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Altair MotionView 2019 Tutorials

MV-3020: Optimization of a Two Spring Mass System

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MV-3020: Optimization of a Two Spring Mass System

MotionSolve is commonly used for performing system level simulation. Simulations are commonly performed to understand how well a specific design performs. Often a goal for such simulations is to find the *right set* of design parameters that permit the system to perform its intended functions in some optimal way.

Commonly used design variables are the location and orientation of various connectors and their force characteristics. Occasionally the mass and material properties of some bodies are also included as design variables. The system behavior is normally characterized with a set of *response variables*. So, the goal of simulations often is to find the values of these design variables such that the response variables attain a desired set of values.

In the past such analysis has been done using techniques such as Monte Carlo simulations and design of experiments. These methods work quite well, but they are computationally intensive and require large sets of simulations.

MotionSolve now supports a capability for analytically computing design sensitivities. Design sensitivity is the matrix of partial derivatives of the response variables with respect to the design variables. A gradient-based optimizer is capable of using these sensitivities to minimize a cost function. This process is known as design optimization. A new optimization toolkit that permits optimization of some design problems is also now available in MotionSolve.

Though not as general as the statistical methods, optimization with design sensitivity is significantly faster and is the preferred solution in many instances.

In this tutorial you will learn how to setup an optimization problem using MotionView's Optimization Wizard. You will learn about:

- Process of Optimization with MotionSolve
- Defining spring stiffnesses as design variables
- Defining displacements as responses
- Using the responses as objectives
- Running the optimization and post-processing the results

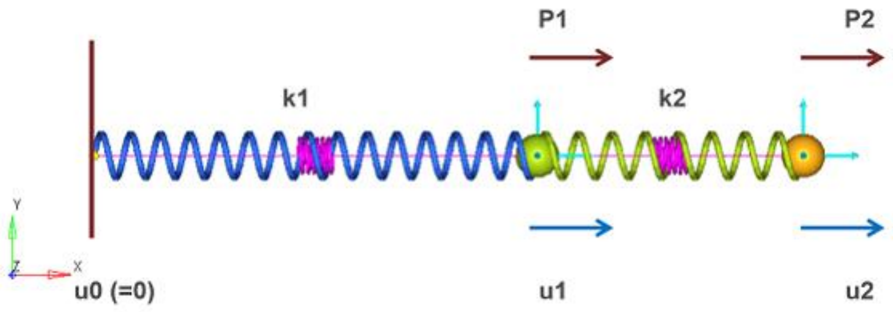
Introduction

Two springs are connected in series. The stiffness of spring-1 is k1 and that of spring-2 is k2. One end of spring-1 is fixed to ground while a force, P1, acts at the other end. Spring-2 is subjected to a force of P2 at the other end.

The objective of the analysis is to determine the sensitivities of stiffnesses of the springs to displacements u1 and u2 and use them to identify or tune k1 and k2 of the system to achieve specific values of u1 and u2.

MotionSolve's DSA (Design Sensitivity Analysis) capability to calculate sensitivities is utilized in this example. A Step-by-step procedure to define and run the model is given below.

The figure below shows the problem setup. Properties used in the problem are also given.



Springs in Series – Model Description

Here are the properties of the system:

<u>Displacement</u>:

u0 = 0 (Fixed)

<u>Force</u>:

P1 = 1 N

P2 = 2 N

<u>Stiffness</u>:

k1 = 2 N/mm

k2 = 3 N/mm

Response Variables (RV): u1 and u2

Design Variables (DV): k1 and k2

Analysis Type: Static Analysis with DSA

The process of optimization starts with setting up a model in MotionView. MotionView's Optimization Wizard is used to setup design variables, responses and objectives. The wizard also guides the user to run and plot/print results of optimization. It is also able to export a design from a particular iteration into a new MDL for further analyses.

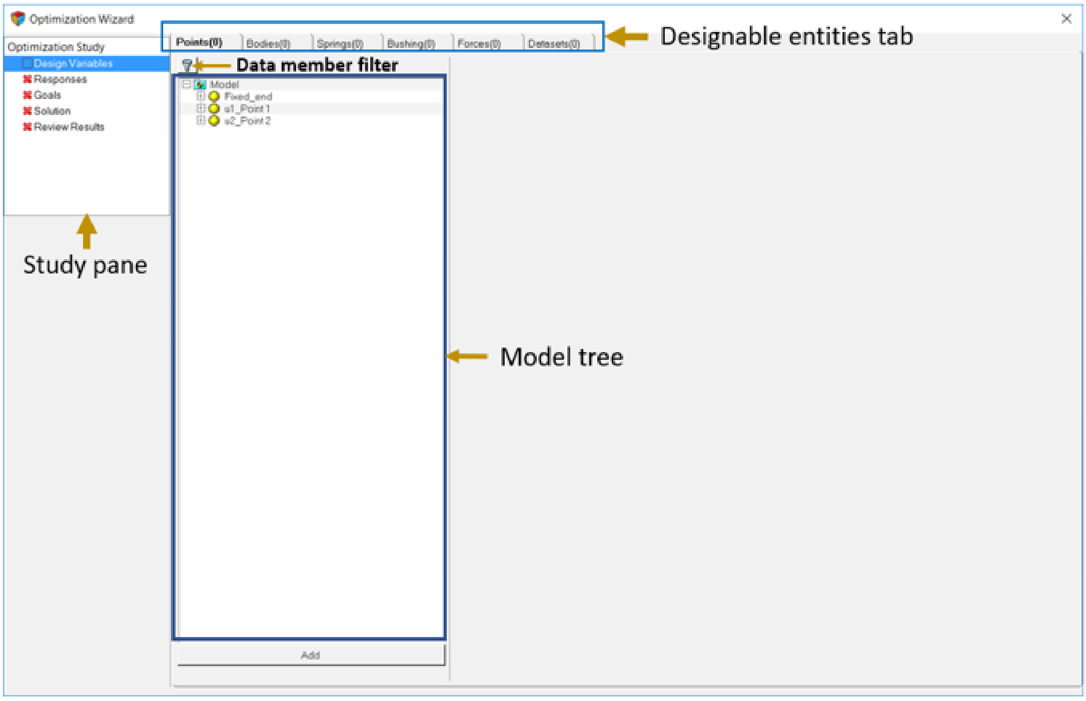
Model Setup

Copy the file `mv_3020_initial_two_springs.mdl` located in the `mbd_modeling\motionsolve\optimization\MV-3020` into your `<working directory>`.

Step 1: Adding Design Variables.

1. Open `mv_3020_initial_two_springs.mdl` in MotionView.
2. Right-click on ***Model*** in the browser and click ***Optimization Wizard***.

   The **Optimization Wizard** is displayed.



The wizard consists of an Optimization Study pane that guides the user through each step of solving an optimization problem with MotionSolve. The wizard opens with the **Design Variables** page active that enables the selection of design variables.

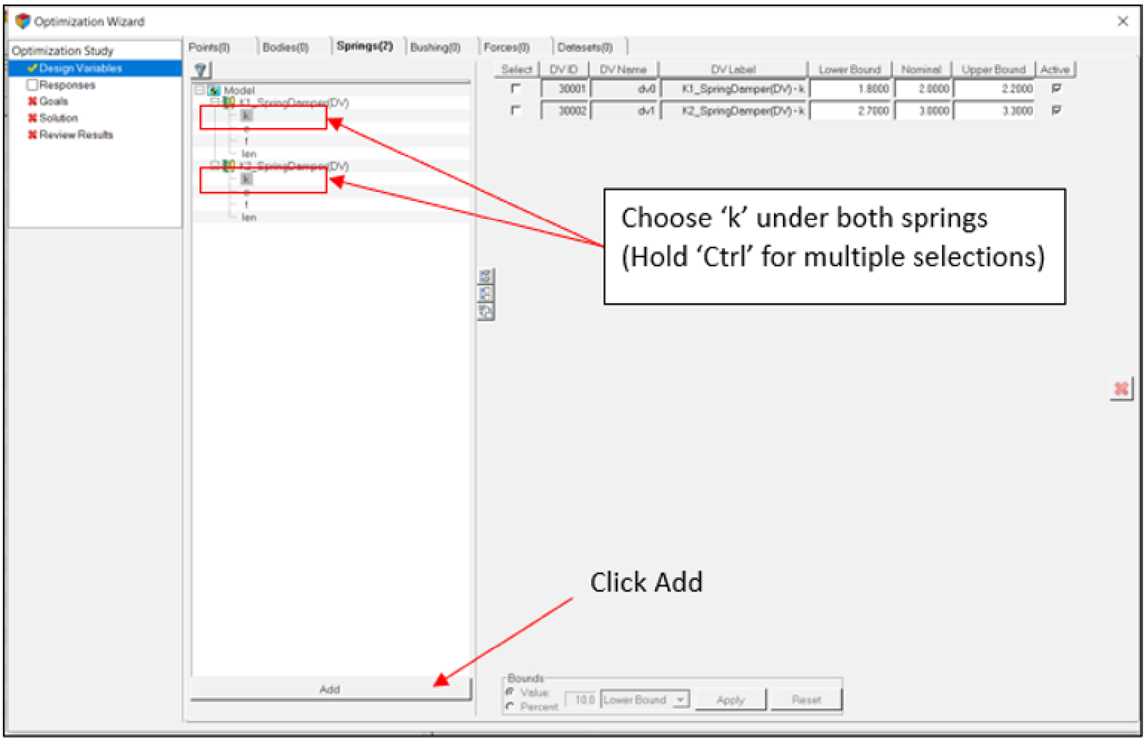
3. Under **Design Variables**, click on the ***Springs*** tab. Two SpringDampers will be listed:

   a. K1_SpringDamper

   b. K2_SpringDamper

   The spring stiffness of these springs are made as designable.

   Expand the two springs by clicking on '+' button, the data members that can be made designable are displayed as in the figure below.



Spring data members that can be made as designable

   Using the 'Ctrl' button, select the ***k*** (stiffness) data members of both the springs. Click the ***Add*** button available at the bottom of the model tree.

   The stiffness of SpringDampers are added as design variables with default upper and lower bound. The default value used by MotionView for calculating bounds is 10% of nominal value.

4. Modify the upper and lower bounds of stiffness as below:

DV	Lower Bound	Upper Bound
sd_0.k	0.25	4.0
sd_1.k	0.25	4.0

Note The number within parenthesis of the designable entities tab at the top (Springs(2) in this case) indicates the number of design variables defined of that entity type.

Defining design variables is now complete and we can move to the Response Variables.

Step 2: Adding Response Variables.

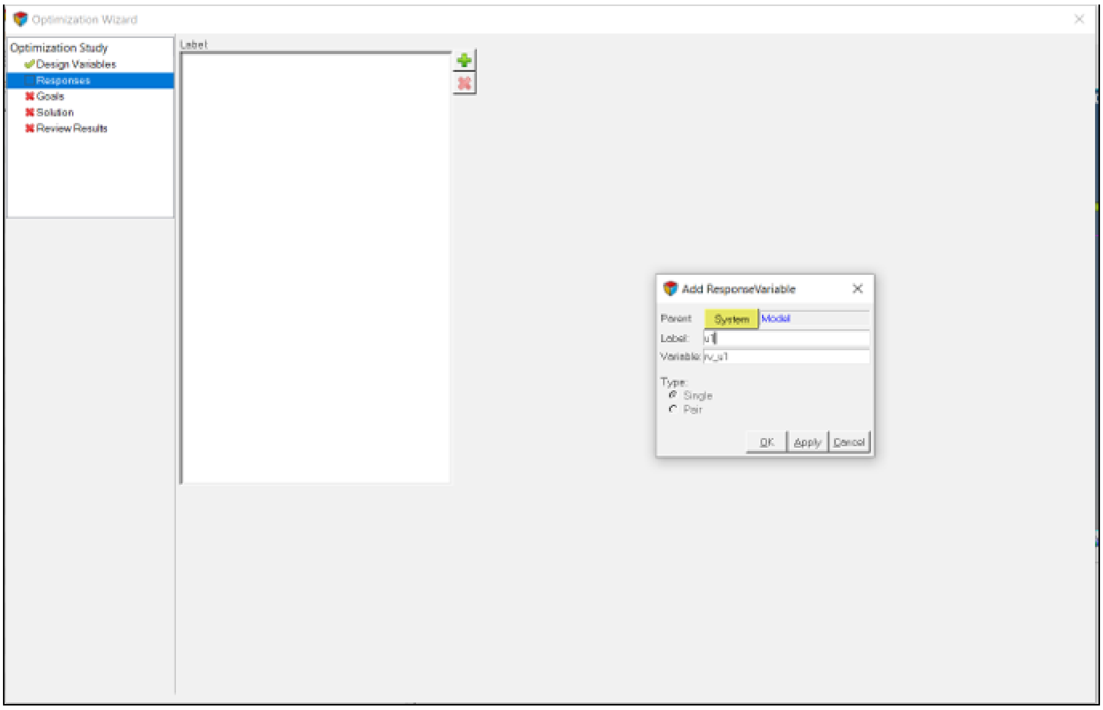
There are two responses in this problem:

a. Displacement u1: To make u1 to reach a value of 3, the metric (1-u1/3)**2 is used

b. Displacement u2: To make u2 to reach a value of 4, the metric (1-u2/4)**2 is used

1. Click on the ***Responses*** page.

2. Add a response variable by clicking the button'. In the Add ResponseVariable dialog that appears, change the label to '`u1`' and click ***OK***.



Adding response1 – u1

The ResponseVariable is added and appears in the list. The panel also appears.

2. In the panel, change the **Response Type** to ***Generic*** using the combo box.

3. The scale can be left at default value of 1.0.

4. In the **Response Expression** key in the the following expression:

```
`(1-DM({b_0.cm.id},{m_0.id})/3)**2`
```

where:

b_0.cm.id = ID of the CM marker of *Body 0*

m_0.id = ID of the marker on ground body located at *u1_Point 1*

Note During optimization, the optimizer tries to minimize the entire expression and as the value of DM({b_0.cm.id},{m_0.id}) approaches 3, the value of this response is minimized.

5. Check on the ***Use derivative*** check box. When checked, the computed value of the expression at the last time step of the simulation is used as the response.

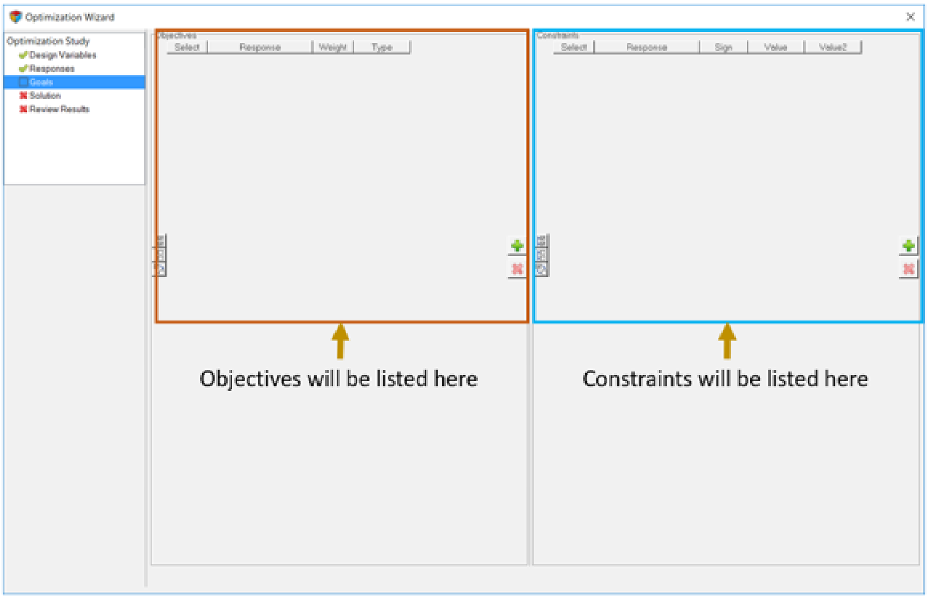
6. Follow the same procedure from the steps above to add another ResponseVariable *u2* of the type ***Generic***. The response expression is: `(1-DM({b_1.cm.id},{m_1.id})/4)**2`.

Adding Responses is now complete. Next, we can proceed to setup objectives and constraints and solve the model.

Step 3: Adding Objectives and Constraints.

The problem has two objectives: the value of u1 should be 3 and value of u2 should be 4 at the end of optimization. We can use the responses that have been created in the previous section as objectives.

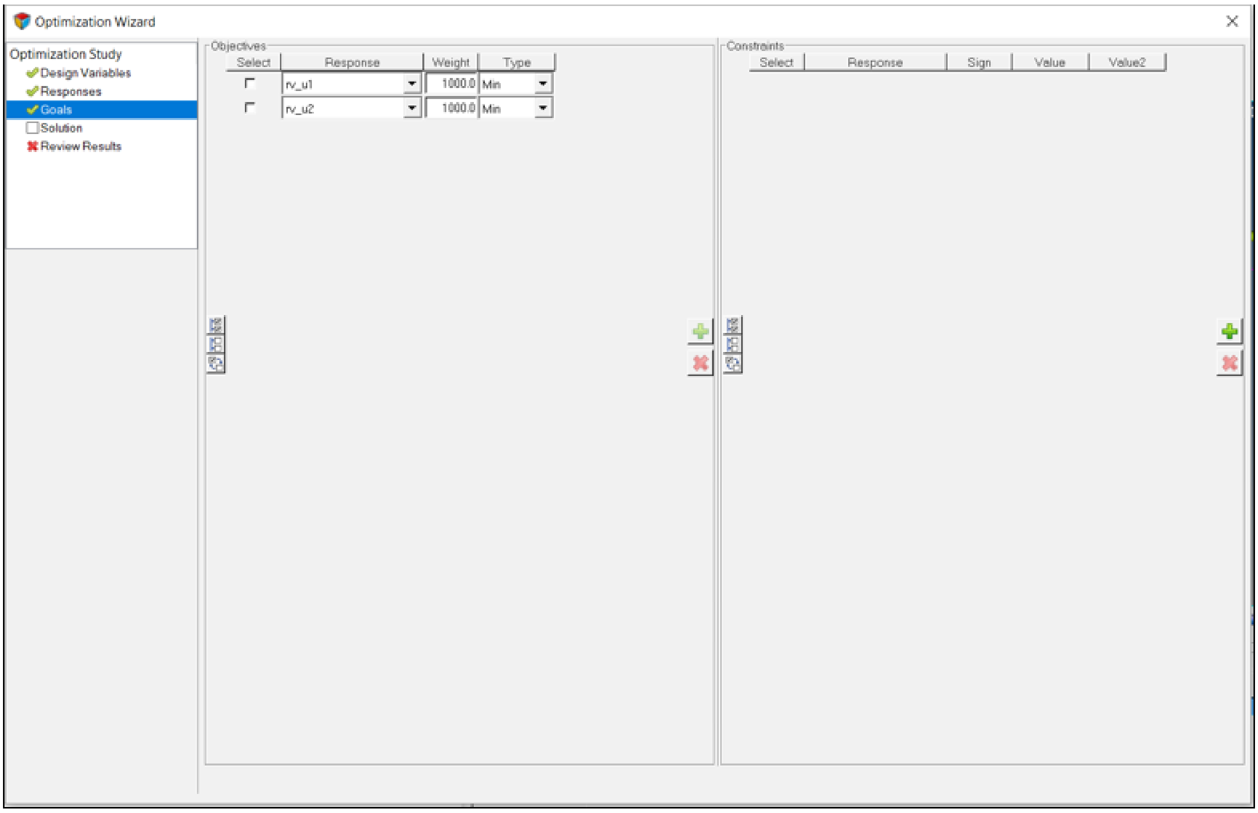
1. Go to the **Goals** page. This page has two sections: **Objectives** and **Constraints**.



2. Click on the  button under **Objectives**. An objective is added with response rv_u1.

   – Change the **Weight** to `1000` and retain the **Type** as ***Min*** since we want to minimize this response.

3. Repeat the above step to add another objective. rv_u2 is automatically chosen. Change the **Weight** as *1000* and retain the **Type** as ***Min*** since we want to minimize this response as well.

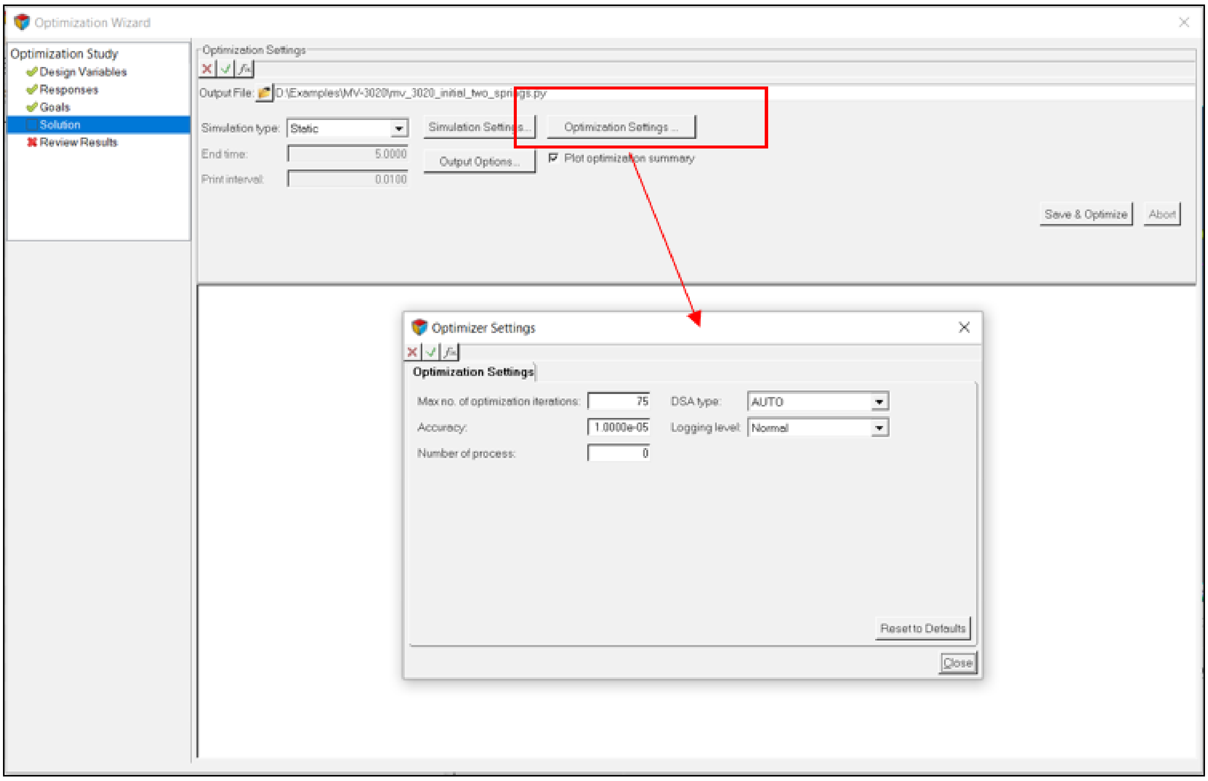


Defining objectives

There are no constraints in this problem. The model setup is now complete, and it is ready to run.

Step 4: Running the Optimization.

1. Go to the **Solution** page, to specify optimization settings and run the analysis. Please note that the model is saved before running, and if this is not desired, the model can be saved with a different mdl file name before starting the optimization. This can be done by closing the wizard, saving the model with a different name and returning to the wizard again.
2. Click on the ***Optimization Settings*** button. In the Optimizer Settings dialog that appears, change ***Accuracy*** to 1.0e-5.



Optimization settings for this problem

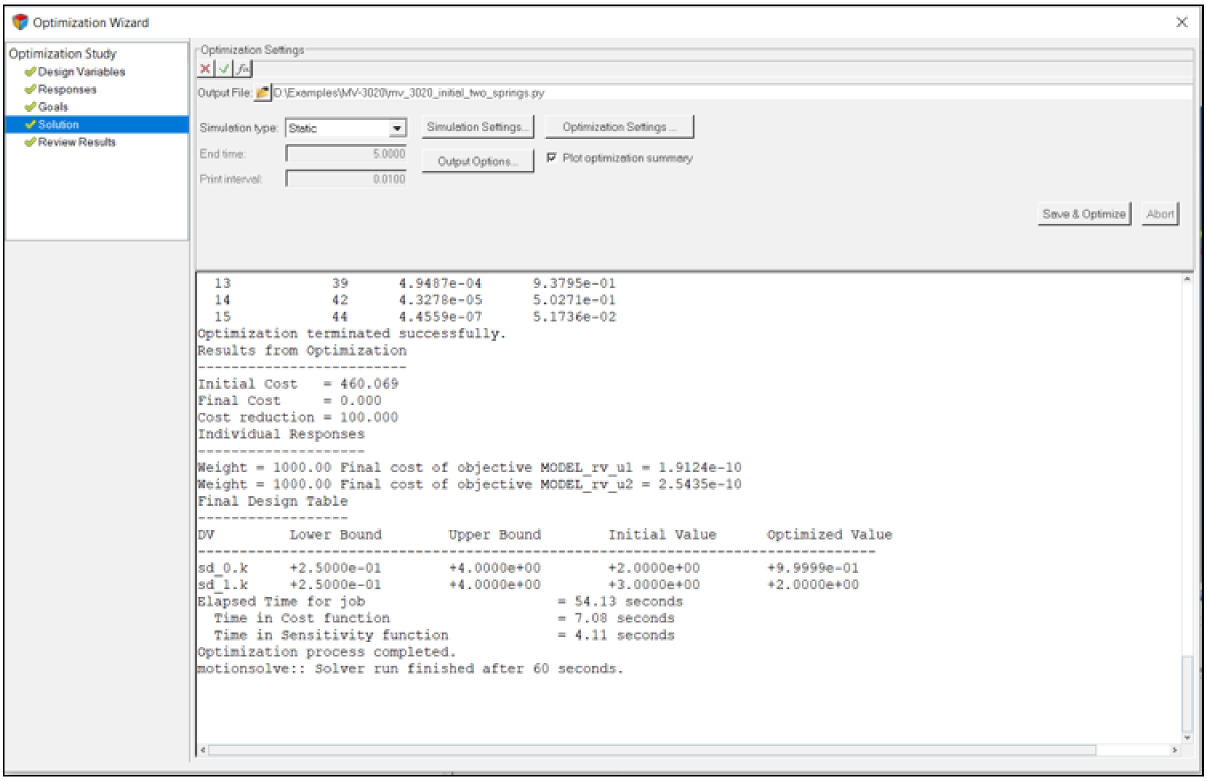
3. The rest of the parameters can be retained with the default values. ***Close*** the dialog.
4. Click on ***Save & Optimize***; optimization starts.

   While the optimization is running, a plot of total weighted cost vs. iteration number and a plot of individual cost vs. iteration number are displayed in a separate window (after the initial simulation).

Once the optimization is complete a summary is listed in the text window.

Note - you may have to scroll down to the end and/or to the right to see results of the optimization.

The text window should appear as in the image below.



Text window after the optimization is complete

Some important information available in the output window are:

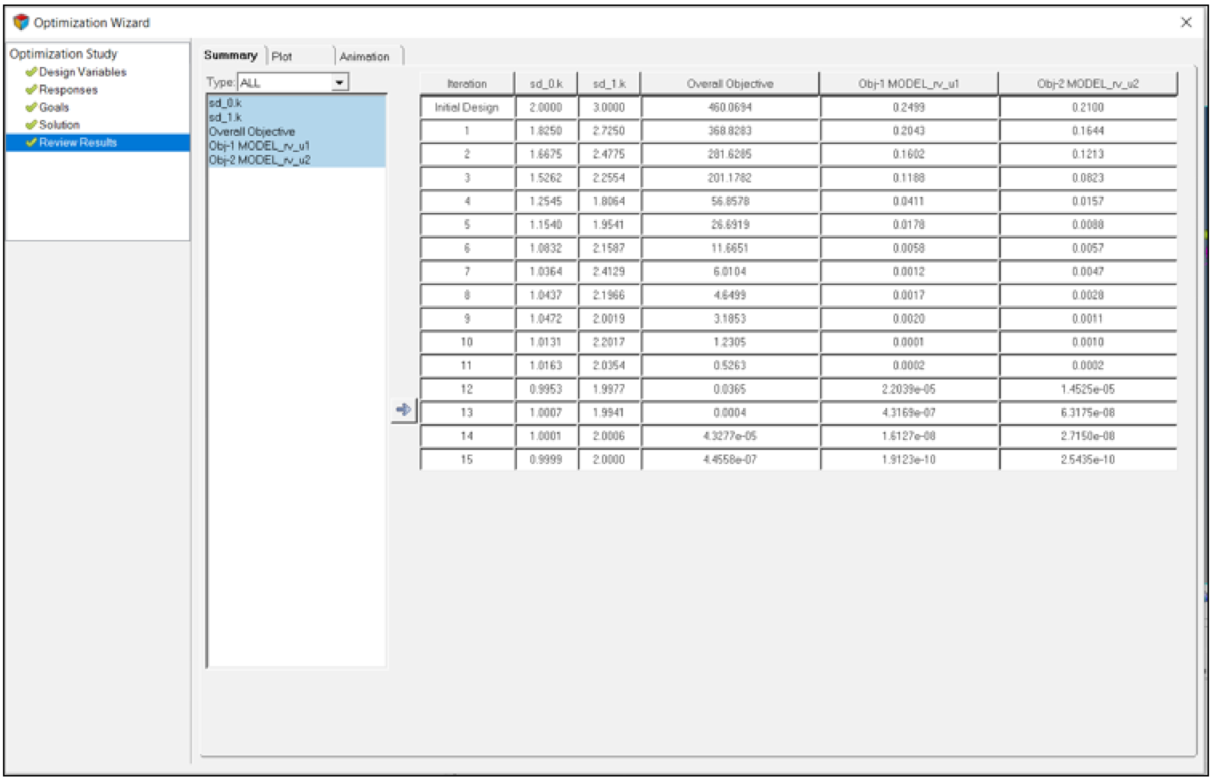
A. Optimizer settings
B. Iteration summary - Value of cost function by iteration number
C. Results from optimization - Initial cost, final cost and percentage reduction in cost
D. Final value of each objective at the end of optimization
E. Final design table with information on
    a. Design variable bounds
    b. Initial and optimized values of design variables
F. Elapsed time for calculating cost and sensitivity

Step 5: Post-processing

MotionView provides the ability to list, plot and animate results of optimization. It also provides capability to export mdl model corresponding to any design iteration.

1. Go to the ***Review Results*** page. The **Summary** tab appears that lists the history of design variables, responses and objective functions in a tabular format for each iteration of optimization run. \

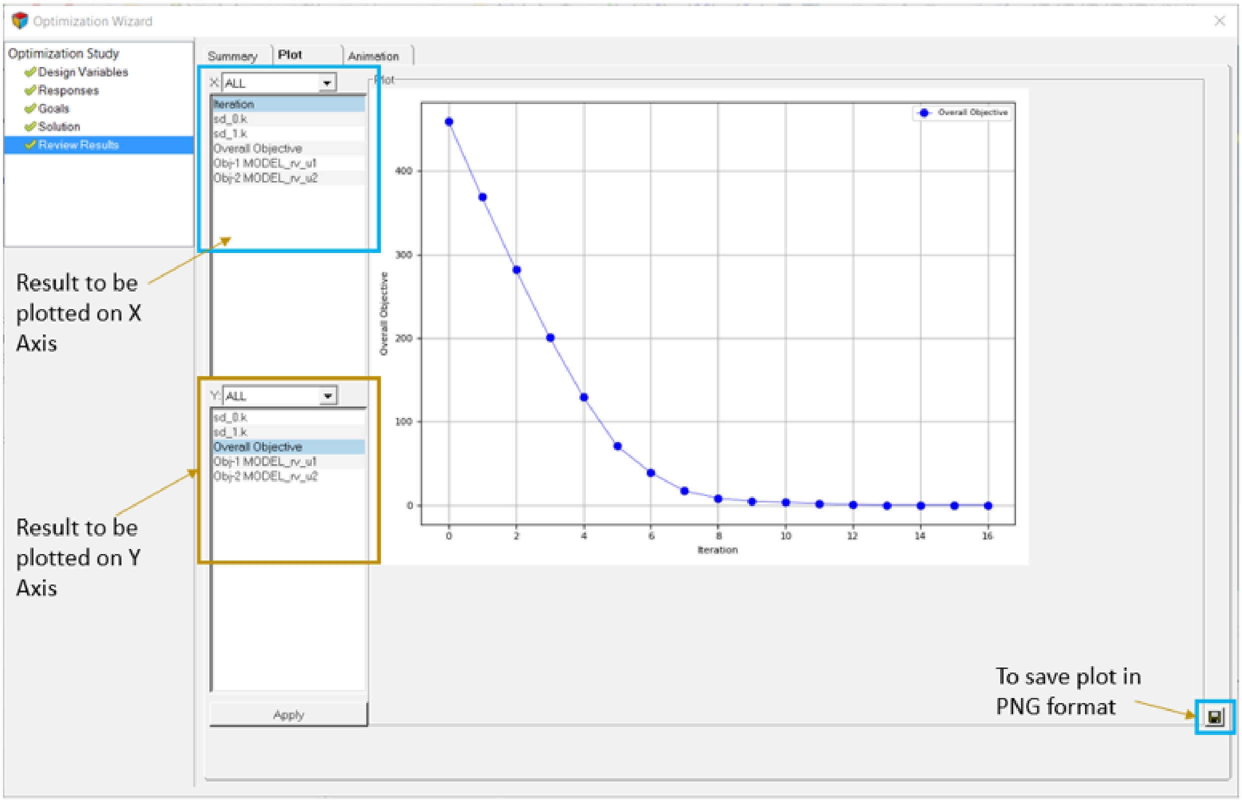
   Note MotionSolve uses SLSQP algorithm for optimization. Hence the last iteration is usually the optimum configuration with least value of cost function. See the figure below.



Iteration	sd_0.k	sd_1.k	Overall Objective	Obj-1 MODEL_rv_u1	Obj-2 MODEL_rv_u2
Initial Design	2.0000	3.0000	460.0694	0.2499	0.2100
1	1.8250	2.7250	368.8283	0.2043	0.1644
2	1.6675	2.4775	281.6285	0.1602	0.1213
3	1.5262	2.2554	201.1782	0.1188	0.0823
4	1.2545	1.8064	56.8578	0.0411	0.0157
5	1.1540	1.9541	26.6919	0.0178	0.0088
6	1.0832	2.1587	11.6651	0.0058	0.0057
7	1.0364	2.4129	6.0104	0.0012	0.0047
8	1.0437	2.1966	4.6499	0.0017	0.0028
9	1.0472	2.0019	3.1853	0.0020	0.0011
10	1.0131	2.2017	1.2305	0.0001	0.0010
11	1.0163	2.0354	0.5263	0.0002	0.0002
12	0.9953	1.9977	0.0365	2.2039e-05	1.4525e-05
13	1.0007	1.9941	0.0004	4.3169e-07	6.3175e-08
14	1.0001	2.0006	4.3277e-05	1.6127e-08	2.7150e-08
15	0.9999	2.0000	4.4558e-07	1.9123e-10	2.5435e-10

Summary tab listing cost function (objective), response variables and design variables

2. Select the **Plot** tab. It helps to visualize variation of design variables, response variables and cost function using graphs. Users can choose to plot any number of variables along y-axis with respect to a variable along x-axis.



3. Select ***Iteration*** from the **X** list and select ***Overall Objective*** from the **Y** list. Click ***Apply***.

   Note Multiple items can be selected and plotted from the Y list.

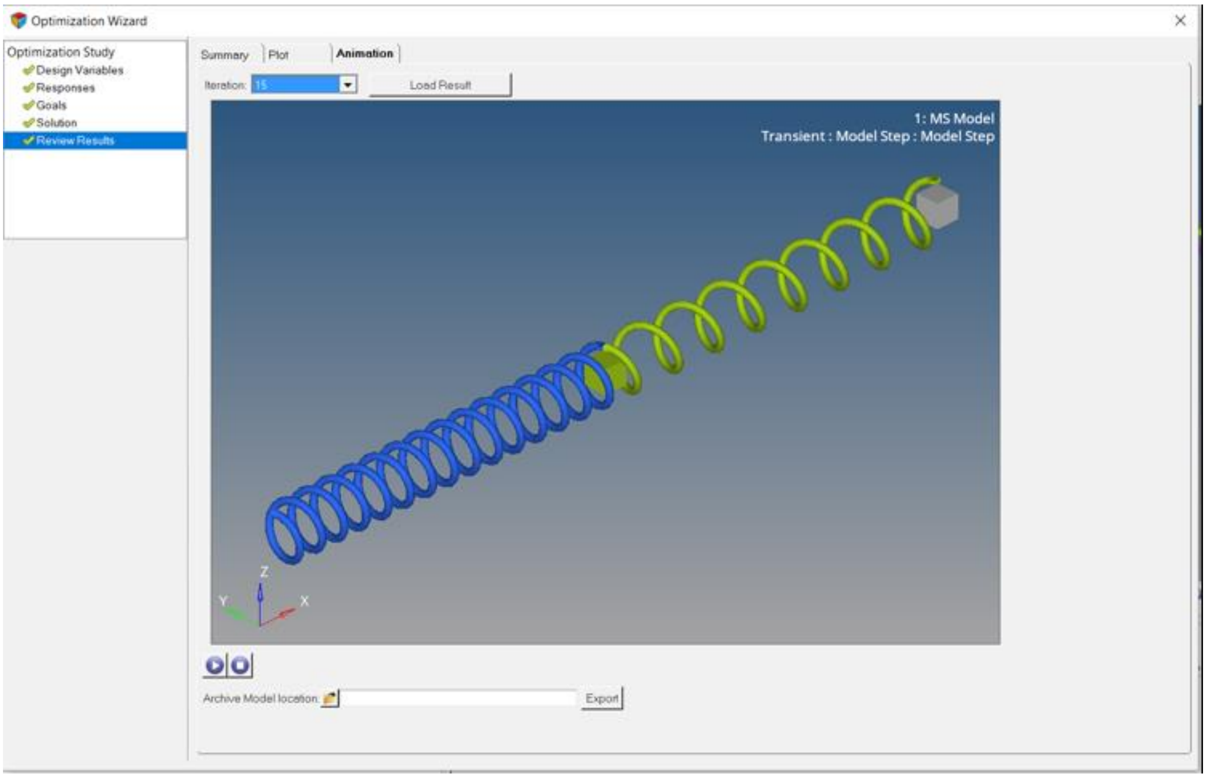
4. Select the ***Animation*** tab to animate the configuration generated during any iteration.

5. Load the result file from the last iteration (iteration 16).

   – Choose ***16*** under the **Iteration** drop-down.

   – Click ***Load Result***. The animation is loaded in the display area.

   – Clicking on '***Play***' (▶). Since this is a static analysis, the animation has only one frame.



Animation tab in the 'Post Processing' page

6. The **Archive Model location** is available in this tab to export the model in MDL format from any iteration.

   – Choose a path.

   – Click on ***Export*** button to create an archive folder which contains an MDL and all other reference files (if any) to run the model. The design variable values are set to the values in the iteration number chosen.