Sage Model Notes

MotionSnubber.scfn

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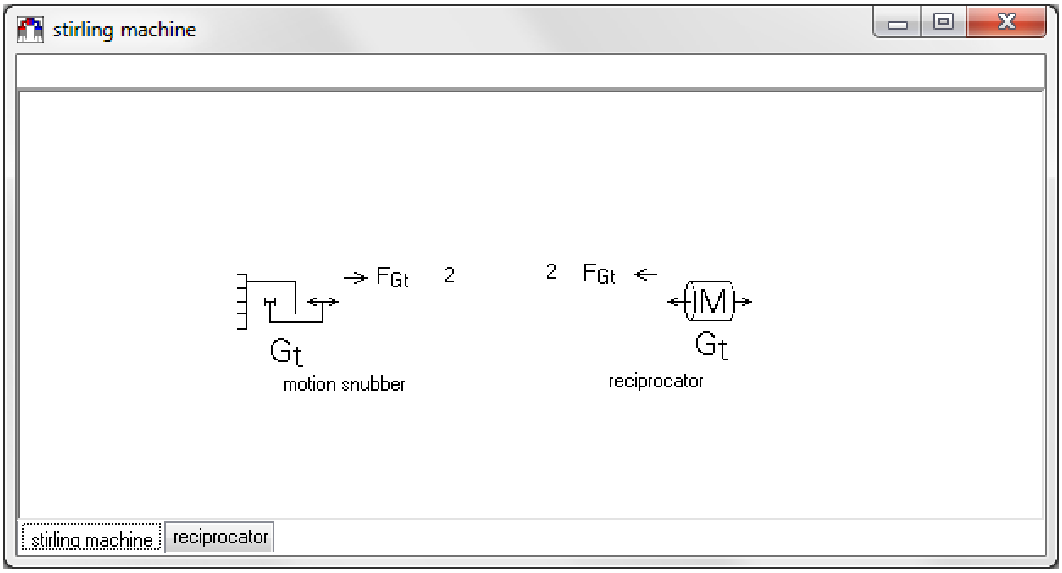
A model that illustrates how the motion snubber component limits the motion of a reciprocating mass driven by a forcing function of increasing amplitude. The Sage model looks like this:



The *motion snubber* component was introduced in Sage v10 as a way to simulate the displacer of a split-cycle stirling cooler hitting end stops during the cooldown period when it is not absorbing much PV power and tends to be over-driven. This model just illustrates how the motion snubber component works without the rest of the stirling cooler components.

The root model defines the top level model inputs, two of which are particularly important for this model, the frequency and number of time nodes in the computational grid

Inputs

NTnode	number time nodes	11
Freq	frequency (Hz)	6.000E+01

The number of time nodes is higher than the usual 7 recommended for models with sinusoidally varying solution quantities. More nodes helps the solution resolve the abrupt forces that occur when the reciprocator *hits* the displacement limits. 11 time nodes allows the solver to resolve up to 5 harmonics in the Fourier series expansion of the reciprocator motion.

The motion snubber imposes displacement limits on the reciprocator, according to these inputs:

Mscale	snubbed mass scale (kg)	1.000E-01

Xlimit	amplitude limit (m)	1.000E-02
Sp	snub factor at X = Xlimit (NonDim)	1.000E+00
Sn	snub factor at X = -Xlimit (NonDim)	1.000E+00
Kfrac	spring content fraction (NonDim)	1.000E-01

The Sage User's guide contains more information about these inputs. For present purposes suffice it to say that the motion snubber will do its best to limit the motion of the attached reciprocator to ±0.01 m by imposing an energy dissipating force beyond those limits scaled for stopping a 0.1 kg ballistic mass (which happens to be the mass of the reciprocator). That force will have a relative spring content of 10%.

The reciprocator represents a reciprocating mass driven by an internal forcing function Its inputs and outputs are:

Inputs

```
  Mass       reciprocating mass (kg)           1.000E-01
  FF         forcing function (N, rad)         0.000E+00...
   ( 2.500)E+02 Amp
   ( 0.000)E+00 Arg
```

Outputs

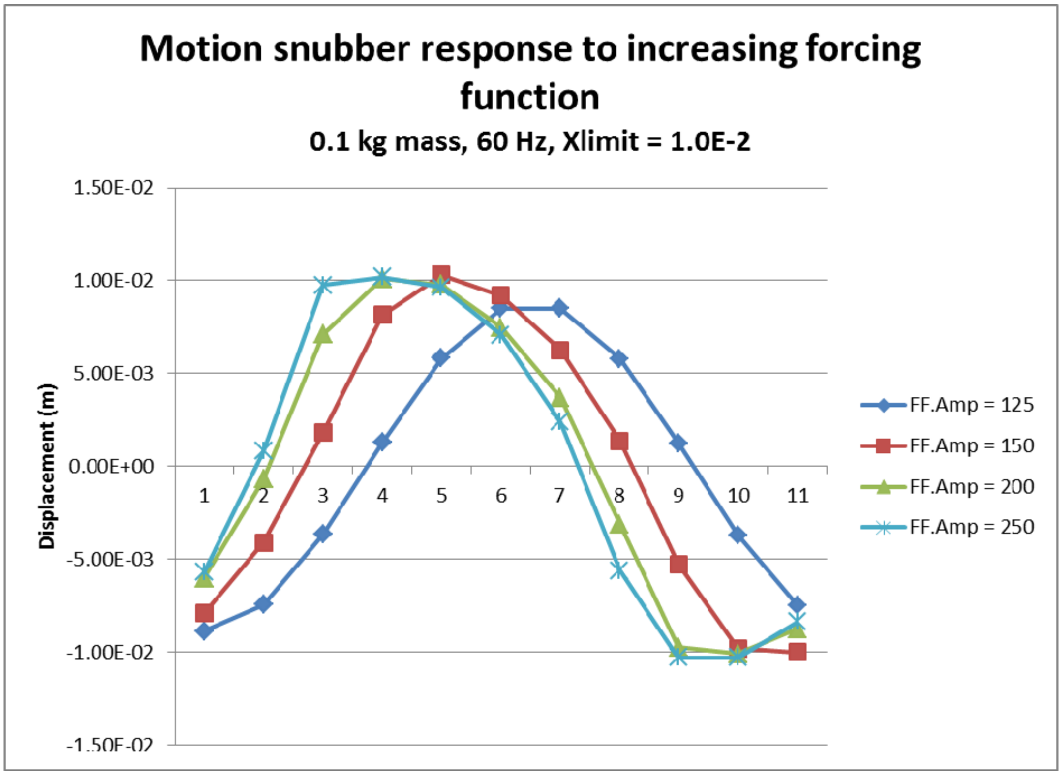
```
  FX         displacement (m, rad)             -3.338E-05...
   ( 1.115,  0.019,  0.140,  0.035,  0.044)E-02 Amp
   (-1.974, -2.971,  2.680,  1.913,  0.948)E+00 Arg
  F          boundary force (N, rad)           -4.416E-18...
   ( 2.378,  0.106,  1.791,  0.786,  1.581)E+02 Amp
   ( 2.482,  0.171, -0.462, -1.229, -2.194)E+00 Arg
  W          boundary power inflow (W, rad)    -4.834E+02...
   ( 0.918,  5.470,  2.676,  6.324,  3.669)E+02 Amp
   ( 0.237,  1.258, -1.293, -1.042,  2.712)E+00 Arg
```

The reciprocator is over-driven. Without the motion snubber connection it would have a free amplitude of 0.176 m, by solving Newton's law in terms of force amplitude F_1, mass m, motion amplitude x_1 and angular frequency $\omega = 2\pi f$.

$$F_1 = m x_1 \omega^2$$

With the motion snubber connected the resulting motion amplitude is lower and also non-sinusoidal, according to Fourier series output FX.

It is difficult to visualize the resulting motion from the Fourier series values alone so it is helpful to use the File|Save Solution Grid menu item to save the grid to a text file where you can examine it in detail. This plot below shows the motion solutions plotted in MS Excel for a sequence of increasing forcing functions, with the above case being the last curve plotted.



The first plot for forcing function amplitude = 125 N is essentially unrestricted free sinusoidal motion within the snubbing limits of ± 0.1 m. The next plot for FF.Amp = 125 N is just barely affected by the limits. It has a free amplitude of 0.106 m, just beyond the limits. The final two plots at FF.Amp = 200 and 250 N are increasingly overdriven. The last plot has a free amplitude of 0.176 m, as noted above but the motion snubber clamps it down within the limits.

For forcing functions much higher than FF.Amp = 250 the motion snubber begins to produce erratic results, allowing some motion beyond the limits and spurious wiggles in the solution. Experimenting with the motion snubber inputs (especially Mscale) should help to remedy such problems in a practical model.

Motion snubber input Kfrac may be of some use in calibrating the snubber model to actual data. A higher value of Kfrac corresponds to more resilient end limits with a higher coefficient of restitution. A lower value of Kfrac corresponds to less resilient end limits that absorb more energy.