Spring design for a vehicle suspension.

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Abstract. Springs carry out an important role in structures, machines, engines and vehicles, the vehicle suspension is modelled like a mass spring damper system it is fundamental in vehicle projects because the suspension is responsible to absorb the hits of the contact with the ground, so a spring at the suspension is so important for stability and comfort to the driver. The spring used in a car's suspension is of kind helical compression because it absorbs energy when it is compressed or extended. Due to a lot of application of springs, there are tables with many materials, where each material is indicated impact loads, fatigue loads, static loads and high temperature, for example, the spring design needs the correct material, otherwise, the spring will fail, besides is necessary to access tables to get standard value, because is cheaper to use standard values of parameters, otherwise is necessary to manufacture an unique part for the design. Is necessary to define spring index, Wahl factor (Kw), and transverse shear factor (Ks), these parameters are essential to design a spring and were used an iterative process to get the wire diameter of the spring. Therefore, is necessary to consult tables to choose the correct material and to choose the correct standard wire diameter, besides is necessary to use an iterative method to get the wire diameter.

Keywords. Spring stability, dynamic load, helical compression spring, stiffness, iterative method.

Introduction

Springs is used in many engineering designs such as vehicles, motorcycles and aircrafts, there are many others projects that use springs. The springs is projected to reduce impacts, noises, return something to your initial position and it is very studied at mechanical vibrations, the system spring mass damper is the most famous. To project a spring is necessary to consult tables and use softwares to get accurate results. There are some types of springs like helical compression spring, helical extension spring, torsion spring, spring belt and multileaf spring, but in vehicle's designs, is used helical compression spring and multileaf spring, the last is more common in trucks and pickup trucks, therefore multileaf spring is used only heavy vehicles, in this case the focus is helical compression spring. Besides, the springs can absorb energy and later released in form of deflections.

Currently, the springs is made of steels and metal alloys, but they not necessarily made of metal, there are springs made of plastics, but your application is only with light loads. The material is very important, because it determines what kind of load the spring will support, besides there are springs heat treated, hardened treated, quenching and temperate.

The spring's material is chosen based on the load type, and the material is one of most important parameters of the spring. The safety factor always is chosen by the designer and to choose a value is necessary to evaluate all conditions to which the spring will be subjected, for example, if the value is equals 3, therefore, the project there are three less chance to fail, but the design will be more expensive, i.e as higher the safety factor higher will be the final cost of the design.

Methodology

First of all, was defined the material of the spring, the spring is subjected to dynamic loads so the more adequated material is ASTM A232, because it is endurance with shock loads and fatigue loads, since the spring is subjected to a dynamic load.

Defined the material, the next step is to define the spring index (C), this index is the division between the mean diameter (D) and diameter of the spring wire (d), the ideal range for spring index is between 4 and 12, so as there are not both diameters, the wire and mean diameter, the index going be the middle value of the range, therefore, spring index is equal 8. Besides, there is another important parameter to define, this parameter is the safety factor (*Nf*) and this factor depends on the design and the risks, for example, if the design can not fail the safety factor is high. Besides, for steels the fatigue limit factor (*Sf*) is defined as 310 MPa, this is the standard value.

So is calculate the Transverse shear factor (*Ks*) and Wahl factor (*Kw*), the equations 1 and 2 shows as these parameters are calculated.

$$K_s = 1 + \frac{0.5}{C} \tag{1}$$

$$K_w = \frac{4C-1}{4C-4} + \frac{0.625}{C} \tag{2}$$

Then is calculated the average force and alternative force, because the load applied is dynamic, so below the equations 3 and 4 shows how to calculate these forces.

$$F_m = \frac{F_{max}+F_{min}}{2} \tag{3}$$

$$F_a = \frac{F_{max}-F_{min}}{2} \tag{4}$$

The wire diameter of the spring is calculated by numeric method, below the equation 5 shows the equation to calculate it.

$$d = \left\{\frac{8CN_f}{0,67\pi A} * \left[K_s * \left(F_m - \frac{N_f-1}{N_f} * F_{min}\right) + \left(1,34 * \frac{A}{S_f} d^b - 1\right) * K_w F_a\right]\right\}^{\frac{1}{b+2}} \tag{5}$$

As noted there are two diameters and one equation, so the system is indeterminate and because of this is necessary to use numeric methods to get de diameter.

Got the spring wire diameter is calculated the mean diameter (*D*), that parameter is multiplication between wire diameter (*d*) and spring index (*C*), as the equation 6 shows.

$$D = C * d \tag{6}$$

So, now, is possible to define the outer diameter (*Do*), this parameter is the sum of mean diameter (*D*) and wire diameter (*d*), as the equation 7 shows

$$D_o = d + D \tag{7}$$

Using Hook's law the spring stiffness (*k*) is calculated, this parameter is the division between the force applied and the deformation of spring, as equation 8 shows.

$$k = \frac{F_{max}-F_{min}}{y_w} \tag{8}$$

Obtained the wire spring diameter (d), spring stiffness (k) and mean diameter (D), is calculated the number of active turns (Na), this parameter shows the number of turns that work, equation 9 shows as to calculate the number of active turns.

$$N_a = \frac{d^4 G}{8D^3 k} \tag{9}$$

Analyzing the equation 9, there is a relationship between the number of active turns (Na) and spring stiffness (k), so is possible to calculate again the stiffness and this value is the real or design spring stiffness, as the equation 10 shows below.

$$k = \frac{d^4 G}{8D^3 N_a} \tag{10}$$

So, now, we will calculate the total number of turns, just sum the number of active turns with 2, the number 2 is used because is necessary to sum the upper and lower turns.

$$N = N_a + 2 \tag{11}$$

To calculate de initial deflection (*Yin*), is used the hook's law, where is realized a division of minimum force by the real stifness as shown the equation 12.

$$Y_{in} = \frac{F_{min}}{k} \tag{12}$$

Finaly the second to last step is calculate the spring free length (*Lf*), this parameter shows the spring work length, so this is very important to design because of the space where the spring will work. Below the equation shows how to calculate the free length.

$$L_f = d * N + 1.15 * Y_w + Y_{in} \tag{13}$$

The last step is calculate the spring stability (*Lf*)*cr*, for it is necessary to multiplicate the mean diameter (*D*) by 5.26. The equations below show how to calculate it.

$$L_f)cr = 5.26 * D \tag{14}$$

And if (*Lf*)*cr* is bigger than free length (*Lf*) the spring is stable.

$$L_f)cr > L_f \tag{15}$$

The equation 15 shown the condition for the spring be stable. Then all parameters to design a spring was determinate or calculate.The figure 1 shows the main parameters that composed a helical compression spring.

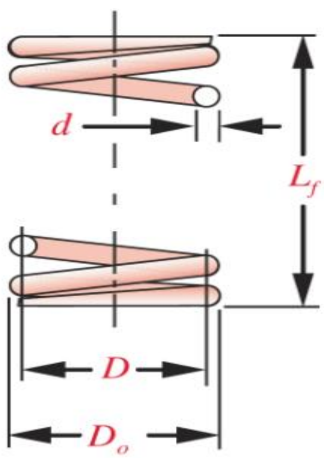

Fig. 1 – Main spring parameters

Results

First of all is knew the material chosen is ASTM A232, the table 1 shows the material and their properties.

Tab. 1 - Spring materials

Material	Composition	Special properties
ASTM A227	Hard drawn	Cold draw. Average stress aplication
ASTM A228	Music wire	Cold draw high and uniform tensile
ASTM A232	Chrome Vanadium	Cold draw, heat treated and used for shock loads

There are specific exponents and coefficients to calculate ultimate tensile strength, the table 2 shows each parameter for each material.

Tab. 2 - Parameters for materials

Material	b Exponent	A coeficient
ASTM A227	-0,1822	1753,3
ASTM A228	-0,1625	2153,5
ASTM A232	-0,1453	1909,9

Figure 2 shows the range of each material's diameter, so it is very important to consult this figure to adopt the correct standard diameter value.

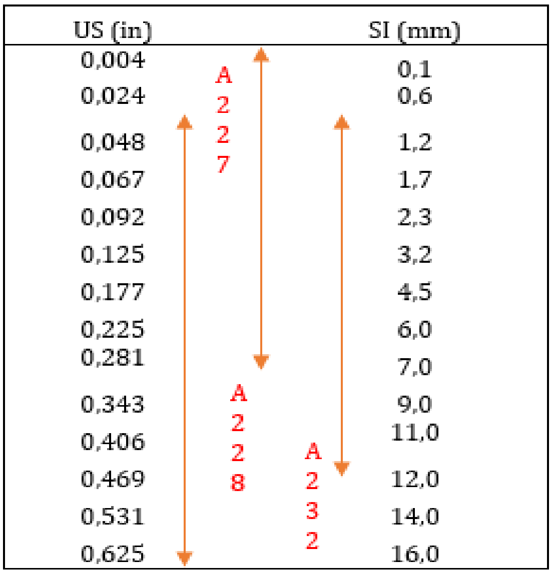

Fig. 2 - Standard diameters range

The vehicle's weight was measured and was defined the force which each spring is subjected and was supposed for the car's weight is distributed uniformly, so each spring is subjected ¼ of the total weight.

Design data:

Total wieght = 950 kg

Local weight = 215 kg

Maximum force = 2975 N

Minimum force = 2110 N

Spring index = 8.0

Safety factor= 2.0

Work deflection = 20 mm

Endurance limit = 310 MPa

Shear modulus of steel = 80.8 GPa

So is possible to calculate mean and alternative forces:

$$F_m = \frac{2975 + 2110}{2} = 2542.5\ N$$

$$F_a = \frac{2975 - 2110}{2} = 432.5\ N$$

Now is calculate the transverse shear factor

$$k_s = 1 + \frac{0.5}{8} = 1.0625$$

Calculus of Wahl factor

$$k_w = \frac{4*8-1}{4*8-4} + \frac{0.625}{8} = 1.1853$$

Now will be calculate the wire diameter, this spring parameter is calculated using a numerical method as was explained, so the table 3 shows the iteration, estimate value and real value of the wire spring until the diameter value converge.

Tab. 3 - Iterative method to get the wire diameter

Iteration	Estimate value [mm]	Real value [mm]
1	5.0	16.03
2	16.03	15.08
3	15.08	15.13
4	15.13	15.13

So the wire diameter is 16 mm, why was chosen 16 mm?

Because always the designer must choose de commercial diameter.

Calculus of the mean diameter

$$D = 8 * 16 = 128\ mm$$

Now we will calculate the spring stiffness

$$k = \frac{2975 - 2110}{0.02} = 43250\ [N/m]$$

The number of active turns can be calculated.

$$N_a = \frac{(16x10^{-3})^4 * 80.8x10^9}{8 * (128x10^{-3})^3 * 43250} \cong 7.29\ turns$$

Therefore,

$$N_a = 8\ turns$$

With the number of active turns calculated, we will calculate the spring stiffness again, then.

$$k = \frac{(16x10^{-3})^4 * 80.8x10^9}{8 * (128x10^{-3})^3 * 8} \cong 39453\ [N/m]$$

This value is the real value of stiffness because it is improved and uses all turns in your calculus.

The initial deflection is calculated below.

$$y_{in} = \frac{2110}{39453} = 0.054\ m = 54\ mm$$

The outer diameter is calculated as shown below.

$$D_o = 16 + 128 = 144\ mm$$

Calculus of the total number of turns (N)

$$N = 8 + 2 = 10\ turns$$

All parameters necessary to calculate the spring free length was calculated earlier, so below the spring free length is calculated.

$$L_f = 16 * 10 + 1.15 * 20 + 54 = 237\ mm$$

Now is so important determine the spring's stability.

$$L_f)cr = 5.26 * 128 = 673.3\ mm$$

So, as spring critical free length $(L_f)cr)$ is bigger than spring free length we conclude the spring is stable.

Below we have the list of main parameters of spring design.

Material: **ASTM A232**

Wire diameter: **16 mm**

Outer diameter: **144 mm**

Total number of turns: **10 turns**

Free length: **237 mm**

Discussion

First of all, in desgn was chosen the spring's material, that is ASTM A232, was chosen because the spring is subjected a dynamics loads and there is the possibility of shock loads, therefore the spring is made with A232 to endure fatigue and shock loads. And about the factor of safety is equal two, i.e. the design has twice less percentage to failure, of course, the suspension of a vehicle can not fail and a safety security equal a two is great, but is necessary analyze the cost of the design, may is necessary to change some parameters to get near results, but a cheaper design. The shear modulus of steel is constant, but there are specific values for each material, but the error is minimum, so is common to adopt the standard value of 80.8 GPa, because it does not implicate big errors.

Table 1 shows some materials for spring design, but there are plenty of other materials that can be used, but is not necessary to input them. Table 2 shows the parameters and exponents to calculate the ultimate strength, and that parameters are fundamental to calculate the wire diameter, as is shown in equation 5.

An important parameter, wire diameter, was got through a numeric method, because there are two diameters and only one equation, according to equation 5, so was used iterative method to calculate the diameter, to begin the process is necessary to estimate an initial value and the process calculate a value with that initial value and the result is used in next step of the process, again, until the convergence result. Table 3 shows the number of the iteration, the estimated value and the calculated value, was necessary for 4 iterations to converge the wire diameter value.

The spring's stability is another important parameter, because it shows if the spring will or not fail, when the spring has a large free length and a small mean diameter there is a big chance of the spring buckling.

Analyzing figure 2, the ideal diameter range for A232 does not comprise the diameter equal to 16 mm, because your range is 0.7 mm until 12 mm, so why was chosen the diameter of 16 mm if the material goes until 12 mm?

Because the design was calculated and the spring is stable, besides from fatigue and shock loads A232 is cheaper than others materials.

So, why the A227 was not chosen for the project?

Because the material A227 is not appropriate to work when there are fatigue and shock loads, as is the vehicle's suspension.

What if the mateiral A227 was chosen?

The material A227 is appropriate just for static loads, therefore the spring will fail and the suspension will not work, besides the security of the vehicle will be compromised.

Conclusion

After to design a spring for a vehicle suspension, was shown the importance of the material choose, because if the material chosen was different, all parameter's values would be different too, so is necessary to analyze the design with big attention, for example to determinate the kind of load, if the design needs a compression or extension spring, therefore the initial analysis is very important to develop a good design.

The spring projected is stable as shown in section results, so the spring will not fail and there are five main spring's parameters that was shown in results section, with those parameters the spring can be manufactured.

The spring's design is fundamental during the project of car's suspension, that is responsible to reduce impacts absorbing energy as deflection.
Finally, the spring designed has 16 mm of wire diameter, 144 mm of mean diameter, a total of 10 turns and free length of 237 mm, the spring is stable, and these are the spring parameters for a vehicle's suspension.

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