Topology Optimization of a Helical Spring using ANSYS

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ABSTRACT

This study examines the topology optimization of a helical spring using ANSYS Discovery. The primary objective of this study is to reduce the material usage while maintaining the load-bearing capacity and structural integrity. A detailed three-dimensional finite element model of a helical spring was developed in ANSYS Static Structural with definite dimensions and material properties. In ANSYS Discovery, boundary conditions were applied. Topology optimization was then used to identify material removal zones and achieve the objective of an effective, lightweight design of the product without compromising its mechanical properties. The findings of this study show that this engineering optimization technique helps us to achieve weight-efficient design, cost effectiveness, and extended life of the mechanical spring.

Keywords: *Topology optimization, Helical spring, ANSYS Discovery, ANSYS Static Structural, Finite element analysis, Lightweight design*

1. Introduction

Helical spring plays a very important role in mechanical systems due to their ability to store potential energy, absorb shocks, and maintain force equilibrium under fluctuating loads. Springs have various applications, such as in automotive suspension systems, aerospace mechanisms, industrial machinery, and consumer products, due to their high capacity to store energy and cyclic durability. The increasing demand for energy-efficient, cost-effective, and sustainable solutions has driven research towards the development of optimized spring geometries that are not only structurally sound but also material-efficient.

The Conventional design of helical springs often relies on empirical formulas, standardised dimensions, and iterative prototyping, but these traditional designs may result in excess material usage, limited adaptability, and inefficiency. In many applications, such as automotive and aerospace engineering, excess material directly translates into greater weight, higher fuel consumption, reduced efficiency, and increased manufacturing cost. Due to this, topology optimization comes into the picture, which meets every limitation of conventional spring methodologies.

Topology optimization is a revolutionary technique in computational design. Unlike all the other optimization techniques, which only adjust the predefined variables, topology optimization fundamentally redefines the material distribution within a design space. By identifying the optimal loads that are being applied to the product and by eliminating the regions of the material that are not being used, topology optimization methods lead to many innovative and efficient ideas for product development. Recent studies show that these transformative methods are widely used in optimizing structural brackets, biomedical implants, and lattice structures.

2. Research Methodology

This section outlines the methodological framework adopted for topology optimization of the helical spring using ANSYS. Each stage of the process, from geometry creation to optimization and validation, is described in detail to ensure clarity.

2.1. Engineering Data

ANSYS Workbench has many options, including static structural, which helps to study the structural behaviour of the design when loads are applied or removed. The foremost step is to select the engineering data of the design. Structural steel, being the most common, is pre-selected by the software itself; also, the choice of structural steel makes the study realistic. After selecting the material on the right sidebar, other mechanical properties of structural steel are mentioned, such as density, Young's modulus, bulk modulus, Poisson's ratio, etc., mentioned below are the properties:-

- Density: 7850 kg/m^3
- Young's Modulus (E): 210 GPa
- Poisson's ratio (υ): 0.3
- Yield strength: 250MPa (nominal value for structural steel grade)

2.2. Geometric Modelling of Helical Spring

After choosing the engineering data, the next step is to create the geometric model of the helical spring. Under static structural, there are many options to create the geometry, like Design Modeller, Discovery, etc.. The most suitable one is the Design Modeller, as it is easier to create a curved surface in this geometric modelling software than in Discovery. In Design Modeller, the units are first changed to the MKS system of units, and then the sketching of a helical spring begins. For the sketching part, first a line is drawn with a finite dimension, and adjacent to that line a circle is sketched with again a finite dimension. The sweep tool is used to create the spring by choosing the path as the line and profile as the circle, and also the pitch of the spring. The following are the dimensions of the respective shapes:

- Free length: 73mm
- Wire diameter: 5mm
- Mean diameter: 40mm
- Pitch: 8mm

2.3. Defining the Boundary Conditions

To have a realistic study, appropriate constraints and loads are applied:-

- Fixed support: One end face of the spring was constrained using a fixed support, eliminating any degree of freedom, whether translational or rotational.
- Applied load: A load was applied to the opposite end, distributed uniformly over the end face to simulate the realistic conditions. The load of 500N was applied.
- Load magnitude: The load was selected such that the spring remained within the elastic deformation range of structural steel, avoiding plastic yielding.

- As the number of turns is 9, we assume that the active coils are 7 and 2 are inactive.

2.4. Meshing

Meshing is important in ANSYS simulations because a high-quality mesh of a geometric model into small, discrete elements is crucial for achieving accurate, reliable, and efficient simulation results. The spring is discretised into tetrahedral solid elements. In static structural, the meshing is done under the model section, and the mesh size can be adjusted easily.

2.5. Topology Optimization Framework

Topology optimization was performed in ANSYS Discovery using a density-based algorithm, which gradually eliminates underutilised material while preserving load paths. The main objective is the mass reduction of the spring (lightweight design). The optimization is allowed to act on the entire helical spring.
Certain constraints should be taken into account:

- Maximum stress in the spring should always be less than the yield strength of structural steel.
- Maximum deflection should remain within the safe working range, so that the spring does not compress too much.
- The stiffness-to-weight ratio should not be worse than that of the original spring.

3. Theory and Calculation

The principles of mechanics of materials, elasticity, and optimization theory govern the design and optimization of helical springs. The deflection behaviour, stress distribution and energy absorption capacity of the spring primarily depend on the geometry and material of helical springs.
For a helical spring, spring stiffness (k) is defined as the ratio of the applied load (F) to the deflection (δ)

$$k = \frac{F}{\delta}$$

4. Results and Discussion

This section presents the results of the helical spring topology optimisation, including a comparative analysis between the baseline (unoptimized) and optimized spring designs. The optimization process in ANSYS Discovery was constrained to achieve maximum stiffness with the reduction in material volume relative to the baseline spring. Table 1 summarises the comparison between key performance parameters of the baseline and optimized spring.

Table 1: Comparison between baseline and optimized helical spring for reducing excess of material

Parameter	**Baseline spring**	**Optimized spring**	**% change**
Mass	100%	92.1%	-7.9%
Maximum principal stress (Pa)	7.1546e9	1.31e10	+83.11%
Deflection (m)	0.51783	0.516	-0.35%
FEA stiffness(N/m)	1931.136	1937.9845	+0.35%

Figure 1: ANSYS 2024 R1 Static Structural showing the geometry of the helical spring

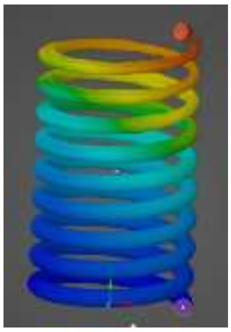

Figure 2: ANSYS 2024 R1 showing baseline as well as optimized model, respectively.

5. Conclusions

This study investigated the Topology Optimization of a helical spring made up of structural steel, which focuses on the reduction of material while evaluating the mechanical consequences of such optimization. This research involves the analysis of a baseline spring through classical analytical methods and finite element simulation in a static structural environment, then comparing it with an optimized model that is developed in ANSYS Discovery. The observation demonstrated that the optimized spring successfully reduced material usage by approximately 10%, highlighting the potential of topology optimization to create lightweight and cost-efficient components. However, there were noticeable performance changes: the total deformation of the optimized model is reduced by 0.35%compared to the baseline helical spring model, while the FEA stiffness increased by 0.35%, indicating a reduction in mechanical rigidity. These results demonstrate the inherent trade-offs between material efficiency and mechanical performance in optimized designs, highlighting the need for careful evaluation of stress distribution and deformation when applying such techniques to structural components. Overall, this research emphasises that topology optimization is a powerful tool for designing efficient helical springs, but it requires careful considerations and boundary conditions to ensure that the resulting designs meet practical engineering requirements.

Conflict of Interest

The authors declare no conflict of interest.

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