# Non-coiled Spring Optimization Assisted by an Analytical Model


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**INTRODUCTION**: The purpose of this work is to look into the fundamental issues regarding spring design and develop a new approach which takes both the merits of analytical solution and numerical solution. With our treatment, engineer can start with a curved non-coiled spring in FEM/Comsol environments to identify the spring's effective spring rate and maximum stress at any thickness and width. With both those identified values and target values, we can plug them into our derived analytical equations and get the predicted dimensions. The performance of new dimensions will be verified in FEM/Comsol environments. Only two iterations of simulation are needed to get the ultimate spring performance.

**COMPUTATIONAL METHODS**: The analytical optimization is based on two equations derived by beam theory:

$$t_{target} = \frac{\sigma_{target} k_{target}}{\sigma_{max\_initial}\, k_{initial}} t_{initial} \,,$$

$$w_{target} = \frac{{\sigma_{max\_initial}}^3 {k_{initial}}^2}{(\sigma_{target})^3 {k_{target}}^2} w_{initial} \,.$$

While the FEM model is based on linear elastic constitutive equation throughout the domain:

$$\varepsilon = \frac{1}{2}(\nabla u + \nabla u^T)$$

with the following governing equation:

$$\nabla \bullet \sigma + F = 0 \,.$$

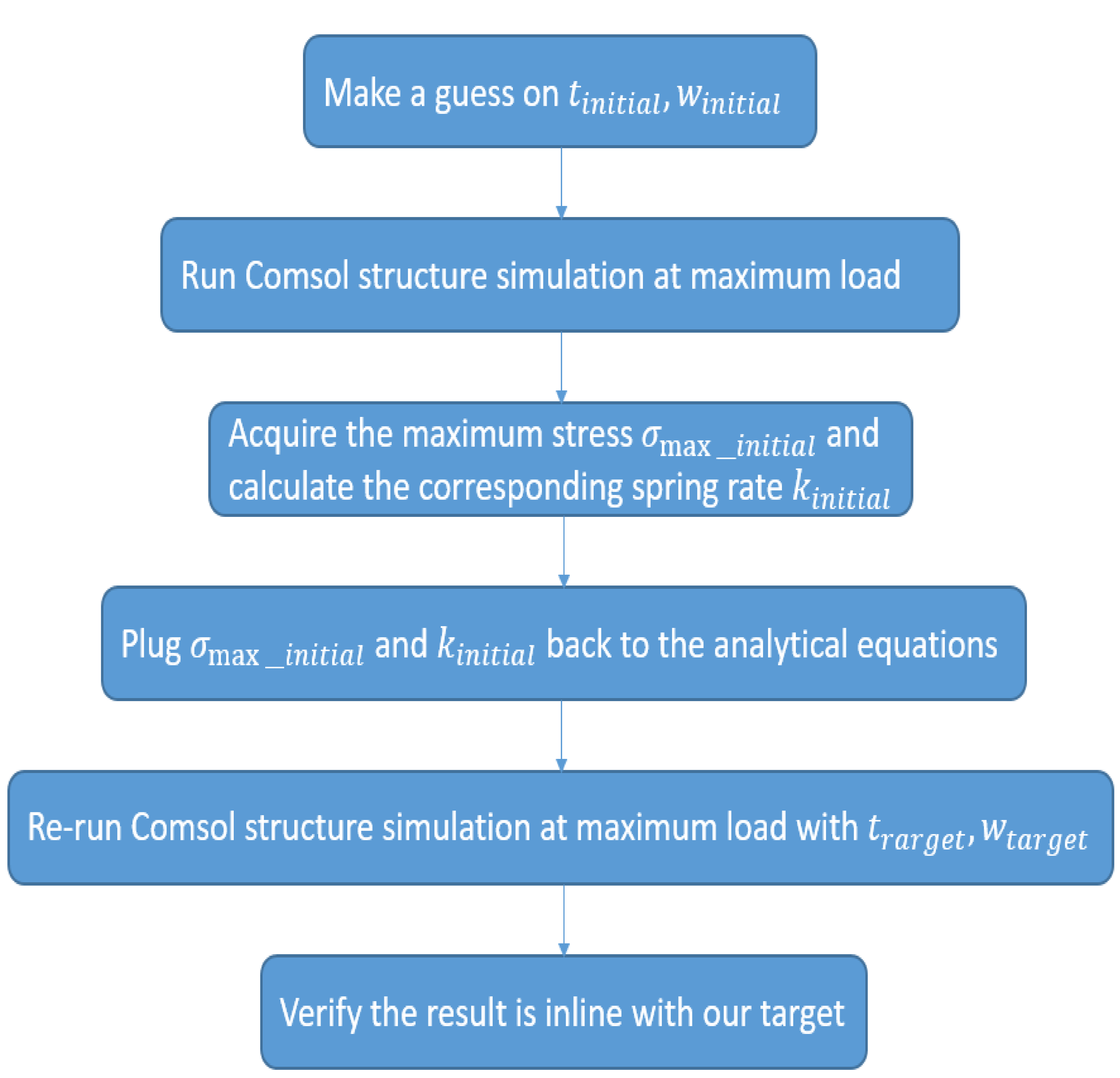


**Figure 1**. The flowchart of non-coiled spring optimization of utilizing FEM model assisted by an analytical model

**RESULTS**:

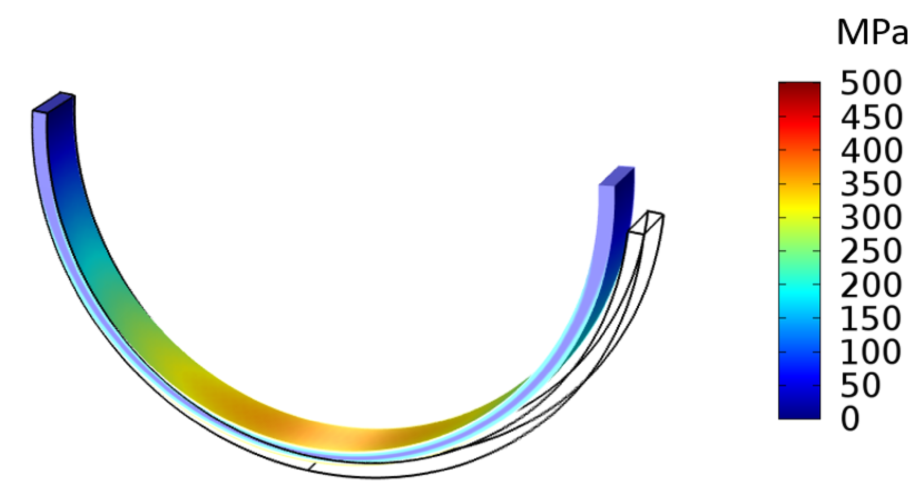


**Figure 2**. Stress distribution of the spring with initial guessed design variable value: $t_{initial}$=0.5$mm$, $w_{initial}$=2$mm$.

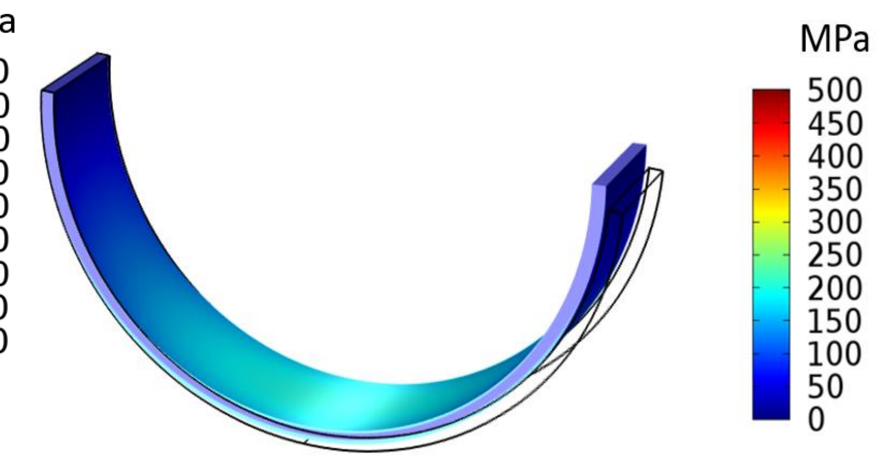


**Figure 3**. Stress distribution of the spring with assisted analytical model predicted design variable value: $t_{target}$=0.465$mm$, $w_{target} = 4.234mm$.

Beyond directly applying our approach, we can inverse the analytical model and get the maximum stress and spring rate predicted w.r.t. to each set of spring thickness and width.

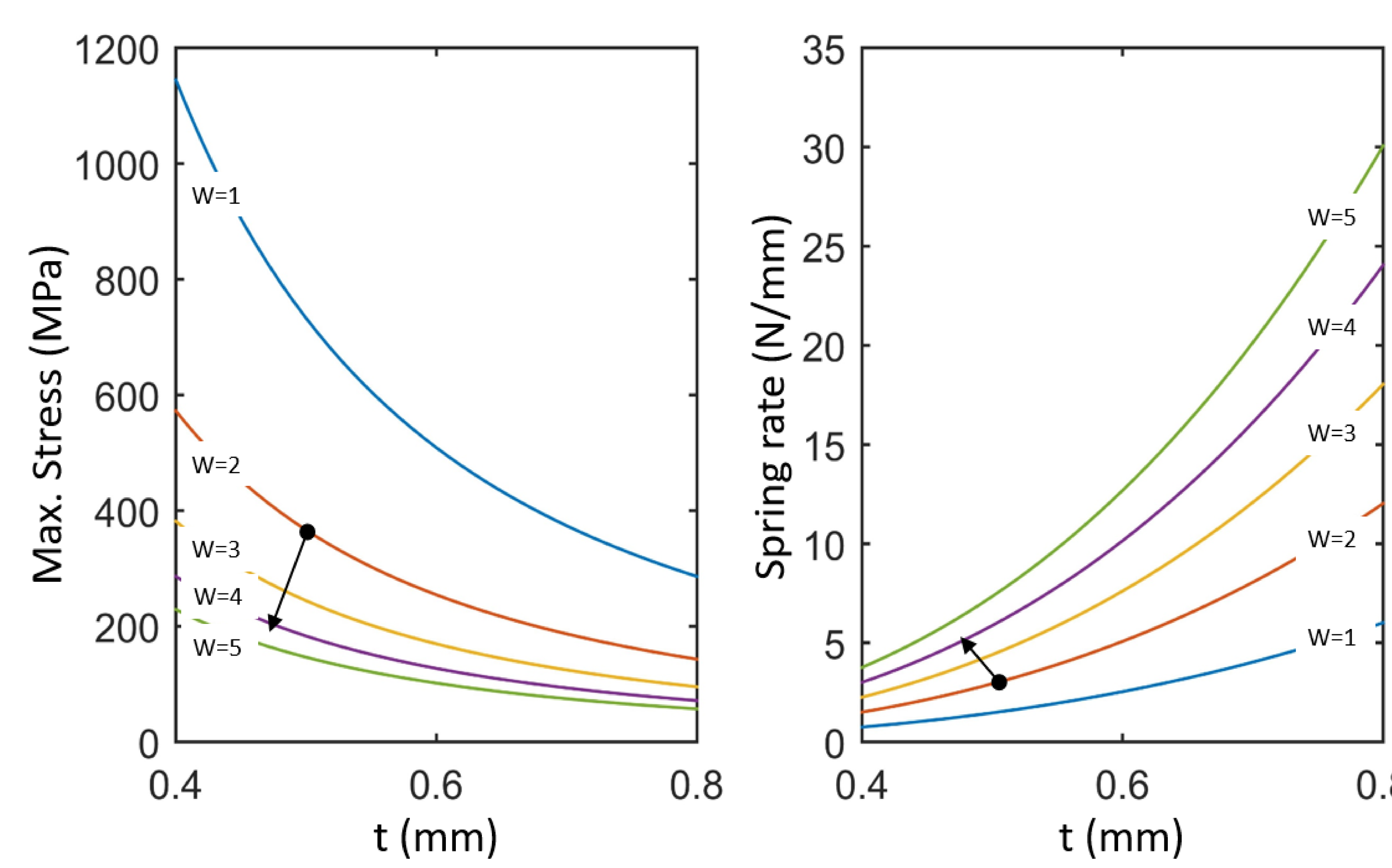


**Figure 4**. Spring performance w.r.t. design variable space. The arrow represents the optimization trajectory.

**CONCLUSIONS**: In this work, we have proposed a time efficient approach to optimize the characteristics of a non-coiled spring to the desired spring rate and maximum strength based on beam theory and structural FEM. One application of this approach was presented and an average 3% accuracy on spring rate and maximum stress was achieved.

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