanently deformed by sliding against itself are defined. The excessive shear strain can cause a spring to break or loss the precision. The yield strength defines the maximum force that a material (metal coil) used can withstand before it begins to permanently deform. Hence, the working range is definitely clarified by the range of operating conditions within which springs can function without becoming permanently deformed or loss the precision. The active coils move or deflect under a load. The material type is paramount, its properties determines its tensile strength, thus, succumb the subject force.

As shown in the above figure (figure 3), the bogie has four main parts, namely: Center plate, Bolster, coil spring and side frame. The mass of the wagon body and its lading are carried on the center plate. The bolster transfers this load to the side frames, supported by the springs in the bolster pocket. As the mass is dropped onto the bogie it first compresses the friction wedge springs and then the main springs.

The purpose of the main springs is to isolate the main mass of the wagon from the unsprung mass of the wheelsets, so that track errors do not elicit a response from the full mass of the wagons'. It is critical that the wagons' body is not permitted to bounce or otherwise vibrate continuously on these springs. To prevent this, compression of the friction wedge springs forces a friction wear plates affixed to the side columns. This effectively takes energy out of the main springs and stabilizes wagon body oscillations**.**

3.1 Stratification

Table 1: Stratification for the eminent causes of the problem to the helical coil and stabilizer springs

Manpower(Operators)	Routine check, incorrect installation and operation
Material	Tensile strength, deflection(elasticity) and spring size
Environment	Humidity, improper coating
Operating conditions	Heavy load, tilt and uneven rail-line

Scenarios to be taken into consideration in the feasibility study:

3.2 Common causes of variation

Natural variation is an inherent (variation is random) and it's characteristic of the process, and furthermore is expected even in a process that is in control. These are variations contributed during the process of the helical coil springs and stabilizer springs due to the property of the material, the working condition of the machines, processing environmental effect and moreover the actions by the operators.

Common cause variation is not natural, but is due to a specific cause such as the faulty raw material, readings and sampling. These variations are taken in as the defects not identified during inspection or quality control exercise. Cause-and Effect diagram aids to identify which input variables (possible causes) are having effect on the output variable (Deflection of the Helical and Stabilizer Spring). Some of the conditions affecting working range are illustrated by (Figure 5) the cause-and-effect diagram below:

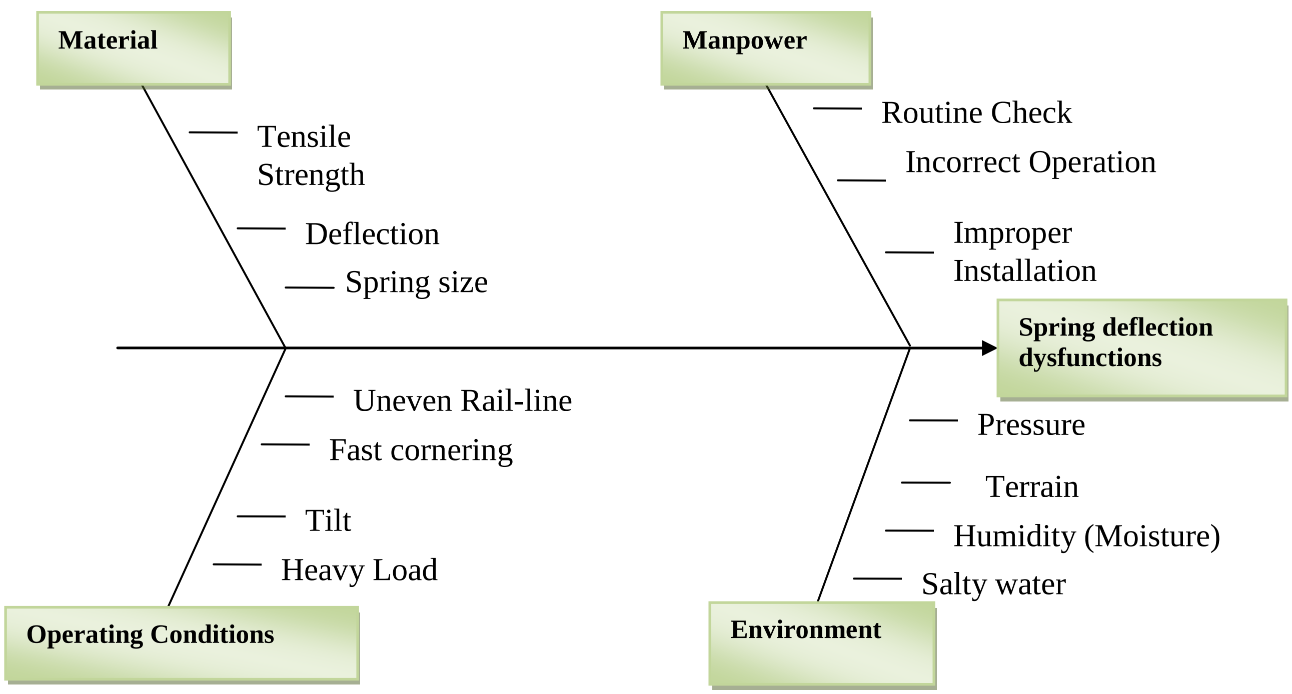

Figure 5: The cause-and-effect diagram for the helical and stabilizer spring deflection dysfunction

Predisposing factors from the Cause-and-Effect diagram that harbours' spring deflection:

- Routine Check gives the operators the clues of the springs' state. If the maintenance officers are not keen the worn out and imposition of the spring shorten the lifespan of the opposite or immediate ones.
- Incorrect operation leads to failure of the springs before the stipulated time of warranty.
- Improper installation of the springs will lead to breakage or improper functioning that harbours' its deflection effect.
- Pressure due to overloading or impacts exertion shortens the lifespan of the springs. The load rate of the springs is prescribed by the speed at which load is presented to a component.
- Terrain should be suitable geographical hence sharp corners will affect the spring's suspension system.
- Humidity environment in the manufacturing plant affects the spring's deflection inputs due to impurities.
- Salty water degrades the metallic property of the spring as rusty condition inhibits decay of the springs.
- Heavy load on wagons affect the springs suspension characteristic by loads force due to maximization of the customer to reduce the cost of transport.
- Tilt affects the sides of the loads flow force due to uneven rail-line.
- Fast cornering operations harm the springs' function results from the train drivers' no adhering to the rules and regulations for short time scheduling to complete day-to-day trip.
- Tensile strength of the material used inherent the deflection deficiency of the springs due to manufacturing property.
- Deflection characteristic of the springs itself not accommodating the purpose of absorbing shock or unevenness of the rail-line.
- Spring size in form of the height and diameter variation (the inner, outer and coil bar diameters) brings forth the effect of inconsistency of suspension function.

4. Data Collection

This section presents the raw data collected at Spoornet Dynamic Testing Facility in order to meet project objectives. All parameters were measured as accurately as possible and the maximum and minimum values were obtained from the design specification.

4.1 Specify the maximum and minimum value for each parameter

The Specific the minimum and maximum value for each parameter are derived from the measured value in comparison with the allowed tolerances of the precision of the springs. The tabulated measured values at this standpoint are raw-given per the measurements taken in the field. This is just the paperwork.

The determinants of sample size criteria:

- The level of precision (*sampling error)*,
- The level of confidence or risk, and
- The degree of variability in the attributes being measured (Miaoulis and Michener, 1976).

4.2 The Level of Precision

The level of precision is the range in which the true value of the helical coil springs and stabilizer springs collection is estimated to be. This range is often expressed in percentage points, (e.g., a precision rate of ±5 percent). Thus, the measurement of the helical coil spring and stabilizer springs can be the tolerance of ±0.5 mm upon the deflection rate.

4.3 The Confidence Level

The confidence or risk level is based on ideas encompassed under the Central Limit Theorem. The key idea encompassed in the Central Limit Theorem is that when a helical coil springs and stabilizer springs collection is repeatedly sampled, the average value of the attribute obtained by those samples is equal to the true helical coil springs and stabilizer springs collections value. Furthermore, the values obtained by these samples are distributed normally about the true value, with some samples having a higher value and some obtaining a lower score than the true helical coil springs and stabilizer springs collection value. In a normal distribution, approximately 95% of the sample values are within two standard deviations of the true population value (e.g., mean) which is figured out by the stabilizers and inner springs for coil bar diameter.

In other words, this means that, if a 95% confidence level is selected, 29 out of 30 samples will have the true helical coil springs and stabilizer springs collection value within the range of precision specified. Samples with extreme values, that does not represent the true population value, are represented by the shaded areas or outside the specification limits. This risk is reduced for 99% confidence levels and increased for 90% (or lower) confidence levels.

4.4 Degree of Variability

The degree of variability in the variables being measured refers to the distribution of variables in the helical springs and stabilizer springs collections. The more heterogeneous a helical coil springs and stabilizer springs collection, the larger the sample size required to obtain a given level of precision. The less variable (more homogeneous) a helical springs collections the smaller the sample size. Note that a proportion of 50% indicates a greater level of variability than either 20% or 80%. This is because 20% and 80% indicate that a large majority do not or do, respectively, have the attribute of interest. Because a proportion of 0.5 indicates the maximum variability in a sample, it is often used in determining a more conservative sample size, that is, the sample size may be larger than if the true variability of the helical springs collections variables were used.

The specific factors that affect both the accuracy and precision of the measure system are experimenter and gauges applied.

Components of the measurement errors:

- Random component causes a spread in the results of measurement.
- Systematic component causes a bias in the results of measurement.

5. Data Analysis

In this section all the tools and methodology used are explained in detail. The validity of using below mentioned tools is also explained. The short or brief history of each methodology is also given in the beginning of each sub-heading.

5.1 Statistical Process Control (SPC) Run Chart

Statistical Process Control was pioneered by Walter A. Shewhart and taken up by W. Edwards Deming with significant effect by the Americans during World War II and to Japanese industry after the war to improve industrial production through visually monitoring manufacturing processes.Dr Shewhart created the basis for the control chart and the concept of a state of statistical control by carefully designed experiments to display controlled variation that is natural to the process, whereas others display uncontrolled variation that is not present in the process causal system at all times. The Statistical Process Control allows the user to continuously monitor, analyze, and control the process of variation and how it affects the output of any process.

Variation is the amount of deviation from a design nominal (Target) value. Not every product that is produced will exactly match its design nominal (Target) values. That's why tolerances allowances on the nominal (Target) values are accorded for the product to be acceptable or not. The closer the variation to the nominal value the better the product output is. Control charts are one SPC tool that enables us to monitor and control process variation.

The above-stated description of the SPC chart analogy clarify our motive of having it the best analytical tool to analyze variations in this project by aiming at achieving good quality characteristic during spring life-service. To prove further, the quality of the helical coil springs and stabilizer springs, the Cause-and Effect diagram, the normal distribution curve and the Histogram has been incorporate. The SPC uses the process data collected (Precision and tolerances) in real time and compares current measures to baseline measurements-goodies after-service. The quality derived from the SPC for the after-services springs quantifies the prevention of the springs from being totally worn or permanently deformed hence causes deflection dysfunction characteristic-discomfort to passengers and impact to body (locomotive and wagon). The variability prevention is the SPC charts’ principle on quality characteristic by minimizing as much as possible for the clarity and justification of the Quality assurance of the springs.

5.1.1 Variable control chart (the $\overline{\mathbf{X}}$chart)

Variable control chart measures and quantify the characteristic variable data measurements within the specification limits (Tolerance). The quantity that we plot in the variable control chart is the sample average, $\overline{\mathbf{X}}$ showing the value of the quality characteristic versus the sample number. If the quality characteristic are within the appropriate tolerance/ specification limits hence determined to be used. The mean of each quality characteristic is as close as possible to the target value of the characteristic. Specification limits are used to determine if the process is in a state of statistical control (i.e., is producing consistent output) whereas, Specification limits are used to determine if the product will function in the intended fashion.

5.2 Normal distribution curve

This is the graphical representation of the density function (frequencies) of the normal probability distribution of the helical coil springs and the stabilizer springs. The normal distribution curve provides us with a measure of the "peaked-ness" of a distribution (i.e. Kurtosis). The normal distribution curve determines the quality level of the springs draw from the spread of the data collected. The variation in a data set is depicted. The actual measurement are spread upon a given specification limits (the sample range) and the awarded measurements are the measured values as per the vernier caliper, the dynamic actuators and the tape measure used.

Drawing normal distribution curve, there are two specific parameters used, i.e., the mean (μ) and the standard deviation (σ) of the whole data collected on each parameter. Frequency of the sample is illustrated via the bandwidth which is a measure of frequency range.The standard deviation is a statistic that tells how tightly all the various samples are clustered around the mean in a set of data. When the samples results are spread apart and the bell curve is relatively flat, that tells how a relatively large standard deviation is.

The mathematical expression for the standard deviation:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(X_i - \mu\right)^2}$$

, where "N" is the sample size of the helical and the stabilizer springs.

Hence:

Upper Specification Limit $= \mu_w + k\sigma_w$

Center Line (Target value) $= \mu_w$

Lower Specification Limit $= \mu_w - k\sigma_w$

where *k* is the distance of the specification limits from the center line, expressed in terms of standard deviation units.

$$\mathbf{z} = \frac{X - \mu}{\sigma}$$

, where **z** is the number of standard deviation (σ) X is above the mean (μ).

$$\sigma = \frac{\sqrt{\Sigma\left(x - \bar{x}\right)^2}}{n-1}$$

The mean (average) lies at the center of the normal probability distribution of the sample, i.e., the theoretical long-run arithmetic mean of the outcomes of repeated trials, such as the samples of the helical coil springs and the stabilizer springs for this case.

5.3 Control chart for Inner springs

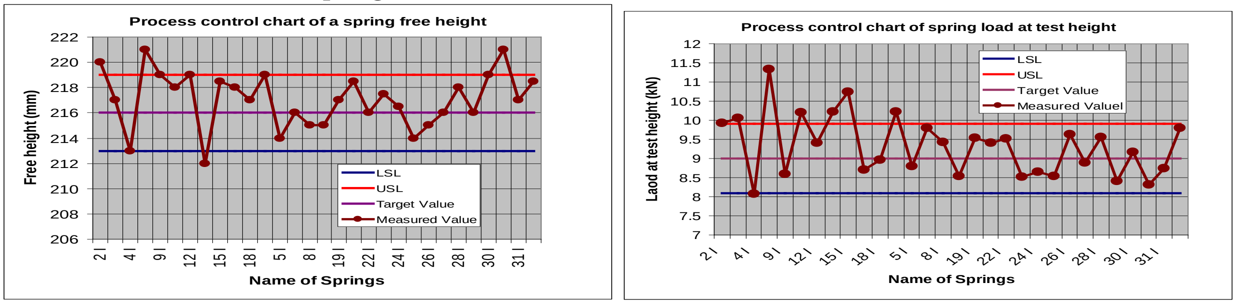

Figure 7: PC chart of inner helical spring load at test height and inner helical spring free height

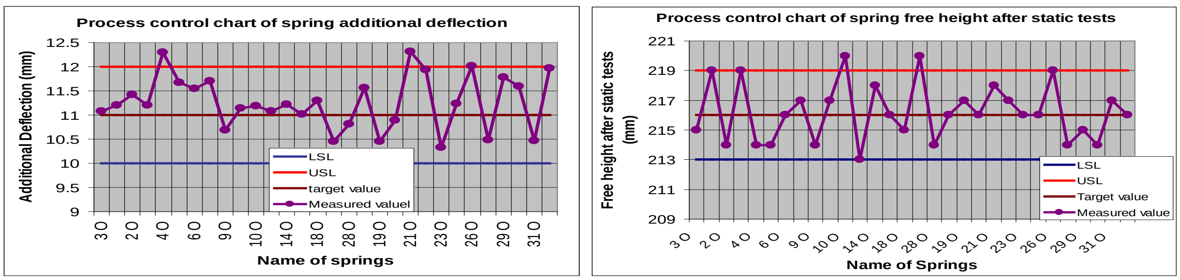

Figure 9: PC chart of outer helical spring free height after static test and outer helical spring additional deflection

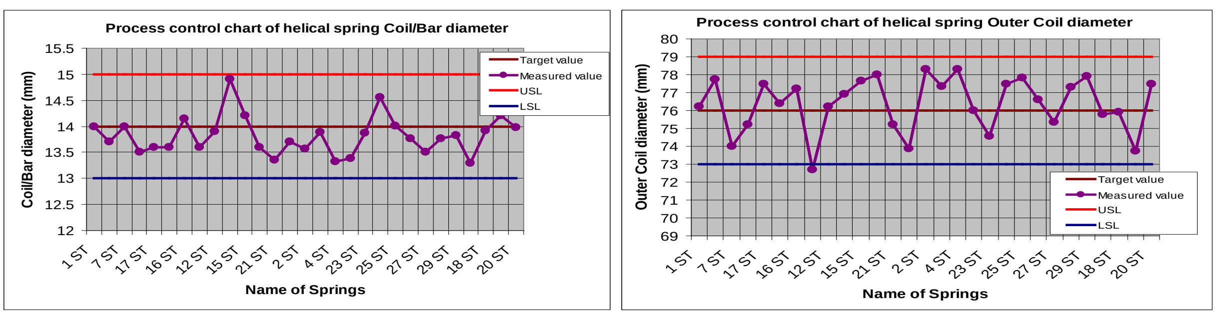

Figure 1: PC chart of stabilizers helical spring outer coil diameter Figure and stabilizers spring coil/bar diameter

5.4 Six sigma calculations

In this section, the outlined results of the six sigma calculations of all types of spring with all parameters are considered. The process capability and defects per million of all the parameters are also evaluated. All the results evaluated are compared with the six sigma benchmarking values of 2700 DPM.

5.4.1 Six sigma Evaluations

Six-sigma simply means a measure of quality that strives for near perfection via data-driven approach and defect elimination methodology in any process from manufacturing to transactional and from product to service. Thus, the Six-sigma evaluations for the types of spring with their parameters/ characteristics are drawn. The defects per million (DPM) of all the parameters are also outlined. All the results are compared with the Six Sigma benchmarking values of 2700 DPM. The Six-sigma approach brings about the actual variation of the springs from the target value of the dispersion. The Six-sigma is the corrective action method after the SPC run chart provision of detecting, monitoring and understanding the spring's deflection system.

Table 2: Standard deviation of all parameter and spring types

Std dev of all Parameters	Types of springs		
	Inner Std dev	Outer Std dev	Stabilizer Std dev
Free height	2.17696	2.38886	2.46975
Load at test height	0.76729	1.33534	0.257888
Additional deflection	0.61697	0.54391	0.666232
Free height after static height	1.73686	1.92181	2.580573
Coil/bar diameter	0.457236	0.32972	0.356415
Outer Coil diameter	1.56464	1.43579	1.494963
Inner coil diameter	0.896767	1.57929	0.99749

Table 3: Inner spring six sigma results

Inner Spring						
	Z	Sigma	Six Sigma	Probabilities	Defects per million	6-sigma DPM
Free Height	1.378067	2.756134	6	0.9162	83800	2700
Load at test height	1.172959	2.345918	6	0.879	121000	2700
Additional deflection	1.620821	3.241642	6	0.9463	53700	2700
Free Height after static test	1.72726	3.45452	6	0.9573	42700	2700
Coil/bar diameter	2.187053	4.374106	6	0.9857	14300	2700
Outer coil diameter	1.91737	3.83474	6	0.9719	28100	2700
Inner coil diameter	2.230233	4.460466	6	0.9868	13200	2700

Table 4: Outer spring six sigma results

Outer Spring						
	Z	Sigma	Six Sigma	Probabilities	Defects per million	6-sigma DPM
Free Height	1.255828	2.511656	6	0.8944	105600	2700
Load at test height	1.162253	2.324506	6	0.8749	125100	2700
Additional deflection	1.838553	3.677106	6	0.9664	33600	2700
Free Height after static test	1.56103	3.12206	6	0.9394	60600	2700
Coil/bar diameter	3.03284	6.06568	6	0.9987	1300	2700
Outer coil diameter	2.08944	4.17888	6	0.9817	18300	2700
Inner coil diameter	1.266391	2.532782	6	0.898	102000	2700

Table 5: Stabilizer spring six sigma results

Stabilizer springs						
	Z	Sigma	Six Sigma	Probabilities	Defects per million	6-sigma DPM
Free Height	1.518375	3.03675	6	0.9345	65500	2700
Load at test height	1.318403	2.636806	6	0.9049	95100	2700
Additional deflection	1.500978	3.001956	6	0.8664	133600	2700
Free Height after static test	1.453166	2.906332	6	0.9251	74900	2700
Coil/bar diameter	2.805718	5.611436	6	0.9974	2600	2700
Outer coil diameter	2.006739	4.013478	6	0.9772	22800	2700
Inner coil diameter	2.005033	4.010066	6	0.9772	22800	2700

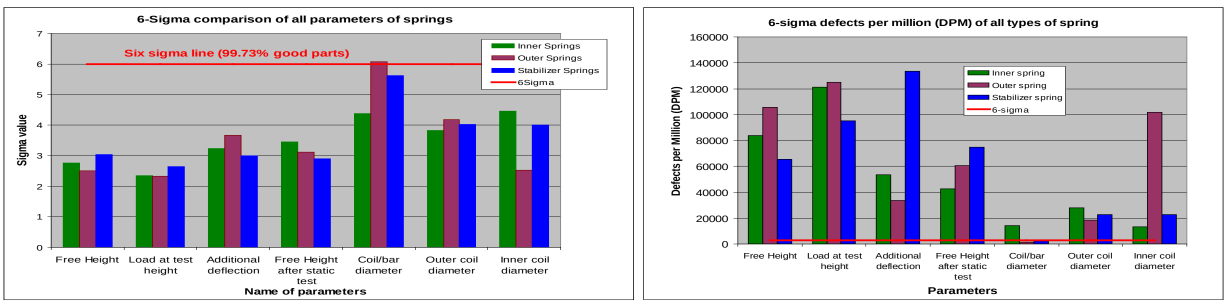

Figure 19: Six sigma comparison of all parameters of springs and defects per million of all types of springs

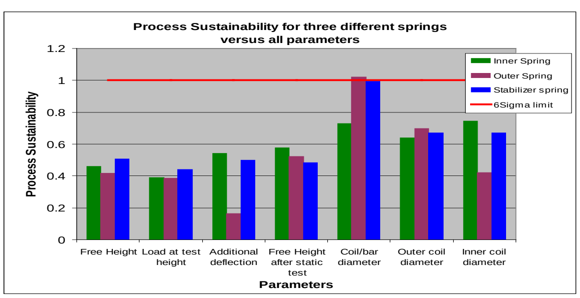

Figure 2: Process sustainability (Cp) for three different springs versus all parameters

6. Discussion of Results

All results for all parameters considered on the project are discussed on this section. It must be noted that six-sigma is the most important tools used in the project and therefore it is given special attention. The statistical process control gives the fundamental understanding of all the parameter behaviour.

6.1 Statistical process control chart

The statistical process control charts are shown from figure 2 to figure 4. It can be clearly seen from figure 8 that most of springs for load at test height on inner spring are out of control. In other words they are above or below the lower or upper specification limit line. However for the same spring for additional deflection, the process is very controllable or is within the specification limit as shown in figure 9. In general, most parameters for all the spring types are out of specification limit. A very strong indication of the behaviour of all parameter was obtained from statistical process control chart.

6.2 Normal distribution probability curve

The normal distribution curve as shown by figure 13 was obtained by normalizing the data collected. From the normal distribution curve, the standard deviation and the mean were obtained by using Microsoft excel built in function. All standard deviations calculated are shown in table 8.

6.3 Six-sigma requirements

After calculating the standard deviation for each parameter, the Z-values were also calculated by using relevant formula. The Z-value leads to the sigma vale. It is also important to note that the Z-value also provide the probabilities of the process. From table 9, it is shown that the inner coil diameter has 98.68% which is higher as compared to other parameter for the same spring, inner spring. 98.68% can be simply converted to 13200 Defects per million. Again 13200 defects per million is still very low as compared to the six sigma value of 2700 defects per million.

It is a surprise to note that for outer spring the parameter with the lowest sigma vale is coil/bar diameter. The coil/bar diameter has the probability of 99.87%, which can be converted to 1300 defects per million. This is a very good value as it is even smaller than of six sigma requirements. This is shown in table 10. For stabilizer spring the coil/bar diameter has the lowest sigma value of 5.611 which can be converted to the probability of 99.74%. The probability shows that 2600 defects per million are in the process. The sigma value or probability is still very good for six sigma value.

6.4 Histogram

Figure 19, figure 20 and figure 21 compare the different parameter for all parameters considered. As explained above it can be seen from figure 19 that coil/bar diameter for outer and stabilizer springs meet the six sigma line. As shown on the above mentioned figure all other parameters for all springs considered do not meet the six sigma requirement. Again figure 20 shows the defects per million as a function of spring parameters. It can be concluded from the figure that all spring parameter for all spring do not meet the six sigma requirement except for coil/bar diameter. The conclusion can also be reached by using the process capability chart of spring parameters. It can be seen from figure 21 that all spring parameters have the process capability of less than one (six sigma requirement) except for coil/bar diameter.

7. Conclusion

The analytical tool used in the project depicts the wholesome of the feasibility analysis of the helical coil springs and stabilizer springs variability. The lifespan of the springs depend upon the metal property, improper coating and its applications. The operating conditions are prime factors of the corrosion and friction. Company is losing more money on spring's replacement due to the Fishbone-illustrated factors analysis of causes. The analysis tools used facilitates forecasting and management of the expected life service of the springs apart from the manufacturers warranty. Based on six sigma analysis, the company must buy new springs rather than re-using the old spring.

Acknowledgements

I would like to acknowledge Daniel Misoi for his valued ideas.

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