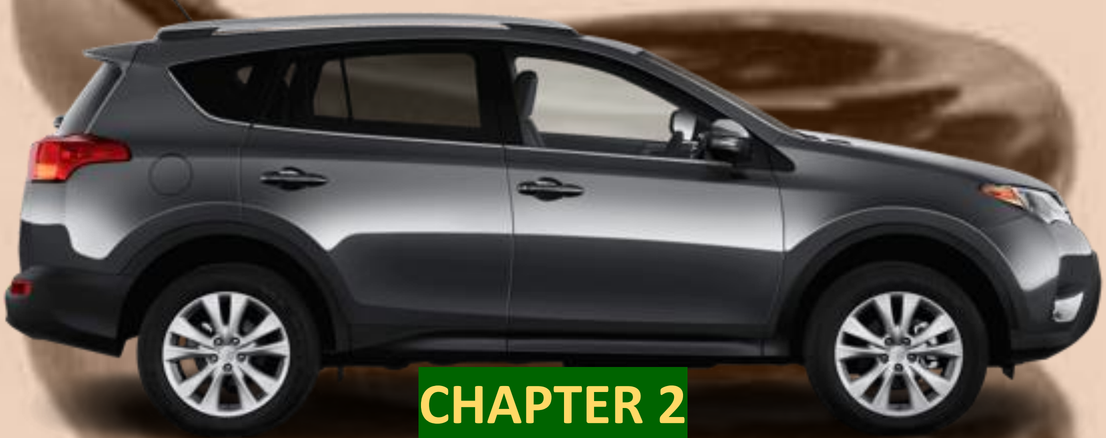
# PROJECT 2
# FATIGUE ANALYSIS OF HELICAL COIL COMPRESSION SPRING FROM TOYOTA RAV4 XLE 2015



## CHAPTER 2
## Dimensions, Material, and Environment Conditions

PRANAV MOHAN

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# Chapter 2: Dimensions, Materials, and Environmental Conditions

In this chapter, we are concerned with finding the different dimensions of the helical coil compression spring, considering the various material properties also.

## Section 2.1: Geometry and Dimensions

As mentioned in the title, the mechanical component we are interested in this book is the helical coil compression spring. This is a relatively simple mechanical component and is similar to the springs we see in day to day life. However, it has a much higher spring constant, which allows it to take the weight of the whole car, that is, thousands of pounds of weight. Finding out the basic parameters are crucial to our understanding of the spring and further carrying out the fatigue analysis carried out later in the book.

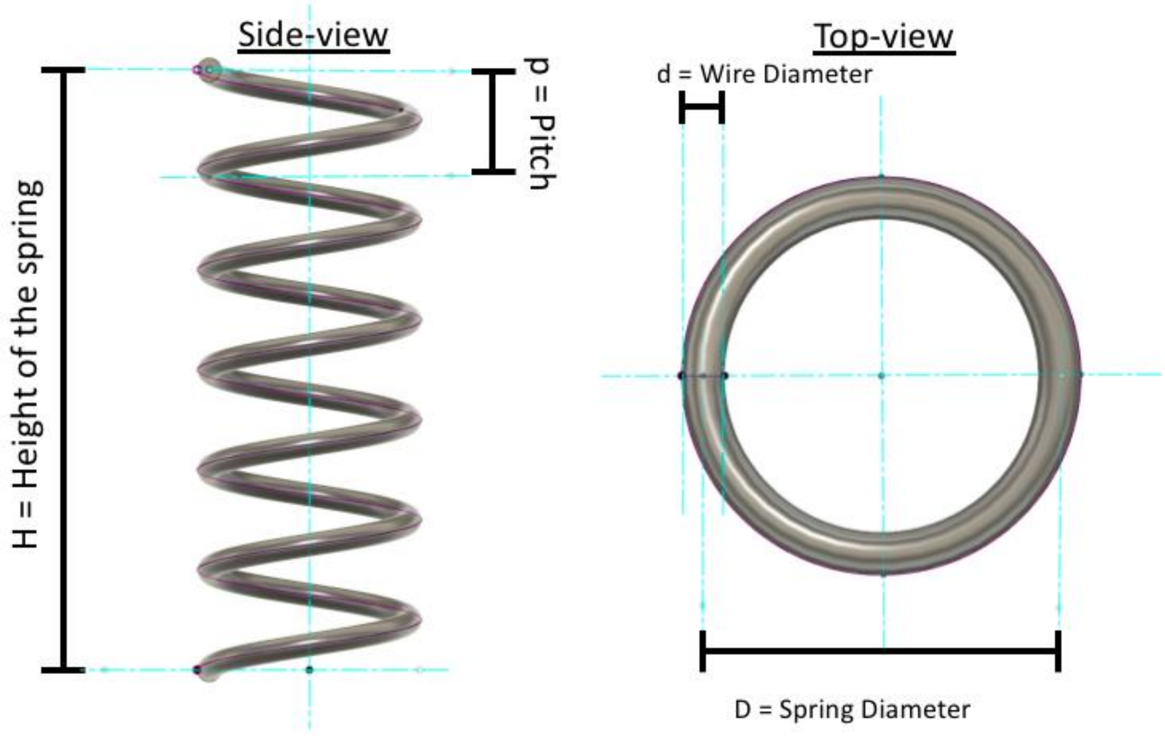
These springs have to be standardised for safety issues. For example, the wire diameter, the spring constant, or the diameter of the complete spring has to be standardised to a certain extent. This is also so that when the consumers purchase the product, they can be more confident in the product they are buying. For this customer satisfaction, American Society of Testing and Materials (ASTM) have developed a set of instructions that if the material is going to be ASTM tested, then it must have some exact properties. This ensures that the customers can purchase standardised and trustworthy products, which in our case is helical coil compression spring.

The picture below shows a picture of the helical coil compression spring placed on a white mat that we are analysing.

Figure 2.1-1: Helical Coil Compression Spring

Since the spring has a very simple structure, we only need to measure very few parameters. The very first parameter of concern is the number of complete turns the wire goes through the whole spring. Looking at the Figure 2.1-1, we can count it to be 6. We have to be sure that we are counting a complete circle, and not just the half of the spring at the ends.

As mentioned in section 1.1 that the springs follow the Hooke's law. Therefore, we are concerned with the unstretched length (H) or the height of the spring. We have built a Figure 2.1-*2* to come up with a replica of the exact spring with exact dimensions. This model is developed on AutoCAD Fusion 360.[i] For the spring measurements, we can use a ruler or a tape. Please refer to Figure 2.1-2-a to measure these. We measure it from the centre of the wire from the top to the centre of the wire at the bottom. This value is 381 mm or 0.381m in metric units, which is 15 inches in English units. When forces act on the spring, numerous moments act on it. Therefore, in order to carry out these calculations later, we must know the diameter of the wire and of the spring. The diameter of the spring is measured from the centre of the outside wire to the centre of the opposite sides. This measurement is shown in the Figure 2.1-2-b. The diameter of the spring (D) is 127mm or 0.127m, which is 5 inches. The blue guided axis lines help in making these measurements. Similarly, the wire diameter is measured and to be 15.84 mm or 0.01584mm, which is 0.6 inches. Once again, these have been measured using these guided blue lines.




a. b.

Figure 2.1-2: Side and Top of view of the spring

We counted that there are six total coils in the spring. Finding the pitch of the spring is hard because we do not know exactly the where the spring revolves into just once. Also, realistically, the pitch is not constant between all revolutions. We must make an approximation. Therefore, we will approximate that to be the total length divided by 6 to find the average value of the pitch using Equation 2.1.

$$P = \frac{H}{6} = \frac{0.381\text{m}}{6} = 0.0635\text{m} = 2.5\text{ in} \qquad \text{Equation 2.1}$$

Therefore, we have found that the pitch (P) of the spring is 0.635m or 2.5 in, from the above calculation. Another important that constant that we need to find to carry out the analysis is the ratio of the spring diameter to the coil diameter. This constant helps in quantifying the real thickness of the spring.

$$C = \frac{D}{d} = \frac{0.0127\text{mm}}{0.001524\text{mm}} = \frac{25}{3} \qquad \text{Equation 2.2}$$

Finally, the most important factor we require is the spring constant (k). This has been provided in the project requirement to be 43781.71 $\frac{N}{m}$ or 250 $\frac{\text{lbs}}{\text{in}}$.[ii] We have provided numerous parameters, therefore, we will summarise them all in the following Table 2.1-1.

**Table 2.1-1: Geometric dimensions of helical coil compression spring**

| Notation | Parameter | Value | Metric Units | Value | English Units |
|---|---|---|---|---|---|
| N | Number of turns | 6 | None | 6 | None |
| D | Coil diameter | 0.127 | m | 5 | In. |
| D | Wire diameter | 0.01524 | m | 0.6 | In. |
| H | Coil height | 0.381 | m | 15.0 | in |
| P | Coil pitch | 0.0635 | m | 2.5 | in |
| C | Ratio of diameters: coil/wire | 25/3 | none | 25/3 | none |
| K | Spring constant | 43781.71 | N/m | 250 | Lbs./in. |

## Section 2.2: Materials

The project description makes it compulsory to use the above specified string. In the instructions, it has been mentioned that it is a chromium silicon steel with ASTM A-401 strength mechanical properties.[ii] This specification allows us to extract numerous properties from the specified standard. This is the standard section 2.1 was talking about which is able to generalize numerous large properties and bring them together through the standards created by ASTM – not just in terms of measurement techniques, but also in terms of bring the properties of different materials together.

ASTM mentions that chromium-silicon alloy steel spring wire is by far the best one to use in terms of managing fatigue stresses and working in elevated temperatures.[iii] The chemical composition of chromium silicon steel is given in the Table 2.2-1 below:

**Table 2.2-1: Chemical composition of Chromium-silicon steel**

| Property | Ranges and Limits |
|---|---|
| Carbon, C | 0.51 – 0.59% |
| Manganese, Mn | 0.60 – 0.80% |
| Phosphorus, max, P | 0.035% |
| Sulphur, max | 0.040% |
| Silicon, Si | 1.20 – 1.60% |
| Chromium, Cr | 0.60 – 0.80% |
| Iron, Fe | 98.51 – 98.48% |

For most cars, the normal operating engineer temperature is in a range of 195 to 220°F or 90 to 104°C.[iv] These temperatures might seem to be very high but they are only small fractions in comparison to the melting points of the above listed compositions. Also, the hottest temperature on earth is to a max of 64°C, therefore, we will assume that the car is in the range of operation of the

Chromium-silicon steel spring.[v] Besides these, the spring is also exposed to a lot of dust that lifts from the roads and forms a layer on top of the spring. The dust may include particles ranging from soil to salt particles, or water, or corrosives. It is expected out of the spring to be able to withstand such environments. Similarly, since it is not dissolvable in water, it can withstand very high humidity near the equator also. Toyota cars are sold in extreme weathers like Libya and Niger, and also in Russia and Greenland. Similarly, Toyota cars are also sold in sea-side cities and also in extreme humidity.[vi] There was no information available for potential galvanic cell conditions for the lug stud.

## Section 2.3: Material Properties

As mentioned above, the helical coil compression spring is made of is Chromium-Silicon alloy steel. In this section, we will cover the various properties for the helical coil compression spring. The following list presents the various definition of the parameters we are going to define.

1. $S_u$ = Ultimate Tensile Stress – This is the maximum axial stress a material can take when it is elongated without breaking.[vii] In the stress-strain curve, this is the stress at the maximum point.
2. $S_{us}$ = Ultimate Shear Stress – This is the maximum shear stress a material can take when it is elongated without breaking. In the shear stress-strain curve, this is the shear stress at the maximum point.
3. $S_y$ = Tensile Yield Stress – This is the material property defined as the axial stress at which a material begins to deform plastically.[viii] In the stress-strain curve, this is the stress when the linear relationship at the beginning stops.
4. $S_{ys}$ = Shear Yield Stress - is the material property defined as the shear stress at which a material begins to deform plastically. In the shear stress-strain curve, this is the shear stress when the linear relationship at the beginning stops.
5. E = Modulus of elasticity – This is a number that measures an object or substance's resistance to being deformed elastically (i.e., non-permanently) when a stress is applied to it.[ix] In the stress-strain curve, this is the slope of the linear relationship curve at the beginning.
6. G = Shear Modulus – This is defined as the ratio of shear stress to the shear strain.[x]
7. v = Poisson Ratio – This is the signed ratio of transverse strain to axial strain.[xi] When an object strains on one side but compresses on the other side, the poisson ratio describes the change in length in different directions.
8. C = Reduction of Area – When fasteners undergo mechanical testing, they are pulled to failure and the diameter of the point at which the fastener breaks is measured and compared to the original diameter.[xii] This ratio represented in terms of percentage is C.
9. B = Bulk Modulus – This determines how much an object will compress under a given amount of external pressure. The ratio of the change in pressure to the fractional volume compression is called the bulk modulus of the material.[xiii]
10. ρ = Density – The volumetric mass density, of a substance is its mass per unit volume.[xiv]
11. $T_{max}$ = Maximum temperature – Maximum operational temperature of the material identified.
12. α = Thermal Conductivity – The degree to which a specified material conducts electricity, calculated as the ratio of the current density in the material to the electric field that causes the flow of current. It is the reciprocal of the resistivity.[xv]

All the above twelve parameters are extremely crucial to our understanding of the chromium-silicon steel, and therefore, in turn of understanding the helical coil compression spring. Using the above-mentioned parameters, we can decipher the fatigue properties of the string and following that, carry out a fatigue model using numerous available literature models.

**Table 2.3-1: Material properties of the helical coil compression spring**

| Serial Number | Parameter | Value | Metric Units | Value | English Units |
|---|---|---|---|---|---|
| **1** | Ultimate Tensile Stress ($S_u$) | 1600 | MPa | 232.06 | ksi |
| **2** | Ultimate Shear Stress ($S_{us}$) | 1280 | MPa | 185.65 | Ksi |
| **3** | Tensile Yield Stress ($S_y$) | 1440 | MPa | 208.85 | ksi |
| **4** | Shear Yield Stress ($S_{ys}$) | 831 | MPa | 120.58 | ksi |
| **5** | Modulus of Elasticity (E) | 200 | GPa | 29,007.55 | ksi |
| **6** | Shear Modulus (G) | 80 | GPa | 11,603.02 | ksi |
| **7** | Poisson Ratio (v) | 0.29 | None | 0.29 | None |
| **8** | Reduction of Area (C) | 30 | % | 30 | % |
| **9** | Bulk Modulus (B) | 200 | GPa | 29000 | Ksi |
| **10** | Density (ρ) | 7860 | $Kg/m^3$ | 0.284 | $Lb/in^3$ |
| **11** | Maximum temperature ($T_{max}$) | 245 | °C | 475 | °F |
| **12** | Thermal Conductivity (α) | 52.0 | W/m-K | 361 | BTU-in/hr-ft²-°F |

Using the above values, we conclude that the spring is safe to use in very humid conditions, since the density (10) is much higher than water, and the dissolvability is low. Similarly, the maximum operating temperature (11) is 245°C, which is much higher than the highest temperature on the earth. The Chromium-Steel alloy is very robust in terms of reacting to various acids and water.[xvi]

## Section 2.4: Table of Data

**Table 2.4-1: Dimensions and the mechanical properties of the spring**

| Notation | Parameter | Value | Metric Units | Value | English Units |
|---|---|---|---|---|---|
| N | Number of turns | 6 | None | 6 | None |
| D | Coil diameter | 0.127 | m | 5 | In. |
| D | Wire diameter | 0.01524 | m | 0.6 | In. |
| H | Coil height | 0.381 | m | 15.0 | in |
| P | Coil pitch | 0.0635 | m | 2.5 | in |
| C | Ratio of diameters: coil/wire | 25/3 | none | 25/3 | none |
| K | Spring constant | 43781.71 | N/m | 250 | Lbs./in. |
| ($S_u$) | Ultimate Tensile Stress | 1600 | MPa | 232.06 | ksi |
| ($S_{us}$) | Ultimate Shear Stress | 1280 | MPa | 185.65 | Ksi |
| ($S_y$) | Tensile Yield Stress | 1440 | MPa | 208.85 | ksi |
| ($S_{ys}$) | Shear Yield Stress | 831 | MPa | 120.58 | ksi |
| (E) | Modulus of Elasticity | 200 | GPa | 29,007.55 | ksi |
| (G) | Shear Modulus | 80 | GPa | 11,603.02 | ksi |
| (v) | Poisson Ratio | 0.29 | None | 0.29 | None |
| (C) | Reduction of Area | 30 | % | 30 | % |
| (B) | Bulk Modulus | 200 | GPa | 29000 | Ksi |
| (ρ) | Density | 7860 | $Kg/m^3$ | 0.284 | $Lb/in^3$ |
| ($T_{max}$) | Maximum temperature | 245 | °C | 475 | °F |
| (α) | Thermal Conductivity | 52.0 | W/m-K | 361 | BTU-in/hr-ft²-°F |

**Table 2.4-2: Chemical Composition of the Chromium-Silicon steel**

| Property | Ranges and Limits |
|---|---|
| Carbon, C | 0.51 – 0.59% |
| Manganese, Mn | 0.60 – 0.80% |
| Phosphorus, max, P | 0.035% |
| Sulphur, max | 0.040% |
| Silicon, Si | 1.20 – 1.60% |
| Chromium, Cr | 0.60 – 0.80% |
| Iron, Fe | 98.51 – 98.48% |

## Section 2.5: Reference

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## Section 2.6: Level of Effort

To put this report together, I spent around 15 hours working on this chapter 2.