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The Study of Premature Failure of Springs Used In Railway Coaches

M.Sudhakar Reddy[1],B.Madhusudhan Reddy[2]
(Department Of Mechanical Engineerig, G.Pullareddy Engineerig College (Autonomous) /Jntu Anantapur, India)
(Department Of Mechanical Engineerig, G.Pulla Reddy Engineerig College (Autonomous) /Jntu Anantapur, India)

Abstract: *The springs used in the bogie suspension of railway coaches are compression springs. They are made of an elastic wire material formed into the shape of a helix. They are commonly referred to as a coil spring or a helical spring. They are used to store energy and subsequently release it to absorb shock or to maintain a force between contact surfaces. The spring returns to its natural length or position when unloaded. Springs used in railway coaches have been failing prematurely much before their intended service life. The springs are made with quality materials. Before being put to service, the springs are tested with extensive Non Destructive Testing Methods which are approved by ISO standards to make sure that quality parts are used. However the springs still fail before their service life ends.*
Keywords: *chromium vanadium steel, , helical spring,design constrain , and analysis.*

I. Introduction

The Indian railways is one of the largest and busiest rail networks in the world transporting over 18 million passengers and more than 2 million tons of freight daily. With more than 1.4 million employees, it is known to be the world's largest commercial or utility employer. This project will involve creating a solid model of the helical spring using Pro/ENGINEER software with the given specifications and analyzing the same model using ANSYS software. Here the spring behavior will be observed under prescribed loads to find out if any stress points exist. Based on this analysis, design recommendations will be made to improve its service life.

II. Methodology

The steps involved in creating a model of the spring. A model of the spring will be first created usign Pro/Engineer software. Then the model will be imported to ANSYS to complete static and dynamic structural analysis.

III. Review Of Previous Research Studies

A research study was done on multiaxial fatigue and failure analysis of helical compression springs in 2005. Although uniaxial fatigue analysis has been done in the past, results from multiaxial fatigue analysis are few. The study is mainly done to see if predicted fatigue life of a spring is different from experimental results. To estimate the fatigue life of mechanical springs, the study uses different types of criteria and methods to provide the best results. The fatigue lives are estimated using Fatemi-Socie, Wang-Brown and Coffin-Manson criteria. These results are then compared with experimental results. A model of the spring is created using ANSYS software and the stress analysis results are fed into numerical analysis software called nCode. NCode uses this data to conduct multiaxial fatigue analysis. NCode also predicts the most likely location for the spring to fail. A failure analysis is also performed to get the exact location of spring failure and compare it with the one obtained from numerical analysis. The results show different fatigue life predictions for different criteria. "The Fatemi-Socie critical plane approach gives a good prediction of fatigue life while the Wang-Brown criterion overestimates fatigue life. Also, the Coffin-Mason model gives very conservative results". The above results were obtained from nCode software. It is observed that inner surface of the coil is most susceptible to damage. This is similar to the one obtained from experimental observation. The results of this study can help determine the best model to analyze fatigue behavior of a helical compression spring.The results of this study can help current research investigate if any particular area of the spring experiences more deformation than other areas. Results will reveal if the top or the bottom coil show more deformation than the rest of the body.

IV. Mathematical Analysis

4.1 SPRING SPACE
Wire Diameter = 33.5mm
Outer Diameter = 242mm
Inner Diameter = 175mm
No. of coils = 6.75
Free Height = 360mm
Pitch = 53.33

4.2 MATERIAL DATA
Type of steel = Chromium Vanadium Steel - 52Cr4Mo2V
Built to BIS IS: 3195 specifications
Young's Modulus = 2.068E+11 Pa
Density = 7833.4 kg/m3
a) Stress Concentration factor "k" = 1.264
b) Deflection under 1000 kg "y" = 21.22mm
c) Shear Stress = 832kg/cm2
d) Home stress with "k" = 7465 kg/cm2
e) Modulus of rigidity G = 8155 kg/mm2

4.3 LOADS
A load of 2 MT (metric ton)/19.62 KN is applied on top of the spring.

4.4 BOUNDARY CONDITIONS
The bottom of the spring needs to be fixed i.e. fixed supports.

V. Concept Of Spring Design
The design of a new spring involves the following considerations
• Space into which the spring must fit and operate.
• Values of working forces and deflections.
• Accuracy and reliability needed.
• Tolerances and permissible variations in specifications.
• Environmental conditions such as temperature, presence of a corrosive atmosphere.
• Cost and qualities needed.
The designers use these factors to select a material and specify suitable values for the wire size, the number of turns, the coil diameter and the free length, type of ends and the spring rate needed to satisfy working force deflection requirements. The primary design constraints are that the wire size should be commercially available and that the stress at the solid length be no longer greater than the torsional yield strength.

VI. Method Of Testing Springs
Load testing**.** The spring is placed on a flat rigid metal support and an incremental increasing load is applied as specified. Each spring is placed under load for 2 minutes. The height of the spring under this load is determined and noted. The spring is rejected if "the tolerance on the height of the spring under nominal and maximum load is more than ±3% of design deflection value at nominal load and ±6% of design deflection value at maximum load". Magnetic crack detection test.In this test a spring is "magnetized by current flow along the axis of the wire". Current intensity is adjusted based on the dimensions of each spring. Once the current is passed, the surface of the spring is sprayed with magnetic ink containing Ferro magnetic particles. If a crack exists in a spring, the Ferro magnetic particles are drawn to the leakage of magnetic field. A black light or an ultraviolet lamp is used to observe the spring as cracks are now easily visible. The springs are checked for corrosion and dents manually. Visual inspection is done to see if springs have suffered any damage. If any corrosion or dents exist, springs are discarded immediately. In chapter two, case studies involving the use of Ansys software will be examined. Also, types of analysis performed using Ansys software will be explained. Companies which have used the software to make design improvements to their products will be discussed.

6.1 SPRINGS
All materials to some degree show elastic properties and will deform to some extent when they are subjected to external loads. "When the load is removed, the material will return to its original shape" without any deformation provided its elastic limit is not exceeded. A material which shows these properties can be

considered a spring. Most structures when they are designed will undergo acceptable deformation under specified loading conditions, but their main requirement is to remain rigid. A spring, however, will store energy elastically due to its relatively large displacement.

6.2 TYPES OF SPRINGS AND THEIR APPLICATIONS

There are many types of springs available commercially and they come in a variety of shapes and sizes. They are extensively used in the engineering and industrial fields and are classified by their ability:

1) To absorb or store energy and to mitigate shock and vibration, e.g., buffers, vehicle suspensions, etc.
2) To apply a definite force or torque, e.g., valves, pipe supports, governors, etc.
3) To indicate or control load or torque, e.g., weighing machines, dynamometers, etc.
4) To provide an elastic pivot or guide, e.g., balancing machines, expansion bends, etc.

Different springs can be used for the above functions, but helical springs are usually preferred because of the following:

1) They show good linear load/deflection characteristics.
2) They have a wide range of movement.
3) They can be made compact, which is important where springs are needed to absorb energy.

One of the important characteristics of helical springs is that their internal friction is very small, so they return or release a high proportion of any energy stored.

6.3 TYPES OF HELICAL SPRINGS

1) Helical compression springs
2) Helical tension springs
3) Helical torsion springs
4) Conical disc springs
5) Flat or leaf springs

We will be discussing helical compression springs since they are the type of helical spring being examined in this project.

6.4 HELICAL COMPRESSION SPRINGS

Helical compression springs are usually open coiled and they can resist compressive loads. They are available in a variety of shapes and sizes and are very widely used. They are usually made from a circular section material, and their coil diameter remains uniform throughout their length; however, square or rectangular section materials are also used where space is very limited and are needed to absorb large amount of energy. Springs which are of the open-ended type are used if axial length is restricted. Springs which have their ends closed and are ground flat are used more widely because they are able to better distribute the end load. For this project springs whose ends are closed and ground flat are considered as they are the only type used by Indian Railways. Springs with plain ground ends are avoided as they become tangled during the manufacturing process. Springs with ends closed and ground are easy to manufacture and ensure that load distributed will be axial.

6.5 MATERIALS FOR HELICAL SPRINGS

The materials used in the manufacturing of round wire helical springs are classified below:

1. Patented cold drawn materials – here the mechanical properties required are induced by the drawing process.
2. Annealed materials – here the required mechanical properties are gained by heat treatment.

Group one type springs are cold formed to the required shape. After they are manufactured, they require a low temperature stabilizing treatment. They can be sub-divided into the following:

a)Carbon steels
b)Austenitic stainless steels
c) Alloy steels
d) Non-ferrous materials
e) Specials, e.g., titanium alloys

Group two type springs are usually hot formed. They are sub-divided as:

Silicon-manganese steels

a) Chromium-vanadium steels
b) Silicon-manganese steels

Material is chosen based on its suitability for a particular application. Several factors must be considered before deciding upon the type of material; these include:

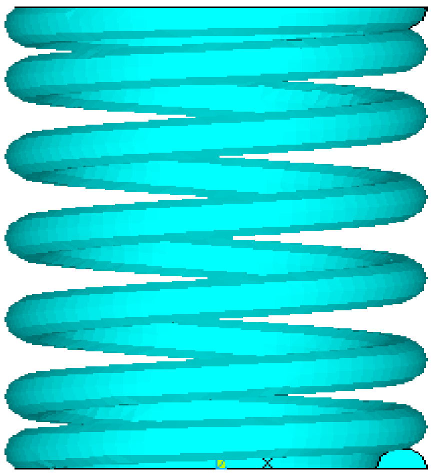
3. Type of loading
4. Static or dynamic
5. Operating temperature and stresses

VII. Analysis On Closed End Spring

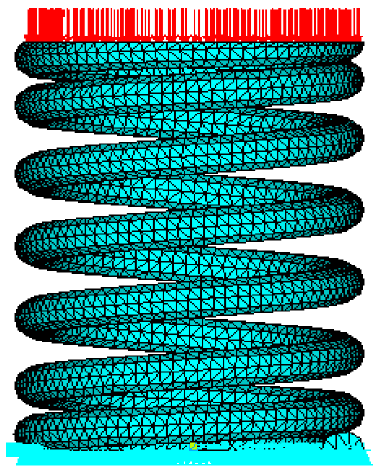
The Finite Element Analysis has been carried out for Closed end Mechanical Spring for given operating conditions. Please refer to Appendix for the design considerations. The spring is simulated using higher order Solid 92 elements. The geometry model is generated using Pro-E simulation software. The Model is imported to Ansys to carry Static Analysis followed by the Dynamic Analysis.

7.1 GEOMETRY MODELING

The geometric model developed in Pro-E is shown below

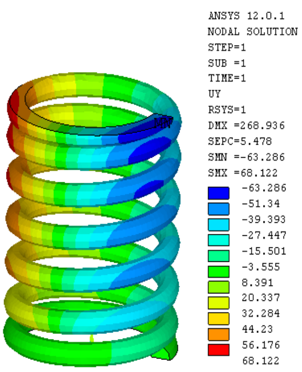


Geometric Model of the Closed End Spring

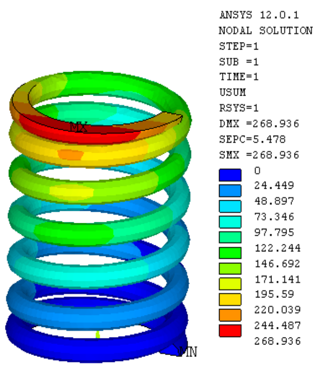


FE Modeling of Closed End Spring with Boundary Conditions

7.2 STATIC ANALYSIS OF THE CLOSED END SPRING

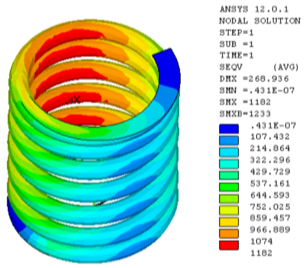


Displacement of the Spring in UY Direction



Displacement of the Spring in USUM Direction

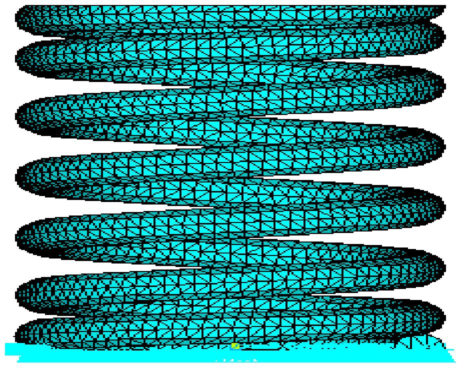
The Vanishes Stress is shown below; the Vanishes stress 1359 Mpa is more than the Yield strength of the material. The spring may fail for the given loading and boundary conditions



Vonmises Stress of the Closed End Spring

7.3 MODEL ANALYSIS OF THE CLOSED END SPRING:

The modal analysis is carried out to study the dynamic response of the structure for the given loading and boundary conditions. The modal analysis outputs the natural frequencies of the structures and its respective mode shapes. The natural frequencies help to study the operating frequency and its amplitude response characteristics.



FE Model with Boundary Conditions for Closed End Spring

7.4 NATURAL FREQUENCIES FOR THE CLOSED END SPRING

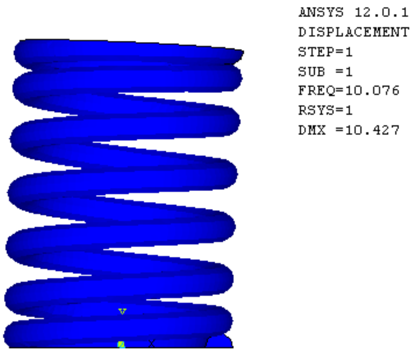
The natural frequencies of the Closed End Spring is listed below

***** INDEX OF DATA SETS ON RESULTS FILE *****

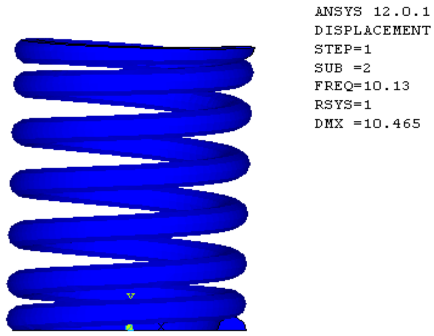
SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
1	10.076	1	1	1
2	10.130	1	2	2
3	15.680	1	3	3
4	17.722	1	4	4
5	36.365	1	5	5
6	37.071	1	6	6
7	46.141	1	7	7
8	52.191	1	8	8
9	71.159	1	9	9
10	72.499	1	10	10

The First Mode of Natural Frequency:

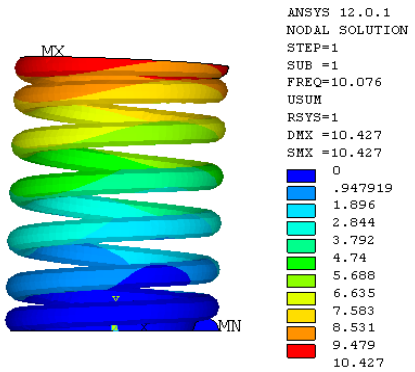
The Second Mode of Natural Frequency:



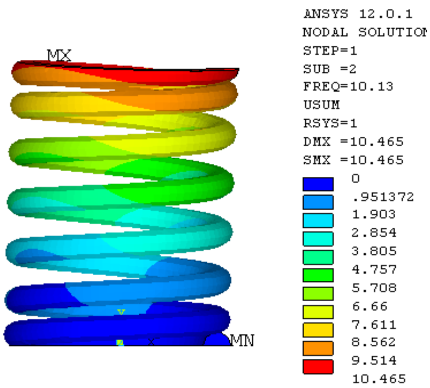
First Mode of Natural Frequency



Second Mode of Natural Frequency



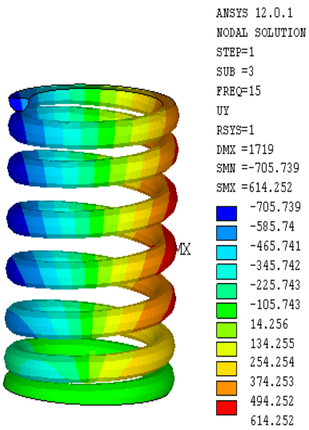
Resultant Displacement for First Mode of Natural Frequency



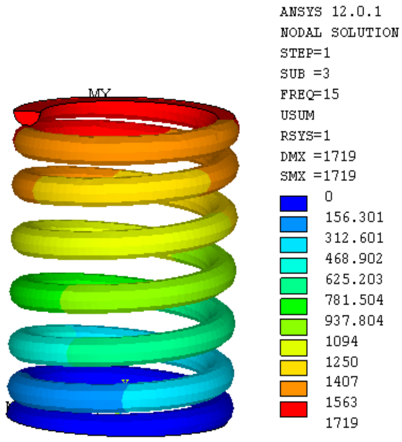
Resultant Displacement for Second Mode of Natural Frequency

7.5 HARMONIC ANALYSIS OF THE CLOSED END SPRING:

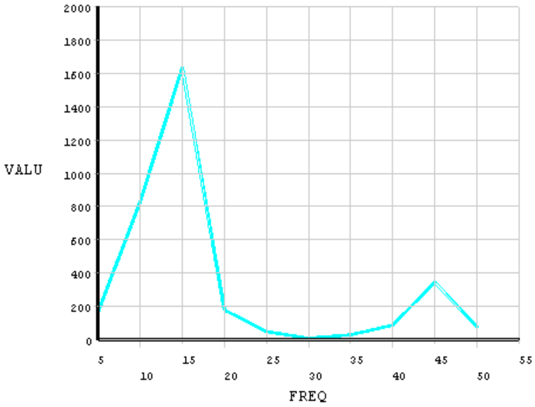
The Harmonic Analysis is carried to study dynamic behavior of the spring for the given operating Conditions 0 to 60 Hz. If the spring natural frequency is matches with the operating condition than it amplitudes shoots up and it will be under resonating conditions.

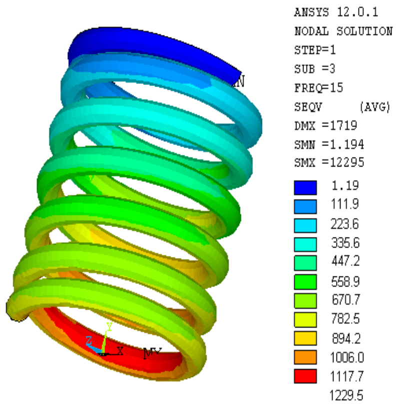


Displacement in Y direction for Closed End Spring



Resultant Displacement for Closed End Spring

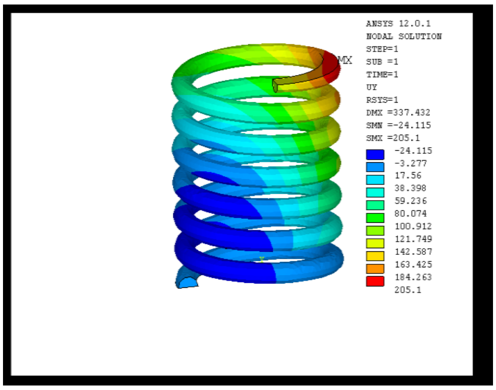


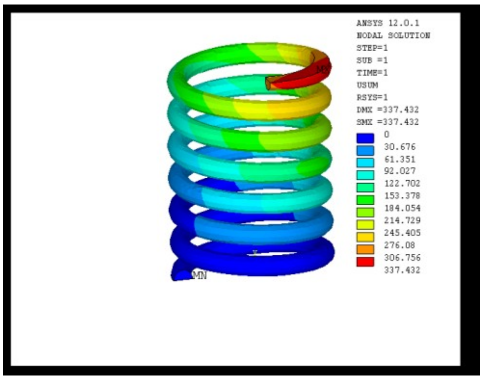


Amplitude Vs Frequency for Closed End Spring

Vonmises Stress for Closed End Spring

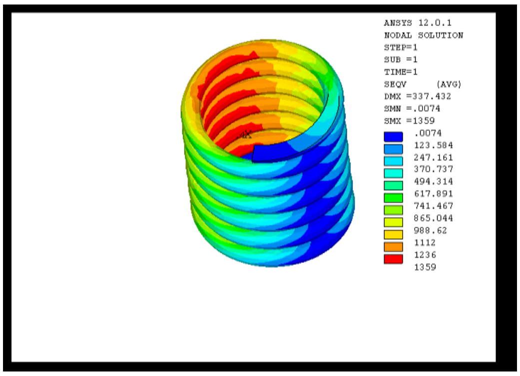
7.6 *STATIC ANALYSIS OF THE OPEN END SPRING*





Displacement of the Spring in UY Direction

Displacement of the Spring in USUM Direction



Vonmises Stress of the Open End Spring

7.7 MODEL ANALYSIS OF THE OPEN END SPRING:

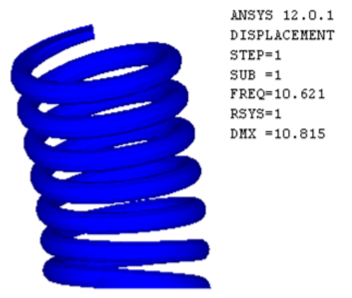
The modal analysis is carried out to study the dynamic response of the structure for the given loading and boundary conditions. The modal analysis outputs the natural frequencies of the structures and its respective mode shapes. The natural frequencies help to study the operating frequency and its amplitude response characteristics.

7.8 NATURAL FREQUENCIES FOR THE OPEN END SPRING:

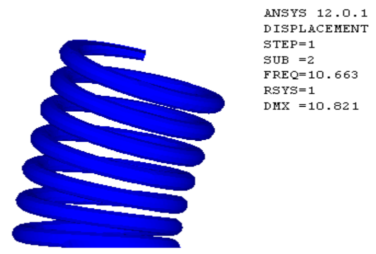
The natural frequencies of the Open End Spring is listed below

***** INDEX OF DATA SETS ON RESULTS FILE *****

SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
1	10.621	1	1	1
2	10.663	1	2	2
3	15.510	1	3	3
4	17.529	1	4	4
5	35.387	1	5	5
6	36.057	1	6	6
7	45.691	1	7	7
8	51.613	1	8	8
9	71.464	1	9	9
10	72.061	1	10	10

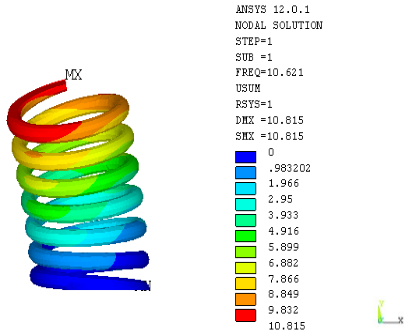


The First Mode of Natural Frequency

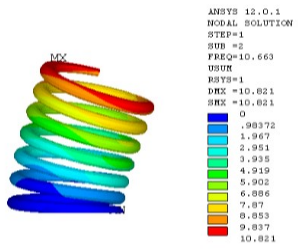


The Second Mode of Natural Frequency

10



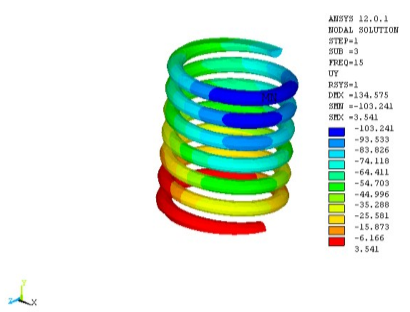
Resultant Displacement for First Mode of Natural Frequency

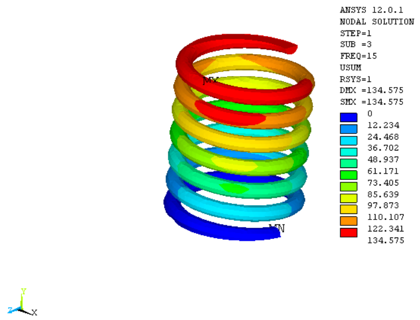


Resultant Displacement for Second Mode of Natural Frequency

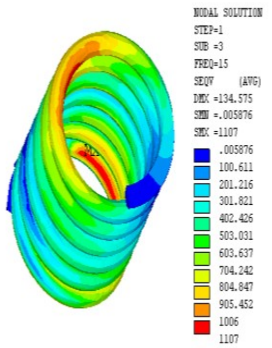
7.9 HARMONIC ANALYSIS OF THE OPEN END SPRING

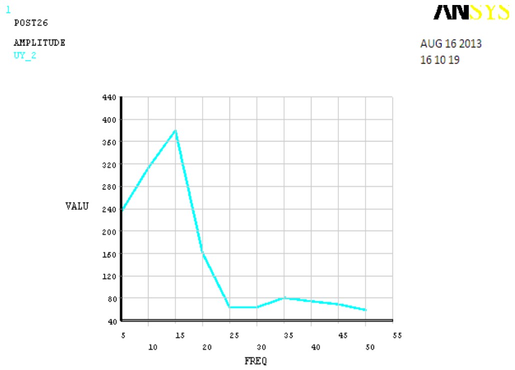
The Harmonic Analysis is carried to study dynamic behavior of the spring for the given operating Conditions 0 to 60 Hz. If the spring natural frequency is matches with the operating condition than it amplitudes shoots up and it will be under resonating conditions.





Displacement in Y direction for Open End Spring　　　　Resultant Displacement of Open End Spring





Vonmises Stress for Open End Spring　　　　Amplitude Vs. Frequency for Open End Spring

VIII. Results Summary

The Analysis is carried out for Open End Spring and Closed End Spring of the same material for the given Loading and Boundary Conditions and the results are summarized as below:

The Vonmises Stress for Open End Spring is around 1359 Mpa, Which is more than the Yield Strength of the material. Hence Material will for the given Loading and Boundary Conditions.

The First Natural Frequency of the Open End Spring is observed as 10 Hz, if it won't fall near to the operating frequency. The spring will be safe under dynamic Conditions, or else it will have higher amplitudes and tend to undergo resonance.

The Vonmises Stress for Open End Spring for Harmonic Analysis is observed as 1107 Mpa, which is more than the Yield Strength of the Material, Hence design will fail under dynamic operating conditions.

As a general rule, the ratio of Endurance Limit to Ultimate Strength of the Material is 0.6, hence the spring stress is less than Endurance Limit of the Material, the spring will not have infinite life, and the life of the spring is less 1e5 Cycles.

For Closed End Spring,

The Vonmises Stress for Closed End Spring is around 1182 Mpa, Which is more than the Yield Strength of the material. Hence Material will for the given Loading and Boundary Conditions.

The First Natural Frequency of the Closed End Spring is observed as 10 Hz, if it won't fall near to the operating frequency. The spring will be safe under dynamic Conditions, or else it will have higher amplitudes and tend to undergo resonance.

The Vonmises Stress for Closed End Spring for Harmonic Analysis is observed as 1230 Mpa, which is more than the Yield Strength of the Material, Hence design will fail under dynamic operating conditions.

As a general rule, the ratio of Endurance Limit to Ultimate Strength of the Material is 0.6, hence the spring stress is less than Endurance Limit of the Material, the spring will not have infinite life, and the life of the spring is less 1e5 Cycles.

Compare to Open End Spring, Closed end spring will take more loads under given Loading and Operating Conditions. The Closed End Spring will be better when Compare to Open End Spring.

IX. Conclusion

To study the dynamic behavior of the springs, 3D solid model of helical springs are modeled with PRO/E. Static and Dynamic stress analysis are carried out using ANSYS to understand the Structural and Dynamic response of the springs. Spring behavior will be observed under prescribed or expected loads. Based on the results design modifications will be suggested for better life without failure in service.

X. future Scope

Design optimization can be carried out either by changing material type or changing the design of spring. The research could throw light on why the springs fail early and why they break only at the inactive coil. The study could also present suggestions to increase the life of the spring.

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