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Research Article

# Design, Simulation and Fatigue Analysis of Physically-loaded Helical Springs

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## I N F O

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## A B S T R A C T

Mechanical springs are used in machine designs to exert force, provide flexibility and to store or absorb energy. Springs are manufactured for many different applications such as compression, extension, torsion, power, and constant force by changing the spring parameters such as mean coil diameter, wire diameter, spring constant, spring material, pitch and free length. Here the function of these springs to store or absorb energy and compression application applied. This chapter will give an overview design, non-linear type simulation and safe fatigue for helical compression springs. We have considered the design of spring steel (51CrV4) and alloy Steel (ss) but fatigue test was performed on alloy steel (ss) at different load with the help of Solid works software (Version-2017). Absorption and subsequent release of the external loads comes in a form of elastic energy and, due to their material and design, springs tend to return to their initial length when unloaded.

**Keywords:** Design, Fatigue Analysis, Physically-Loaded Helical Spring, Simulation

## Introduction

A spring is defined as an elastic machine element, which deflects under the action of the load & returns to its original shape when the load is removed. A spring is a resilient member capable of providing large elastic deformation. The applications involved as to apply forces and controlling motion in brakes and clutches, measuring forces as in the case of a spring balance, storing energy as in the case of springs used in watches and toys and many more at high levels as shock absorber in railways, automobile industries etc. Youli Zhu, Yanli Wang and Yuanlin Huang (2014) focused on the failure analysis of a helical compression spring for a heavy vehicle's suspension system in his paper. They considering a case study and explained why a compression coil spring fractured at the transition position from the bearing coil to the first active coil in service, while the nominal stress here should always be much less than that at the inside coil position of a fully active coil. They found that once the initial crack was formed, it was the maximum principal tensile stress that forced the crack to propagate along spring wire axis. They used the fracture photographs of the failed spring, SEM photograph of the fracture surface and fatigue origin after ultrasonic cleaning. They also discussed stress analysis by FEM results of stress distributions in the contact zone. They strongly recommended adopting a non-closed ends design to avoid wear and corrosion of the suspension spring.[2] Goran Vukelica and Marino Brcicb (2016) discussed the frequent failures of coil springs on a specific type of motor vehicle and performed detailed Scanning Electron Microscopy (SEM) examination at suitable magnifications then employed to characterize the fine microstructure of the fractured surface and reveal flaws that served as crack initiation points. They suggested that this was an example of corrosion fatigue failure. In their examination, they found protective paint layer of the wire was damaged as pits appearance. This pits served as crack initiation points from which fracture. They also used the image of optical magnification of fracture surface around crack initiation point and SEM image of fracture surface around crack initiation point.[3] Gajendra Singh Rathore and Upendra Kumar Joshi (2013) discussed detailed literature review on fatigue stress analysis of helical compression spring. The objective of work was to provide the information about the fatigue stress for the helical compression spring. Springs are mechanical shock absorber system. The researchers throughout the years had given various research methods such as Theoretical, Numerical and Experimental. Researchers employ the Theoretical, Numerical and FEM methods. They conclude Finite Element method was the best method for numerical solution and calculating the fatigue stress, life cycle and shear stress of helical compression spring.[3] Supriya Rahul Burgul and Atul. P. Kulkarni (2015), discussed the fatigue analysis for helical compression spring for determining design alternatives for enhanced life and performance. In the Internal Combustion Engine, they found percentage ratio of premature fatigue failure of an exhaust valve spring of a constant speed I.C. engine is more. The spring was modeled using CAD software CATIA V5. Then they further evaluated using FEA software (CAE) for fatigue analysis and examined safe life of the spring is expected to be about 50,000 cycles as per the standards. Results indicate that the considerations of changes in design parameters like pitch and wire diameter can increase in fatigue life of spring. They applied tetrahedral mesh model zoom view, rigid and solid element connectivity, and spring with boundary condition, maximum deflection of spring and maximum von mises stress in the spring.[4] Vishal Chaudhari and Prof. G. V. R. S. Rao (2016), they used the die set system in which the wire straightening and cutting system was comprised of die plate, bolster plate and guides with mutually helped by helical compression spring as the number of turns affects the deflection and shear stress adversely and as the number of turns increases the deflection decreases. The life of spring was improved by optimum design and analysis by variation of wire diameter. Results indicate that the maximum shear stresses are decreased for increase values of wire diameter and number of turns of coil spring. They applied 1000N load, von mises stress 1000N load and examined load vs. deflection for existing spring, load vs. stress for existing spring, load vs. stress for new spring.[5] Rinaldo Puff, Marcos Giovani Dropa de Bortoli & Raul Bosco Jr (2010), discussed the operation of hermetic compressors/ reciprocating compressors for fatigue analysis of helical suspension springs. They found lateral motion of the suspension springs during the compressor start/stop has an important influence on the springs fatigue life and compressors suspension were usually evaluated at 500,000 cycles of start/stop. They estimated that this number of cycles represents about 10 or 15 years of the compressor life. They applied analytical approach, fatigue design flow chart, Schematic diagram showing the movement of the compressor assembly inside the shell during start/stop conditions and the spring displacement and Stress intensity for helical spring with axial displacement by FEM.[6] Noshirwaan Aibada, Siddhant Sundaram, Dinesh Kalani, Praveen Kumar Loharkar (2018), represented the detailed review of studies on helical compression springs with a perspective of material, methods and failure. They found that utility of composite springs and its various advantages over the conventional helical spring had been demonstrated by various authors. They promoted failure can be due to excessive loads, adverse environmental conditions or fatigue. But majority of the springs failed due to fatigue failure, crack initiation in the cross section of the wire and intensifications was one of the significant modes of failure, improper manufacturing and imbalance in the composition may also cause failure.[7] Ronak B Chaudhari and Dr. L. G. Navale (2017) focused on effect of change in parameters like material, wire diameter; pitch on fatigue life of helical spring used in stamping machine. Taguchi method and analysis of Variance were used to optimize the parameters affecting on stresses and fatigue life of spring. Simulation technique also used effectively to optimize the design parameters. They concluded that the proposed optimization approach was successful and validated with experiments which increase life of modified spring than standard spring. The spring was designed and modeled using CAD software. This further evaluated using FEA software for static, fatigue analysis for cyclic loading and produces the best suitable compression spring.[8]

## Design of Helical Springs of Various Positioning

When creating a helix spiral, first plan out your sketch geometry to include a circle for the helix diameter and a smaller circle for the suite profile. In place of a helix, users can implement a straight line for the suite path. Activating the “Swept Boss/Base” command, under the Features task bar, pick the small circle for the profile and the line for the suite path. Nothing previews, but when selecting “Twist along Path,” under the “Orientation/twist type” drop down menu, users are presented with the option to define the twist using degrees, radians or turns. In the video example above, we select turns and set a number. After confirming changes, the straight line and smaller circle sketches used to define the suite are absorbed. Users can still control the diameter of the helix by adjusting the unabsorbed circles diameter. To do so, select “Dia,” located in the feature tree, then select the unabsorbed circle.

A "Modify" window should pop up, allowing users to make any necessary changes. One of the benefits of creating a helix this way is that the path followed does not have to be straight – a user's helix can be modified to include arcs. To do this, select "Path," under "Sweep" in the feature tree and click on the "Edit Sketch" option. The Following Steps are involved as:-

**Table 1.Units for solid model**

| Unit system: | SI (MKS) |
|---|---|
| Length/ Displacement | mm |
| Temperature | Kelvin |
| Angular velocity | Rad/sec |
| Pressure/ Stress | N/m^2 |

- Start button of Software 'solid works'(version-2017)
- Make one circle of mean diameter required
- Go to Insert---> Curve ---> Helix.
- Select the Circle and adjust the parameters like Pitch, No of revolution and helix angle.
- Now select a plane normal to helix path.
- Go to feature tab select with 'Sweep' command.

Design of helical spring for spring-steel material used single spring at centre of resting plate which was made of mild steel as seen in Figure 1.

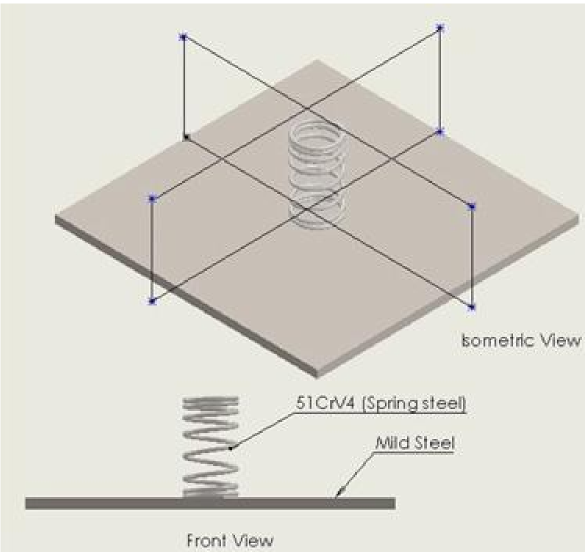



**Figure 1.Single spring-steel spring**

Similarly, design of helical spring for single alloy-steel material used single spring at centre of resting plate which was made of mild steel as seen in Figure 2.

Design of helical spring for spring-steel material used double springs at centre of resting plate which was made of mild steel as seen in Figure 3. Similarly, design of helical spring for Alloy-steel material using double spring at centre as seen in Figure 4.

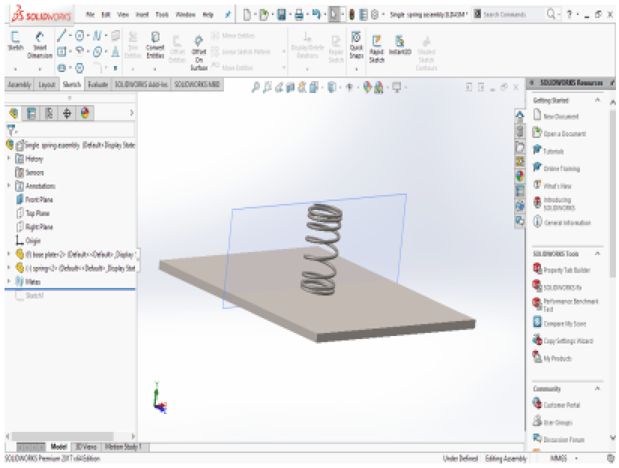


**Figure 2.Single alloy-steel spring**

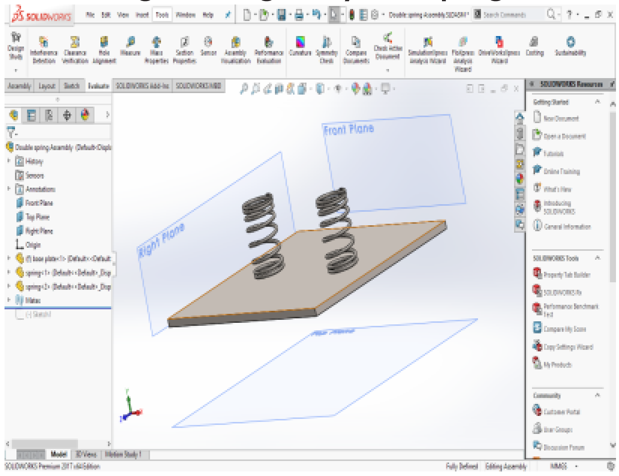



**Figure 3.Dual alloy-steel springs**

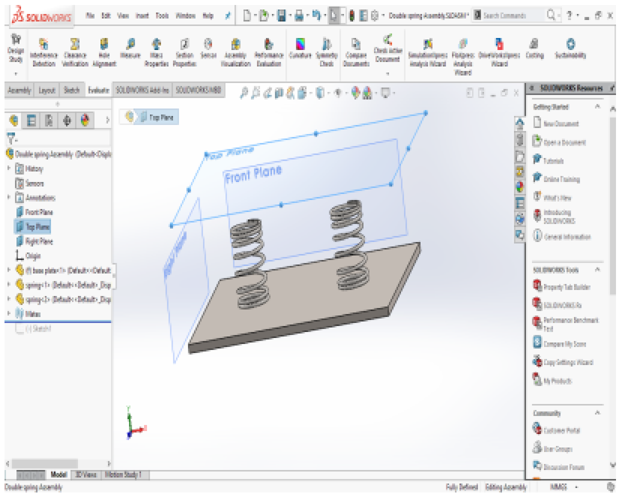



**Figure 4.Dual spring-steel springs**

Design of helical spring for *spring-steel material* used triple springs with respect to centre of gravity at resting plate which was made of mild steel as seen in Figure 5. Similarly, design of helical spring for Alloy-steel material using triple springs with respect to centre of gravity at resting plate which was made of mild steel as seen in Figure 6.

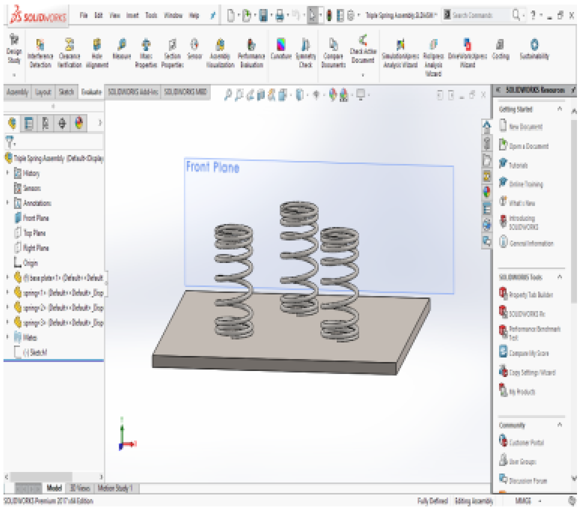


Figure 5.Triple spring-steel springs

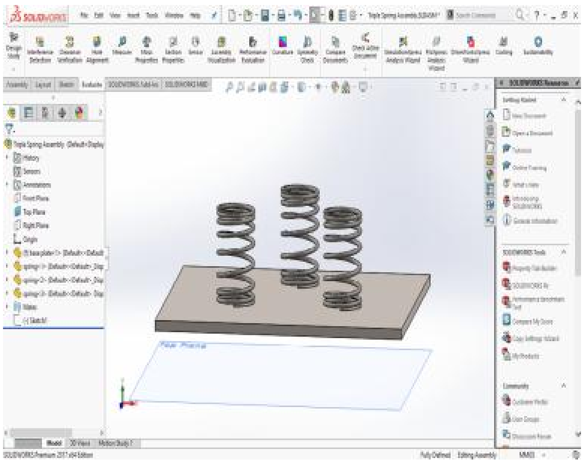
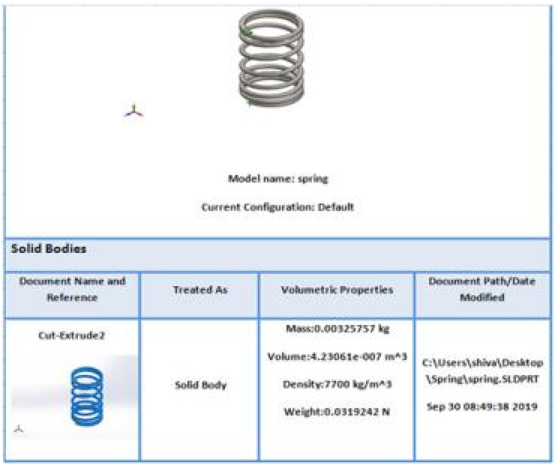


Figure 6.Triple alloy-steel springs

## Simulation of Helical spring

The detailed description of simulation included the model information with assumptions, material properties, loads and fixtures, contact information, mesh information, resultant Forces and finally study results.



Model name: spring

Current Configuration: Default

| Solid Bodies | | | |
|---|---|---|---|
| Document Name and Reference | Treated As | Volumetric Properties | Document Path/Date Modified |
| Cut-Extrude2 | Solid Body | Mass:0.00325757 kg<br>Volume:4.23061e-007 m^3<br>Density:7700 kg/m^3<br>Weight:0.0319242 N | C:\Users\shiva\Desktop\Spring\spring.SLDPRT<br>Sep 30 08:49:38 2019 |

Figure 7.Model Information

## Model Information with Assumptions

Helical spring treated as solid body; The all units are taken in SI (MKS) as mentioned in Table 1 as units for solid model. The model name here used as spring can be seen in Figure 4 and various values of mass, volume, weight and density are represented.

## Material Properties

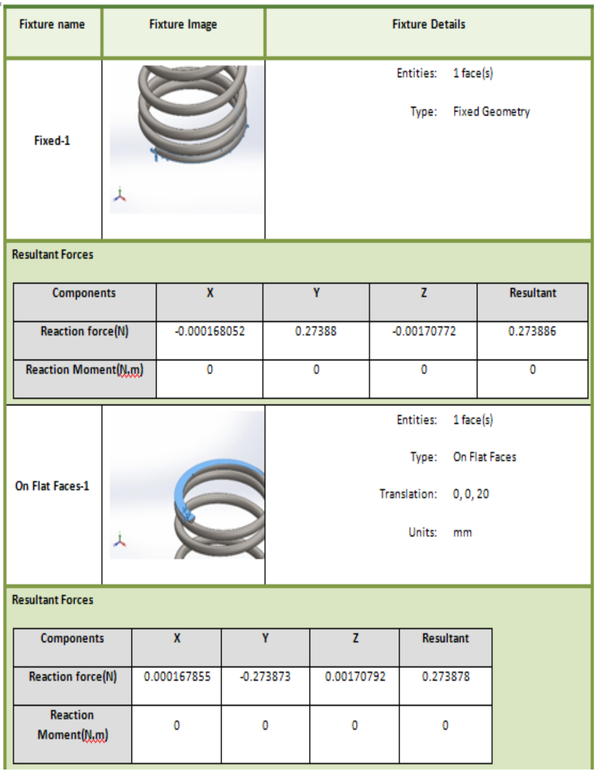
The various properties as Yield strength, Tensile strength, Elastic modulus, Mass density, Thermal expansion coefficient etc. can be seen in table no. 2.

**Table 2.Material Properties**

| Model type: | Linear Elastic Isotropic |
|---|---|
| Default failure criterion: | Max von Mises Stress |
| Yield strength: | 6.20422e+008 N/m^2 |
| Tensile strength: | 7.23826e+008 N/m^2 |
| Elastic modulus: | 2.1e+011 N/m^2 |
| Poisson's ratio: | 0.28 |
| Mass density: | 7700 kg/m^3 |
| Shear modulus: | 7.9e+010 N/m^2 |
| Thermal expansion coefficient: | 1.3e-005 /Kelvin |

## Loads and Fixtures

These mentioned Loads and Fixtures can be seen in Figure 8.



| Fixture name | Fixture Image | Fixture Details |
|---|---|---|
| Fixed-1 | | Entities: 1 face(s)<br>Type: Fixed Geometry |

Resultant Forces

| Components | X | Y | Z | Resultant |
|---|---|---|---|---|
| Reaction force(N) | -0.000168052 | 0.27388 | -0.00170772 | 0.273886 |
| Reaction Moment(N.m) | 0 | 0 | 0 | 0 |

| Fixture name | Fixture Image | Fixture Details |
|---|---|---|
| On Flat Faces-1 | | Entities: 1 face(s)<br>Type: On Flat Faces<br>Translation: 0, 0, 20<br>Units: mm |

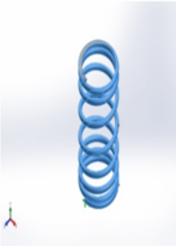
Resultant Forces

| Components | X | Y | Z | Resultant |
|---|---|---|---|---|
| Reaction force(N) | 0.000167855 | -0.273873 | 0.00170792 | 0.273878 |
| Reaction Moment(N.m) | 0 | 0 | 0 | 0 |

Figure 8.Loads and Fixtures

## Contact Information

These mentioned contact, contact image, contact properties can be seen in Figure 9.

| Contact | Contact Image | Contact Properties |
|---|---|---|
| Contact Set-1 |  | Type: No Penetration contact pair<br>Entites: 1 face(s) (Self-Contact)<br>Advanced: Surface to surface |

Contact/Friction force

| Components | X | Y | Z | Resultant |
|---|---|---|---|---|
| Contact Force(N) | -2.5806E-015 | 4.012E-014 | 6.4889E-015 | 4.0724E-014 |

**Figure 9.Contact Information**

## Resultant of Simulation

The Figure 10 represented the simulation results. It also informed about the Reaction forces and Reaction Moments.

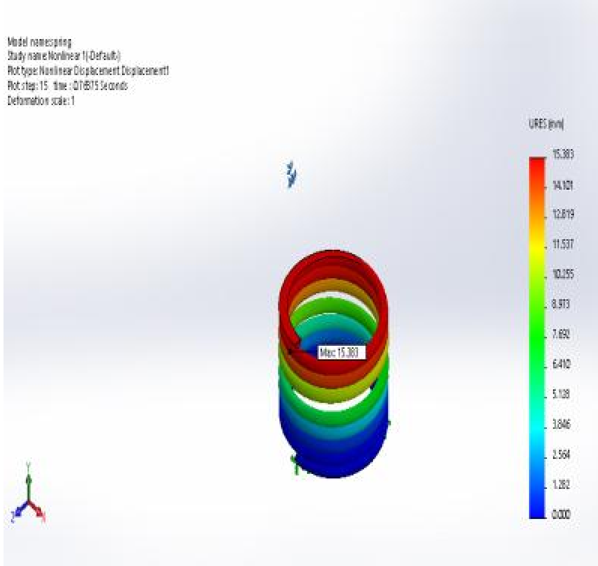



**Figure 10.Simulation result**

**Table 3.Mesh information**

| Mesh criteria | | Mesh information - Details | |
|---|---|---|---|
| Mesh type | Solid Mesh | Total Nodes | 73925 |
| Mesher Used: | Curvature-based mesh | Total Elements | 42104 |
| Jacobian points | 4 Points | Maximum Aspect Ratio | 17.111 |
| Maximum element size | 10 mm | % of elements with Aspect Ratio < 3 | 99.7 |
| Minimum element size | 0.5 mm | % of elements with Aspect Ratio > 10 | 0.00475 |
| Mesh Quality Plot | High | % of distorted elements (Jacobian) | 0 |
| | | Time to complete mesh(hh;mm;ss): | 0:00:06 |

**Table 4.Reaction forces**

| Selection set | Units | Sum X | Sum Y | Sum Z | Resultant |
|---|---|---|---|---|---|
| Entire Model | N | -1.82532e-007 | 7.68643e-006 | 2.01908e-007 | 7.69124e-006 |

**Table 5.Reaction Moments**

| Selection set | Units | Sum X | Sum Y | Sum Z | Resultant |
|---|---|---|---|---|---|
| Entire Model | N.m | 0 | 0 | 0 | 0 |

## Stress Strain curves

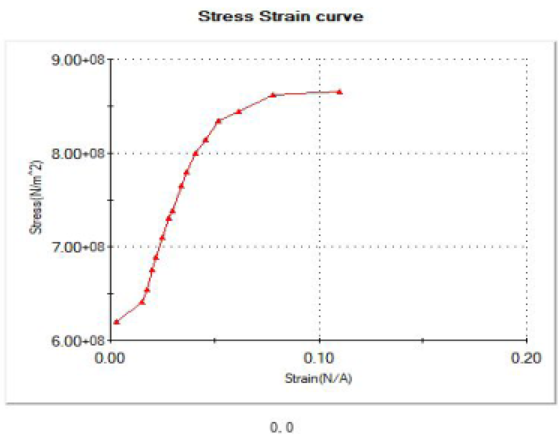



Figure 11.Stress-strain curve

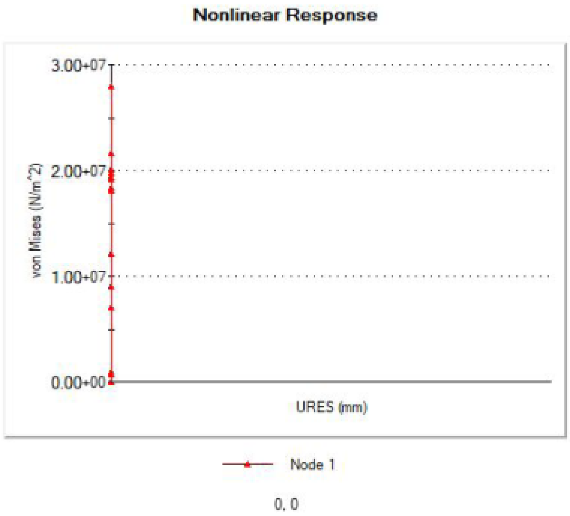
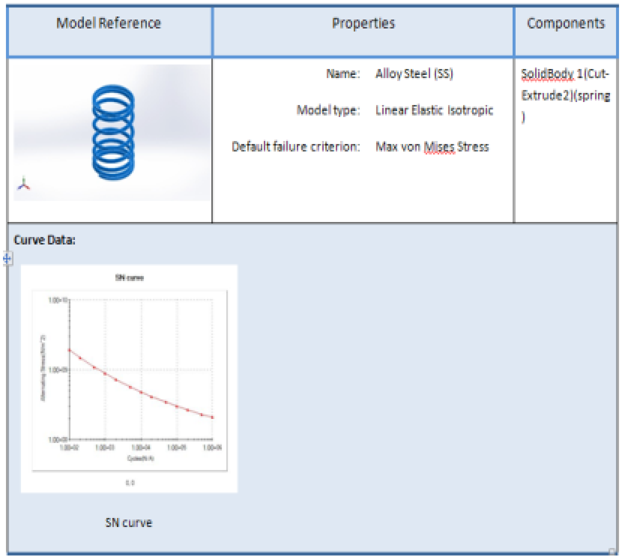



Figure 12.Nonlinear curve



| Model Reference | Properties | Components |
|---|---|---|
| | Name: Alloy Steel (SS)<br>Model type: Linear Elastic Isotropic<br>Default failure criterion: Max von Mises Stress | SolidBody 1(Cut-Extrude2)(spring) |
| Curve Data: SN curve | | |

Figure 13.Material properties

## Fatique Result

The stiffness is defined as the load per unit deflection in order to take into account the effect of direct shear and change in coil curvature a stress factor.

Material properties showed the properties with model reference and components also mentioned.

Loading Options was divided into the no. of events As shown in table no. 4.

**Table 6.Loading Options**

| Event Name | No. of cycles | Loading Type | Study Association | | |
|---|---|---|---|---|---|
| | | | Study name | Scale Factor | Step |
| Event-1 | 1000 | Fully Reversed (LR=-1) | Nonlinear 1 | 1 | 1 |
| Event-2 | 500000 | Fully Reversed (LR=-1) | Nonlinear 1 | 1 | 1 |
| Event-3 | 50000 | Fully Reversed (LR=-1) | Nonlinear 1 | 1 | 1 |
| Event-4 | 200000 | Fully Reversed (LR=-1) | Nonlinear 1 | 1 | 1 |

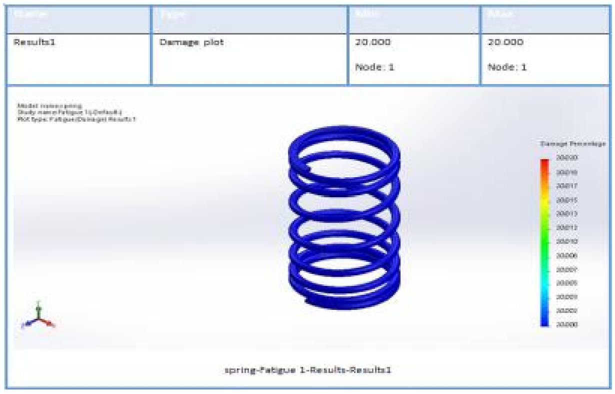



Figure 14.Study result first

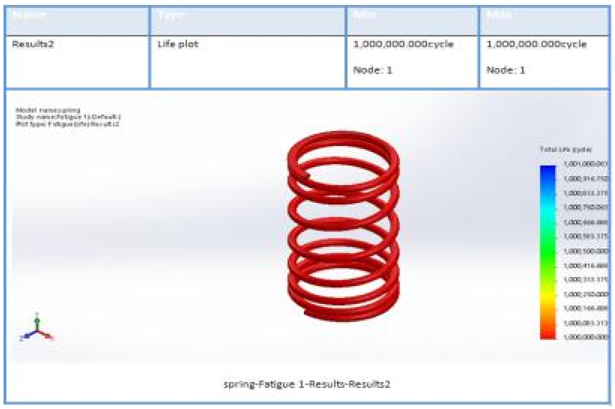



Figure 15.Study result second

## Conclusion

The design of spring steel (51CrV4) and alloy steel (ss) springs were done at centre of resting plate which was made of mild steel for the single spring , dual springs and triple springs. The fatigue test was performed on alloy steel (ss) at different load with the help of Solid works software (Version-2017). Before the fatigue analysis/ results the Nonlinear simulation analysis is also considered. The fatigue results starts from 5N, 20N, 50N and 100N are discussed.

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