Structural and magnetic analysis of electro-magnetic suspension spring

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Abstract. Suspension is the term given to the arrangement of springs, shock absorbers and linkages that interfaces a vehicle to its wheels. Unlike conventional suspension systems that smother the vibrations by scattering the vibration energy into waste heat, the regenerative suspension with vitality reaping shock absorbers can change over the generally squandered vitality into electricity. Thus in this work, designing of the suspension spring for Hero Splendor Plus bike by applying Nimonic 80A material. Specifically, it focuses on a static and dynamic study of the suspension spring. This framework uses electromagnets as inactive dampers, which is utilized to lessen displacement and acceleration of spring mass so as to enhance drive ease.

1. Introduction

Energy collecting from the shock absorbers is directly transforming into a huge advancement in the structure up the electrical vehicles. As per the degree of controllability, suspension systems are delegated passive, semi-active, and active suspension systems. The passive suspension frameworks are intended to scattered vibration vitality through liquid or dry friction, and they take advantage of financial worth and straightforwardness. As a rule, the framework is comprising of springs and single or twin-tube dampers. Semi-active suspension framework exploits changing the damping power by outer power when vehicle experience different road irregular inputs. Active suspension framework depends on outer capacity to disengage the vehicle body from ground. The presentation of active suspension framework utilizing input control is absolutely remarkable. In active suspension framework, an actuator goes about as the outside power to stifle the vibration

Regenerative suspensions with the vitality reaping shock absorber have increased colossal consideration in a previous couple of years as promising bearings in-vehicle inquire about in view of its capability to empower the suspension framework giving upgraded dynamic execution as well as changing over the wasted vibration vitality to power.
Zhang et al. [1] demonstrated an original aberrant drive regenerative shock absorber framework that uses an arm-teeth component to accomplish direct to turning movement change and to enhance its input speed for expanding vitality gathering yield. Quadri et al. [2] designed the suspension spring for two different bike models i.e. splendor and TVS by applying three materials Nimonic 80-A, High Carbon Steel, Inconel analysis is carried out in Ansys.

In this work, the drafting of helical spring of a shock absorber by using 3D parametric software CATIA for Hero Splendor Plus bike, and also the analysis was performed by using ANSYS 16.2. To validate the strength of the model, the structural analysis on the helical spring was done by selecting NIMONIC 80A material, which is having minimum deformation.

2. Modelling of Suspension Spring

2.1 Spring Specifications

- Wire diameter (d) = 8 mm,
- Coil outer diameter (D) = 40 mm,
- Coil free height (h) = 200 mm,
- No. of active coils (n) = 12,
- Pitch (P) = 15 mm

2.2 For splendor Plus

- Coil diameter = 8mm,
- Total length= 208mm
- Spring length= 192mm
- No. of turns= 13

Figure1. Prototype of Linear Regenerative Electromagnetic Suspension System
2.3 Properties of Selected Material (Nimonic80A)

Ultimate tensile strength = 1000 N/mm²
Proof stress = 620 N/mm²
Modulus of rigidity = 85 KN/mm²

2.4 Theoretical calculations of spring

Weight of bike = 130 kgf = 1275 N
Weight of 1 person = 75 kgf = 735.5 N

For 1 person sitting
Total weight = 130 + 75 = 205 kgf
= 205/4 = 51.25 kgf
= 502.591 N
Spring Index, (C) = D/d = 40/8 = 5
What’sFactor (K) = \(\frac{4C - 1}{4C - 4} + \frac{0.615}{C}\)
= 1.3105
Maximum shear Stress (\(\tau\)) = \(\frac{K*8*W*D}{\pi*d^3}\)
= 131.156 MPa
Deflection of spring (\(\delta\)) = \(\frac{8*W*C^3*n}{G*d}\)
= 13.714 mm

For 2 persons sitting
Total weight = 130 + (75*2) = 280 kgf
= 280/4 = 70 kgf
= 686.46 N
Maximum shear Stress (\(\tau\)) = \(\frac{K*8*W*D}{\pi*d^3}\)
= 179.11 MPa
Deflection of spring (\(\delta\)) = \(\frac{8*W*C^3*n}{G*d}\)
= 18.225 mm
2.5 Drafting of suspension spring

Coil spring modeled in CATIA V5R20 is shown in Figure 2. Then the model is converted into the IGES format which is most suitable and easy access for any other software.

![Figure 2. Design of helical coil spring in CATIA V5](image)

2.6 Static Structural Analysis

Static structural analysis is the way to find out the effects of loads on structures and their components. Here, ANSYS 19.2 version is used for performing static structure analysis on coil spring.

2.6.1 Meshing

Meshing is an essential part of the finite element analysis process. The shape and size of the mesh affects the exactness, merging and speed of the solution.

![Figure 3. Meshing model in ANSYS 19.2](image)
2.6.2 Boundary Conditions

A boundary condition is a spot on a structure where either the outside power or the removals are known toward the beginning of the examination. The boundary conditions are where the structure communicates with nature either through the utilization of an external force or through some restriction that is forcing a displacement. Here, in coil spring design we have applied two boundary conditions. First, one end of coil is kept fixed by applying support. Second, static load is applied axially on the second end of coil.

**Applied loads**

1. One person load (510N)  
2. Two person load (687N)

![Figure 4. Applied support on coil spring](image)

![Figure 5. Applied static load](image)

![Figure 6. Equivalent von-mises stress with one person load (510N)](image)

![Figure 7. Equivalent von-mises stress with two persons load (687N)](image)
**Figure 8.** Deformation for one person load (510N)  
**Figure 9.** Deformation for two persons load (687N)  
**Figure 10.** Factor of safety for one person load  
**Figure 11.** Factor of safety for two persons load
2.7 Modal Analysis

Modal analysis is done to decide the relocations for various frequencies for number of modes. A modal analysis decides the vibration qualities (characteristic frequencies and mode shapes) of a structure or a machine segment.

2.7.1 Deformation Results V/S Frequency Response

![Figure 12. Translational response in plane 1](image12)

![Figure 13. Translational response in plane 2](image13)

![Figure 14. Rotational response in plane 1](image14)

![Figure 15. Rotational response in plane 2](image15)
3. Magnetic Analysis (Theoretical)

Calculation Based Approach

Force between two cylindrical magnets:

\[ F \propto \frac{1}{x^4} \]

\[ F \propto m_1 \cdot m_2 \]

From the above proportionalities;

\[ F = \frac{3}{2} \left( \frac{\mu_0 \pi}{\mu} \right) (m_1 \cdot m_2) \left( \frac{1}{x^4} \right) \quad (1) \]

Where, \( m \) is the magnetic moment;

\[ m = \frac{NAL}{L} \quad (2) \]

\( N \) = number of turns
\( L \) = length of electromagnet
\( I \) = current through coil
\( A \) = cross sectional area of coil
x = air gap or distance between the magnetic poles
\[ \mu_0 = \text{permeability of free space (air)} = 4\pi \times 10^{-7} \]

The diameter (D) of the electromagnet of the electromagnetic suspension according to the design parameters is 23mm. The magnetic moments of the two electromagnets are same.

Therefore,
\[ m_1 = m_2 = (NI/L) \times \pi \times D^4 \quad (3) \]

Substituting equation (3) in equation (1) and solving for the given value of diameter of coil, we get;
\[ F = 10.2 \times \left( \frac{N^2}{L^2} \times \frac{I^2}{x^4} \right) \times 10^{-14} \quad (4) \]

Taking the reference of the values from the design parameters and solving the above equation by taking the load of two persons as 687N, we get;

Length of the electromagnets = 160mm
Maximum spring deflection = 20mm
Wire diameter = 0.25mm
Pitch of coil = 0.25mm
Number of turns = 320

Initially the gap between the electromagnets were assumed to be 30mm assuming the maximum spring deflection as 20mm, we get the value of minimum air gap as 10mm. Again substituting the above mentioned values in equation (4) and solving for the value of current in the coil, we get;

\[ I = 4.09A \]

It can be concluded that the amount of current required for the repulsive action of the two electromagnets in a suspension system is 4.09A.

4. Results & Discussion

4.1 Static analysis results

The results obtained from static analysis are noted. As shown in Table 1, the maximum distortion, maximum von-mises stress and factor of safety with one person & two person loads are mentioned.

| SL NO. | Deformation(mm) | Von-mises Stress(MPa) | Factor of safety |
|--------|----------------|-----------------------|-----------------|
|        | Min.           | Max.                  | Min.            | Max. | Min. | Max. |
| 1. One person load(510N) | 0.00 | 0.014551 | 0.00 | 454.18 | 2.2766 | 15 |
| 2. Two persons load(687N) | 0.00 | 0.019601 | 0.00 | 611.81 | 1.6901 | 15 |
4.2 Modal Analysis Results

| Statistics          |               |
|---------------------|---------------|
| Bodies              | 1             |
| Active Bodies       | 1             |
| Nodes               | 69372         |
| Elements            | 19312         |
| Mesh Metric         | None          |

**Figure 18.** Details of no. of nodes and elements

**Figure 19.** Meshing elements details

**Figure 20.** Results: Frequency and Deformation

5. Conclusions

Structural analysis is carried out in ANSYS 19.2 workbench with Nimonic 80A material at different loads for 1 person and 2 persons sitting at loads of 510N, 687N. Von mises stress, distortion and factor of safety are noted. From the investigation results and previous literature
findings we can conclude that Nimonic 80A is best material among all suited materials. Nimonic 80A has equal stress value of high carbon steel but has less deformation. Hence material with less deformation is preferred. Modal analysis is performed on splendor plus suspension springs, deformation on respective frequencies on different mode shape is noted and tabulated.

References

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