OPTIMIZATION OF SUSPENSION CHARACTERISTIC OF A PUSHROD ACTUATED SUSPENSION SYSTEM OF AN FSAE CAR

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Abstract- Since ages, we are trying to find out how things behave. In this process, we started to design the mechanical system based on our knowledge of physics and mathematics. Here is an approach to relate physics and mathematics in engineering problems- of how to optimise the suspension characteristics of a FSAE car. Whenever the suspension geometry is under consideration, the spring and damper acts as the major systems and undergoes fatigue loading which includes many variables. All these variables are reduced to 3 main variables; Factor of safety, diameter of spring wire and motion ratio. Study shows that the ultimate strength of the wire and carbon content is related to the diameter of the spring wire. FOS is related to spring index in turn to the diameter of spring wire and the diameter of the spring is related to the number of coils. Spring rate and motion ratio defines the geometry of the suspension system. A surface fit is obtained between motion ratio, diameter of the wire and FOS by collecting the sampling points. By using Bi-variate interpolation methods, the 3D surface is obtained for the above parameters in x, y and z axis. The obtained surface is chopped off for any value of x, y, z in that particular plane. Mathematically, the intersection of two planes is always a line. This line will be the direct relation between the other two parameters excluding the cut/intersecting plane. Thus all the points in this line satisfy all the design consideration and thus an optimum solution is obtained.

Keywords- Bi-variate interpolation, carbon content, diameter of spring wire, Factor of safety, motion ratio, stiffness, Spring index, ultimate strength, Wheel travel, Wahl stress factor.

I. INTRODUCTION

The Formula SAE is a competition conducted by SAE where the main aim is to build and race formula cars under certain rules and regulations. The competitors undergo certain tests including virtual rounds where their respective designs are critiqued and whose viability is checked. The following problem is stated and the solution is scripted by taking into consideration all of the rules and regulations of the Formula SAE arena in building a car. The other reigning conditions of the car are taken into account and the simulations are carried out. The main parameter to be highlighted from the rulebook is that, the minimum bump and droop that the car must experience during analysis is 1 inch (25.4 mm), which means the minimum wheel travel is 2 inch (50.8mm).[1] The thesis provides a way for making a decision on the optimum wire diameter of the spring. Other parameters of the spring can be calculated from the diameter of the wire depending on the required and necessary conditions (parameters).

II. CONCEPT

Motion Ratio is defined as the ratio of shock travel and wheel travel. The spring actuates when the wheel moves up and down. The whole suspension characteristic depends on the spring rate i.e. stiffness of spring. The stiffness is a non- linear function of diameter of the spring which in turn depends on the motion ration. Thus the diameter of the spring also plays an important role in the optimisation of the system. Usually a motion ratio close to 1.0 is preferred in order to prevent the buckling of the suspension system due to bending moment. Practically it is arduous to get motion ratio equal to 1.0. Thus while designing the spring system it is very important to consider the force acted upon it by the suspension which is a function of motion ratio. Over or under designing the spring will enervate the whole suspension system.

The strength of the spring material depends on the diameter of the wire of the spring but it is blinkered most of the time. In order to overcome this, the relation between the diameter of the spring wire and the ultimate strength has been determined statistically (with 99.99% confidence bounds) from the data for each of the grades of cold drawn spring steel. On the close observation it can be noticed that, as the carbon content increases the strength increases under the limits. From the above relations, the fatigue analysis of the spring is done keeping the number of active coils and the spring index constant and variation of motion ratio and the diameter of the wire is monitored for FOS. Mathematically variation of the motion ratio with respect to FOS is taken as the front view and the variation of diameter of the wire is taken as the side view. Combination of these two curves can be done by bi-variate interpolation methods which gives the surface. The sampling points are chosen so as to reduce the sum of squares of errors in the interpolated system so that the surface can be used for the optimisation purpose.

A plot can be chopped off from any x, y ,z values in order to obtain the corresponding values of the surface fit.

III. DESCRIPTION

A pushrod actuated suspension system provides a better setup to achieve the calculated motion ratio. Also, motion ratio can be easily varied in a pushrod actuated suspension system. Motion ratio can be achieved by varying parameters such as pushrod length, pushrod placement, bell crank angle, bell crank lengths and placements of the spring and bell crank. Few parameters are pre-defined and the rest of the parameters are determined for a given motion ratio. One of the method for achieving motion ratio is explained below.

Initially, the mounting of the pushrod on the A-arm is determined after analysing the stress concentration at the point of mounting. Then the chassis mounts for the spring and bell crank are chosen making sure that the whole setup appears on a single plane. Now, the unknown parameters are the bell crank, bell crank lengths and pushrod length is constrained by choosing suitable values and the bell crank lengths vary until the required motion ratio is achieved. If a situation demands for a change in motion ratio, then it can be achieved by providing extra pushrod mounting points on the bell crank.

In this paper achieving the motion ratio is not given importance but after achieving the motion ratio the choosing of spring is given importance.

There are few specific properties which has lead us to come up with this kind of optimisation:[3],[4],[5]

- Fatigue load acting on the spring is always pulsating.
- Yield strength of the spring material depends on the diameter of the spring wire.
- The bending and direct stress acting on the spring will be added by introducing Wahl's stress factor.

Relation between diameter of wire, carbon content and the ultimate strength has been derived from the statistical data available in [2] Data Hand book is shown below. While deriving the relation, a statistical software Minitab has been used to get the regression curve of 99.99% confidence interval .

Grade 1:

Carbon – 0.50% - 0.75 % [2]
Silicon – 0.15% - 0.35%
Manganese – 1.00%
Copper- 0.120 %

The equation for this grade is found to be

σ_{ut}=1733-166.8d+12.80d^2-0.3699d^3 (1)

Grade 2:

The grade2 Spring Steel has the following properties:[2]

Carbon – 0.60%-0.85%
Silicon – 0.15%-0.35%
Manganese – 0.80%
Copper- 0.120%

The relation between ultimate tensile strength and diameter of wire is found out .The equation is as follows:

σ_{ut}=2097-208.d+15.29d^2-0.4195d^3 (2)

Grade 3:

Spring steel has following properties[2]

Carbon – 0.75%-1.00%
Silicon – 0.15%-0.35%
Manganese – 0.80%
Copper- 0.120%

The relation between the ultimate tensile strength and diameter of the wire is found to be.

σ_{ut}=2490-272.3d+21.38d^2-0.6025d^3 (3)

Grade 4:

Spring steel has following properties[2]

Carbon – 0.75%-1.10%
Silicon – 0.15%-0.35%
Manganese – 0.80%
Copper- 0.120%

The relation between ultimate tensile strength and diameter of wire is found to be

σ_{ut}=2699-301.9d+25.10d^2-0.7343d^3 (4)

On plotting all four equation in the single graph as shown in the Fig 1.0, the following important relations can be derived.

- As the carbon content increases, the graph tends to move up i.e. the yield strength increases.
- As the diameter of the spring wire increases the yield strength decreases.

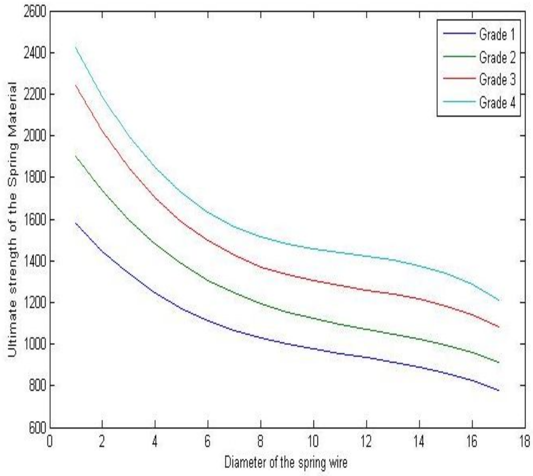

Fig 1.0 :Graph between Dia of spring wire and ultimate strength

Reduction to three variable form

By using empirical relations, the problem is reduced to three variable form:

- Diameter of the wire is related to spring index and diameter of spring wire.
- Stiffness of the system is related to diameter of the wire.
- Active number of coils are kept constant.
- As the motion ratio changes the force, both are related based upon the angle made by the spring with push rod.
- Free length is calculated based on the deflection and pitch in turn diameter of the wire.

A excel programming has been done and a part of the sample(one of the sample taken for MR=0.5 and wire diameter =10m for grade 1 spring steel) shown in the Fig 2.0 [6],[7],[8],[9]

	A	B	C
1	**Variables**	**Value**	**Unit**
2	**Motion Ratio**	**0.5**	
3	**Diamater of spring wire (d)**	**10**	**mm**
4	Spring Index(C)	7	
5	No of coils(N)	10	
6	**Modulus of rigidity, G**	80000	Mpa
7			
8	**From Relation**		
9	Stress		
10	Ultimate Yeild Stregth(Su)	1455.7	Mpa
11	endurance Stress(Sse)	305.697	Mpa
12	Yeild Stress(Sy)	611.394	Mpa
13			
14	**outputs**		
15	Force(max)	955	N
16	Wahl Stress Factor(k)	1.212857143	
17	Wahlfactor (Ks)	1.071428571	
18	Amplitude force(Fa)	477.5	N
19	Mean Force(fm)	477.5	N
20	Shear St (tm)	91.19578239	
21	Shear Stress(ta)	103.2336257	Mpa
22	**factor of safety**	**1.525066337**	
23	Diameter of Spring	70	mm
24	Spring stiffness	29.15451895	
25	deflection	32.7565	mm
26	Free Length	137.2565	mm

Form the programming, the sampling points (co-ordinates for the surface) is collected as shown in Fig 3.0, even though 9 to 16 points are good enough to plot the curve, we have considered 30 points to increase the accuracy of the method.

Grade--1					
FOS	**d**				
MR	**10**	**12**	**14**	**16**	**18**
1	0.51078	0.70559	0.9154	1.10751	1.2229
0.9	0.56754	0.78399	1.01711	1.23057	1.35878
0.8	0.63848	0.88199	1.14425	1.38439	1.52863
0.7	0.72969	1.00799	1.30771	1.58216	1.747
0.6	0.8513	1.17598	1.52566	1.84585	2.03817
0.5	1.021	1.41118	1.8308	2.215	2.4458

IV. SURFACE PLOT

Bi-variate interpolation method is an effective tool that can be used to find the equation of the sampling points which fits in the sampling model and the same can be interpolated or extrapolated using the same equation. The collection of sampling points can be either done by collecting the diagonal lines of the surface or edges of the surface. From this method, a plot has been made keeping diameter of the spring wire in the x axis,motion ratio in the y axis and the FOS in the z- axis as shown in Fig 4.0 and Fig 5.0.

Surface Equation

Grade 1:

$$f(x,y) = -0.5656 + 0.3757*d-2.867*MR -0.003842*d^2 -0.1882*d*MR + 2.48*MR^2 \quad (5)$$

Goodness of fit of equation (5) is measured by analysing Sum of Squares of Error (SSE) whose value is found out as 0.05238, Adjusted R-Square value is 0.9911 and Root Mean square error is found to be 0.04672 which has a confidence bounds of 99.11%.

Grade 2:

$$f(x,y) = -0.5534 + 0.4061*d -3.221*MR - 0.003167*d^2 -0.216*d*MR + 2.809*MR^2 \quad (6)$$

Goodness of fit of equation (6) is measured by analysing Sum of Squares of Error (SSE) whose value is found out as 0.03026, Adjusted R-Square value is 0.9963 and Root Mean square error is found to be 0.03551 which has a confidence bounds of 99.63%.

Grade 3:

$$f(x,y) = -0.5739 + 0.4774*d -3.899*MR - 0.004143*d^2 -0.2403*d*MR + 3.229*MR^2 \quad (7)$$

Goodness of fit for equation (7) is measured by analysing Sum of Squares of Error (SSE) whose value is found out as 0.08012, Adjusted R-Square value is 0.9929 and Root Mean square error is found to be 0.05778 which has a confidence bounds of 99.29%

Grade 4:

$$f(x,y) = -1.434+ 0.641*d -4.244*MR -0.00794*d^2 - 0.2846*d*MR + 3.696*MR^2 \quad (8)$$

Goodness of fit for equation (8) is measured by analysing Sum of Squares of Error (SSE) whose value is found out as 0.007665, Adjusted R-Square value is 0.9947 and Root Mean square error is found to be 0.05651 which has a confidence bounds of 99.47%.

V. SURFACE PLOT

From the above equation, the graph has been plotted to analyse the system by using Matlab. The plot contains four layers of the surface each representing each grade as shown in Fig 4.0 and Fig 5.0. The lower the grade, the lower is the plot position. The whole graph can be intersected by any value of FOS or MR or diameter of the spring wire to get the relation between other two values.

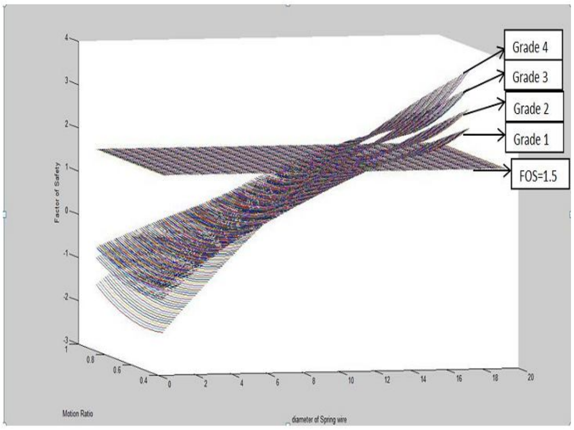

Fig 4.0 :Surface plot for the equations

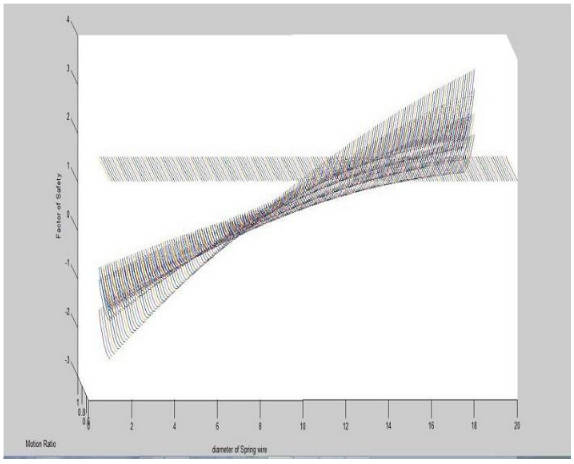

Fig 5.0 : surface plot for the equation and intercepting equation

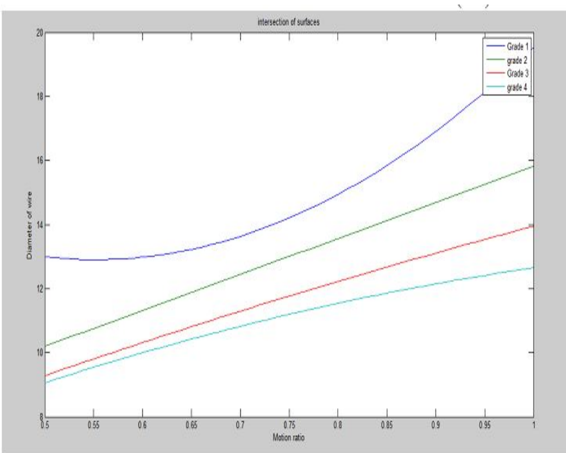

Fig 6.0: Final intersection of FOS=1.25 and surface plots.

CONCLUSION

From the graph it is clear that as the carbon content increases (grade increases), the surface tries to shift upwards. Four surfaces indicate the four grades of spring steel wire. By intersecting the FOS=1.25 surface with the grades surface, it has been observed that the graph intersects and lives a intersecting line in each and every surface thus giving the optimum solution. Here for an example, the whole graph is chopped off for the value of the FOS=1.25, the results observed is shown in the equation (9), (10), (11), (12): the plot has been observed in Fig 6.0

$$d1= 22.87-36.18*MR+32.81*MR^2 \quad (9)$$

$$d2= 4.614+11.14+0.064*MR^2 \quad (10)$$

$$d3=3.4+13MR-2.454*MR^2 \quad (11)$$

$$d4= 2.723+15.43*MR-5.507*MR^2 \quad (12)$$

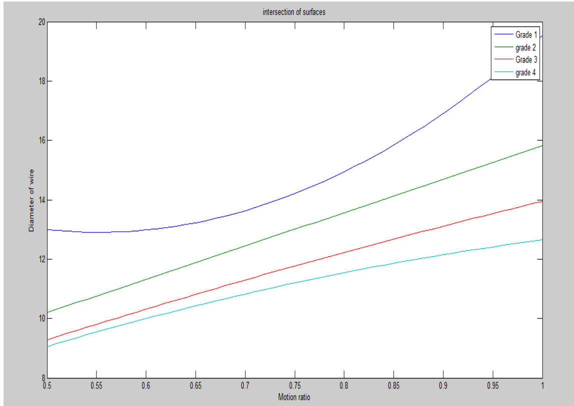

Fig 6.0: Final intersection of FOS=1.25 and surface plots

CONCLUSION

From the above graphs we can conclude that as the carbon content increases, the ultimate strength increases till it reaches a limit. As the diameter decreases, the ultimate strength of the spring increases. As we vary the carbon content in order to obtain the 3D surface, the surface moves upward as the carbon content increases. The optimum curve also shifts upwards as the carbon content (grades) increases.

In this paper we have tried to give new optimisation method which can be applied to any system. The surface plot gives the relation between the selected variables and the chopping can be done by any selected variable (in this paper, FOS). Thus the curve obtained is the optimum curve which satisfies all the design consideration.

ACKNOWLEDGMENTS

I would like to thank Prof Dr N R Shetty , Director of NMIT for providing us with the facilities for successfully carrying out the paper research and its related activities. I would also like to thank the Dean of Academics, Dr Ranganath Shetty and Dr Kiran Aithal , HOD of Mechanical Department for constant moral support and appreciation for the work being carried out . I would even like to extend my gratitude towards Dr H V Nagaraj, Principal , NMIT.

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