DOES and ANSYS DesignXplorer Model Optimization

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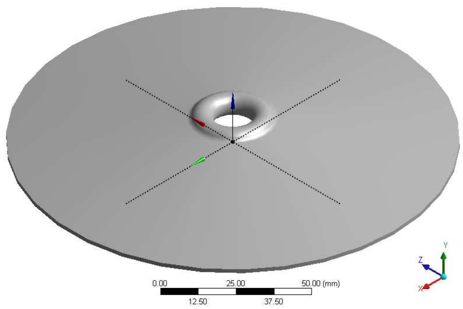
Table of Contents

Creating the Original Parametric Design

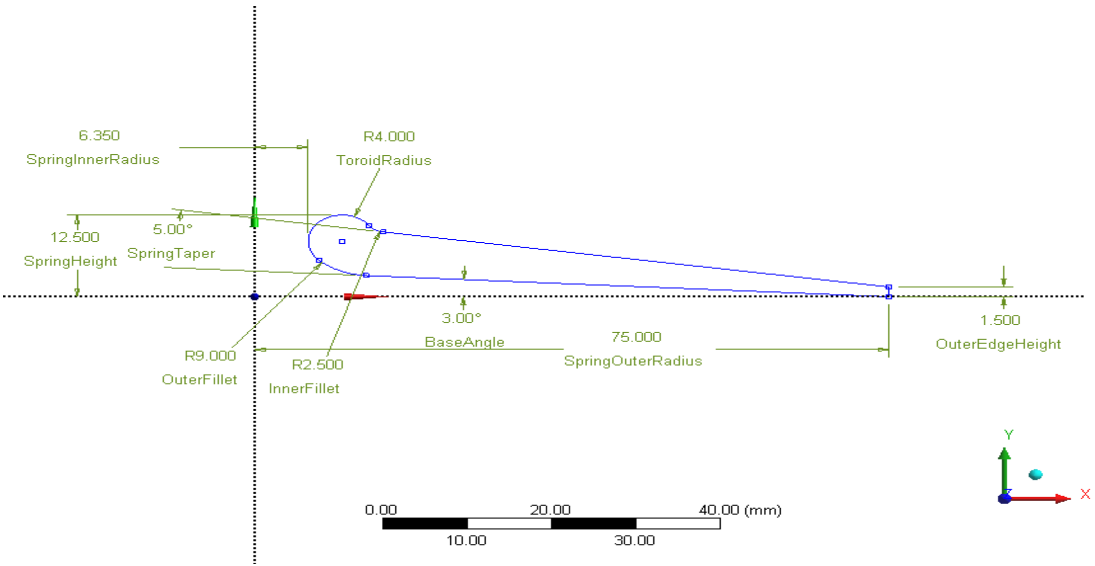
This document has been prepared to present some of the capabilities and features of the "**D**esign **O**ptimizing **E**xpert **S**ystem" (***DOES***) from OPTIMUM Power Technology. The case study demonstrates some of the benefits of using ***DOES*** to optimize the "Flexible Spring Mount" model shown below:

The model was created and manually optimized for several days by a customer's engineer before it was given to OPTIMUM Power Technology. The solid model of the mount was created using the Design Modeler from ANSYS, Inc.



The goal of the optimization was to achieve the most deflection of the mount in the – Y direction while staying within the allowable yield strength of the material.

In order to perform a good optimization, it was essential to start with a high quality parametric model that could be fully optimized without compromising the part's original design intent. The following sketch shows the actual parameters assigned to the mount.



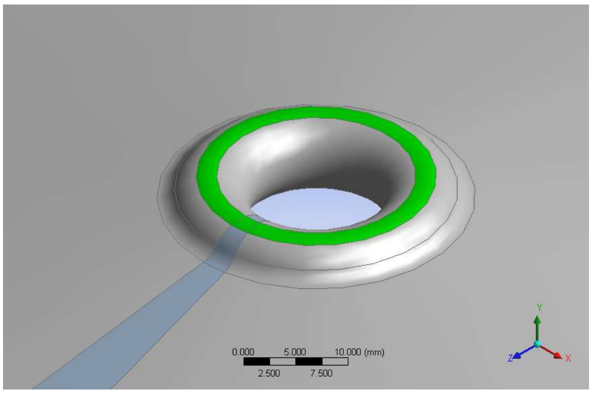
The model for the mount was created with optimization in mind. Both parameters which were fixed design constraints and those which could be varied to optimize the performance of the mount needed to be specified.

The remainder of this document will detail the results of analysis of the original manually optimized mount and the ***DOES*** optimization that dramatically improved its performance.

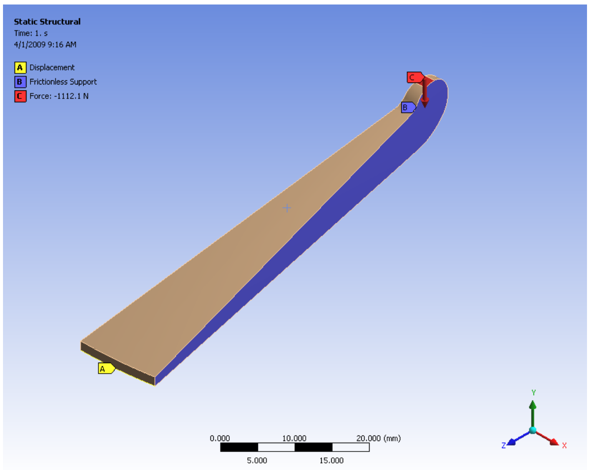
Analysis of the Baseline Flexible Spring Mount

Before any downstream optimization is performed it is essential to analyze the initial baseline part. For this spring mount it was determined that symmetry could be used to significantly reduce the time required to perform the analysis of the part.

Using the Design Modeler from ANSYS it is possible to segment the model, as shown below, without modifying the original CAD model. As such, a 10-degree segment of the mount was created to perform the analysis.



In this analysis, we set up parameters that reflected the original design intent of the model with a load of 9000 pounds or 40034 Newtons. A force of 1112.055 Newtons represents the load on a 10-degree segment of the mount. This load was applied to the segment.



The segment was constrained at the outer edge against vertical displacement. The cut surfaces were constrained as frictionless supports to simulate symmetry. The diagram below reflects the loaded and constrained final segment to be analyzed.

Once constraints and loads were applied to the segment, meshing and analysis settings were defined in the ANSYS Mechanical product.

The “Sweep Method” and “Mesh” settings that were used are shown in the two dialog boxes below.

Details of "Sweep Method" - Method

Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No
Method	Sweep
Element Midside Nodes	Use Global Setting
Src/Trg Selection	Manual Source and Tar...
Source	1 Face
Target	1 Face
Type	Number of Divisions
Sweep Num Divs	2
Sweep Bias Type	No Bias

Details of "Mesh"

Defaults	
Physics Preference	Mechanical
Relevance	0
Advanced	
Relevance Center	Coarse
Element Size	Default
Shape Checking	Standard Mechanical
Solid Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Initial Size Seed	Active Assembly
Smoothing	Low
Transition	Fast
Statistics	
Nodes	642
Elements	78

The “Analysis Settings” were specified to allow for non-linear large deflection analysis.

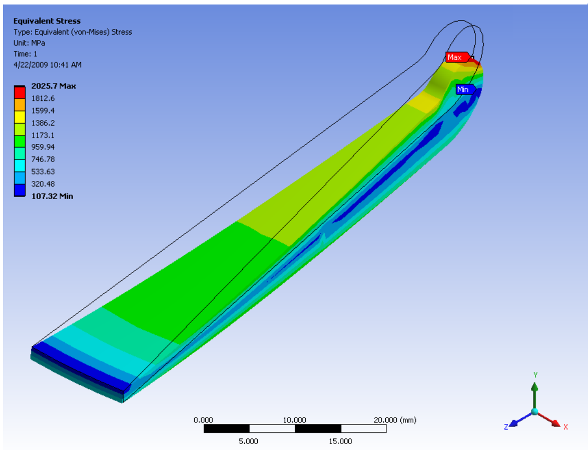
With these settings, loads and boundary conditions, the analysis of the baseline model showed an equivalent maximum stress of **2025.7 MPa** and a deflection of **-4.6561 mm**.

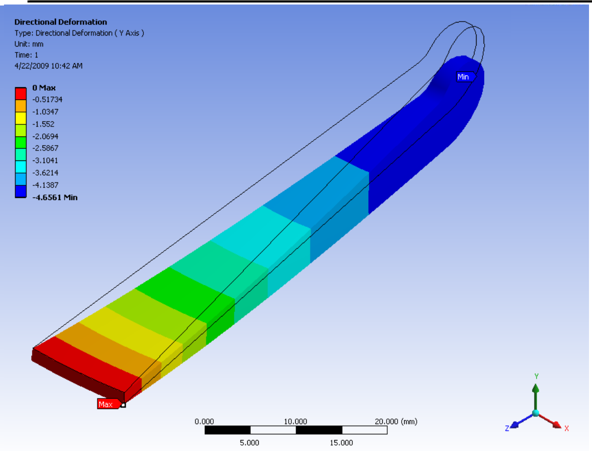
The resulting displays of the analysis results are shown below.

Note that the rigidity of the baseline mount causes the maximum stress to occur at the point of loading.

Details of "Analysis Settings"

Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	On
Inertia Relief	Off
Nonlinear Controls	
Output Controls	
Analysis Data Management	
Solver Files Directory	C:\Data\Analysis\Flexibl...
Future Analysis	None
Save ANSYS db	No
Delete Unneeded Files	Yes
Nonlinear Solution	Yes
Visibility	



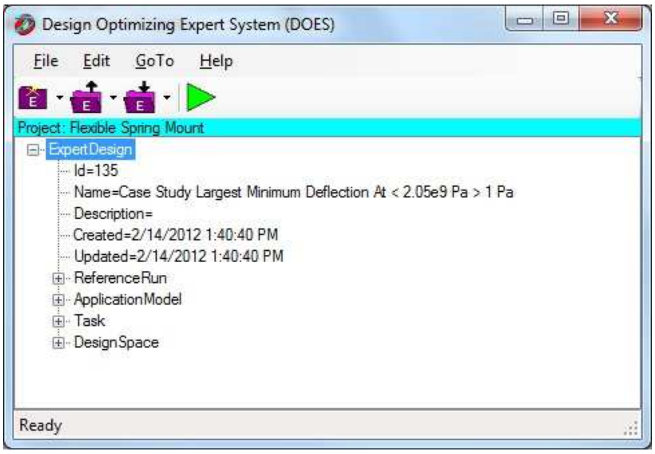


Performing Design Optimization

The next step was to perform an optimization of the baseline mount to meet our original design objectives. In this section we will describe the parameters that were specified in ***DOES*** to set up and create several optimized mounts. To optimize the baseline model with ***DOES*** one uses its **Knowledge Engineering** user interface to create an **Expert Design**. The **Expert Design** defines the objectives and constraints and the model parameters that can be varied to create optimized designs.

Creating a *DOES* Project and Expert Design

First we must create a **Project** (Flexible Spring Mount) and an **Expert Design**.



The **Expert Design** consists of a **Reference Run**, an **Application Model**, a **Task** and a **Design Space.**

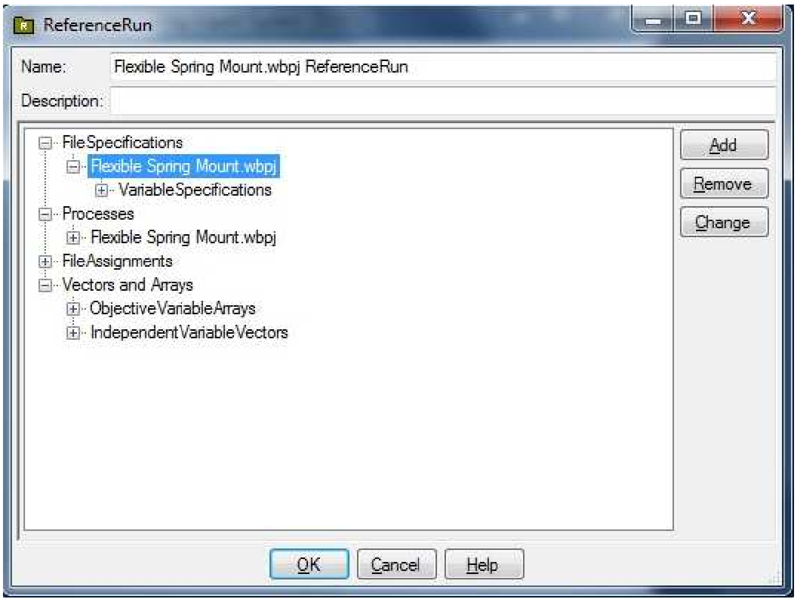
A **Reference Run** is a complete example of a batch run simulation of the device or process that the engineer wants to optimize. It contains specifications for all input, processes and output files required to run a model. It contains all of the information necessary to create different versions of the model that can be run in parallel.

An **Application Model** normally contains a subset of the **Reference Run's** variables that can be used by a particular **Expert Design**.

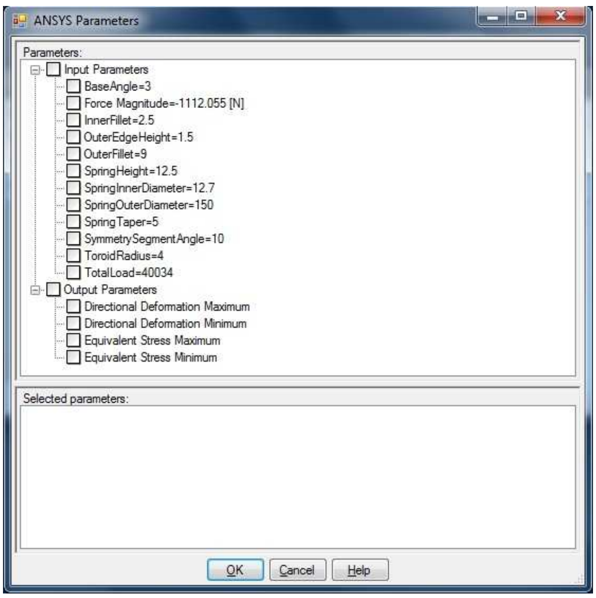
The **Task** defines the **Objectives** and **Constraints** of the **Expert Design** to be performed.

The **Design Space** defines which **Application Model** variables can be changed and how to adjust them to achieve the design **Task**.

The next step in creating the **Expert Design** for the mount was to load information from the Flexible Spring Mount ANSYS Workbench Project into the **Reference Run** of the **Expert Design**. ***DOES*** makes the setup process easy with its intelligent ANSYS tool partner interface that recognizes the type of model and automates many of the definition tasks. To obtain this data we selected the spring mount's ANSYS WBDB file when we created our **Reference Run.**

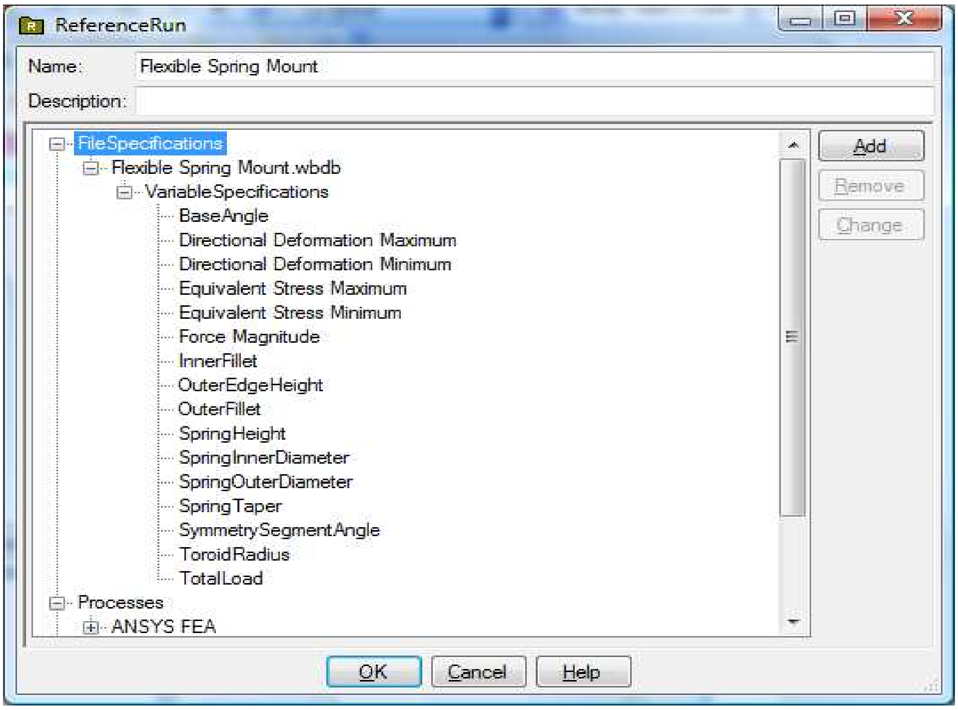


When creating the Variable Specification of the **Reference Run** for a WBDB file, ***DOES*** invokes the ANSYS Workbench Parameter Set to provide all of the input and output variables associated with the ANSYS model:

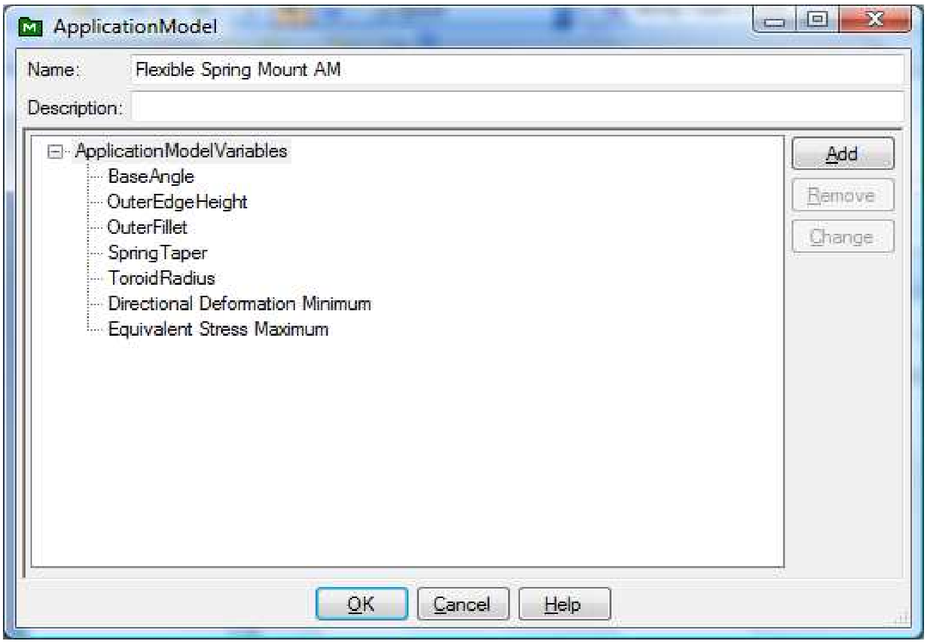


Note that the current values are displayed for all model input variables. The Knowledge Engineer selects the input and output variables from the list that he/she wants to include in the **Reference Run** and any subsequent **Application Models** that may be created using this **Reference Run.**

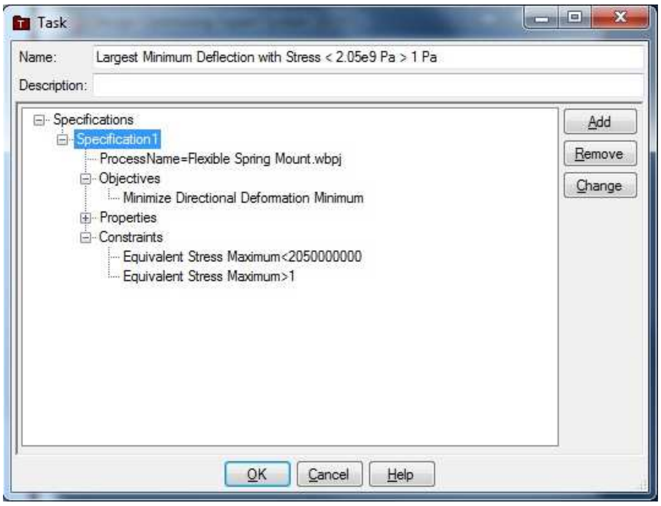
The following display shows all of the model variables that were selected for the **Reference Run:**



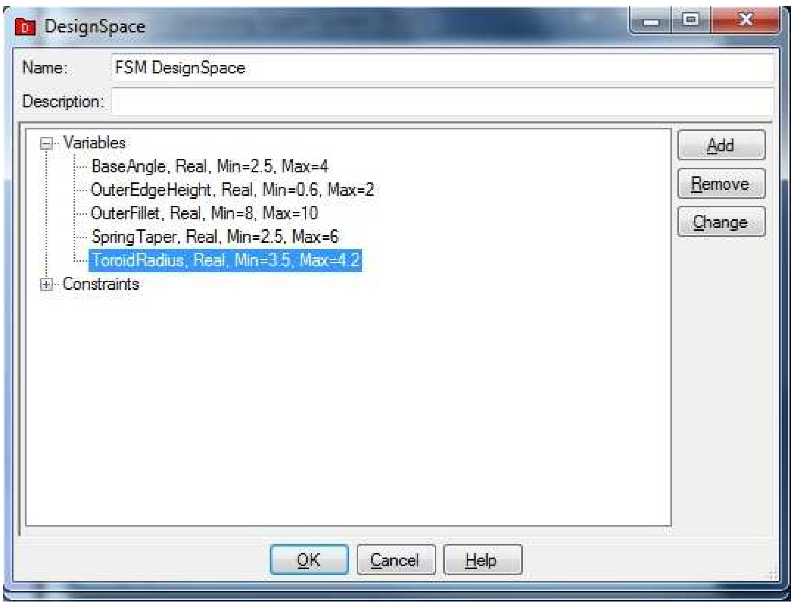
The next step was to use the **Knowledge Engineering** interface to define the **Application Model** and select the **Reference Run Variables** that can be manipulated with this **Expert Design**. The following display shows how simple the **Application Model** is.



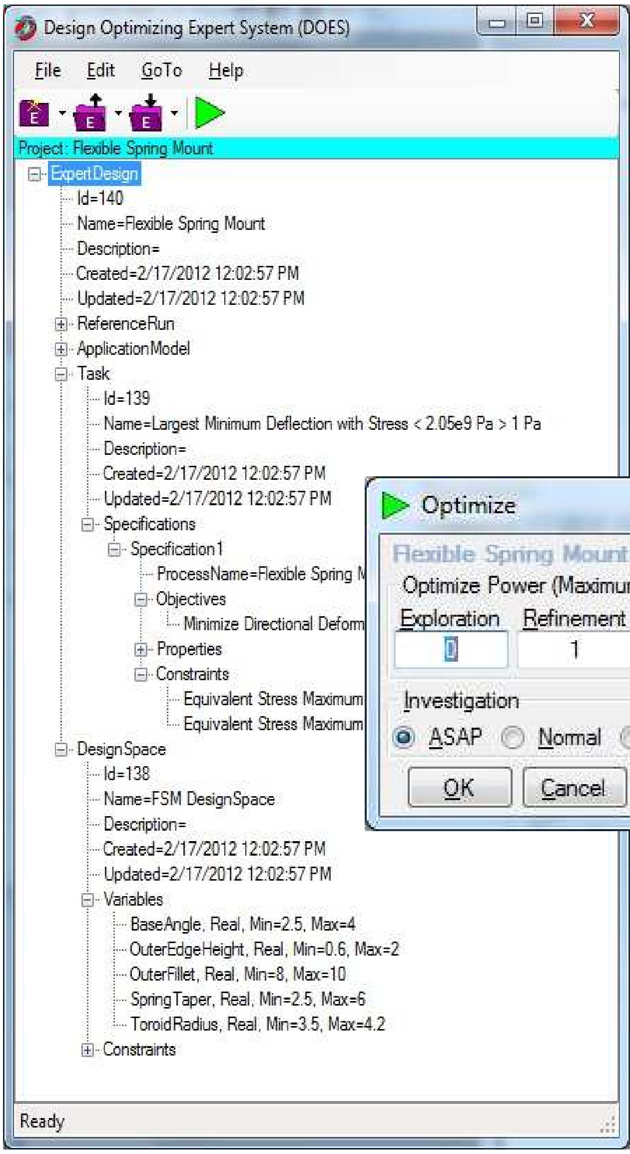
Next the engineer creates the **Expert Design's Task** which specifies the **Objectives** and **Constraints** of the **Expert Design**. ***DOES*** supports multiple **Objectives**; however, in this study the only **Objective** was to create a mount with the largest amount of deflection in the –Y direction. Remember that this **Objective** must be achieved subject to the **Constraint** that the maximum equivalent stress in the model **must be greater than 1 and less than 2050 MPa.**



Once the design **Task's Objectives** and **Constraints** are defined it is necessary to identify the **Application Model** parameters which can be varied in order to achieve the design's **Task**. These parameters are called the **Design Space Variables**. The engineer must also specify the minimum and maximum values that each **Design Space Variable** can be assigned. Not all values need to be viable as those which produce invalid model regeneration are reported at runtime by ***DOES*** and ignored for purposes of determining final results. In this study we optimized the values of five (5) design parameters contained in the **Application Model**. The window below shows the **Design Space Variables** and the ranges for their values.



Optimizing the Spring Mount



Once all of the desired input **Design Space Variables** have been specified, optimizations can be launched by clicking on the **Green Arrow** to obtain improved designs. The **Optimize** dialog box controls the amount of computing that will be performed to optimize the design which in turn determines how long the optimization will run and normally how good the designs will be.

The default **Optimize** parameters, shown in the box below were used to obtain the initial results for this study.

Exploration Power – determines the level of the Design of Experiments (DoE) that ***DOES*** uses during the 1st stage, of the optimization process. If it is not zero, ***DOES*** uses its proprietary DoE algorithms to locate the most promising solution areas within the design space.

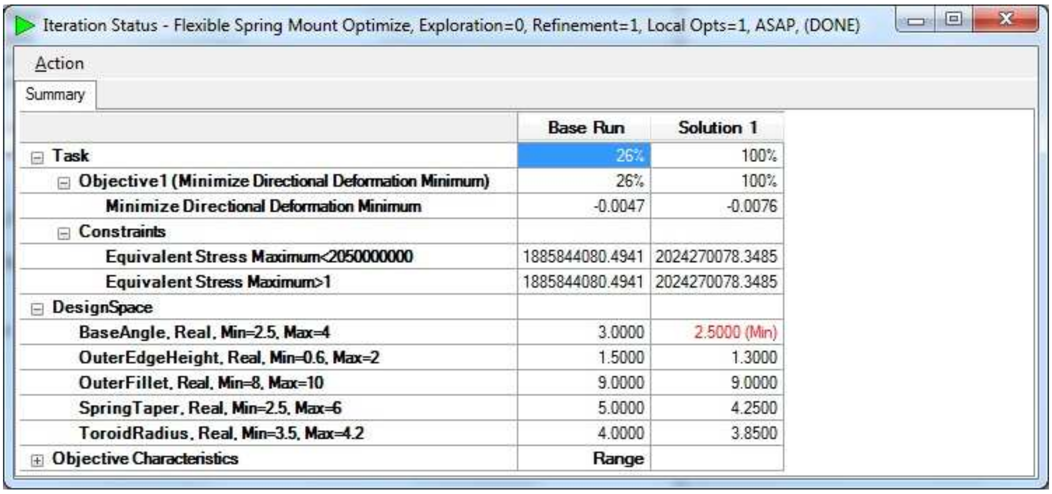
Refinement Power – is the number of levels of refinement that ***DOES*** applied to each **Solution** that was created during **Exploration**. **Refinement** is the second stage of the optimization process.

Solutions – determines the number of improved designs that ***DOES*** will attempt to create. The first **Solution** is the best new design. The second **Solution** is the second best design, etc.

This default **(0,1,1) Optimize** has an **Exploration Power = 0**, which tells ***DOES*** to skip the DoE stage of the optimization process. The **Optimize Power** is equal to **1**. **Exploration Power + Refinement Power = Optimize Power** for the **Iteration**. The number of designs in a ***DOES*** **Optimize** design space is equal to **((2 ^Optimize Power) +1) ^(number of Design Space Variables)**. Thus, for this **Optimize** the design space is very small, ((2^1) +1) ^5, which is **only 243 different designs.** Simply clicking the **OK** button causes ***DOES*** to run many batch mode simulations to completion, without further intervention, to optimize the design.

Results of the First Optimize Iteration of the Spring Mount

During and after the completion of an **Optimize Iteration**, the optimized **Results** can be displayed as shown below.



Iteration Status - Flexible Spring Mount Optimize, Exploration=0, Refinement=1, Local Opts=1, ASAP, (DONE)

Action

Summary

	Base Run	Solution 1
Task	26%	100%
Objective1 (Minimize Directional Deformation Minimum)	26%	100%
Minimize Directional Deformation Minimum	-0.0047	-0.0076
Constraints		
Equivalent Stress Maximum<2050000000	1885844080.4941	2024270078.3485
Equivalent Stress Maximum>1	1885844080.4941	2024270078.3485
DesignSpace		
BaseAngle, Real, Min=2.5, Max=4	3.0000	2.5000 (Min)
OuterEdgeHeight, Real, Min=0.6, Max=2	1.5000	1.3000
OuterFillet, Real, Min=8, Max=10	9.0000	9.0000
SpringTaper, Real, Min=2.5, Max=6	5.0000	4.2500
ToroidRadius, Real, Min=3.5, Max=4.2	4.0000	3.8500
Objective Characteristics	Range	

The first **Iteration** of this **Expert Design improved the mount's deflection by a whopping 65%** allowing a deformation of -**7.6 mm,** with a maximum equivalent stress of **2024.270078 MPa,** which was about 24 MPa less than the maximum allowed.

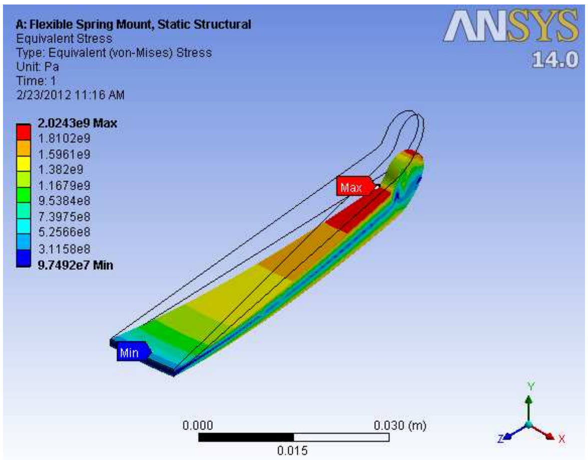
This **Iteration** ran for less than **23 minutes,** in the background on a notebook PC with no user intervention, and created and analyzed only **20 new designs** to create this vastly improved design.

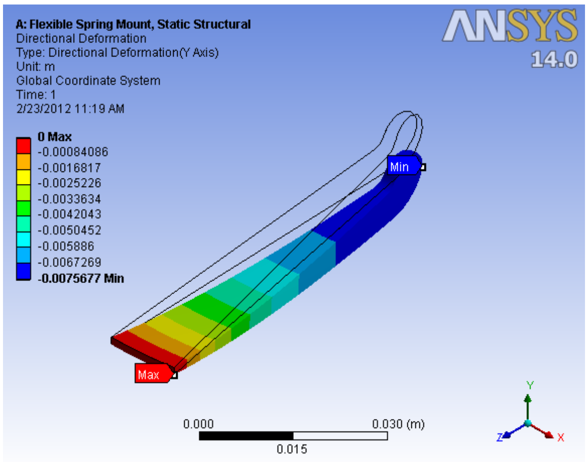
All ***DOES*** **Results** are stored in a design **Project** within the ***DOES*** SQL Knowledge Base.

ANSYS Analysis of the First Optimize Iteration of the Spring Mount

Once the **Iteration** was completed, the optimized design was viewed within the ANSYS Workbench environment. At this point the engineer is able to select any of the new **Solutions** created by ***DOES***.

The following displays show an ANSYS analysis of the stress and deflection of the optimized spring mount created by the 0,1,1 **Iteration** with ***DOES***.





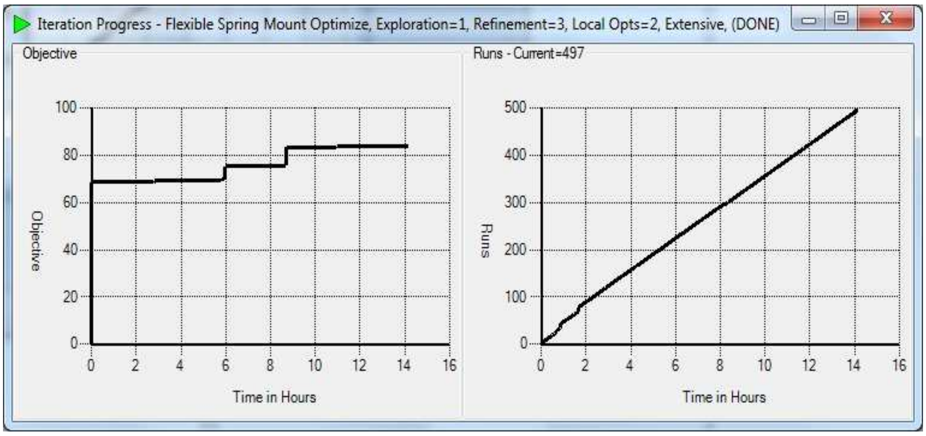
Unlike "DesignXplorer", every design created by DOES is the result of a successful, complete execution of an ANSYS simulation. They are all Hard Points and no validation is ever required.

Results of Additional Optimize Iterations

Because the first quick default **Optimize** was so successful, we decided to perform additional, more powerful **Iterations** to see if ***DOES*** could create even better designs.

In order to obtain two optimized designs from the second **Iteration** we specified the minimum ***DOES*** "design of experiments" exploration by incrementing the **Exploration Power** from 0 to **1**. We increased the **Refinement Power** from 1 to **3** to increase the number of possible designs in the design space from 243 to **1,419,857**, and we selected an **Extensive Investigation** rather than ASAP so that **DOES** would evaluate more new designs during this **Iteration** while ***DOES*** attempted to create the best designs within this much larger design space.

This second iteration highlights an important feature of ***DOES***. Note in the progress chart below that the Objective quickly jumped to over 60%:



This highlights ***DOES'*** powerful underlying knowledge base architecture. All of the 20 designs analyzed during the first **Optimize Iteration** were stored in its knowledge base. **No designs are ever rerun during the Iterations of a *DOES* Expert Design.** Thus, the previous **Iteration's** best **Solution** is found quickly at the beginning of the second iteration. Only new designs need to be evaluated.

This second **Iteration** created a significantly better design with the deformation increasing from 7.7mm to **8.7mm**:

Iteration Status - Flexible Spring Mount Optimize, Exploration=1, Refinement=3, Local Opts=2, Extensive, (DONE)

Action

Summary

	Base Run	Solution 1	Solution 2
Task	36%	100%	84%
Objective1 (Minimize Directional Deformation Minimum)	36%	100%	84%
Minimize Directional Deformation Minimum	-0.0047	-0.0087	-0.0077
Constraints			
Equivalent Stress Maximum<2050000000	1885844080.4941	2040949890.8061	2048724470.8381
Equivalent Stress Maximum>1	1885844080.4941	2040949890.8061	2048724470.8381
DesignSpace			
BaseAngle, Real, Min=2.5, Max=4	3.0000	2.5938	2.6875
OuterEdgeHeight, Real, Min=0.6, Max=2	1.5000	0.6875	1.3000
OuterFillet, Real, Min=8, Max=10	9.0000	10.0000 (Max)	9.3750
SpringTaper, Real, Min=2.5, Max=6	5.0000	5.1250	4.2500
ToroidRadius, Real, Min=3.5, Max=4.2	4.0000	3.5438	3.7625
Objective Characteristics	Range		

In reviewing the 2 **Solutions** found in our second **Iteration** one can see that their geometries are quite different from each other. This indicates that there might be many good diverse optimized designs in the design space rather than a few with similar geometry that yields good results. Encouraged by this progress, we ran a third iteration where we incremented the ***DOES*** **Exploration Power** from 1 to **2**. We then decreased the **Refinement Power** from 3 to **2** to keep the number of possible designs in the design space to **1,419,857**, and we maintained an **Extensive Investigation** as in the second **Iteration**.

This 2, 2, 2 **Iteration** evaluated an order of magnitude more designs than the previous **Iteration** and again created a significantly better design:

Iteration Status - Flexible Spring Mount Optimize, Exploration=2, Refinement=2, Local Opts=2, Extensive, (DONE)

Action

Summary

	Base Run	Solution 1	Solution 2
Task	32%	100%	90%
Objective1 (Minimize Directional Deformation Minimum)	32%	100%	90%
Minimize Directional Deformation Minimum	-0.0047	-0.0094	-0.0087
Constraints			
Equivalent Stress Maximum<2050000000	1885844080.4941	2046673878.6232	2040949890.8061
Equivalent Stress Maximum>1	1885844080.4941	2046673878.6232	2040949890.8061
DesignSpace			
BaseAngle, Real, Min=2.5, Max=4	3.0000	2.6875	2.5938
OuterEdgeHeight, Real, Min=0.6, Max=2	1.5000	0.7750	0.6875
OuterFillet, Real, Min=8, Max=10	9.0000	9.7500	10.0000 (Max)
SpringTaper, Real, Min=2.5, Max=6	5.0000	4.6875	5.1250
ToroidRadius, Real, Min=3.5, Max=4.2	4.0000	3.9375	3.5438
Objective Characteristics	Range		

Note that **Solution 2** of this **Iteration** is the same design as **Solution 1** of the previous **Iteration**, and that the new best design has distinctly different geometry.

In light of the success of the previous **Iteration** it was decided that a fourth iteration should be run to explore this design space even further. This time, we incremented the ***DOES*** **Exploration Power** from 2 to **3** and reduced the **Refinement Power** from 2 to **1** to preserve the same design space. Again we chose **Extensive Investigation** as in the previous **Iterations**. Increasing the **Exploration Power** from 2 to **3** will cause ***DOES*** to create a much longer running **Exploration** so we chose to reduce this run time by limiting the number of **Seed Points** to **200**. This is another feature of ***DOES*** that allows the designer to easily control the run time of an **Iteration**.

Again, this **Iteration** created an even better very different design. Note that once again **Solution 2** of this **Iteration** is the same a **Solution 1** of the previous **Iteration**.

Iteration Status - Flexible Spring Mount Optimize, Exploration=3, Refinement=1, Local Opts=2, Seed=1, Initial runs=200, Extensive, (DONE)

Action

Summary

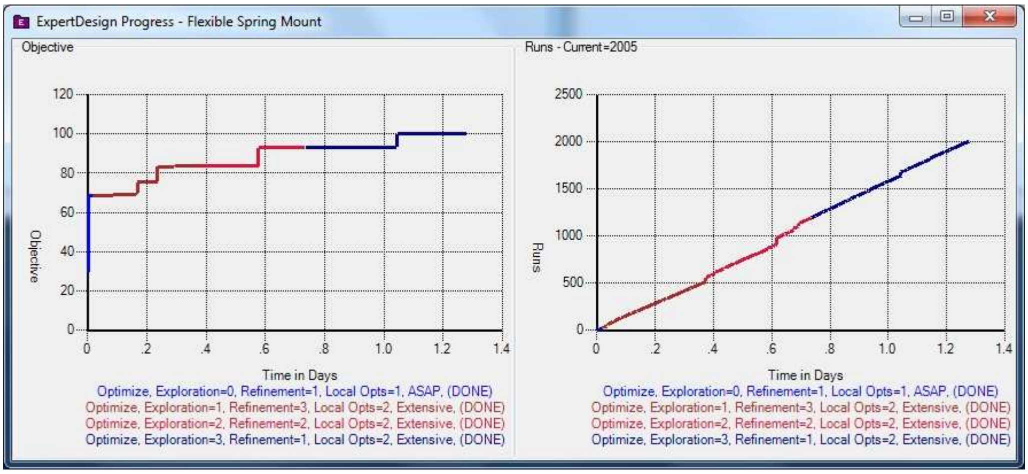
	Base Run	Solution 1	Solution 2
Task	30%	100%	93%
Objective1 (Minimize Directional Deformation Minimum)	30%	100%	93%
Minimize Directional Deformation Minimum	-0.0047	-0.0099	-0.0094
Constraints			
Equivalent Stress Maximum<2050000000	1885844080.4941	2047045141.3727	2046673878.6232
Equivalent Stress Maximum>1	1885844080.4941	2047045141.3727	2046673878.6232
DesignSpace			
BaseAngle, Real, Min=2.5, Max=4	3.0000	2.5938	2.6875
OuterEdgeHeight, Real, Min=0.6, Max=2	1.5000	0.6875	0.7750
OuterFillet, Real, Min=8, Max=10	9.0000	8.0000 (Min)	9.7500
SpringTaper, Real, Min=2.5, Max=6	5.0000	4.6875	4.6875
ToroidRadius, Real, Min=3.5, Max=4.2	4.0000	4.2000 (Max)	3.9375
Objective Characteristics	Range		

A summary of the complete **Expert Design**, shows all four of the iterations and the incremental progress:

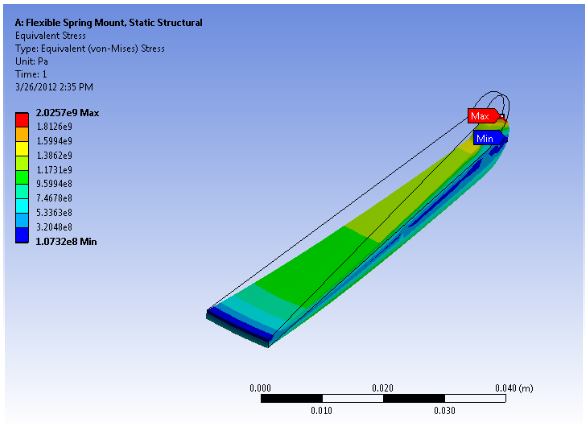
ExpertDesign Status - Flexible Spring Mount

Action

	Base Run	Iteration 1	Iteration 2	Iteration 3	Iteration 4
Task	30%	69%	84%	93%	100%
Objective1 (Minimize Directional Deformation Minimum)	30%	69%	84%	93%	100%
Minimize Directional Deformation Minimum	-0.0047	-0.0076	-0.0087	-0.0094	-0.0099
Constraints					
Equivalent Stress Maximum<2050000000	1885844080.4941	2024270078.3485	2040949890.8061	2046673878.6232	2047045141.3727
Equivalent Stress Maximum>1	1885844080.4941	2024270078.3485	2040949890.8061	2046673878.6232	2047045141.3727
DesignSpace					
BaseAngle, Real, Min=2.5, Max=4	3.0000	2.5000 (Min)	2.5938	2.6875	2.5938
OuterEdgeHeight, Real, Min=0.6, Max=2	1.5000	1.3000	0.6875	0.7750	0.6875
OuterFillet, Real, Min=8, Max=10	9.0000	9.0000	10.0000 (Max)	9.7500	8.0000 (Min)
SpringTaper, Real, Min=2.5, Max=6	5.0000	4.2500	5.1250	4.6875	4.6875
ToroidRadius, Real, Min=3.5, Max=4.2	4.0000	3.8500	3.5438	3.9375	4.2000 (Max)

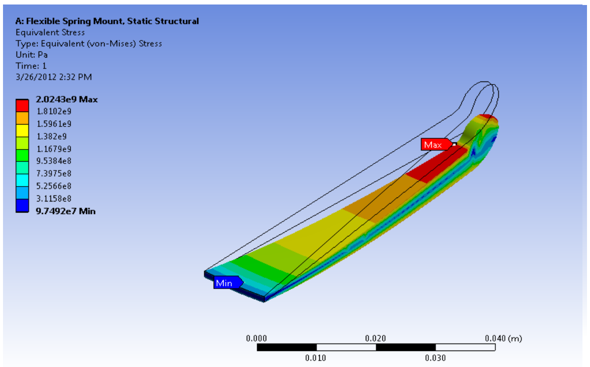


A Graphic Summary of the Spring Mount's Optimization Progress



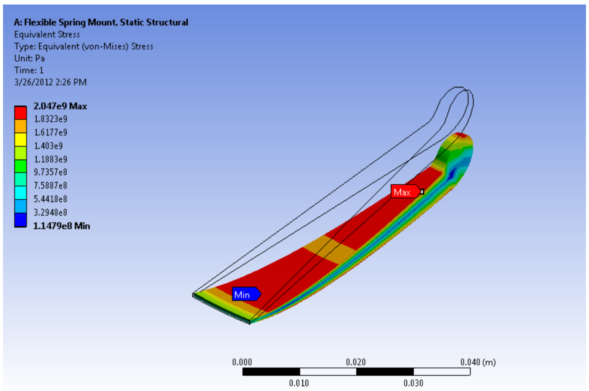
After 4 Days of MANUAL optimization:

Displacement = - 4.6561 mm
Stress = 2025.7 MPa



After 23 Mins of DOES optimization:

Displacement = - 7.6 mm
Stress = 2024.27 MPa



After 1.2 Days of DOES optimization:

Displacement = - 9.9 mm
Stress = 2047 MPa

Benefits of *DOES*

While the desire and need to achieve design optimization have been around for a number of years, viable results have been difficult to obtain. The reasons for this limited success have been in the tools and approaches that were available.

DOES is a totally unique approach to optimization that is the result of over 10 years of development and a series of unique proprietary and patented algorithms created by Optimum Power Technology.

Primary benefits include:

- The product is powerful
- The product is easy to learn and use
- The product produces good results quickly
- The product runs without user intervention
- All variables are considered and analyzed in every optimization.
- All solutions produce valid (accurate) hard point designs.
- Simulation results are captured in an imbedded database so that the results can be used by subsequent Iterations of a design project. Within a Expert Design study NO SIMULATION WILL BE RERUN!
- The User controls speed of the optimizations with simple intuitive controls at the time that the Iteration is launched.