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USING STATISTICAL PROCESS CONTROL AND SIX SIGMA TO CRITICALLY ANALYSE SAFETY OF HELICAL SPRINGS: A RAILWAY CASE STUDY

Abstract: *The paper exhibits the examination of life quality evaluation of helical coil springs in the railway industry as it impacts the safety of the transportation of goods and people. The types of spring considered are: the external spring, internal spring and stabiliser spring. Statistical process control was utilised as the fundamental instrument in the investigation. Measurements were performed using a measuring tape, dynamic actuators and the vernier caliper. The purpose of this research was to examine the usability of old helical springs found in a railway environment. The goal of the experiment was to obtain factual statistical information to determine the life quality of the helical springs used in the railroad transportation environment. Six sigma advocacies were additionally used as a part of this paper. According to six sigma estimation examination only the stabilizers and inner springs for coil bar diameter met the six sigma prerequisites. It is reasoned that the coil springs should be replaced as they do not meet the six sigma requirements.*

Keywords: *statistical process control, helical springs, railway industry engineering, six sigma*

1. Introduction

Suspensions are the imperative machine component of rail vehicles which absorb the shocks and vibration during driving, bending and further secure the axle drive. The helical compression sort of spring is utilized to permit axle bending and further afford some parallel bending at curvature (Kumbhalkar, Bhope, & Vanalkar, 2015; Schiehlen & Iroz, 2015; Zhu, Wang, & Huang, 2014). Railroad vehicles are among the most broadly utilized strategies for transporting travelers and products (Shabana, Zaazaa, & Sugiyama, 2007). The rationale energy to a train is administered by means of the suspension structure (bogie). In the railroad environment, helical coil springs and stabiliser springs are utilised to facilitate a comfortable ride in respect of both the trains and the wagons and to delay the lifespan administration of different segments (Ahmadian & Yang, 1998; Lóránt & Stépán, 1996; Xu, Liang, Li, & Yang, 2015). Helical coil springs are used as part of the suspension of rail vehicles to provide dynamic active supporting capacities

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and suitable spring rate to the drivers, conductors, travelers and cargo (Ayadi & Hadj-Taieb, 2008; Matsumoto et al., 2005; Nishimura, Terumichi, Morimura, & Sogabe, 2009). The helical coil springs that were in operation for no less than 15 years were used. The arrangement of the springs on the suspension creates numerous problems and were therefore investigated (Matsumoto et al., 2005; Sun et al., 2009). Thus, the three types of spring (in bogie assembly) that were investigated, namely inner springs, outer springs and stabiliser springs (Kumbhalkar et al., 2015).

To address the quality characteristics of helical spring several parameters were considered including free height, load at test height, additional deflection, free height after static test, coil/bar diameter and outer and inner diameter. The data collected would enable an informed decision on the quality characteristic of the springs. The minimum and maximum dimensions are given in the spring specification per the spring manufacturer (design specification). The relativity of the variability is seemingly considered as configured in the actual spring-life service. The actual spring-life service is shortened by the operating conditions due to poor environmental conditions (Gaikwad & Kachare, 2013; Refngah, Abdullah, Jalar, & Chua, 2009). Thus, the statistical process control (SPC) run chart would be the most appropriate tool in analysing and justifying the randomly selected after-service springs data. Conclusions can then be drawn based on the analysis done on the inner springs, outer springs and stabilisers (Chandra, 2001; Mulla, Kadam, & Kengar, 2012).

The primarily objective of the research was to assess the life quality of helical springs. It is understood that corrosion influences, friction and chafing marks are the factors that adversely affect the service life of the helical and stabiliser springs. During the manufacturing process the design and evaluation was considered, inclusive of the protection coatings against corrosion. Damage to the surface of the spring occurs as a result of friction against surrounding components (axle), that is when the spring bulges, and this will also lead to a considerable reduction in the service of the springs. The hardness values of the spring cater for the friction action upon the axle. The plain friction action leaves chafing marks on the springs and the spring plank. Hence this causes the variability in the spring’s characteristics, which results in shortening of the spring’s lifespan (service life). The secondary objective of this research was 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, manufacturer fault (in the case of impurities built into coils) and the service action upon uneven rail lines (loose position) and overloading (Berger & Kaiser, 2006; Sawanobori, Akiyama, Tsukahara, & Nakamura, 1985; Zhu et al., 2014).The third objective was to quantify the springs’ quality variability after 15 years of service. The specifications of the helical coil springs are given by the designer/manufacturer of the helical coil springs and the stabiliser springs. Hence, the variation is established by comparing the measurement system of the springs’ quality variability after service with the precision scale from the designer/manufacturer. The fourth objective was 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 variables of the spring components gives the actual measured after-service of the parameters. The helical coil springs and the stabiliser 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, and outer and inner diameter parameters.

2. Literature review

A helical coil spring is of paramount importance in the rail industry, as it is used to accumulate energy and release it to absorb shock in order to maintain equilibrium between contacting forces (Kumbhalkar et al., 2015). Therefore the design of the helical spring is of utmost importance (Venkateswaran, 2005). The following must be considered in the design process:

- Space constraints in operation
- Tolerance specification of working forces and refractions
- Accuracy and reliability parameters
- Environmental conditions
- Raw material specifications
- Material strength
- Diameter
- Length

Due to the complexity in its operation and the assigned task, the spring is required to function optimally in stressful conditions. Thus, the behaviour of the helical spring is characterized by two important parameters, namely critical length and critical deflection (Venkateswaran, 2005). The very nature of operation requires the helical spring to function without failure, therefore it needs to be designed for infinite life. As it is assembled with preload dimensions, it bears additional load in its operation. It is important to maintain an even distribution of load on a wagon. Diagonally opposite springs produce unequal distribution of load on the axles, and need to be within reasonable limits to prevent derailment (Kumbhalkar et al., 2015).

The spring's survival through repeated stress levels is critical in its operation. In addition amplitude and fatigue stress further burden the operational function (Wu & Tang, 1998). In view of helical spring functionality and the consequence of failure, scheduled inspection and maintenance are extremely important. Inefficiencies in this regard may result in loss of lives (Gevorgyan & Schorcht, 2001). Conformance to specifications in the manufacturing process is critical while maintaining conformity in operation is vital. The surface quality of helical springs is crucial in its operative robustness. The fatigue strength of spring steels is influenced by a multiplicity of factors. Flaws in the surface and heat treatments, transverse and longitudinal cracks, scales and rust reduce the strength (Gevorgyan & Schorcht, 2001).

For spring design, four main dimensions are required, namely coil diameter, bar diameter, free height and solid height (Kumbhalkar et al., 2015). All four dimensions are explained below:

- Coil diameter is the height or length of spring not loaded.
- Bar diameter is the measurement of the diameter of the rod.
- Free height is the actual dead load weight supported by spring: the spring does not experience any force or loading.
- Solid height is the height when all coils are in contact, all effective axial movement having been exhausted

The spring manufacturer documented the shear quality of the springs to which the material's specifications need to conform. The inordinate shear strain can cause a spring to buckle, thereby resulting in loss. The yield quality characterises the greatest power that a material (metal loop) can withstand before it starts to disfigure. Subsequently, the working reach is certainly cleared up by the scope of working conditions. The active coils move or deflect under a load. The material type extrapolates the properties to determine the tensile strength. The bogie has four main parts, namely: centre plate, bolster, coil spring and side frame. The mass of the wagon body and its loading is carried on the centre plate. The bolster transfers the 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 mass of the wheel sets, so that track errors do not elicit a response from the full mass of the wagons. It is critical that the wagon's body is not permitted to bounce or otherwise vibrate continuously on these springs. To reduce this, compression of the friction wedge springs forces the friction wear plates affixed to the side columns. This effectively takes energy out of the main springs and stabilises the wagon body.

2.1. Common causes of variation

Natural variation is inherent and is characteristic of the manufacturing 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 stabiliser springs due to the property of the material, the working condition of the machines, processing environmental effect and moreover the actions by the operators. Table 1 shows the stratification for the eminent causes of the problem to the helical coil and stabiliser springs (Bicheno, 2004; Bicheno & Catherwood, 2005). 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 considered as the defects not identified during inspection or the quality control exercise (Masithulela & Ramdass, 2015; Porter & Parker, 1993; Ramdass & Pretorius, 2008). The cause-and effect diagram aids to identify which input variables (possible causes) are having an effect on the output variable (deflection of the helical and stabiliser spring). Some of the conditions affecting working range are illustrated by (Figure 1) the cause-and-effect diagram:

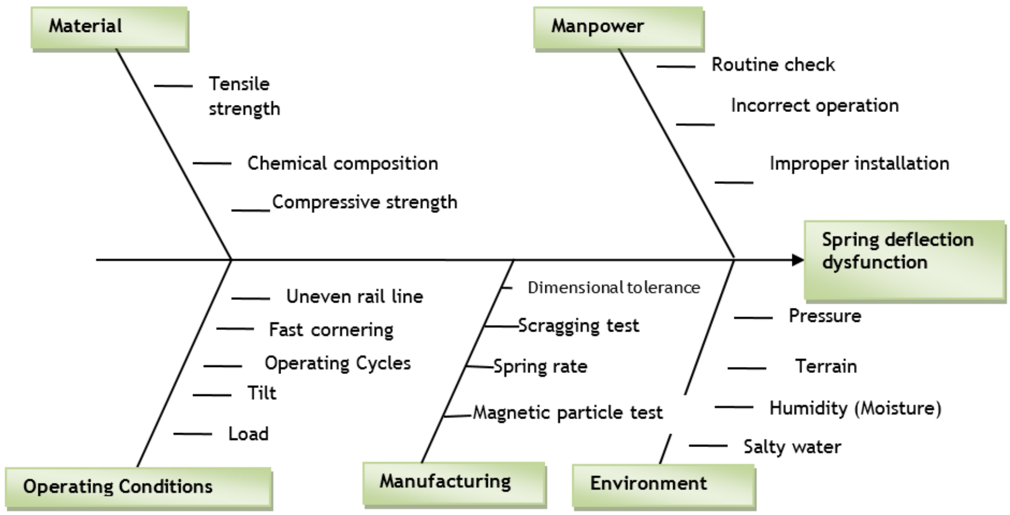

Figure 1. The cause-and-effect diagram for the helical and stabiliser spring deflection dysfunction

Table 1. The leading causes of problems with the helical coil and stabiliser 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

Factors from the cause-and-effect diagram influencing spring deflection:

- Routine analysis provides cues to the springs' condition. If the maintenance officers do not take action, it impacts the lifespan of the opposite or immediate ones.
- Operating outside design parameters may lead to failure of the springs before the stipulated time of warranty.
- Improper installation of the springs leads to breakage or improper functioning that harbours its deflection effect.
- Weight due to overloading or impact 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.
- Geographical terrain with sharp corners affect the spring's suspension system.
- Humidity in the environment of the manufacturing plant affects the spring's deflection inputs due to impurities.
- Salt water degrades the metallic property of the spring, as rust causes degradation of the springs.
- Heavy load on wagons affect the suspension characteristic of the springs due to maximisation of the customer benefit to reduce the cost of transport.
- Slope affects the sides of the loads flow force due to uneven rail-line.
- Fast cornering operations impact the springs' function as train drivers' do not adhere to the rules and regulations resulting in short time scheduling to complete day-to-day trip.
- Tensile strength of the material used is inherent in the deflection deficiency of the springs due to manufacturing property.
- Helical spring deflection characteristic does not accommodate the purpose of shock absorbers or unevenness of the rail line.
- Spring size variation, including height and diameter (the inner, outer and coil bar diameters) causes inconsistency of suspension function.

3. Data collection

This section presents the raw data collected at the organisation's 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.

3.1. Specify the maximum and minimum value for each parameter

The specific 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 presented measured values at this viewpoint are raw-data taken in the field.

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).

3.2. The level of precision

The level of precision is the range in which the true value of the helical coil springs and stabiliser 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 stabiliser springs can be the tolerance of ±0.5 mm upon the deflection rate.

3.3. The confidence level

The certainty or danger level depends on thoughts included under the Central Limit Theorem. The key thought included in the Central Limit Theorem is that when the accumulation of the spring of a helical coil stabiliser spring is over inspected once more, the normal estimation of the quality recorded by those specimens is equivalent to the genuine helical loop springs and stabiliser springs accumulations esteem. Besides, the qualities recorded by these specimens are conveyed typically about the genuine worth, with a few examples having a higher quality and some acquiring a lower score than the genuine helical coil springs and stabiliser springs gathering worth. In a typical circulation, approximately 95% of the example qualities are inside of two standard deviations of the genuine populace esteem (e.g., mean) which is expected of the stabilisers and inward springs for coil bar distance across.

This implies that, if a 95% certainty level is chosen, 29 out of 30 tests will have the genuine helical coil springs and stabiliser springs accumulation esteem inside of the scope of accuracy determined. Tests with great values that do not speak to the genuine populace worth, are spoken to by the shaded regions or outside as far as possible. This danger is decreased for 99% certainty levels and expanded for 90% (or lower) certainty levels.

3.4. Degree of variability

The level of variability being measured alludes to the conveyance of variables in the helical springs and stabiliser springs accumulations. The more heterogeneous a helical loop springs and stabilier springs gathering, the larger the specimen size needed to obtain an accurate reading. The less variable (more homogeneous) a helical springs accumulation the smaller the specimen size. Note that an extent of half demonstrates a more prominent level of variability than either 20% or 80%. This is on the grounds that 20% and 80% demonstrate that a substantial larger part does not or does, individually, have the quality of hobby. Since an extent of 0.5 shows the most extreme variability in a specimen, it is regularly used as a part of deciding a more moderate example measure, that is, the specimen size may be larger than if the genuine variability of the helical spring accumulations 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.

4. Data analysis

In this section all the tools and methodology used are explained in detail. The validity of using the tools is explained. The brief description of each methodology is provided to enhance its application.

4.1. Statistical process control (SPC) run chart

Statistical process control was spearheaded by Walter A Shewhart and taken up by W Edwards Deming with noteworthy implications after World War II (Shewhart, 1926). The Japanese industry was introduced to the methodology by Deming to enhance mechanical generation through the evaluation of assembling processes. Dr Shewhart made the premise for the control outline and the idea of a condition of measurable control via composed tests to show controlled variety that is common to the procedure, though others show uncontrolled variety that is not present in the process causal framework at all times. Statistical process control permits the client to consistently screen, investigate and control the procedure of variety and how it influences the yield of any process (Shewhart, 1926). The statistical process control chart of inner helical spring load at free height is shown in Figure 2. Figure 3 shows process control chart of inner helical spring load at test height and inner helical spring free height. Figure 4 shows process control chart of inner helical spring load at additional deflection.

Variety is the measure of deviation from an outline ostensible (target) esteem. Not every item that is created will precisely coordinate its configuration ostensible (target) values. That is the reason resistances stipends on the ostensible (target) qualities are agreed for the item to be worthy or not. The closer the variety to the ostensible quality, the better the item yield is. Control diagrams are one SPC device that empowers us to screen and control process variety. The above-stated description of the SPC chart analogy clarifies our motive for having it to be the best analytical tool to analyse 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 stabiliser springs, the cause and effect diagram, the normal distribution curve and the histogram have been incorporated. 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 the spring causes deflection dysfunction, such as discomfort to passengers and impact to body (locomotive and wagon). The variability prevention is the SPC charts' principle on quality characteristic by minimising as much as possible for the clarity and justification of the quality assurance of the springs (Farnum, 1994; Montgomery, 2009).

4.2. Variable control chart (the $\bar{X}$ chart)

A variable control chart measures and quantifies the characteristic variable data measurements within the specification limits (tolerance). The quantity that is plotted in the variable control chart is the sample average, **X,** showing the value of the quality characteristic versus the sample number. If the quality characteristic is within the appropriate tolerance/ specification limits, it is hence determined to be used. The mean of every quality trademark is as close as would be prudent to the objective estimation of the trademark. Determination points of confinement are used to figure out whether the procedure is in a condition of factual control (that is creating steady yield), while specification breaking points are used to determine out whether the item will work in the planned manner (Chandra, 2001; Saniga, 1989). Figure 5 shows process control chart of outer helical spring load at free height. Figure 6 shows process control chart of outer helical spring free height after static test coil/bar diameter.

4.3. 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 stabiliser 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 drawn from the spread of the data collected. The variation in a data set is depicted. The actual measurements are spread within given specification limits (the sample range) and the awarded measurements are the measured values as measured width the vernier caliper, the dynamic actuators and the tape measure used.

In drawing a normal distribution curve, there are two specific parameters, that is, 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 sample results are spread apart and the bell curve is relatively flat, it shows how large a standard deviation is.

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

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 centre line, expressed in terms of standard deviation units.

$$z = \frac{X-\mu}{\sigma} \qquad (2)$$

Where **z** is the number of standard deviations (σ) X is above the mean (μ).

$$\sigma = \frac{\sqrt{\sum(x-\bar{x})^2}}{n-1} \qquad (3)$$

The mean (average) lies at the centre of the normal probability distribution of the sample, that is, the theoretical long-run arithmetic mean of the outcomes of repeated trials, such as the samples of the helical coil springs and the stabiliser springs in this case.

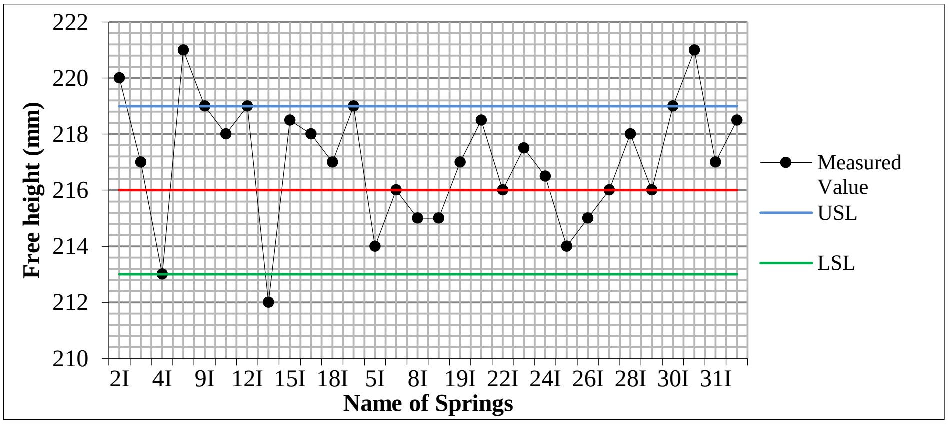

Figure 2. Process control chart of inner helical spring load at free height

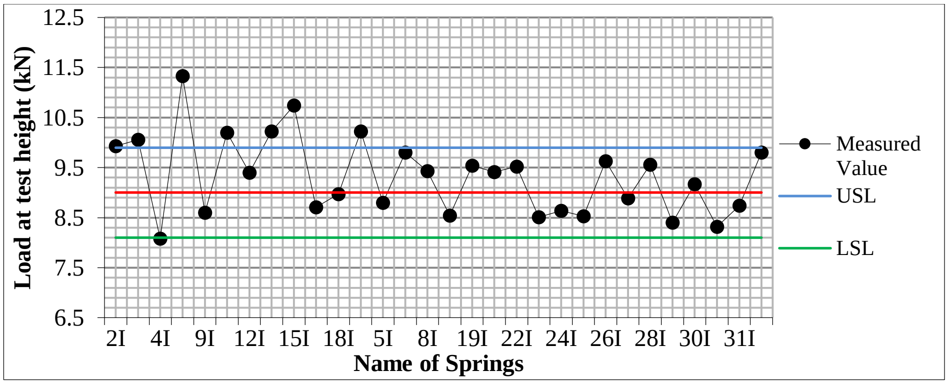

Figure 3. Process control chart of inner helical spring load at test height and inner helical spring free height

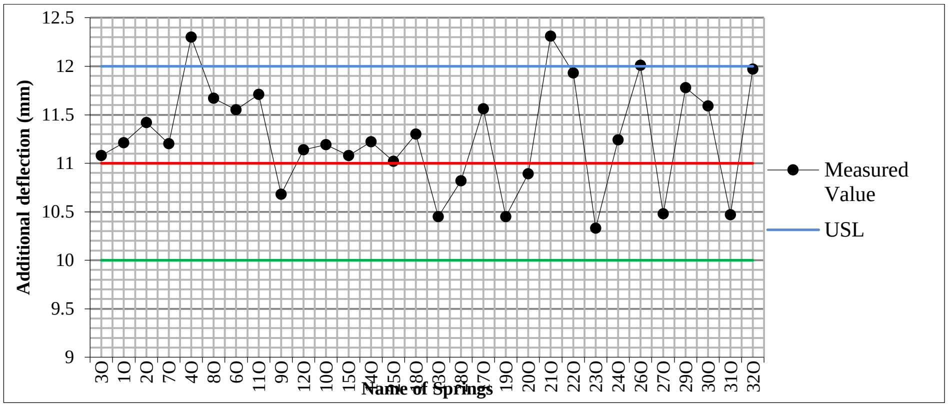

Figure 4. Process control chart of inner helical spring load at additional deflection

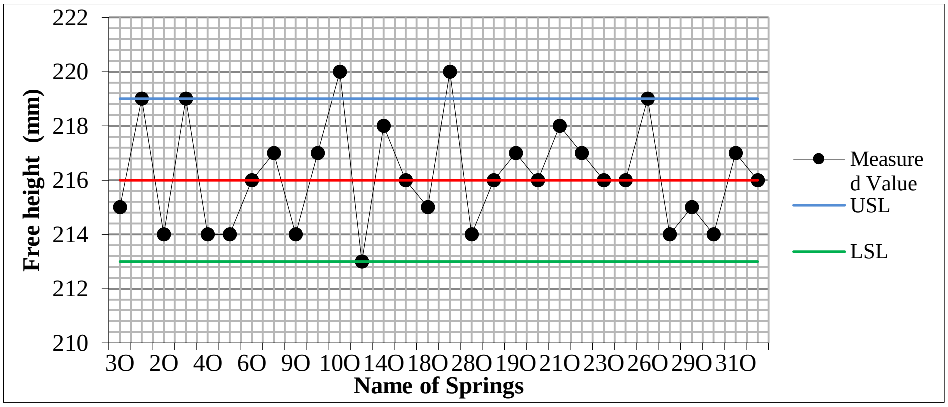

Figure 5. Process control chart of outer helical spring load at free height

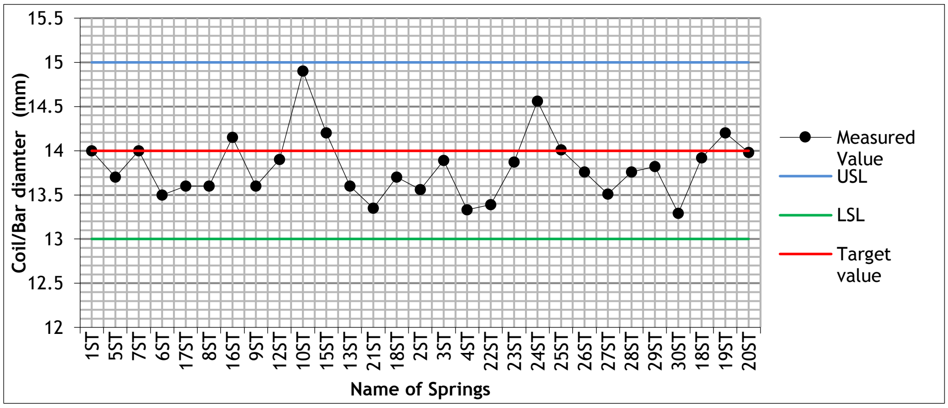

Figure 6. PC chart of outer helical spring free height after static test coil/bar diameter

4.4. 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 (Oakland 2003). All the results evaluated are compared with the six sigma benchmarking values of 2700 DPM. Figure 7 in six sigma comparison of all springs parameters. Figure 8 shows six sigma defects per million of all types of springs and all parameters of springs. The process sustainability (Cp) for three different springs versus all parameters in Figure 9.

4.5. Six sigma evaluations

Six sigma focuses on the reduction of variation within a process through statistical application. By using a set of statistical tools to understand the fluctuation of a process, management can begin to predict the expected outcome of that process. If the outcome is not satisfactory, associated tools can be used to further understand the elements influencing the process. The assumption is that the outcome of the entire process would be improved by reducing the variation of multiple elements. Six sigma includes five steps: define, measure, analyse, improve and control known as DMAIC (Ramdass & Pretorius, 2008).

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. The Standard deviation of all parameter and spring types in shown in Table 2. Table 3 shows inner spring six sigma results. Outer spring six sigma results are shown in Table 4. In addition, Table 5 shows stabilizer spring six sigma results.

Table 2. Standard deviation of all parameter and spring types

Std dev of all parameters	Types of springs		
	Inner Std dev	Outer Std dev	Stabiliser 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	1.378	2.7561	6	0.9162	83800	2700
Load at test height	1.172	2.3459	6	0.879	121000	2700
Additional deflection	1.620	3.2416	6	0.9463	53700	2700
Free height after static test	1.727	3.45452	6	0.9573	42700	2700
Coil/bar diameter	2.187	4.374106	6	0.9857	14300	2700
Outer coil diameter	1.917	3.83474	6	0.9719	28100	2700
Inner coil diameter	2.230	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	1.51837	3.03675	6	0.9345	65500	2700
Load at test height	1.31840	2.636806	6	0.9049	95100	2700
Additional deflection	1.50097	3.001956	6	0.8664	133600	2700
Free height after static test	1.45316	2.906332	6	0.9251	74900	2700
Coil/bar diameter	2.80571	5.611436	6	0.9974	2600	2700
Outer coil diameter	2.00673	4.013478	6	0.9772	22800	2700
Inner coil diameter	2.00503	4.010066	6	0.9772	22800	2700

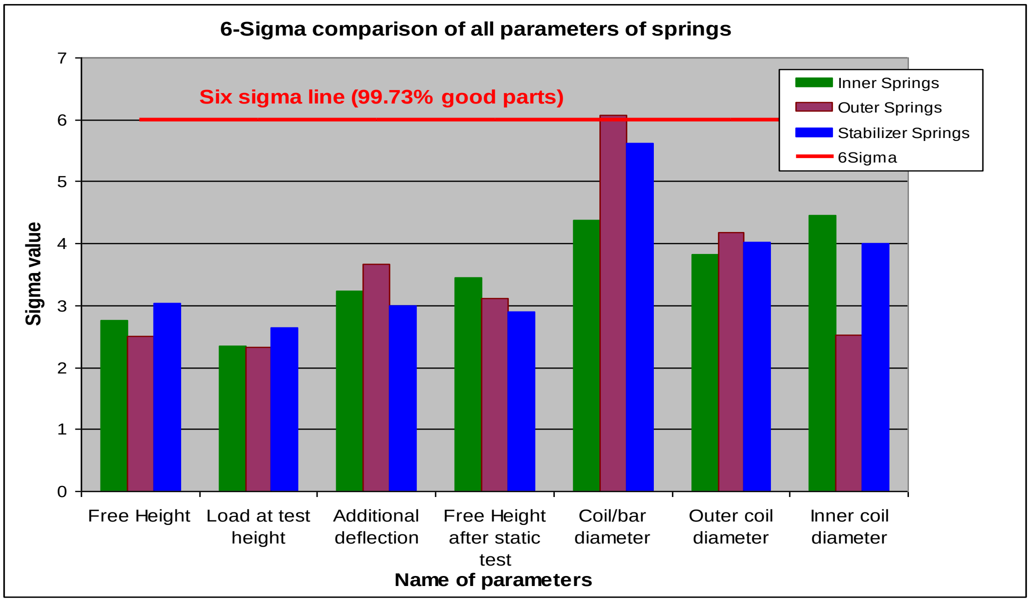

Figure 7. Six sigma comparison of all springs parameters

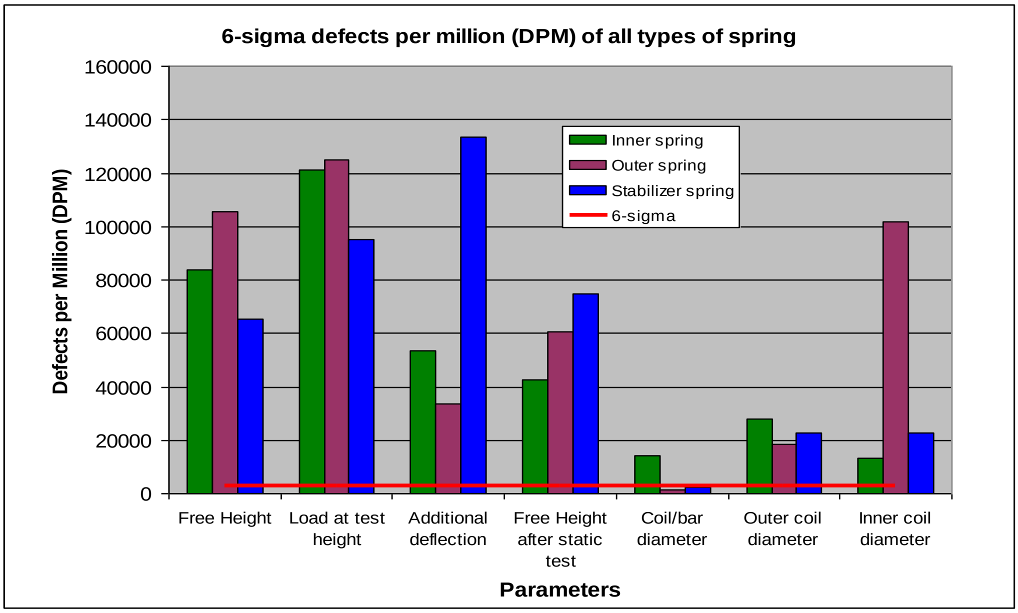

Figure 8. Six sigma defects per million of all types of springs and all parameters of springs

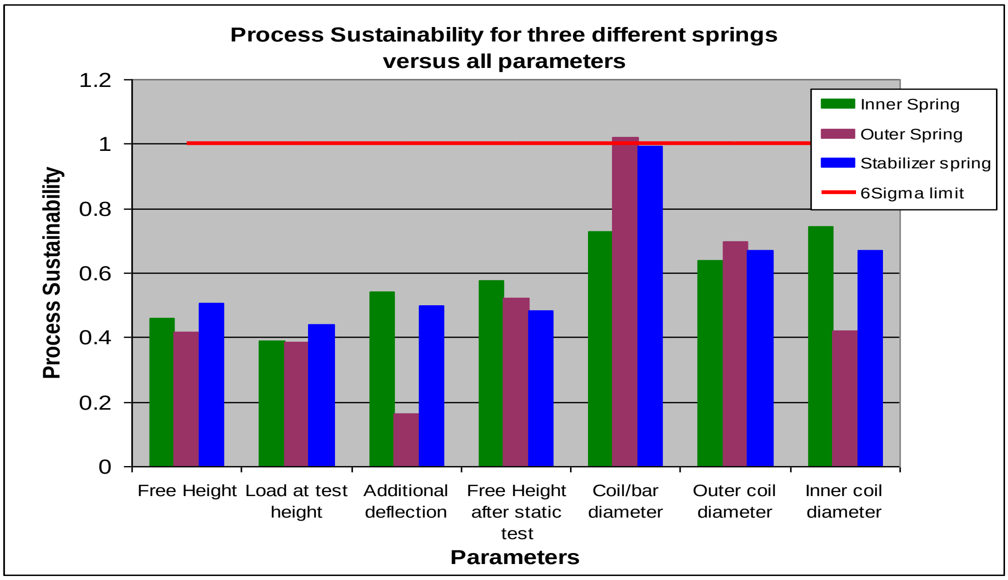

Figure 9. Process sustainability (Cp) for three different springs versus all parameters

5. Discussion and conclusion

All results for all parameters considered in the project are discussed in this section. It must be noted that six sigma is the most important tool used in the project and therefore it is given special attention. The application of six sigma is significant in this study as it enables thorough scrutiny of the helical springs concerned in the study. There is a direct probe into the various identifiable characteristics that provide statistical analysis as to the conditions pertinent in the study. The functionality of the springs from a systems perspective provides vigorous data on all parameters. Six sigma provides quantitative data on the statistical validation of the status of helical springs.

5.1. Statistical process control chart

The statistical process control charts are shown from Figure 2 to Figure 4. Figure 4 shows clearly that most of the 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 in respect of additional deflection, the process is very controllable or is within the specification limit, as shown in Figure 5. In general, most parameters for all the spring types are out of specification limit. A very strong indication of the behaviour of all parameters was obtained from the statistical process control chart (Mulla, Sunil & Vaibhav, 2012).

5.2. Normal distribution probability curve

The normal distribution curve as shown in Figure 4 was obtained by normalising the data collected. From the normal distribution curve, the standard deviation and the mean were obtained by using the Microsoft Excel built-in function. All standard deviations calculated are shown in Table 4.

5.3. Six sigma requirements

After calculating the standard deviation for each parameter, the Z-values were also calculated by the relevant formula. The Z-value leads to the sigma value. It is also important to note that the Z-value also provides the probabilities of the process. Table 4 and Table 5 show that the inner coil diameter is 98.68%, which is higher when 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 very low compared to the six sigma value of 2700 defects per million.

It is important to note that, for the outer spring the parameter with the lowest sigma value is the coil/bar diameter. The coil/bar diameter has the probability of 99.87%, which can be converted to 1300 defects per million. This is an acceptable value as it is even smaller than six sigma requirements. This is shown in Table 5. In the case of the stabiliser 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.

5.4. Histogram

Figures 3 to 5 compare the different parameters for all parameters considered. As explained above it can be seen from Figure 4 and Figure 5 that coil/bar diameter for outer and stabiliser springs meet the six sigma line. As shown in Figures 7 and 8 all other parameters for all springs considered do not meet the six sigma requirements. Again, Figure 4 shows the defects per million as a function of spring parameters. It can be concluded from the figure that all spring parameter 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 5 that all spring parameters have the process capability of less than one (six sigma requirement) except for coil/bar diameter.

6. Conclusions

The theoretical understanding of the functioning of the helical spring and its importance in the railway industry requires scheduled maintenance. Practically, there are numerous characteristics in terms of axial and transverse harmonic displacements of high frequencies that interplay its role (Son, Wysk, & Jones, 2003). It is difficult to evaluate the forces that are transmitted. However, in this case, the research has managed to provide insight in terms of assessment into the lifespan of helical springs used in the railway environment. The analytical tool used in the project depicts the wholesomeness of the feasibility analysis of the helical coil springs and stabiliser springs variability (Rajgopal & Needy 2000; Usher & Chapter 1999). The lifespan of the springs depends upon the metal property, improper coating and its applications. The operating conditions in terms of the environment and operation are prime factors of corrosion and friction. The organisation may experience financial strain due to helical spring replacement in light of the factors. The analysis tools used simplify forecasting and management of the expected life quality service of the helical springs, excluding the manufacturer's warranty. Based on six sigma analysis, the company is encouraged to acquire new helical springs rather than reusing the old spring. Refurbishing used helical springs may be an option, however thorough engineering analysis needs to be done to ensure the guaranteed use of these.

One of the major limitations of this study was that the current study only looked at the mechanical properties of the helical spring. The material requires proper chemical contents to have a better strength for finite or infinite life. Improper contents can affect the ultimate strength which may not bear load for which it has been designed (Abidin, Mahmud, Latif, & Jumahat, 2013; Shabana et al., 2007). Therefore, it would be ideal to set up a study which will look at the microstructure of the used helical springs. The microstructure study could assist a great deal in aligning the concussion of the current study with the microstructural study of the helical spring. The spectroscopy analysis in all helical spring would reveal the chemical composition of material.

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