Design Optimization in Pro/ENGINEER Wildfire 4.0

1   Introduction

The Structure and Thermal Analysis using FEA provide means to evaluate the stress, strain, and heat distributions within in a design model, given the working conditions, and materials.

Using these analysis tools and other build-in performance measuring functions in Pro/E, a user defined design objective (or goal) can be measured. This objective is normally directly related by a number of design dimensions. Changing the values of these dimensions, or design variables, the value of the defined design objective will change accordingly. Design optimization is the tool that automatically search for the best values of these design variables, given the user defined design objectives. In most applications, a number of design constraints are also specified to design the boundaries of the allowed design variations.

Design Optimization tool in Pro/E automatically adjusts one or several design parameters in a series of design-analysis iterations to move closer to the goal while satisfying any limits defined. It can also be used to test the feasibility of a design with respect to some specified constraints or limits. In these feasibility studies, no goal is defined; ProE simply tries to satisfy the pre-defined limits. The goal and limits are each optional, but a study must have at least one goal or one limit.

In this tutorial, we use a gear and gear shaft design example to demonstrate the method of Design Optimization.
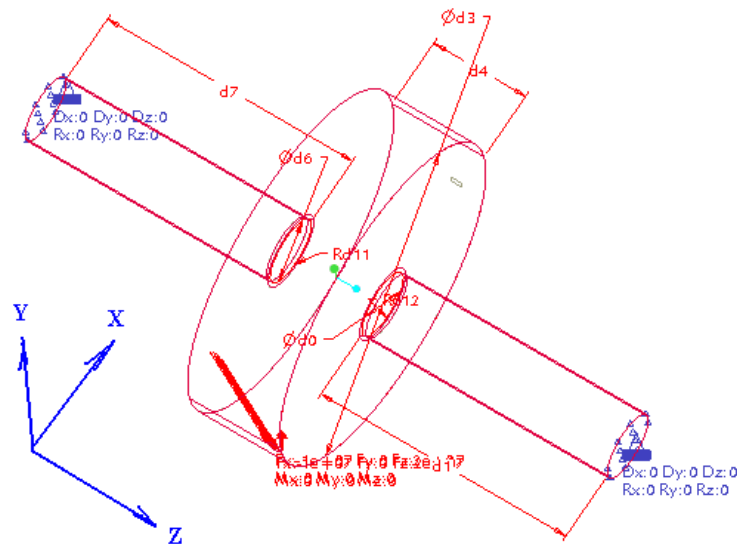
We simplify the problem by assuming that the gear and shaft are one body made using steel, consider minimum weight as the goal of the design, and chose the width of the gear, *d4*, as design variable. Other known parameters include:

Length of Shaft, d7=d1	Diameter of Shaft, d6=d0	Diameter of Gear, d3	Initial Width of Gear, d4	Chamfer Radii d11=d12
8″	2″	10″	3″	0.125″

- Material is Steel.
- Dimensions: d0, d1, d6, d7, d3, d11, d12 and total length of the part are fixed.
- The part cannot bear a stress more than $7 \times 10^8 (\frac{lbm}{s^2 in^2})$ [von_Mises]
- The part is fixed at both ends.
- A work load, $\vec{F} = [1 \times 10^7; 0; 1 \times 10^7]$ (lb), is applied on the outer cylinder surface representing the gear.

The design optimization is to be carried out to get the optimal value of the dimension *d4* that allow the component to have a minimum weight.

2   Model Creation

In this part, we create the geometry model and add mechanical properties to it.

2.1   Create the Solid Model of the Gear-Shaft

In Pro/E, create the part as shown in the previous figure. Since we need to maintain the length of the shaft while adjusting the dimension *d4*, we add a dimension relation:
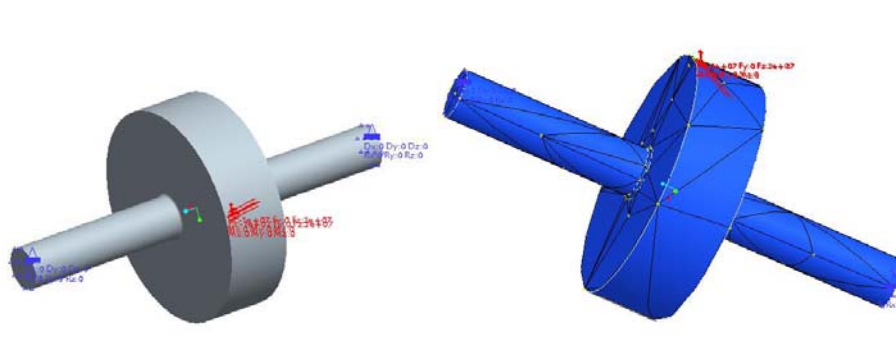
d7=11-d4

2.2   Start Pro/E Mechanica

To begin Structure Analysis, in Pro/E, select:

Application>Mechanica

Then, assign material, add constraints, apply work load and mesh the model as we have demonstrated in the Pro/E Structure Analysis tutorial. Don't forget to insert a surface region to locate the workload.

The finished part should look like this:

The model is ready for design optimization study.

3   Sensitivity Study

In mechanical design, various design parameters are related to the design goal, or design objective, in different ways. To find how these design variables influence the design goal, sensitivity analysis, or sensitivity study, is carried out to identify key design parameters and to better formulate the design optimization problem.

In Pro/E, sensitivity study includes the global sensitivity study and local sensitivity study. Global sensitivity study investigates the influence of a design parameter on the performance of the design model over the whole range of possible values of the design parameter. Local sensitivity study focuses on a specific value of the parameter, and analyzes the influence of the parameter by its trend of change, i.e. the slope of the performance diagram. The sensitivity study methods are illustrated using the following examples.

3.1 Global Sensitivity Study

Global sensitivity study proceeds following these steps:

Click: Mechanica → Analysis → Mechanica Analysis / Studies.

In the **Design Study Definition** dialog box, click **File → New Sensitivity Design Study →** selected **Global Sensitivity** as the study type. This opens the dialog window as shown below.
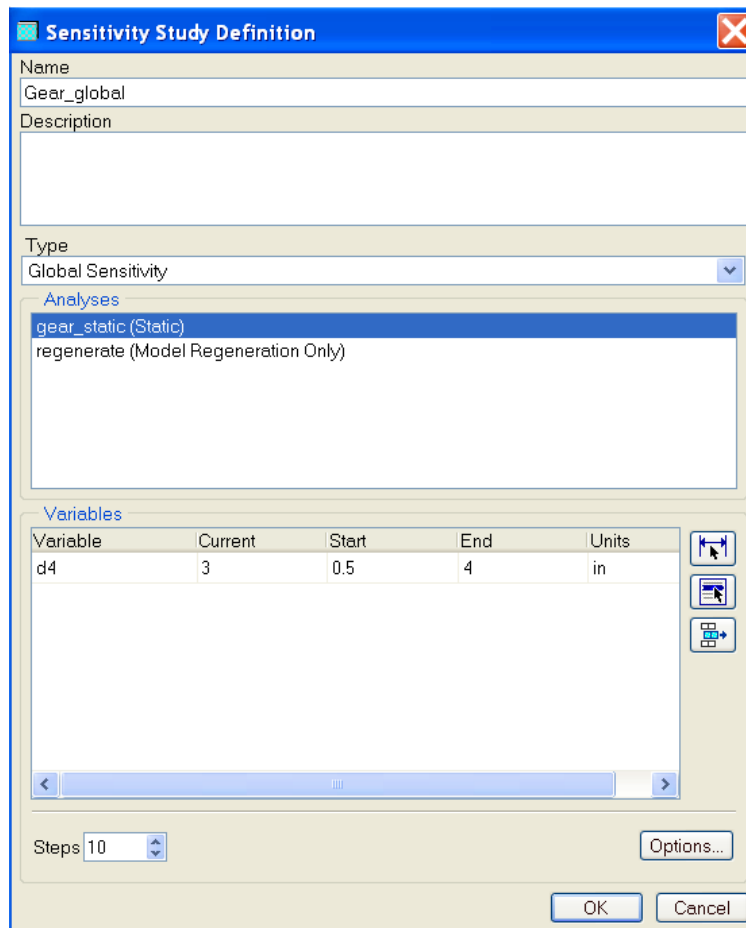
Enter a description for the study (optional). Call the new design study Gear_global

The default type is a Global Sensitivity.

Select the study we have prepared from the list. The analysis to be used is gear_static.

To the right of the **Variables** pane, pick [⟷] the **Select Dimension** button. Pick the gear width dimension d4 from the model. The current value is 3. Set the **Start** value to 0.5 and the **End** value to 4. At the bottom of the window, accept the number steps in the study to 10 as default steps.

Click **OK**.

This analysis result shown on the left indicates that the total mass of the component is proportional to the parameter d4. The value of optimal value of d4 is thus only limited by design constraints. While the result of maximum stress shown on the right indicates that the maximum stress only sharply increases when the value of p4 is less than 0.75. We can thus conclude that the width of the gear, p4, can be decreased to reduce the total mass of the part without significant influence on the maximum von Mises stress as long as parameter its value is greater than 1.
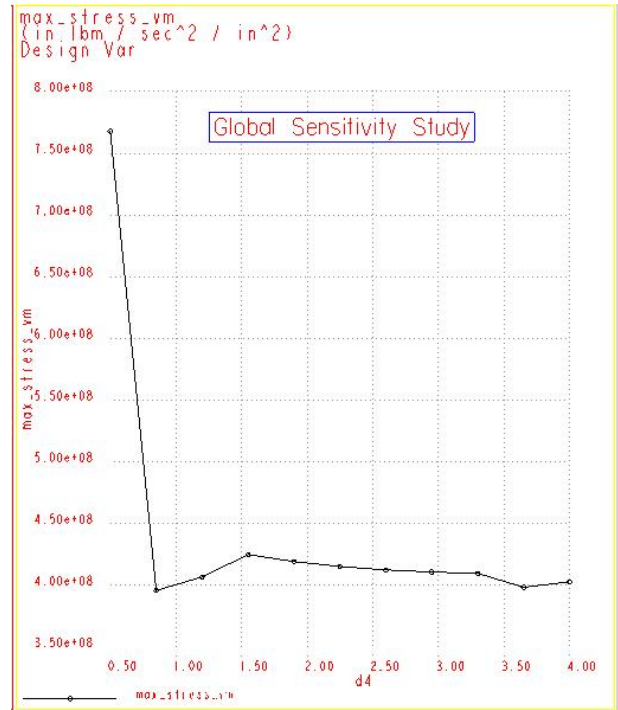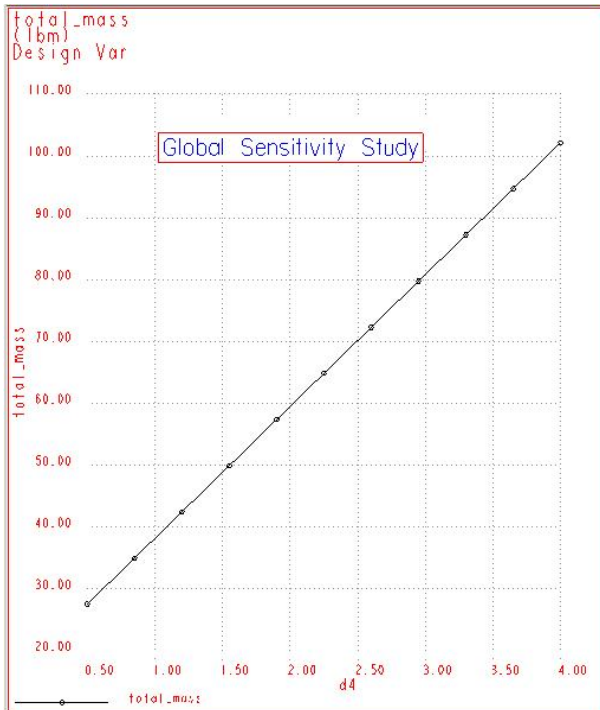
3.2 Local Sensitivity Study

Local sensitivity study proceeds following these steps:

In the **Design Study Definition** dialog box, click File → New Design Study → selected **Local Sensitivity** as the study type. This opens the dialog window as shown below.
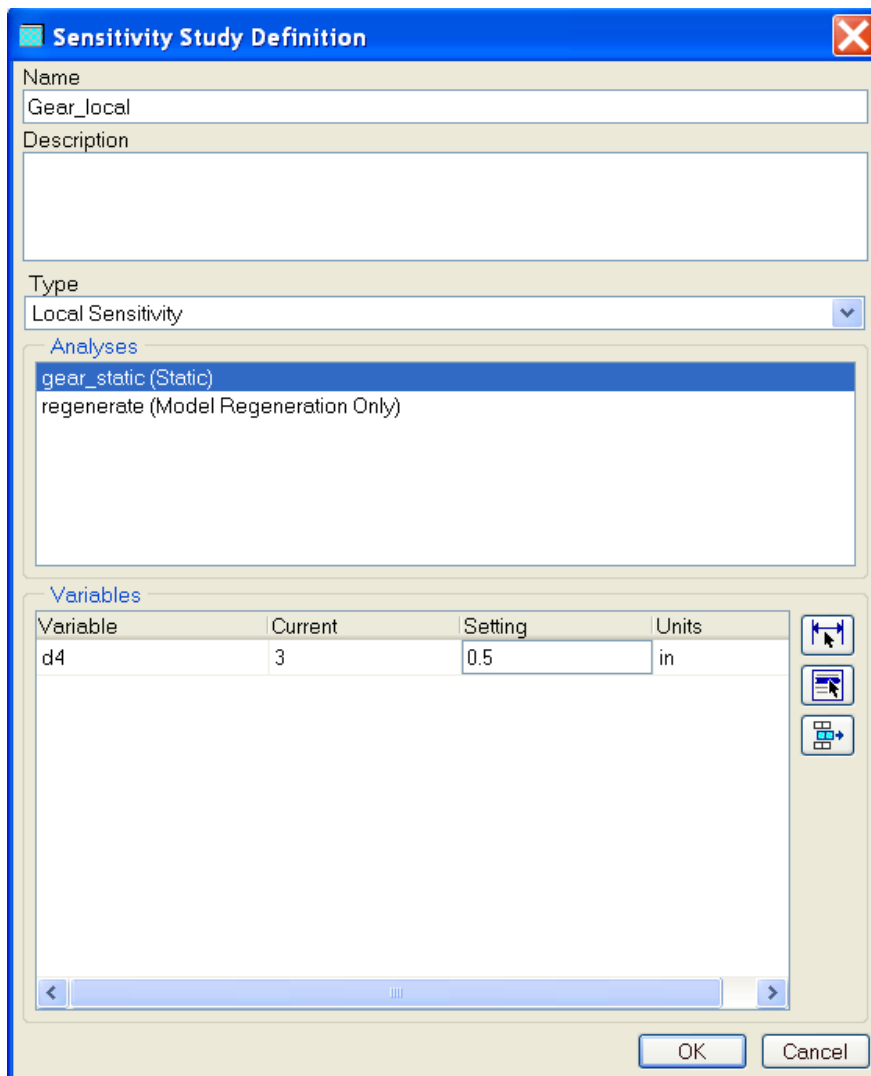
Enter a description for the study (optional).

Select the study we have prepared from the list.

Select d4 as the variable. Beside the variable, there is a column **Settings**. This value decides on which point the local sensitivity study is to be carried out. In this example, the local sensitivity is performed at two points: (a) p4 = 0.5 and (b) p4 = 3.

Click **OK**.

The local sensitivity studies reveal that the design parameter, d4, has similar sensitivity on the total mass of the part, while dramatic different sensitivities on the max_stress_von Mises for the two different values at 0.5 and 3. Since the sensitivity is greater than 1, d4 is a meaningful design variable. This information serves as useful feedback to the design.
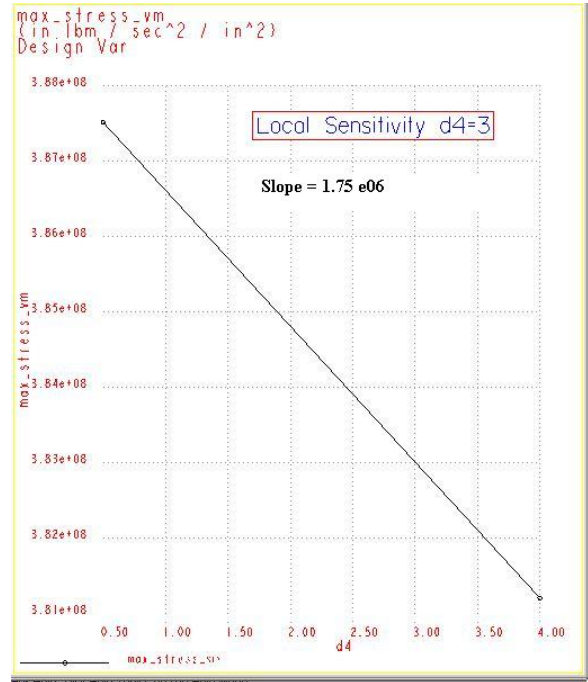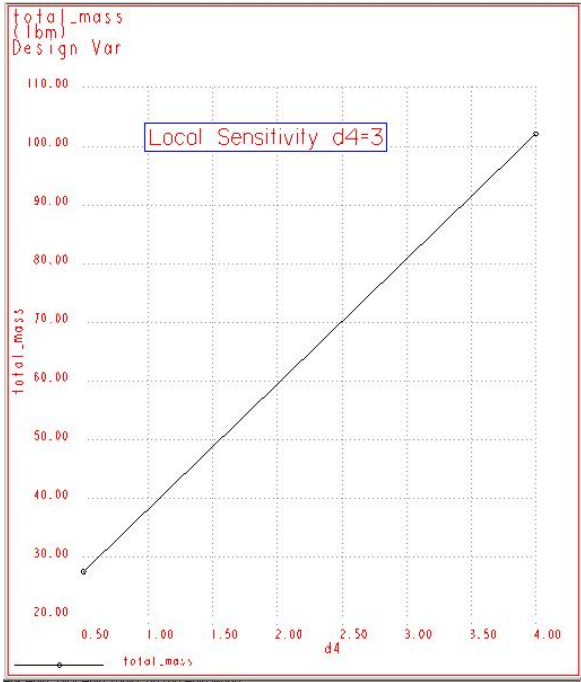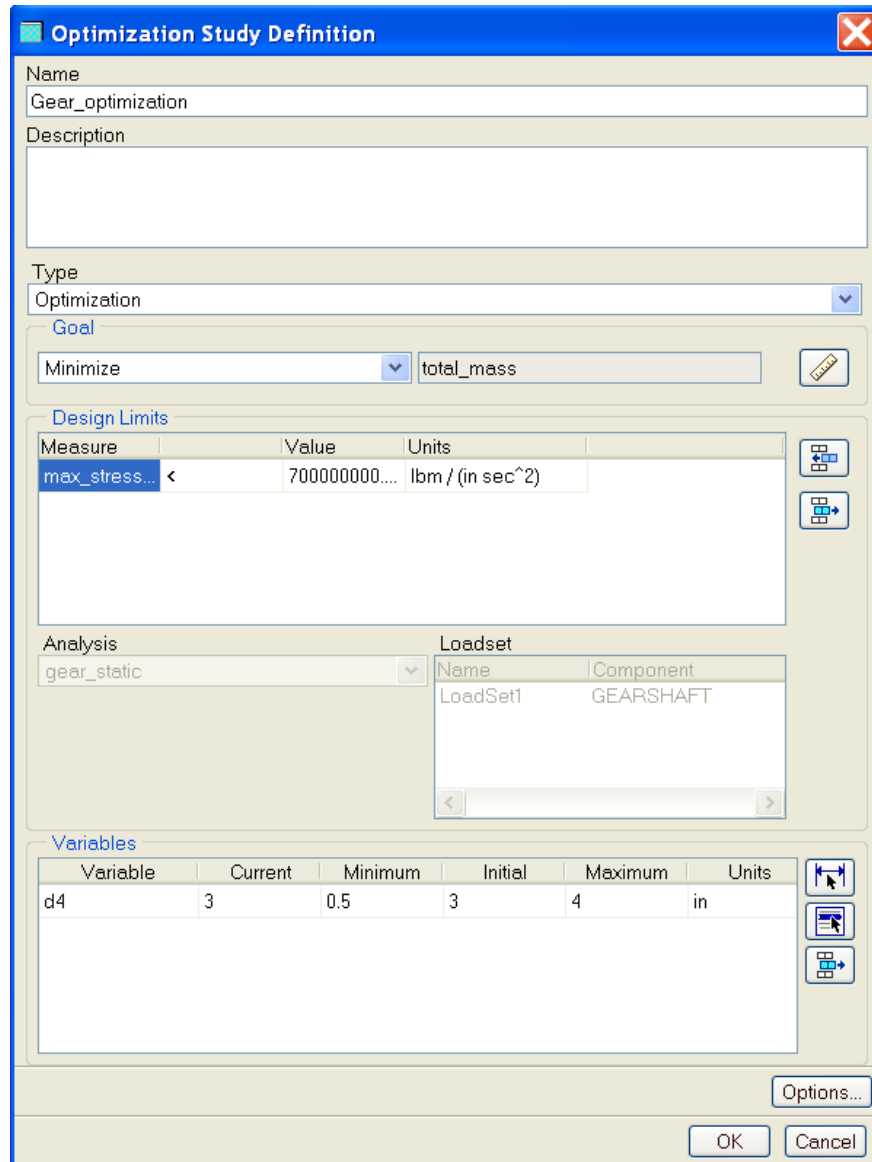
Local Sensitivity Study (d4 = 3)
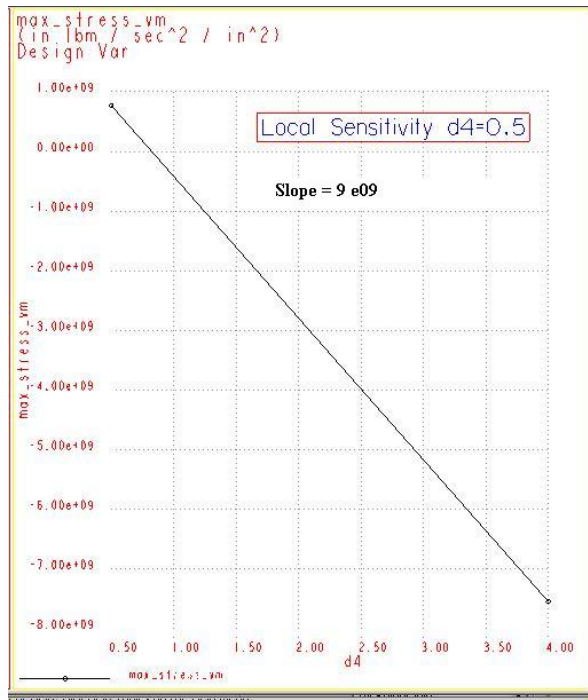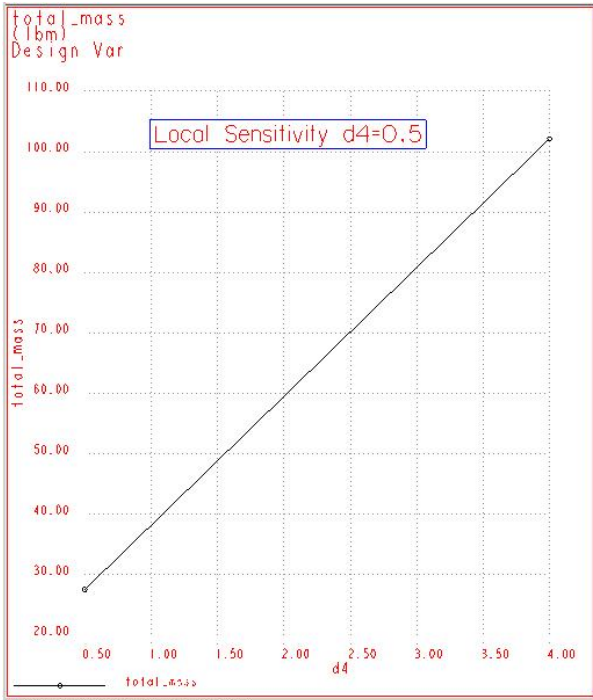
Local Sensitivity Study (d4 = 0.5)

4   Optimization Study

4.1   Defining the Design

Select **Analysis→Mechanica Analysis/Studies→File→New Optimization Design Study.** This opens the dialog window as shown below.

- Enter Gear_Optimization as **Study Name. Type** is Optimization (default)
- **Goal** is Minimize total Mass

- In the Design Limits area, click measure.
   - o   From Measures list select **max_stress_vm** and enter the limiting value to 7e8.

- In the Variable area, click ⊞ **Select Dimension** button at the right to add the gear width. Set the **Minimum** value to 0.5 **and the Maximum value** to 4.
- Select the analysis gear_static for the stress evaluation. This will be the default if there are no other analyses available.
- Check out the Options button in the study definition. Leave the optimization evaluation set to Automatic, and the convergence and iteration limit set to default values.
- From Analysis and Designs Studies Window, Click **Info→Check Model** to make sure there is no problem with the model.
- Then, Click **Run→ Start** to begin the optimization process.
- To monitor the process, Click **Info→Status.**

4.2 *Optimization Results and Reports*

The results of the design optimization can be obtained and reported in the same manner as the Structure Analysis. This design optimization should give the following results:

- Max. Stress (von Mises): 7×10^8 ($lbm/s^2 in^2$);

- Width of the gear:
  $d4 = 0.53''$ (initial value: 3)
- Goal (minimized weight):
  28.096 lb (before optimization: 80.827 lb