UNIMORE
UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA

Dipartimento di Ingegneria
"Enzo Ferrari"

MILLE CHILI

Progettazione Assistita di Organi di Macchine

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Agenda

Goal and nomenclature

Model setup

Modal Analysis loadcases varying the BCs:

- Free-free
- Fixed-fixed
- Fixed-axial rotation free
- Fixed-axial displacement and rotation free

Harmonic loadcases:

- Neglecting damping effect
- Considering damping effect

References

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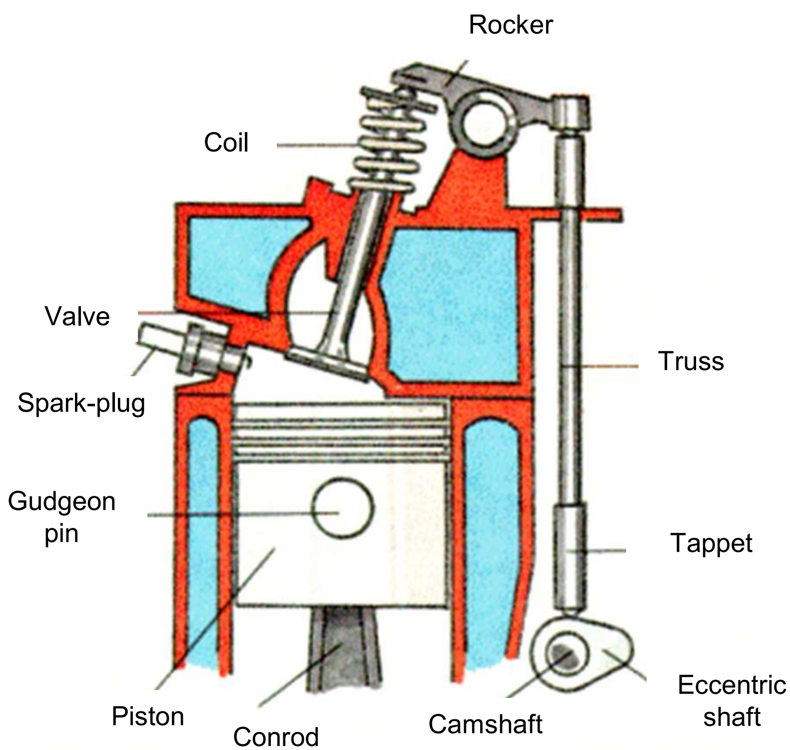
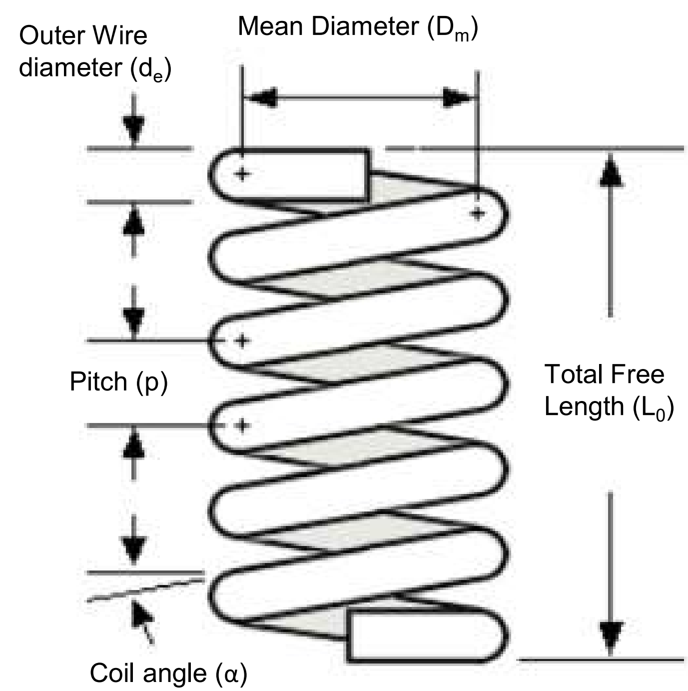
Goal and nomenclature

Distribution coil dynamic response

The present lesson aims to evaluate the natural frequencies and the frequency response occuring in a helical coil applied to a engine system distribution.





Goal and nomenclature
Distribution coil dynamic response

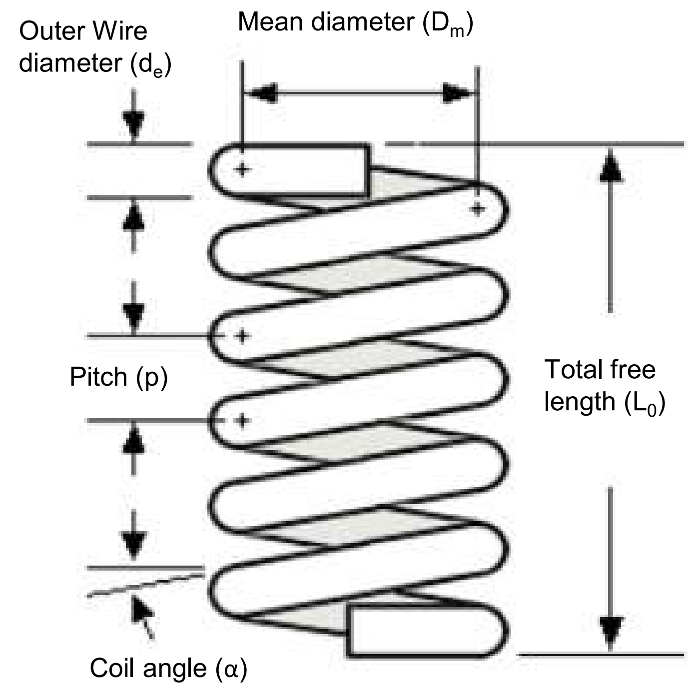
The present lesson aims to evaluate the modal and the frequency response occuring in a helical coil applied to a engine system distribution.

Mean diameter and mean radius:
D_m = 40 mm, R_m 20 mm

Wire outer diameter: D_e = 12 mm
Wire inner diameter: D_i = 6 mm

Coil pitch: p = 15 mm
Total coils: n_t = 4,5

Total length: L_0 = 67.5 mm
Material properties
Titanium:
E = 110 GPa, ν = 0.3,
$\rho = 4.7\ 10^{-9}$ t/mm^3



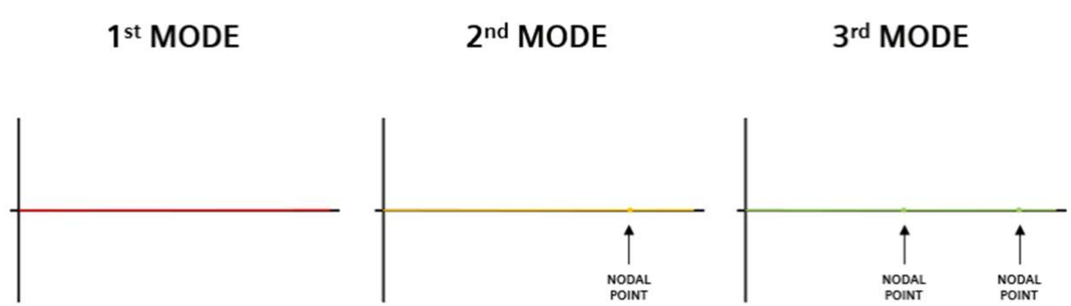
Goal and nomenclature

Modal analysis

The **first mode** or natural frequency is the one at which the component will vibrate after all external excitations are removed. Additional natural frequencies represent the oscillation of the components in other deformed shaped or «modes».
Modal vibration only occurs when the part is beeing shaken at a frequency which is near a naturale frequency.

Without **damping**, an oscillating body is kept in motion forever. Damping represents the inengfficeinties of the material due to energy loss at a molecular level or of the system due to the component interaction. Higher damping factors cause the oscillation’s amplitude to decrease so the component slowly (or not so slowly) stabilized.

Knowing the natural frequencies of a design subject to harmonic inputs is important. When a part is excited at a frequency it is «comportable» vibrating at, the effects of the input are magnified and any cause premature or catastrophic failure.



Goal and nomenclature

Modal analysis

The goal of a modal study is to ensure that the system does not have a resonant frequency near to the operating frequency or in the range of operating frequencies. If the first mode us lower than the operationg speed, the product user will notice a «shudder» on star-up as the speed passes that frequency. To ensure that resonance effects are avoided within the operating frequency range, certain references suggest that natural frequencies occur only below one-third of the minimum operating frequency and above three times the maximum.

A modal analysis provides in understanding the induced mode shapes themselves. Deformation patterns at an operating frequency may be deemed acceptable if they do not affect an inhererently weak section of the system.

A modal analysis does not require BCs but may utilize a constraint case if constraints are present. If the model is not constrained fully in all six DOFs, the first modes will correspond to rigid body motion in each of the unconstrained direction with a frequency of approximately zero. These are called «rigid body modes» and should in theory be of zero magnitude, although numerical round-off may give them a small nonzero value.

Goal and nomenclature

Modal analysis

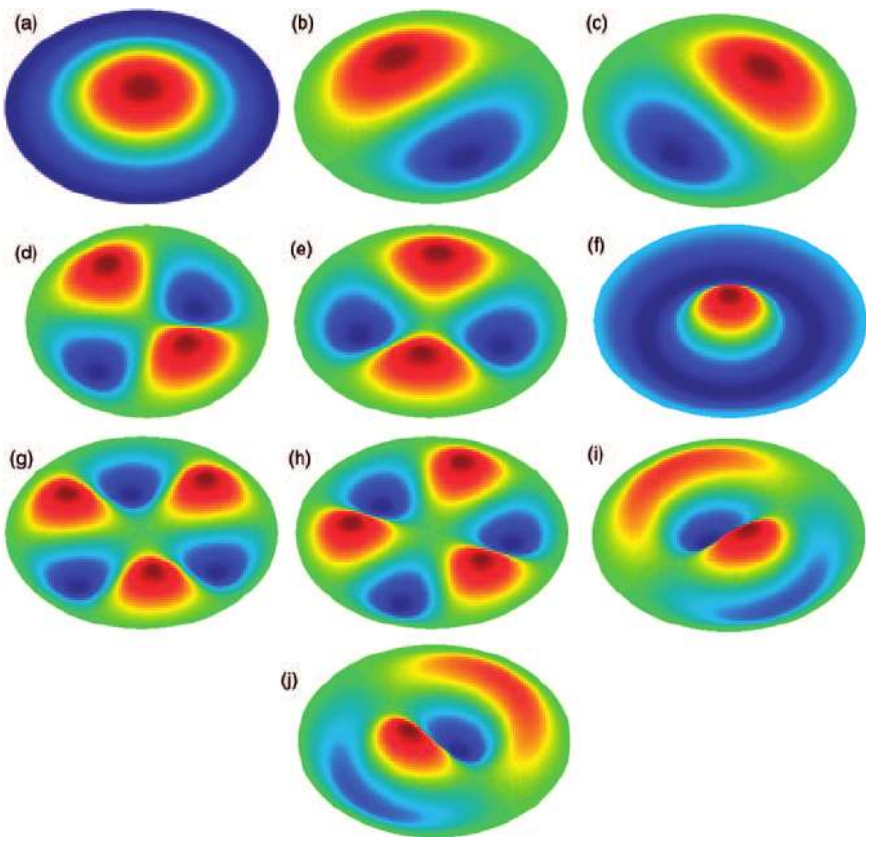
Some solvers (*e.g.* mentat) require you to specify that an unconstrained model is unconstrained before initiating the modal study. An overconstrained model will behave too stiffly and, therefore, results in an overprediction of the first modes.

In most cases, a first or second mode near an operating frequency will cause noticeable vibration amplitude. Adjusting your geometry to move the natural frequency is somewhat of an art. The natural frequency of a part is related to the its weight and its stiffness.
However, many techniques for increasing stiffness also add weight. The proper combination of incresed stiffness, reduced weight, and redistributed weight is required to fine tune natural frequency.

The danger of using symmetry is that there are many more skew-symmetric mode shapes for a general structure than symmetric,. If symmetry is used, the only mode shapes will correspond to the specific symmetriy constraints. If the frequency of interest corresponds to an skew-symmetric mode shape in a full model, an important result will missed in a symmetric model.

Goal and nomenclature

Modal analysis



The first 10 mode shapes for a fully clamped circular disk

Symmetric and skew-symmetric modes are present.

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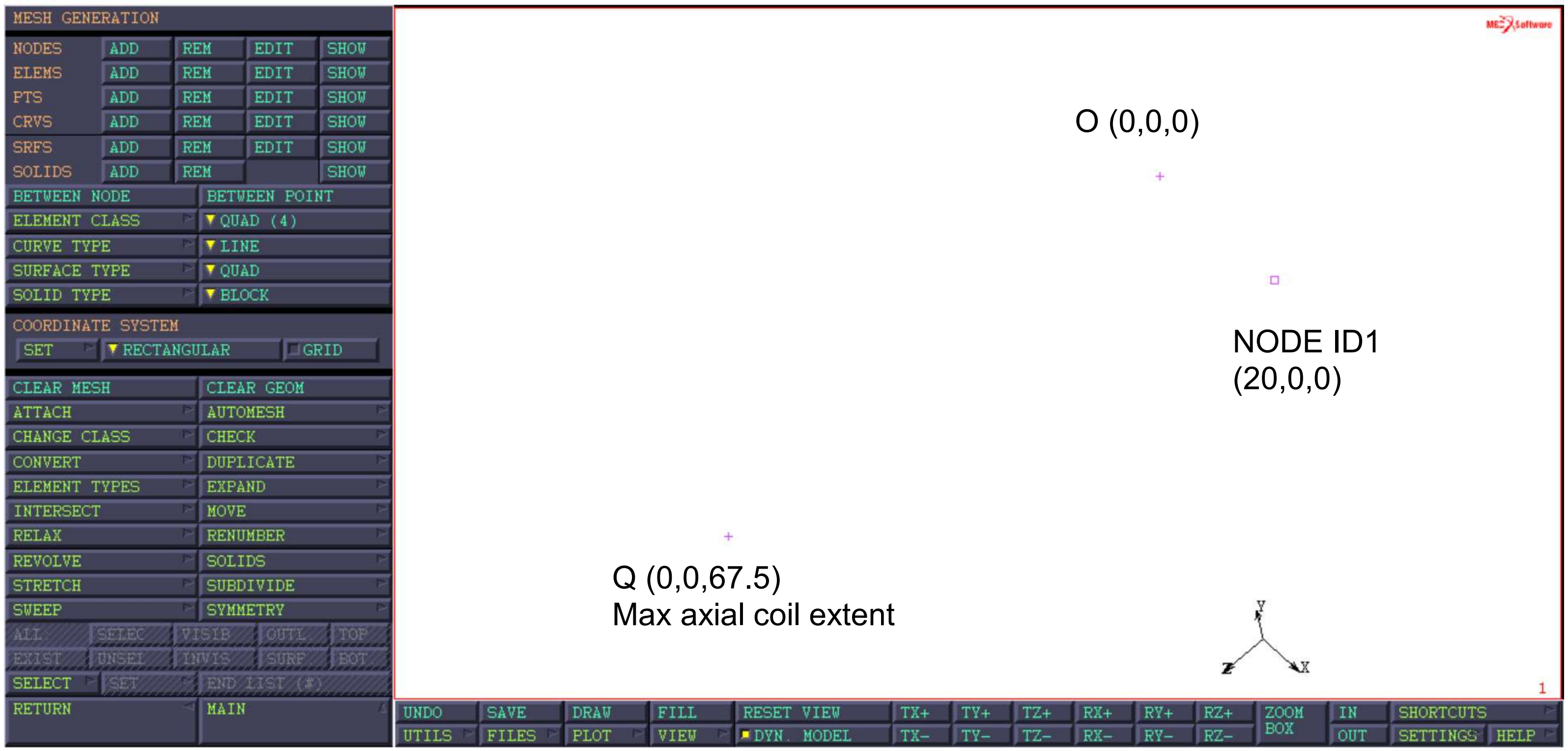
References

Mesh Generation

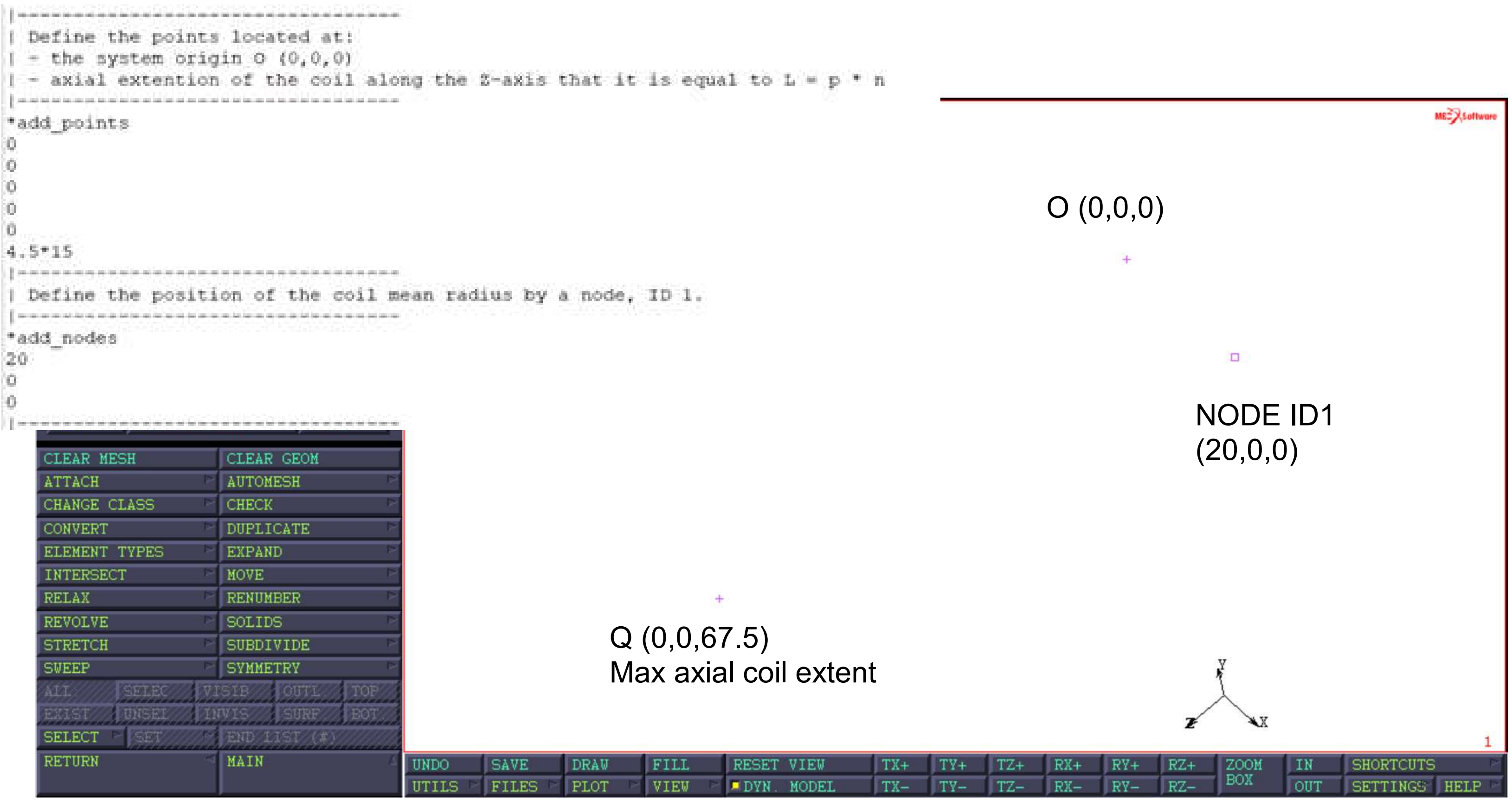
Coil shape definition

The coil will be built starting from crucial node and points proper of this component, by the MESH GENERATION menu.



Mesh Generation

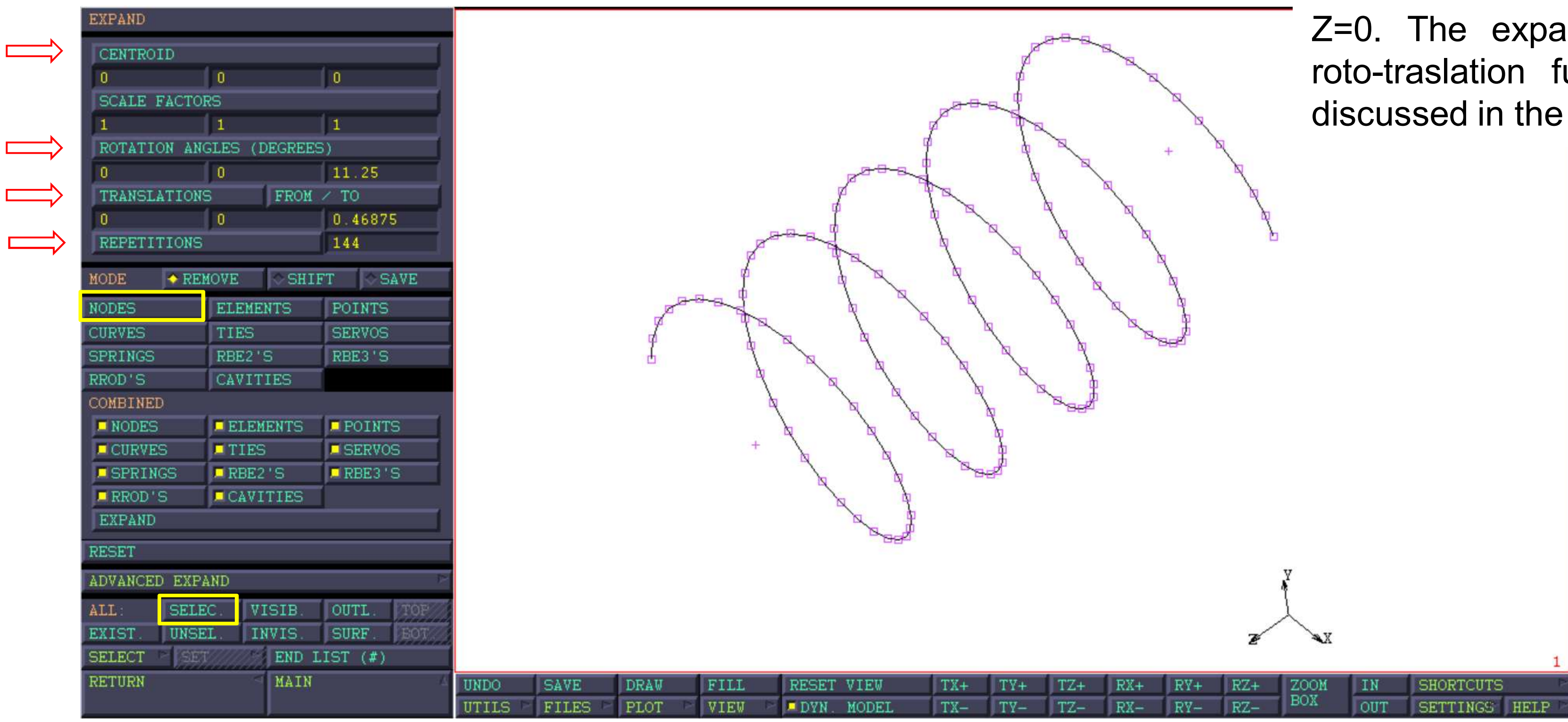
Coil shape definition



Mesh Generation

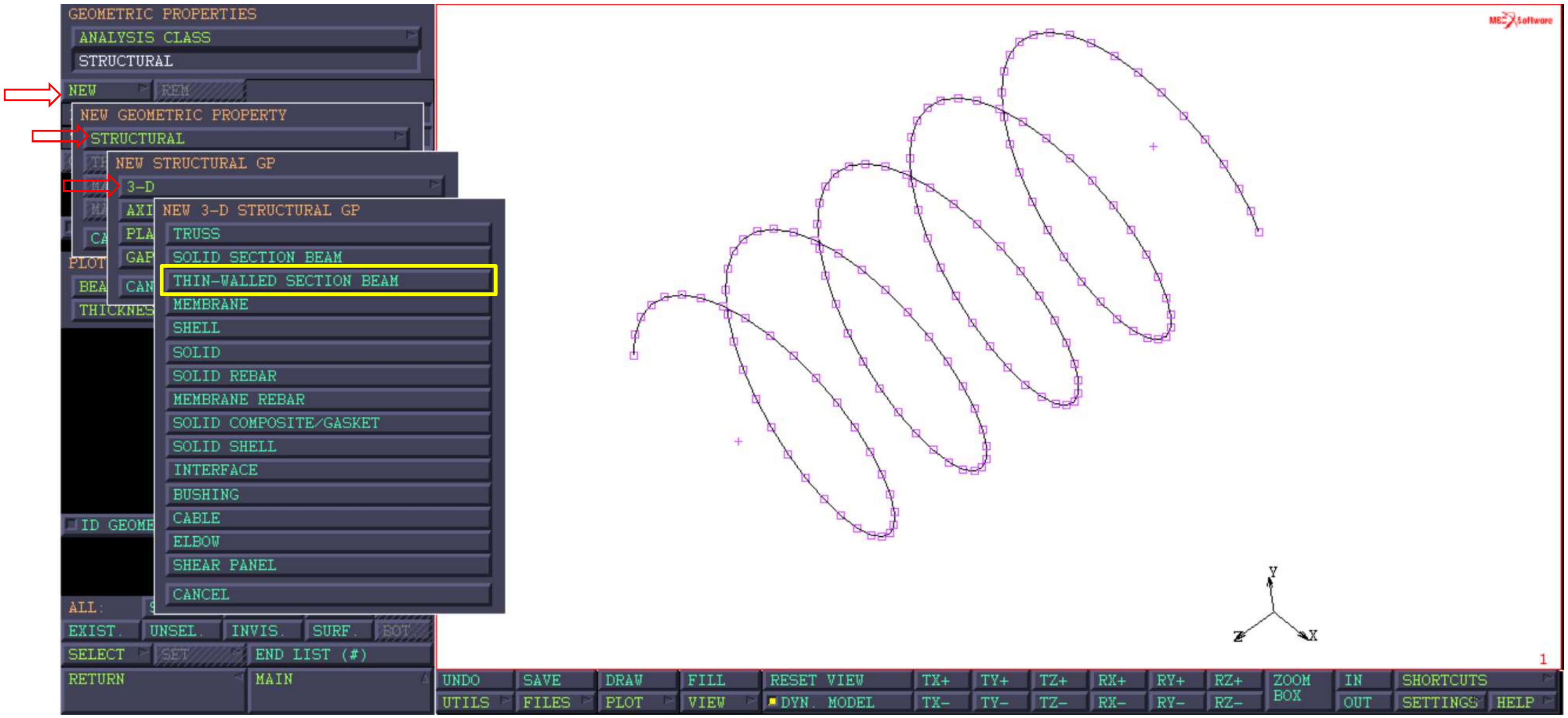
Coil shape definition: expand

The coil is modelled by 1D line elements, obtained from the expantion of the NODE ID1, at the mean radius of the coil lying on the XY reference plane at Z=0. The expantion is a roto-traslation function as discussed in the following.



Geometric properties

Hollow circular cross-section



The coil geometric property is defined for thin-walled section beam, where the hollow circular cross section is assessed setting:

- The wire mean radius (r)

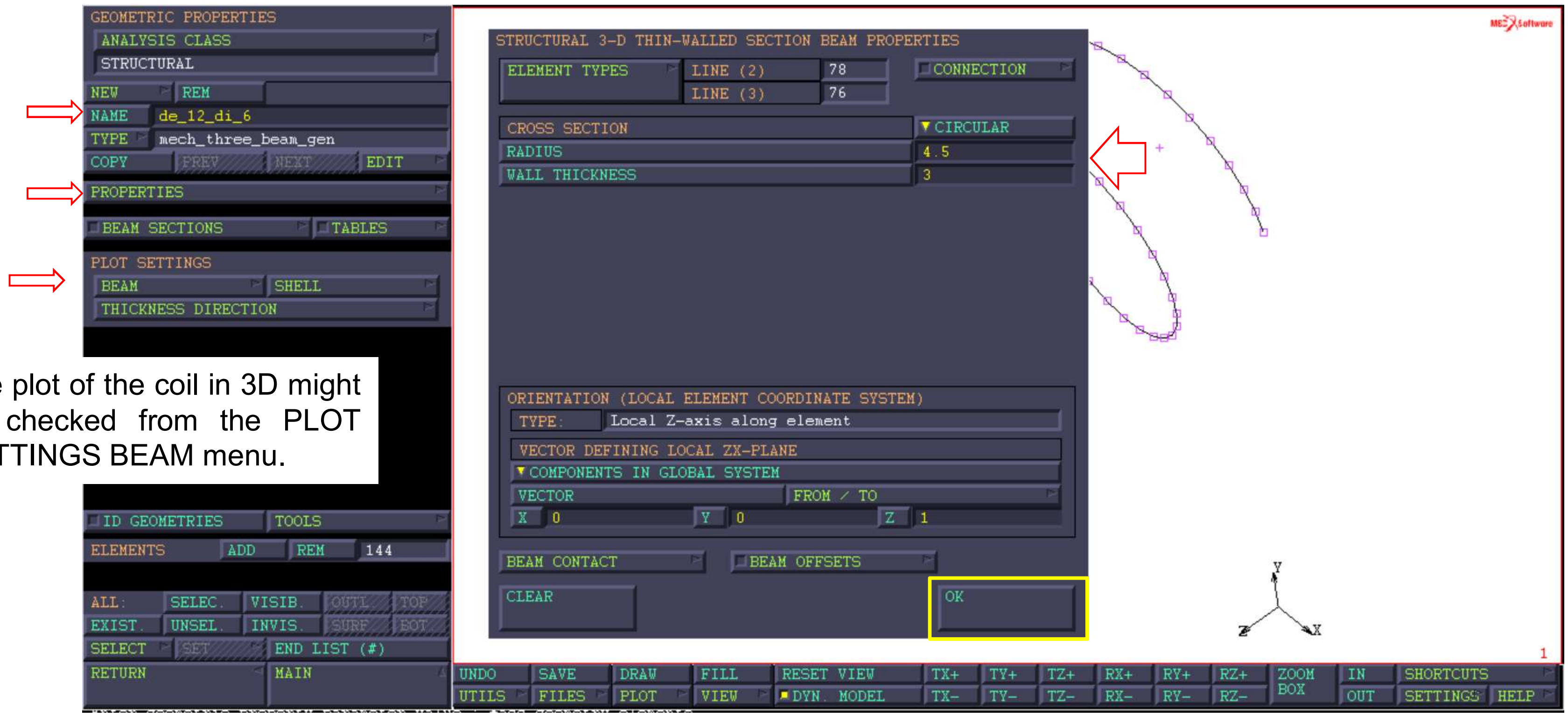
  $r = (d_e+d_i)/4 = (12+6)/4 = 4.5$ mm

- The wire wall thickness is:

  $t = (d_e+d_i)/2 = (12-6)/2 = 3.0$ mm

Geometric properties

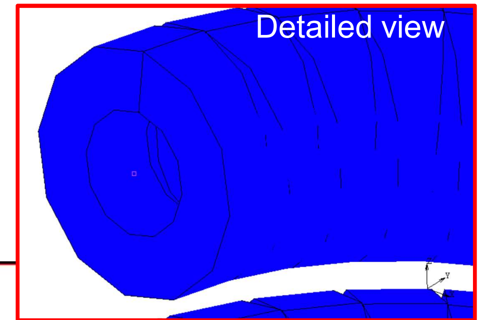
Hollow circular cross-section

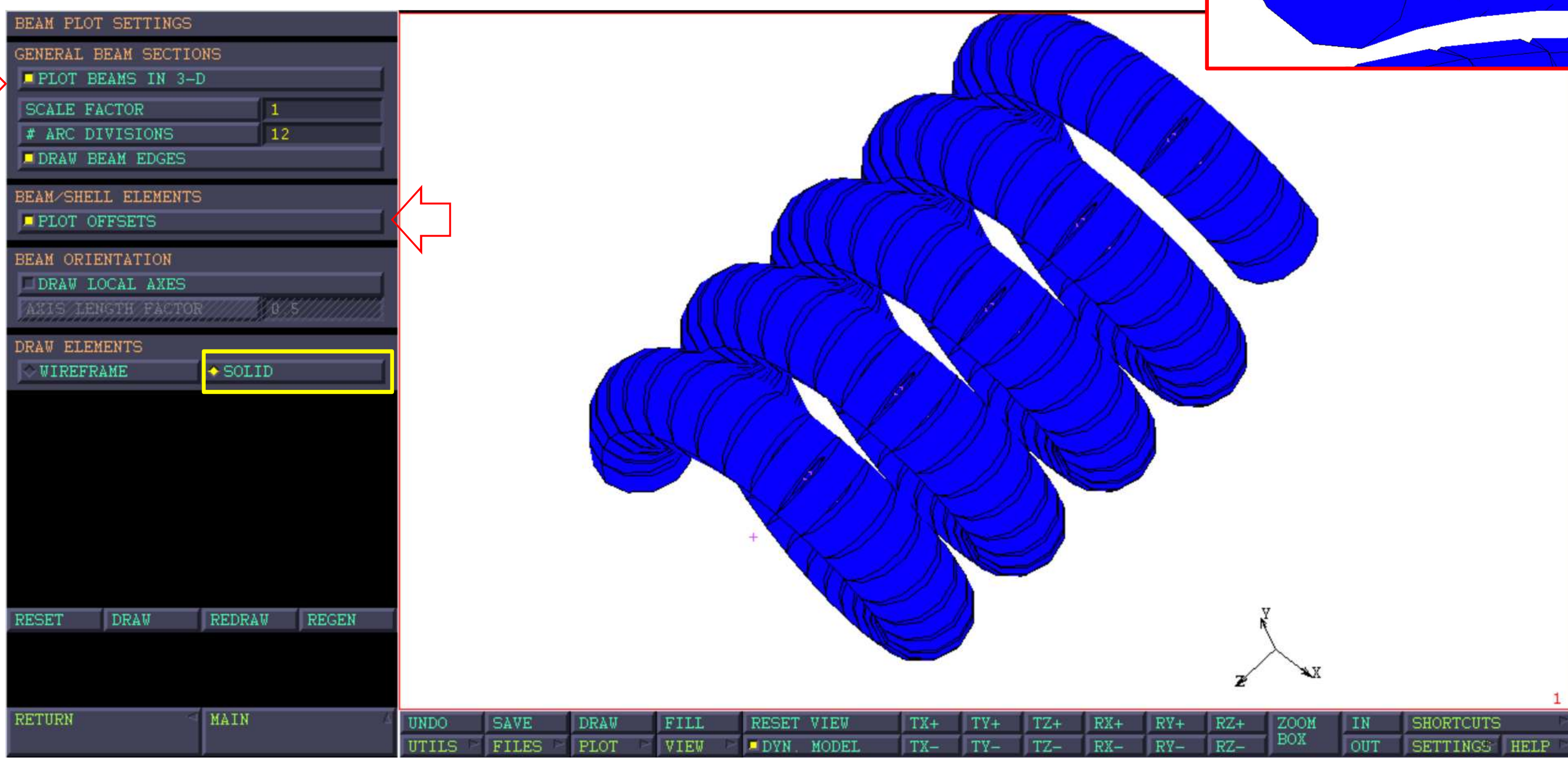


The plot of the coil in 3D might be checked from the PLOT SETTINGS BEAM menu.

Geometric properties

Hollow circular cross-section

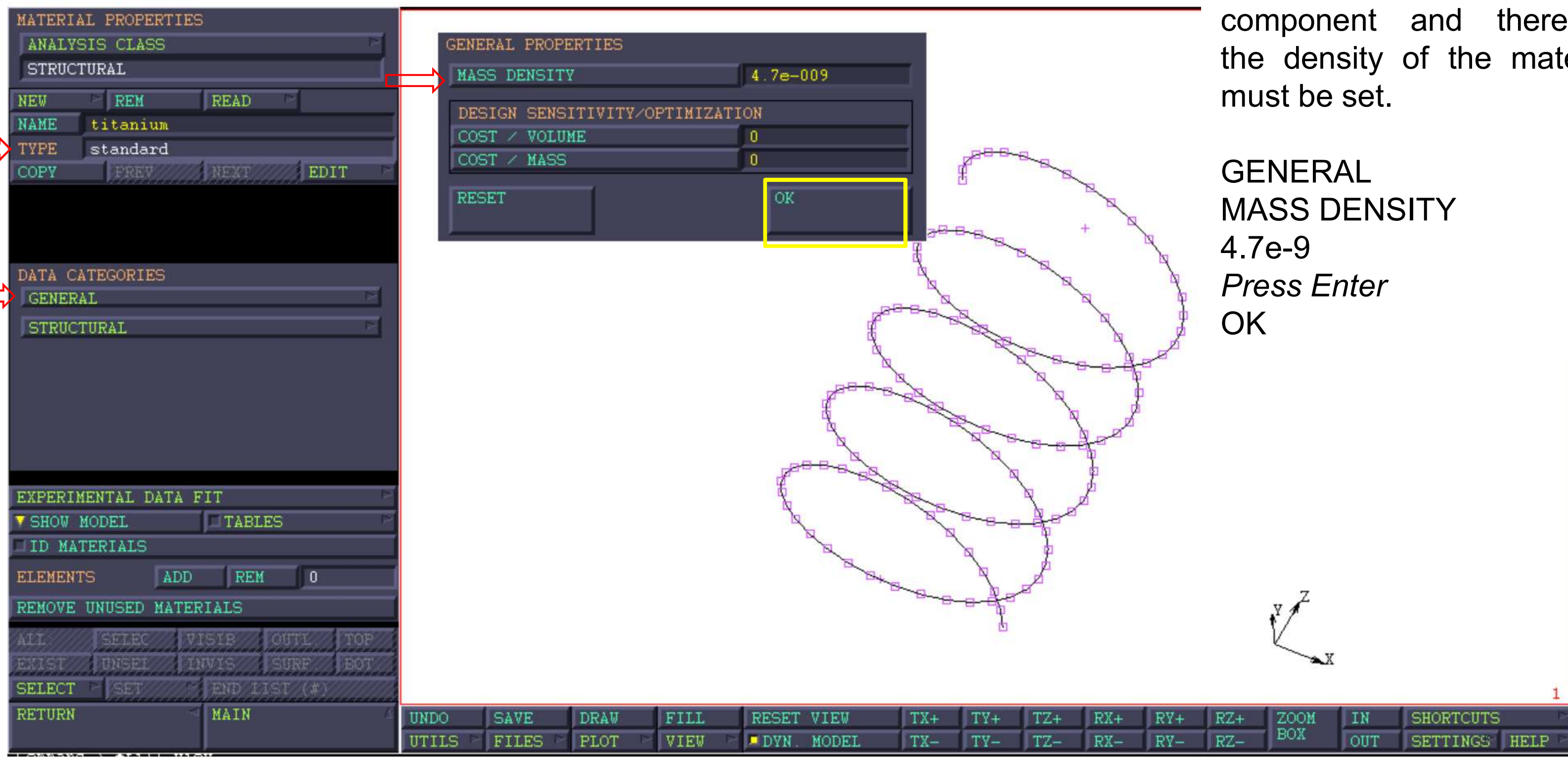




Deflag the PLOT BEAMS IN 3D menu, to return to the beam model visualisation.

Material properties

Isotropic and homogeneous



The modal analysis requires the evaluation of the mass matrix related to the component and therefore the density of the material must be set.

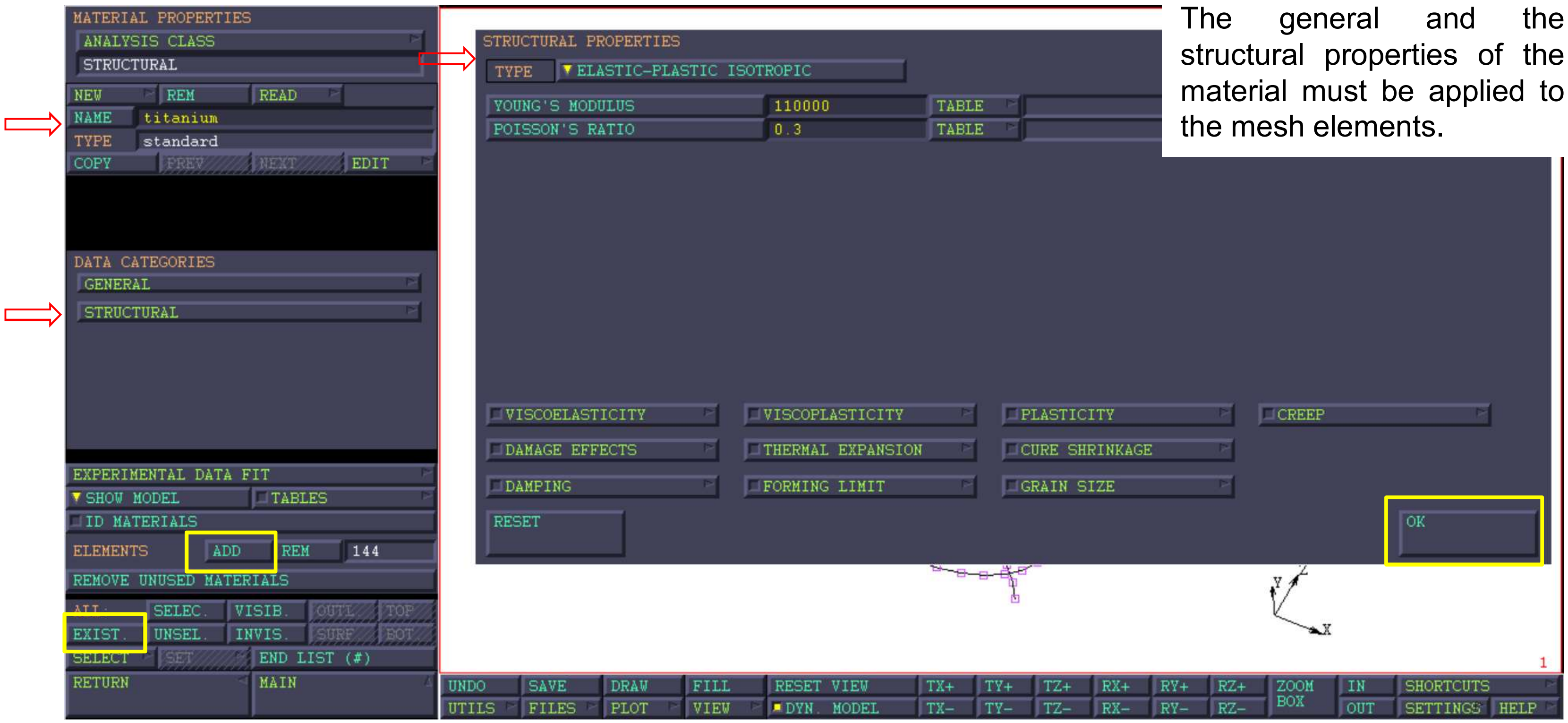
GENERAL
MASS DENSITY
4.7e-9
Press Enter
OK

Material properties

Isotropic and homogeneous

Then, the definition of the elastic constant of the titanium allows the stiffness matrix to be evaluated.

The general and the structural properties of the material must be applied to the mesh elements.



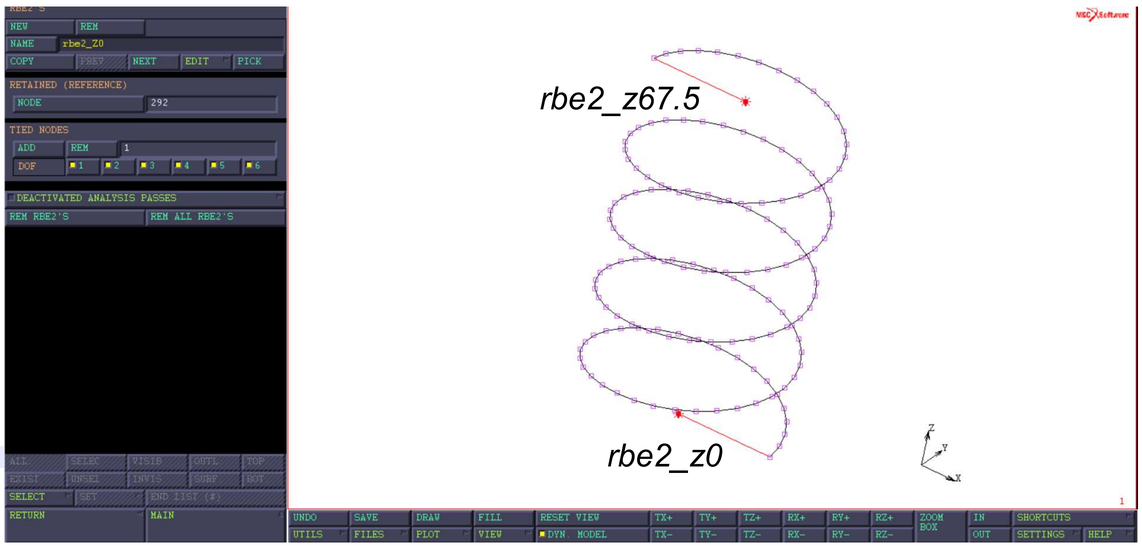
LINKS

RBE2

```
|-----------------------------------
| I create two nodes at the coil axis at Z=0
| and at the other free extremity Z = 67.5
|-----------------------------------
*add_nodes
0
0
0
0
0
4.5*15
|-----------------------------------
|   RBE2 at Z=0
|-----------------------------------
*new_rbe2
*rbe2_name rbe2_Z0
*rbe2_ret_node
 292
*add_rbe2_tied_nodes
 1
# | End of List
*rbe2_tied_dof 1
*rbe2_tied_dof 2
*rbe2_tied_dof 3
*rbe2_tied_dof 4
*rbe2_tied_dof 5
*rbe2_tied_dof 6
|-----------------------------------
|   RBE2 at Z=67.5
|-----------------------------------
*new_rbe2
*rbe2_name rbe2_Z67.5
 291
*add_rbe2_tied_nodes
 290
# | End of List
*rbe2_tied_dof 1
*rbe2_tied_dof 2
*rbe2_tied_dof 3
*rbe2_tied_dof 4
*rbe2_tied_dof 5
*rbe2_tied_dof 6
|-----------------------------------
```

To load and constrain the coil, two RBE2 are defined located at the lower and the upper extremities of the coil, named *rbe2_z0* and *rbe2_z67.5*, respectively.

The retained node is located at the coil axial and the tied node is considered at the coil vertex in both RBE2 cases.



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Harmonic loadcases:

- Neglecting damping effect
- Considering damping effect

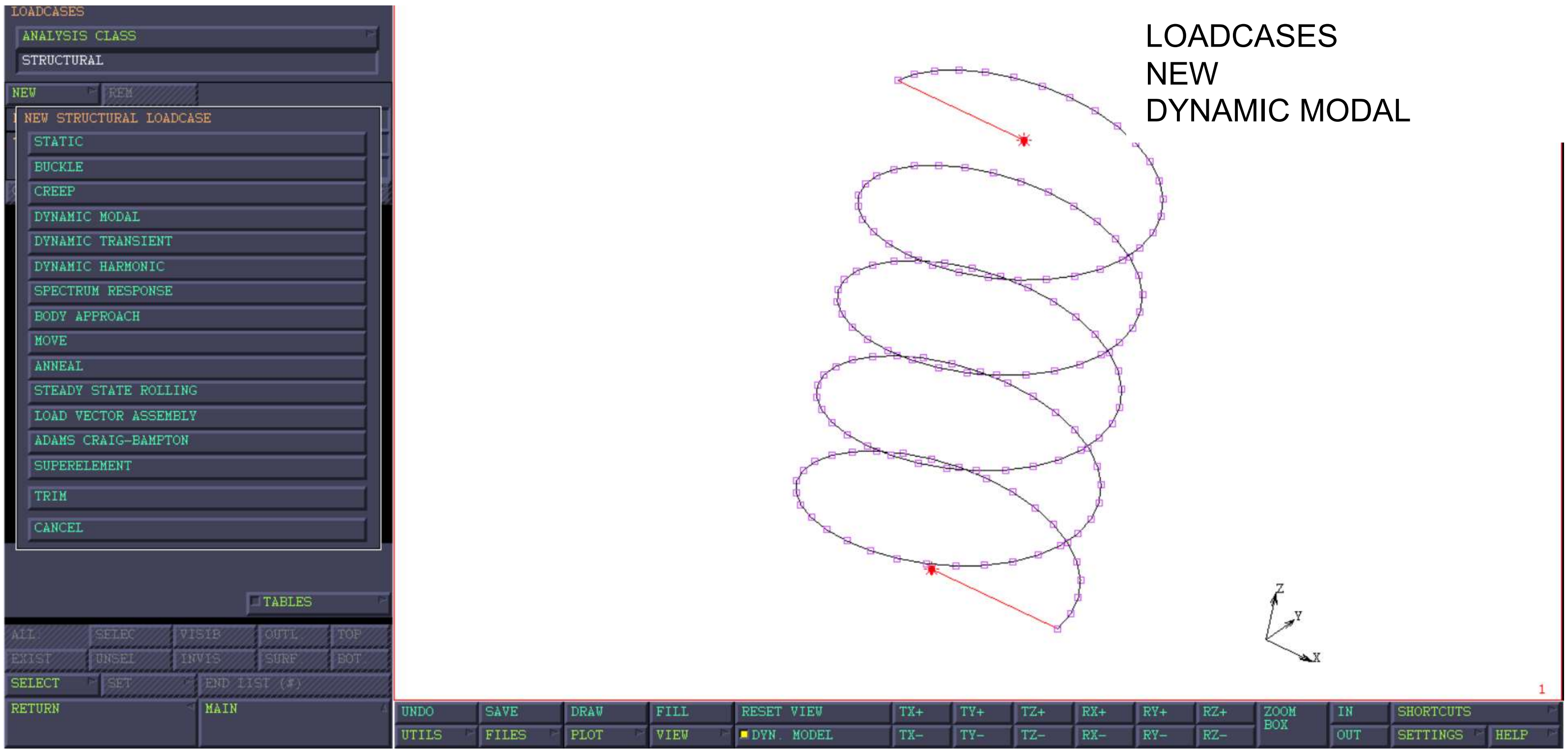
References

Loadcases

Modal analysis

The modal analysis is a dynamic analysis, therefore the loading conditions to be adopted are in:

LOADCASES
NEW
DYNAMIC MODAL



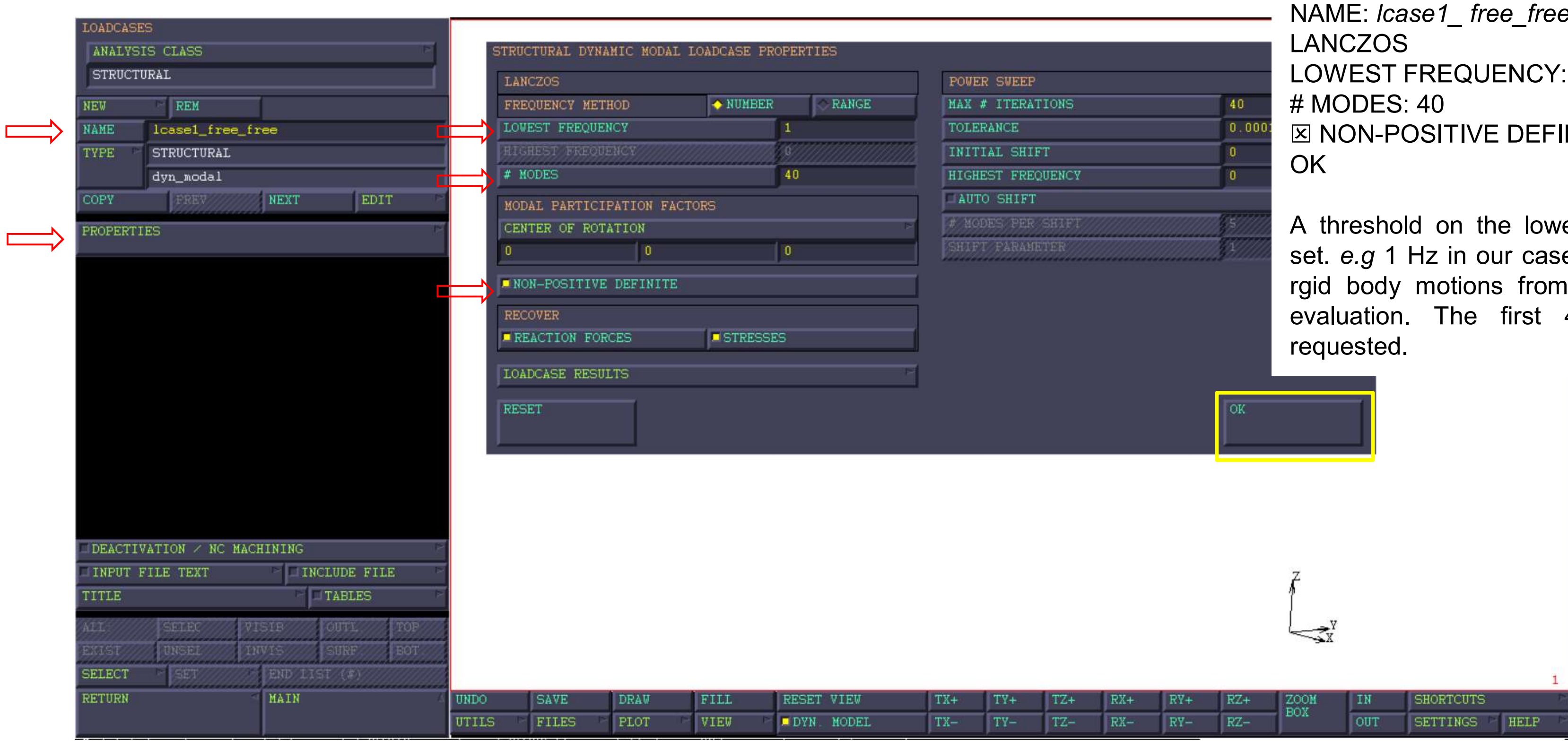
Loadcases

Modal analysis: free-free

To collect the first natural modes neglecting the six rigid body motions due to the absence of any BCs (free-free modal analysis, the model must be set as follows:

LOADCASES
NEW
DYNAMIC MODAL
NAME: *lcase1_ free_free*
LANCZOS
LOWEST FREQUENCY: 1
MODES: 40
☒ NON-POSITIVE DEFINITE
OK

A threshold on the lowest frequency is set. *e.g* 1 Hz in our case, to remove the rgid body motions from the numerocal evaluation. The first 40 modes are requested.



Remembre that the modal response of the structure is influenced by the BCs acting on the component.

Jobs

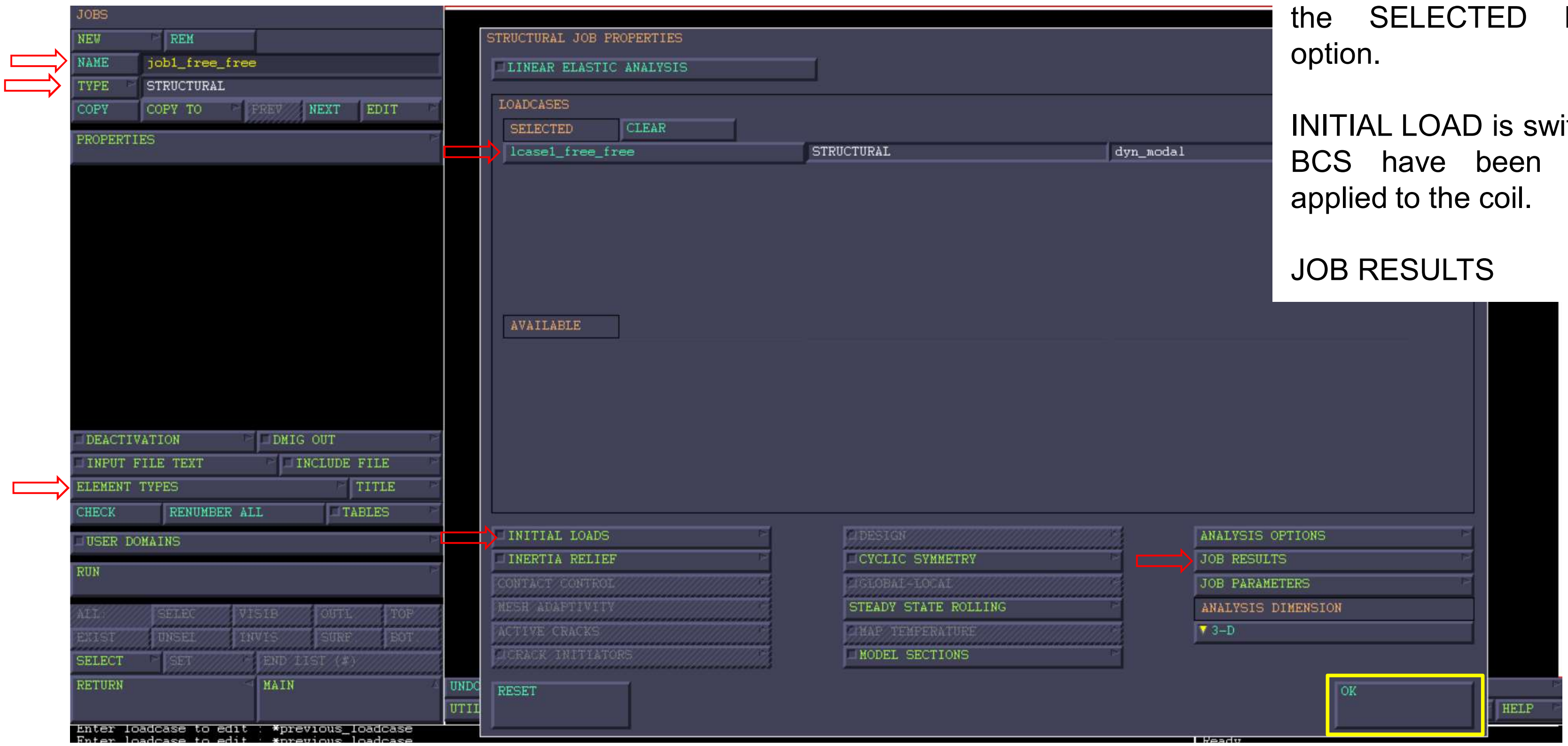
Job results

JOBS
NEW
TYPE: STRUCTURAL
NAME: job1_free_free
PROPERTIES

The *lcase1_free_free* must be updated from the AVAILABLE to the SELECTED LOADCASES option.

INITIAL LOAD is switched off, any BCS have been defined and applied to the coil.

JOB RESULTS

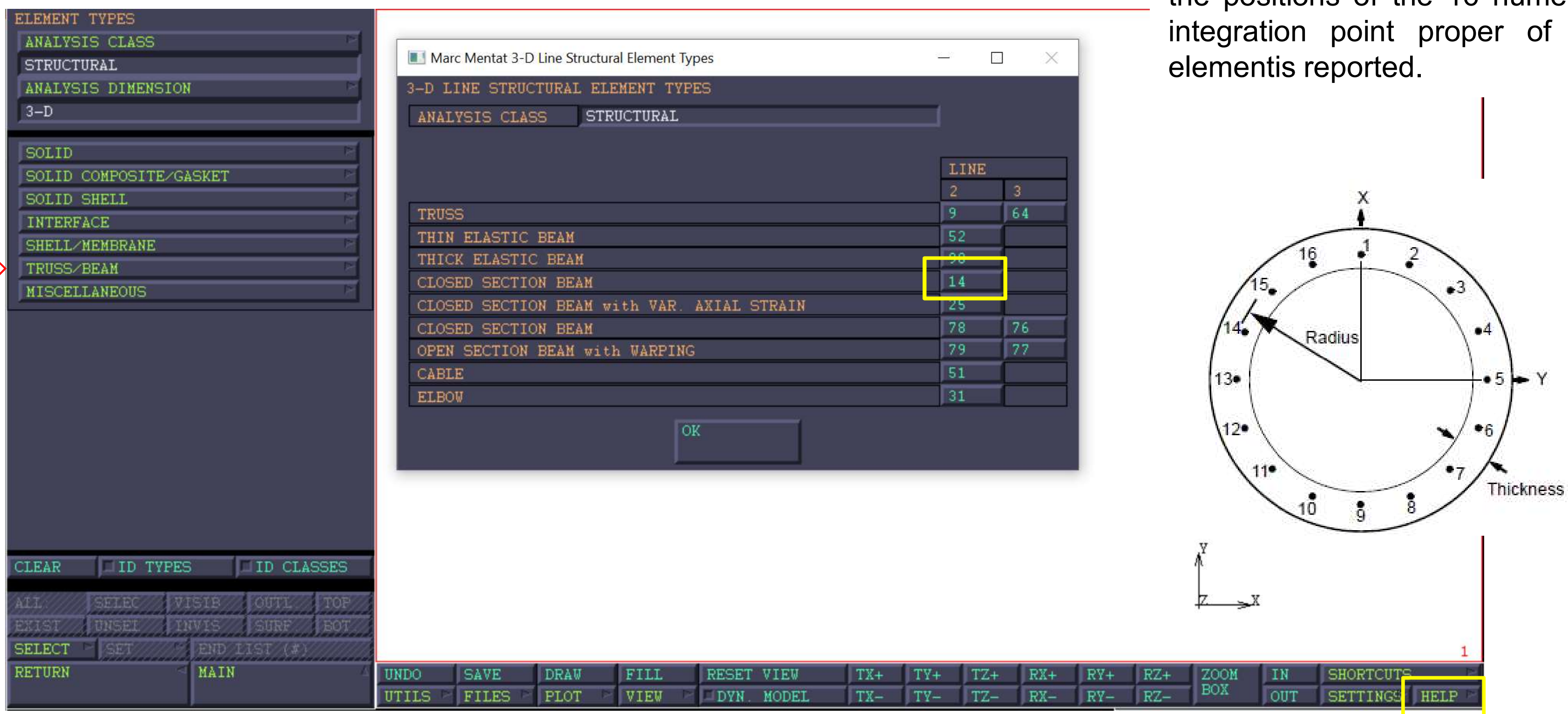


Jobs

Element Type

JOBS
ELEMENT TYPE
3D
TRUSS/BEAM
CLOSED SECTION BEAM
14
OK

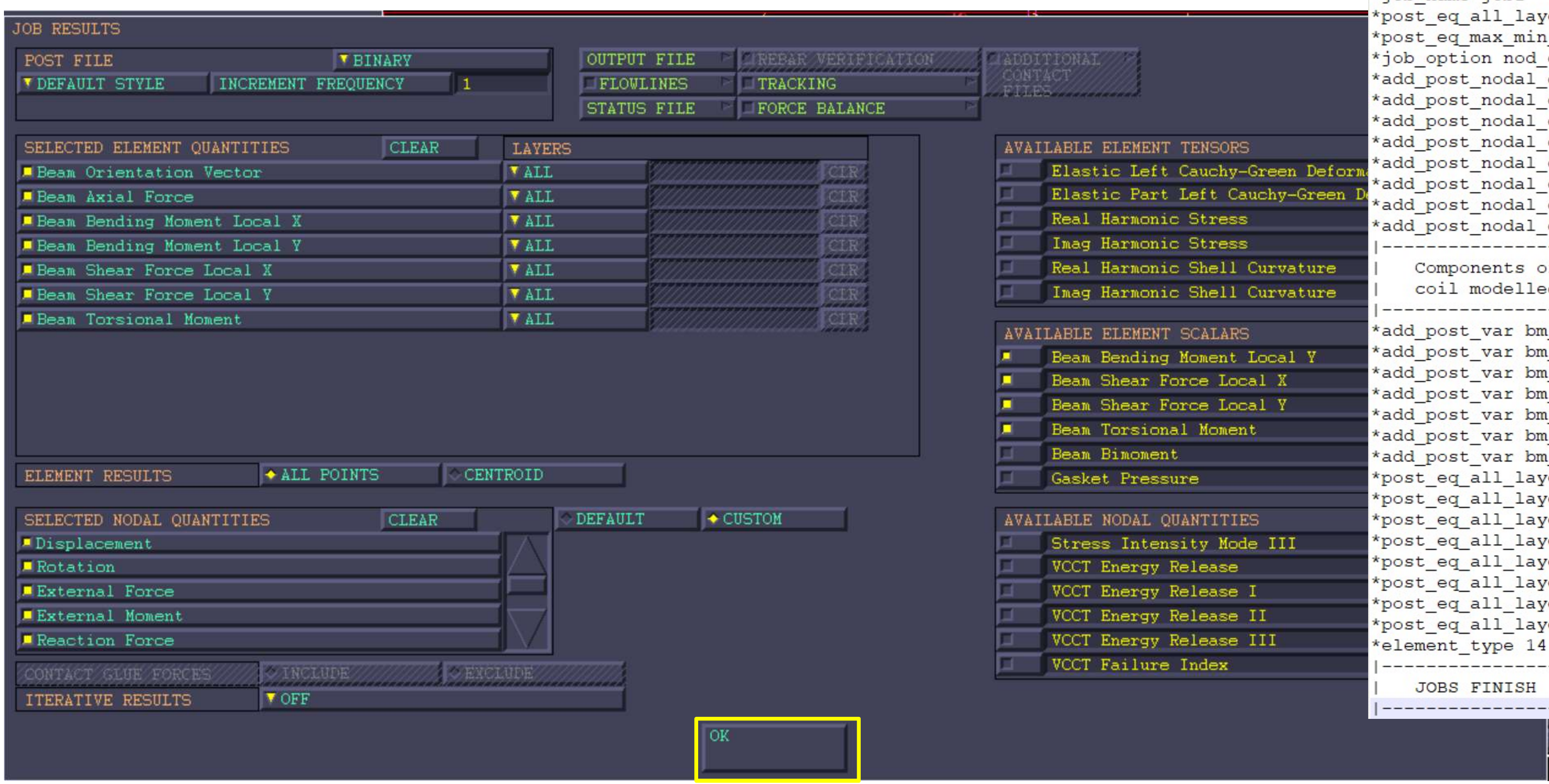
For details, see the HELP guide, the positions of the 16 numerical integration point proper of this elementis reported.



Jobs

Results: Beam Element

The 1D beam stress are requested and evaluated on the element layers (16 integration point), as shown in the help guide.



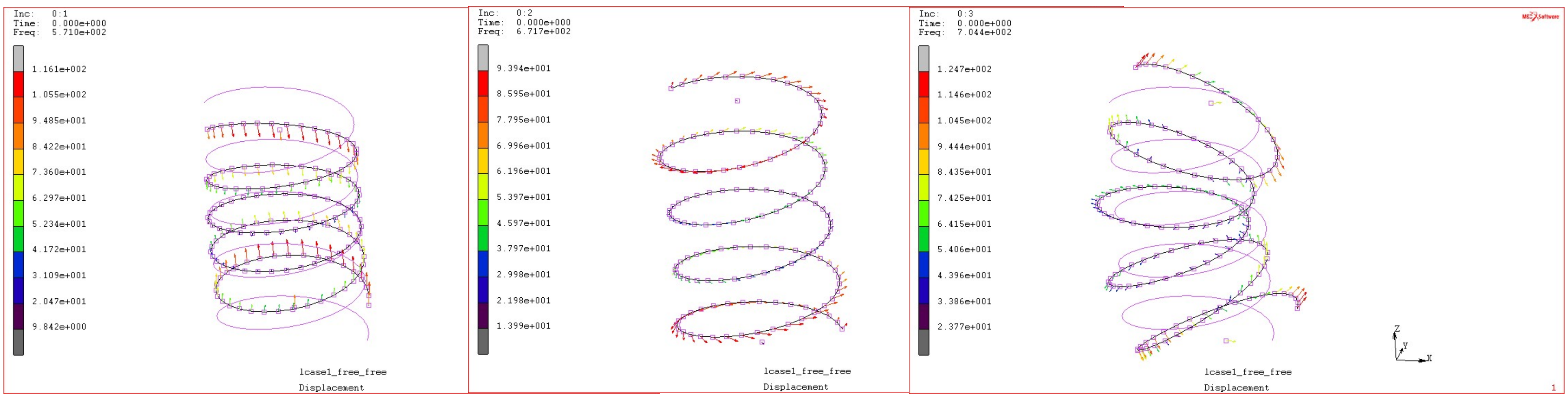

```
|------------------------------------
|   JOBS START
|------------------------------------
*add_job_loadcases
lcase1_free_free
*job_name job1
*post_eq_all_layers stress
*post_eq_max_min_layers von_mises
*job_option nod_quantities:manual
*add_post_nodal_quantity Displacement
*add_post_nodal_quantity Rotation
*add_post_nodal_quantity Ext_Force
*add_post_nodal_quantity Ext_Moment
*add_post_nodal_quantity Rea_Force
*add_post_nodal_quantity Rea_Moment
*add_post_nodal_quantity Ty_Force
*add_post_nodal_quantity Ty_Moment
|-----------------------------------------
|   Components of stress occuring in the
|   coil modelled by 1D elements
|-----------------------------------------
*add_post_var bm_orient
*add_post_var bm_axi_for
*add_post_var bm_bnd_mom_x
*add_post_var bm_bnd_mom_y
*add_post_var bm_shr_for_x
*add_post_var bm_shr_for_y
*add_post_var bm_tor_mom
*post_eq_all_layers bm_orient
*post_eq_all_layers bm_axi_for
*post_eq_all_layers bm_bnd_mom_x
*post_eq_all_layers bm_bnd_mom_y
*post_eq_all_layers bm_orient
*post_eq_all_layers bm_shr_for_x
*post_eq_all_layers bm_shr_for_y
*post_eq_all_layers bm_tor_mom
*element_type 14
|------------------------------------
|   JOBS FINISH
|------------------------------------
```

Now, check, save and run the model!!

Results

Natural frequencies of the coil (#3 modes)

Check the deformation mode of the model in comparison with the undeformed condition.
The scaled factor applied to compare the deformation is set equal to 0.1.
In addition, the displacement field is plotted by vectors from the RESULT MORE menu.



1 mode
Axial compressive mode
Freq: 571.0 Hz

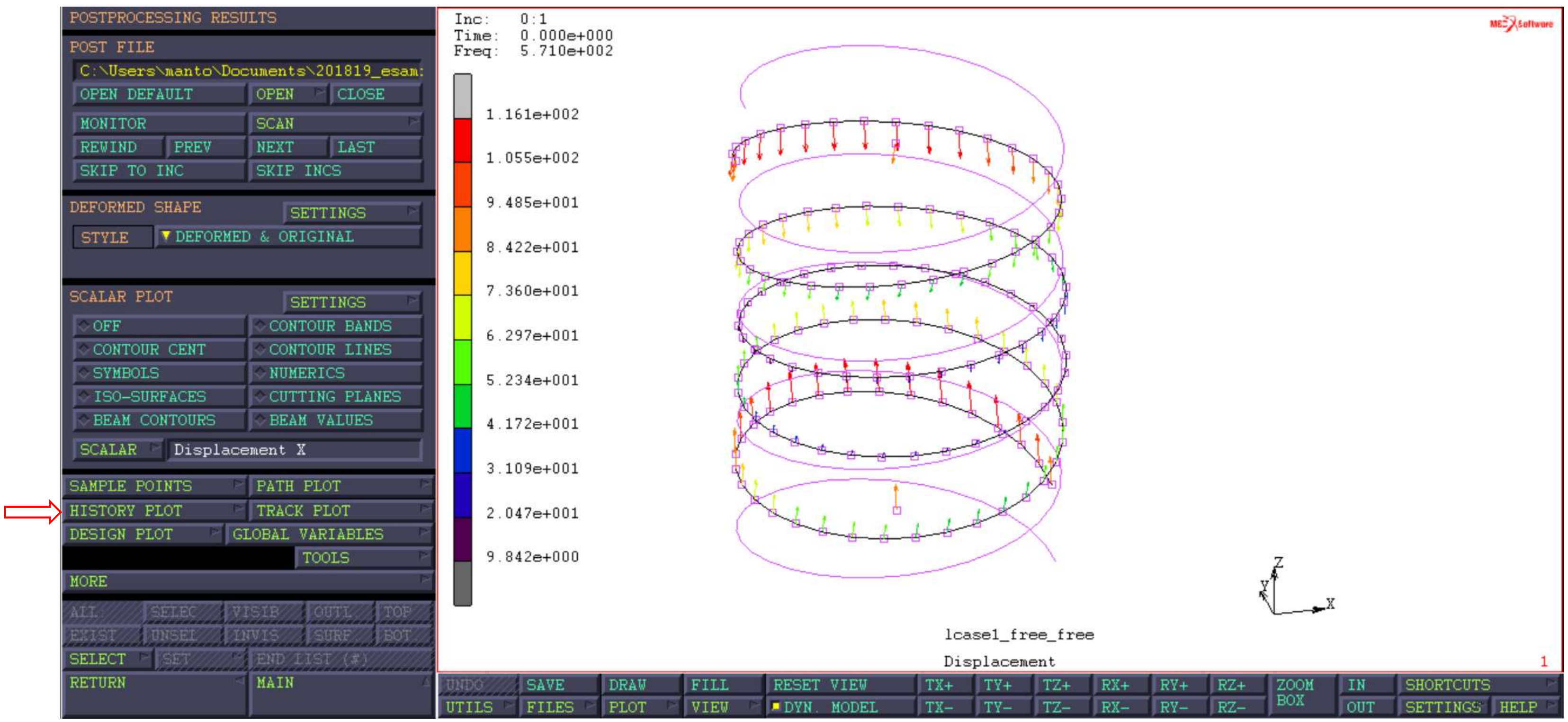
2 mode
Circumferential Expantion mode
Freq: 671.7Hz

3 mode
Lateral bending mode
Freq: 704.4 Hz

Results

Natural frequencies: Hystory plot

The automatic collection of natural frequencies of the coil (#40 modes) can be done by using HYSTORY PLOT option. These date can usually exported to make the post-processing in a Spreadsheet file, *e.g.* .xls, .xlsx, .ods, … files.



Results

Natural frequencies: Hystory plot

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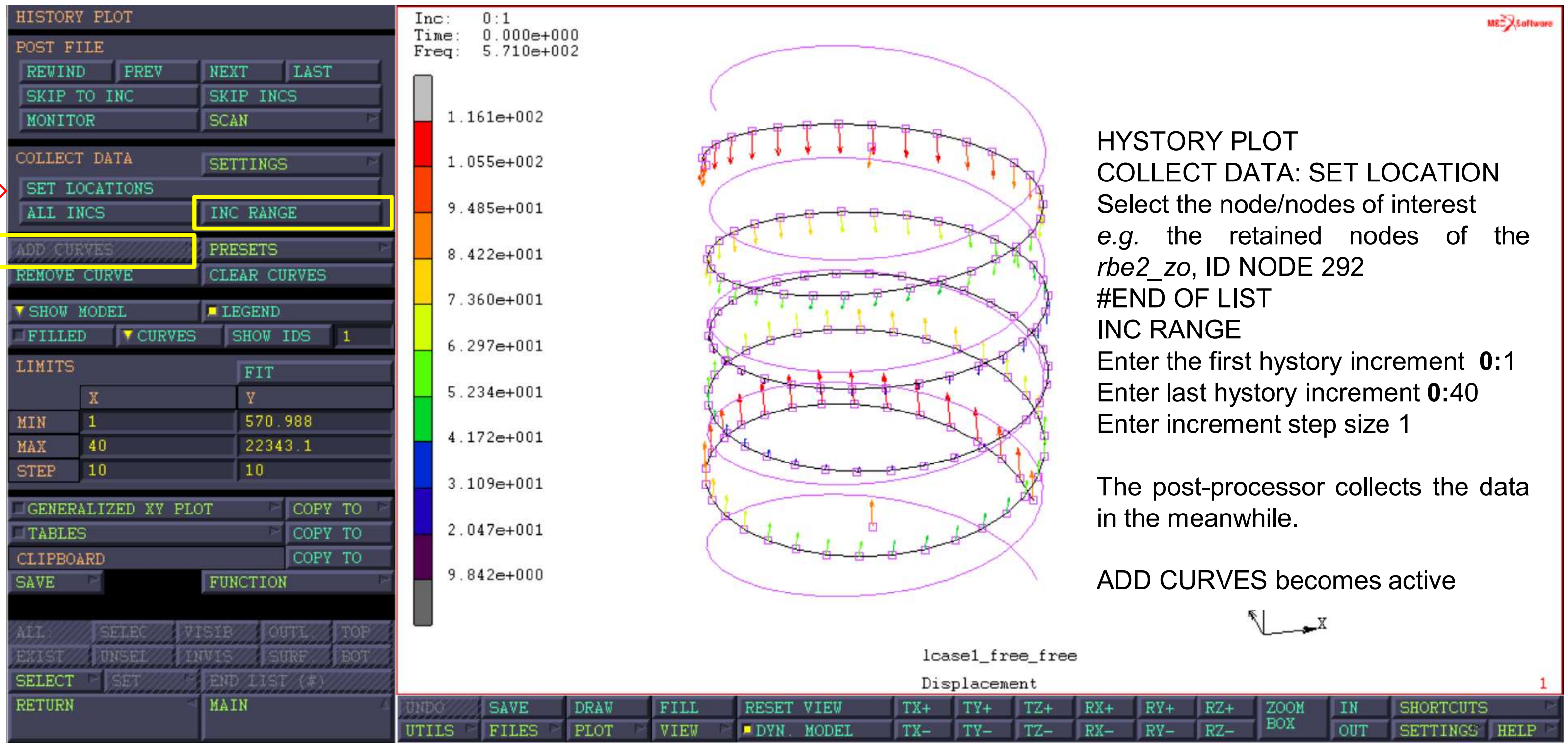

HYSTORY PLOT
COLLECT DATA: SET LOCATION
Select the node/nodes of interest *e.g.* the retained nodes of the *rbe2_zo*, ID NODE 292
#END OF LIST
INC RANGE
Enter the first hystory increment **0:**1
Enter last hystory increment **0:**40
Enter increment step size 1

The post-processor collects the data in the meanwhile.

ADD CURVES becomes active

Command prompt

```
Enter first history increment : 0:1
Enter last  history increment : 0:40
Enter increment step size : 1
```

Results

Natural frequencies: Hystory plot

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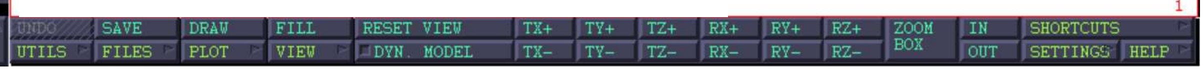
HYSTORY PLOT
COLLECT DATA: SET LOCATION
Select the node/nodes of interest
e.g. the retained nodes of the *rbe2_zo*, ID NODE 292
#END OF LIST
INC RANGE
Enter the first hystory increment **0:**1
Enter last hystory increment **0:**40
Enter increment step size 1

The post-processor collects the data in the meanwhile.

ADD CURVES becomes active

ADD CURVES:
ALL LOCATIONS
GLOBAL VARIABLES:
SUB INCREMENT (The first: x-axis)
FREQUENCY (The second y-axis)
FIT



MILLE CHILI

Results

Natural frequencies: Hystory plot

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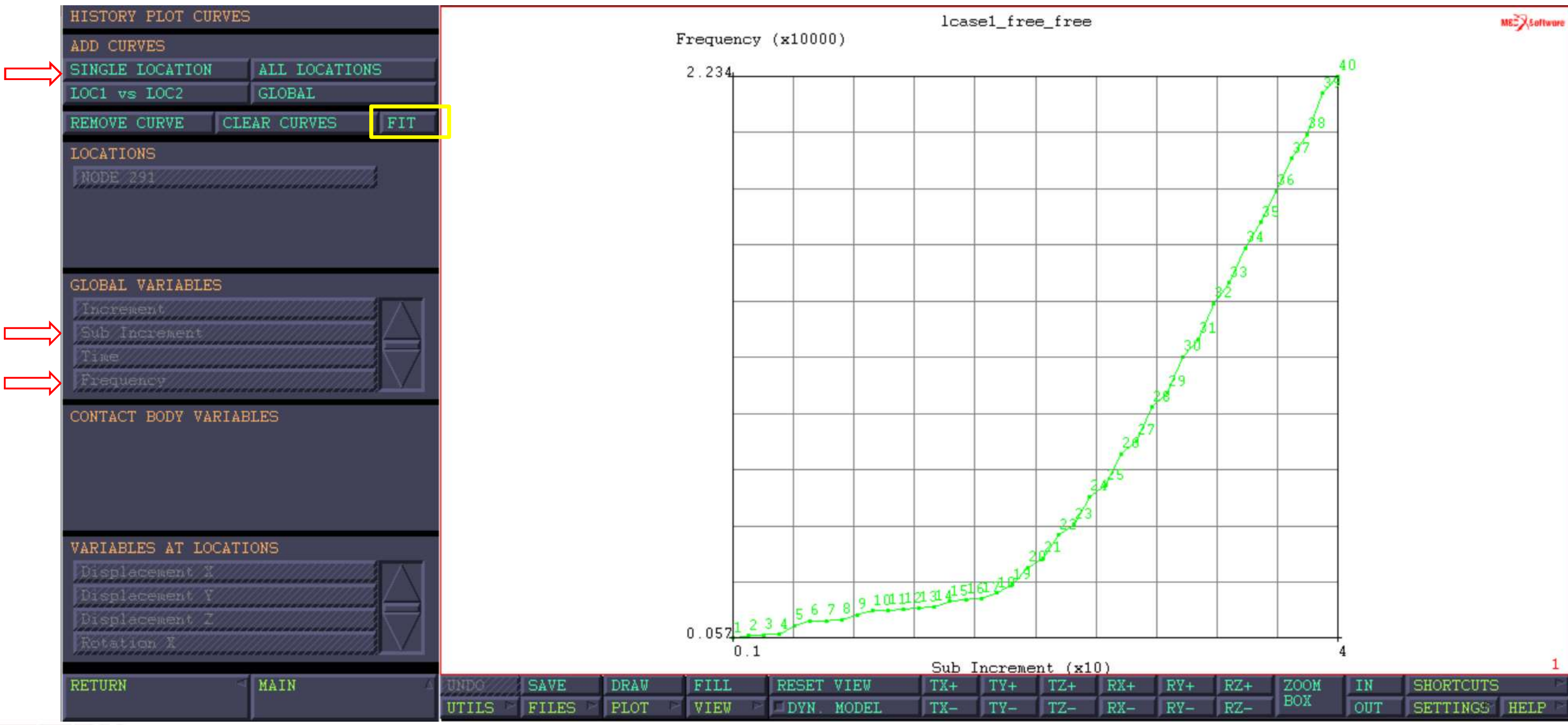

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Natural frequencies: Hystory plot

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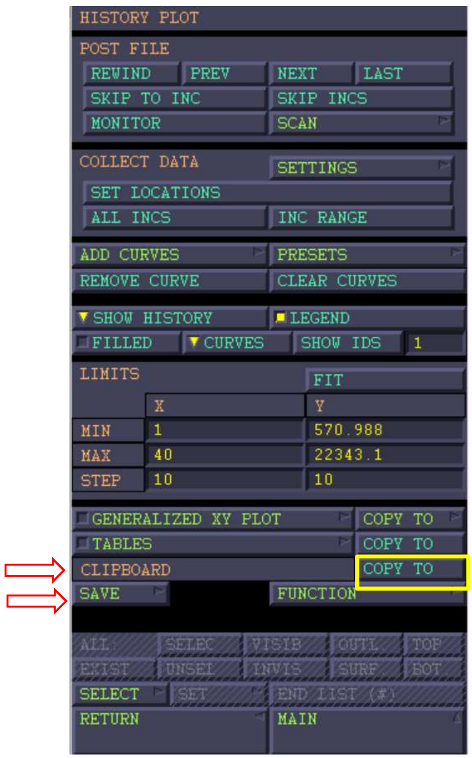

CLIPBOARD:
copy and paste the data from MARC to the Excel file only for Windows.

SAVE:
Save the data in a text file in a defined directory, The .txt file formatting is presented beside.

HISTORY PLOT
jobl_free_free

Curve 1
X : Sub Increment
Y : Frequency

X	Y
1.000000e+000	5.709879e+002
2.000000e+000	6.716981e+002
3.000000e+000	7.044292e+002
4.000000e+000	7.165169e+002
5.000000e+000	1.056302e+003
6.000000e+000	1.245774e+003
7.000000e+000	1.248814e+003
8.000000e+000	1.278027e+003
9.000000e+000	1.482664e+003
1.000000e+001	1.636913e+003
1.100000e+001	1.645826e+003
1.200000e+001	1.693099e+003
1.300000e+001	1.747204e+003
1.400000e+001	1.790561e+003

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Harmonic loadcases:

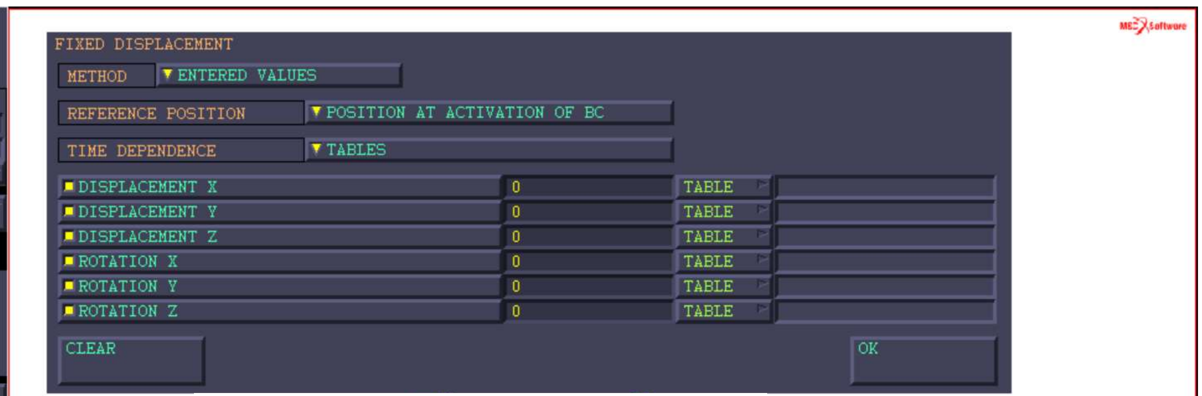
- Neglecting damping effect
- Considering damping effect

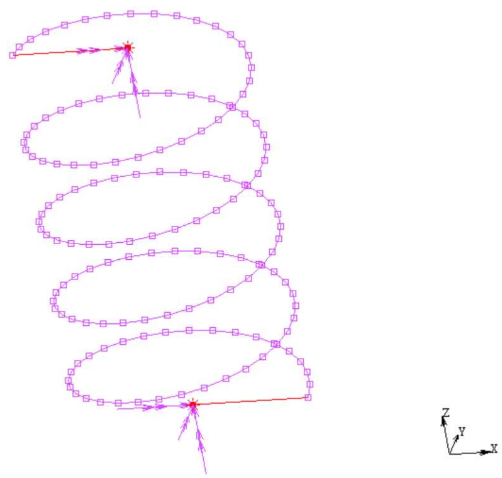
References

BCs

Fixed at both coil extremities

Moving from a free-free modal analysis to a fixed-fixed modal analysis, the natural frequencies of the coil are evaluated. The natural frequency involves the modes proper of the wire preventing the movent of the extremity of the component.

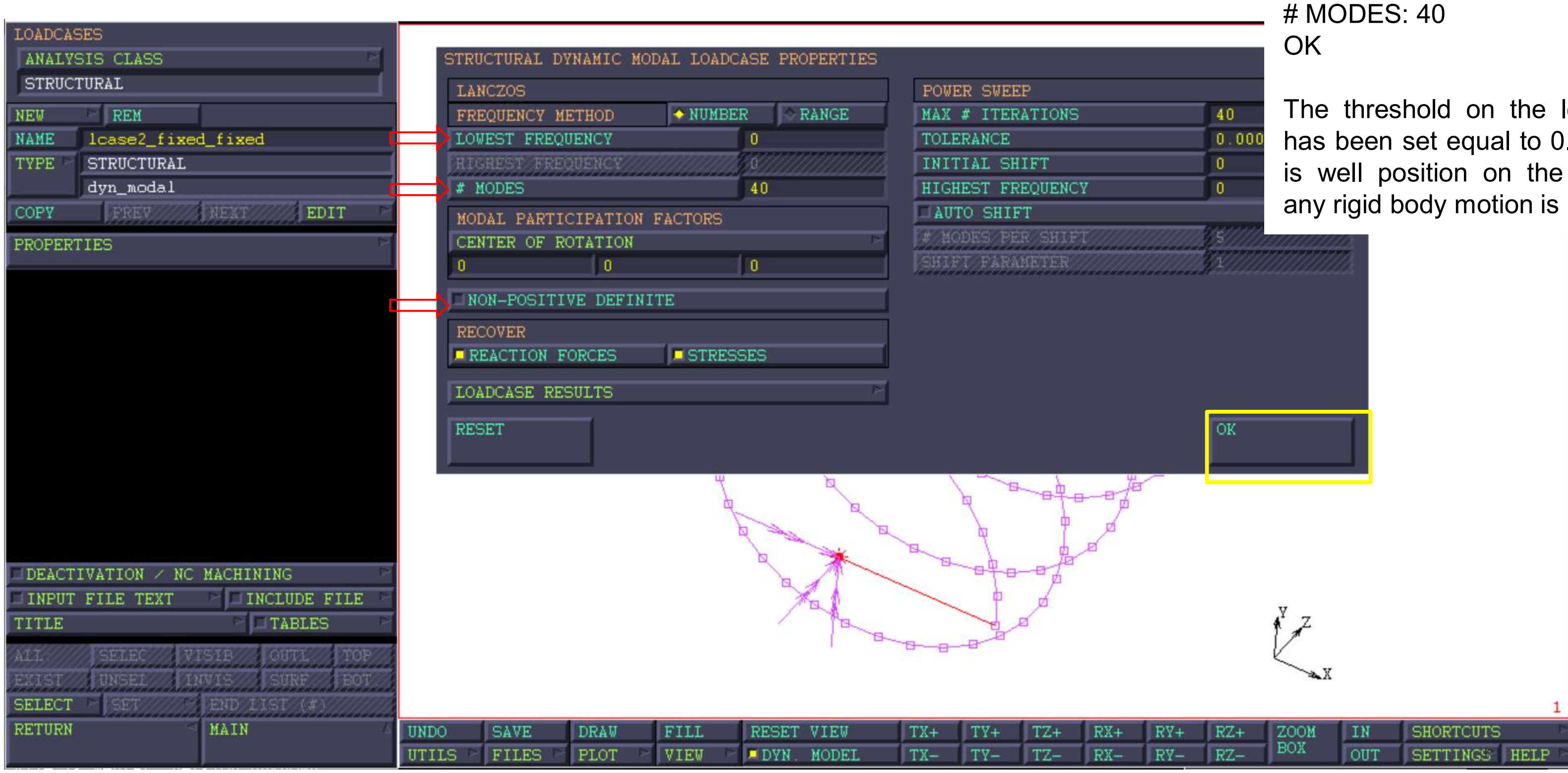




```
|----------------------------------
|   BCs START
|----------------------------------
*apply_name fixed
*apply_dof x *apply_dof_value x
*apply_dof y *apply_dof_value y
*apply_dof z *apply_dof_value z
*apply_dof rx *apply_dof_value rx
*apply_dof ry *apply_dof_value ry
*apply_dof rz *apply_dof_value rz
*add_apply_nodes
 291
 292
# | End of List
|----------------------------------
```

Loadcases

Modal analysis: fixed-fixed



The model loadcase must be set as follows:

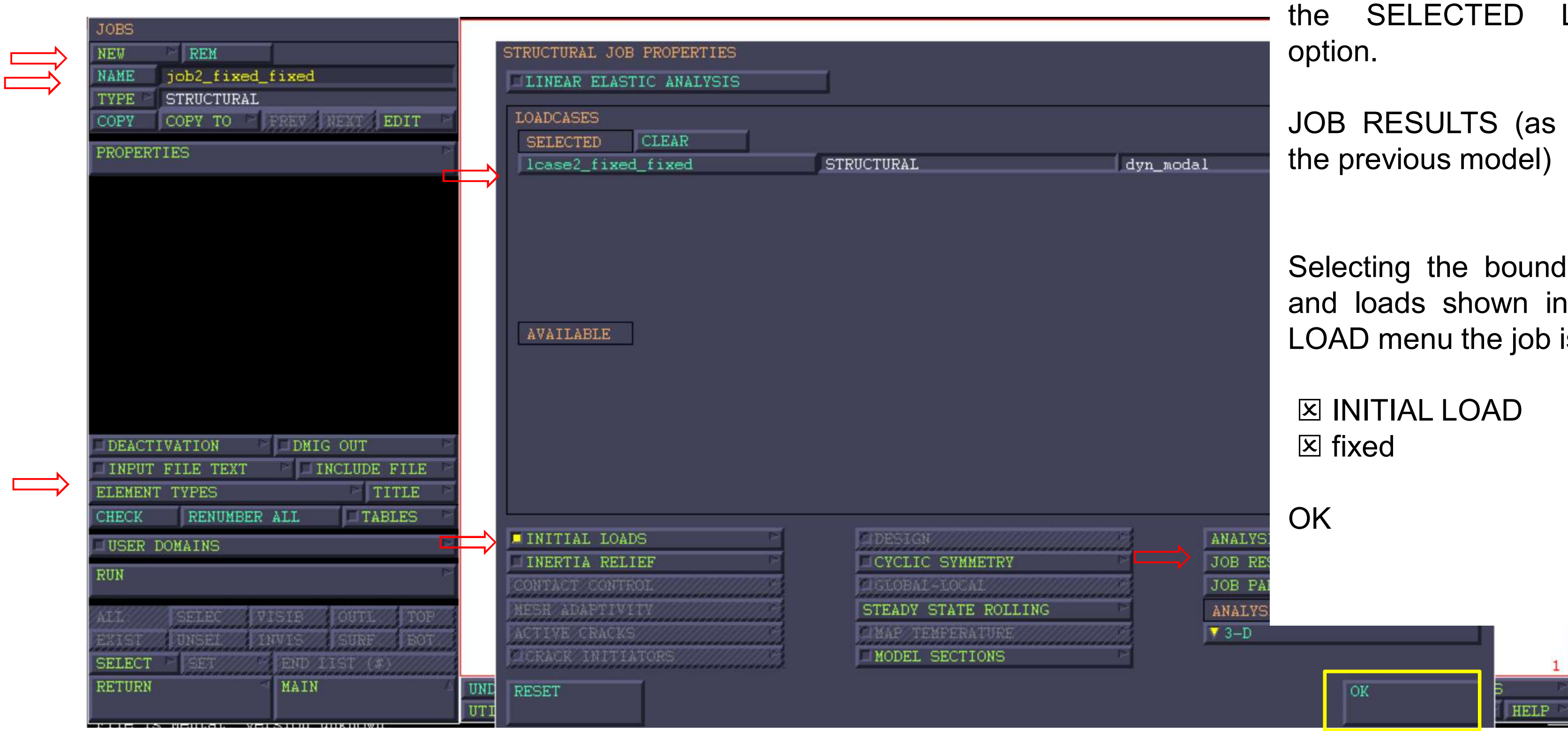
LOADCASES
NEW
DYNAMIC MODAL
NAME: *lcase2_ fixed_fixed*
LANCZOS
LOWEST FREQUENCY: 0
MODES: 40
OK

The threshold on the lowest frequency has been set equal to 0. The component is well position on the modelling area, any rigid body motion is prevented.

Remember that the modal response of the structure is influenced by the BCs acting on the component.

Jobs

Job results



JOBS
NEW
TYPE: STRUCTURAL
NAME: job2_fixed_fixed
PROPERTIES

The *lcase2_fixed_fixed* must be updated from the AVAILABLE to the SELECTED LOADCASES option.

JOB RESULTS (as discussed in the previous model)

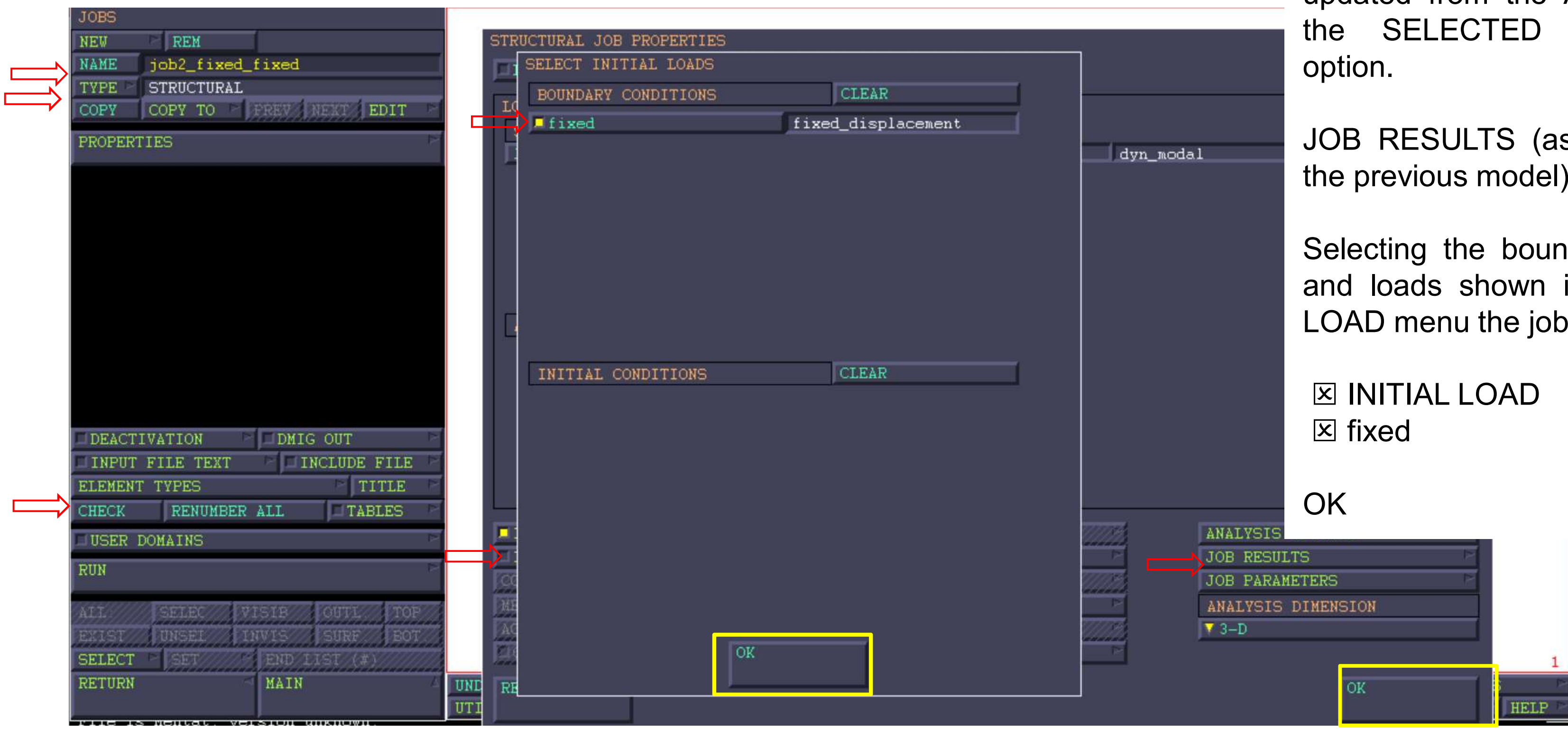
Selecting the boundary condition and loads shown in the INITIAL LOAD menu the job is defined.

☒ INITIAL LOAD
☒ fixed

OK

Jobs

Job results



JOBS
NEW
TYPE: STRUCTURAL
NAME: job2_fixed_fixed
PROPERTIES

The *lcase2_fixed_fixed* must be updated from the AVAILABLE to the SELECTED LOADCASES option.

JOB RESULTS (as discussed in the previous model)

Selecting the boundary condition and loads shown in the INITIAL LOAD menu the job is defined.

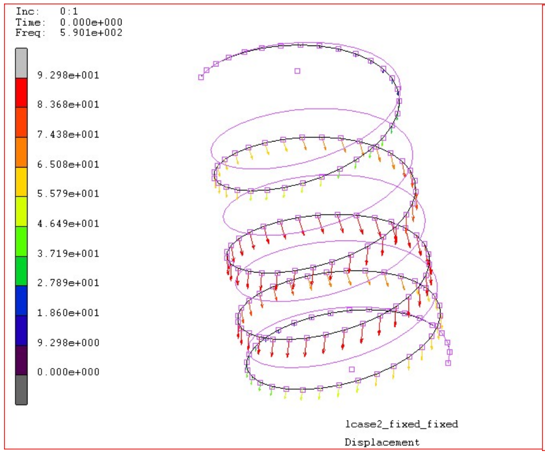
☒ INITIAL LOAD
☒ fixed

OK

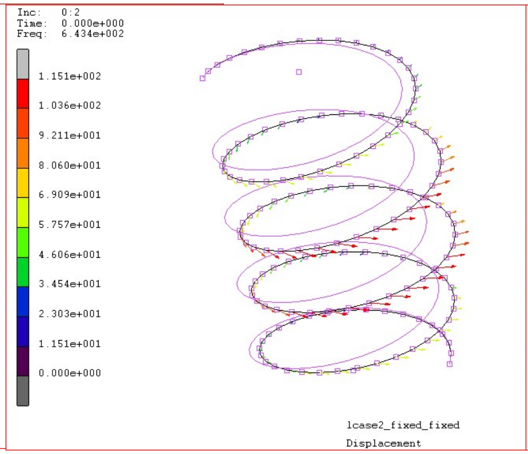
Results

Natural frequencies of the coil (#3 modes)

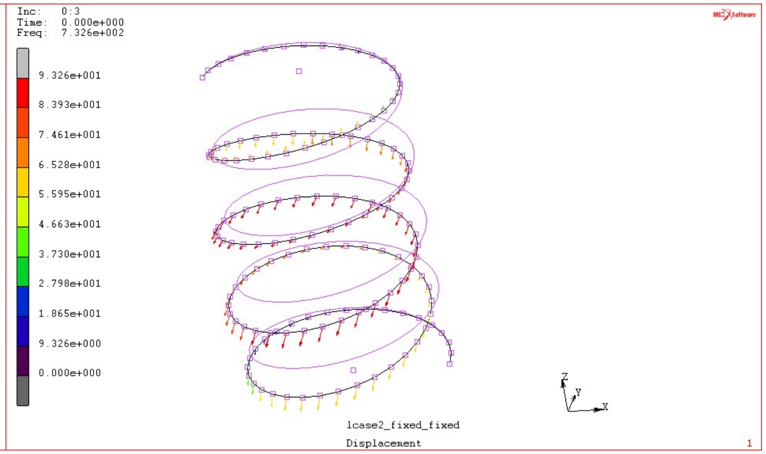
Check the deformation mode of the model in comparison with the undeformed condition.
The scaled factor applied to compare the deformation is set equal to 0.1.
In addition, the displacement field is plotted by vectors from the RESULT MORE menu.



1 mode
Axial compressive mode
Freq: 590.1 Hz



2 mode
Circumferential Expantion - lateral bending mode
Freq: 643.4Hz



3 mode
Mixed mode
Freq: 732.6 Hz

Results

Natural frequencies: Hystory plot

The automatic collection of natural frequencies of the coil (#40 modes) can be done by using HYSTORY PLOT option. These data can usually exported to make the post-processing in a Spreadsheet file, *e.g.* .xls, .xlsx, .ods, … files.

CLIPBOARD:
copy and paste directly the data form MARC to the Excel file only for Windows.

SAVE:
Save the data in a text file in a defined directory, The .txt file formatting is presented beside.

```
HISTORY PLOT
job2_fixed_fixed

Curve 1
X : Sub Increment
Y : Frequency

       X                Y
------------------------------
  1.000000e+000   5.901064e+002
  2.000000e+000   6.434000e+002
  3.000000e+000   7.325642e+002
  4.000000e+000   7.561287e+002
  5.000000e+000   1.112751e+003
  6.000000e+000   1.163618e+003
  7.000000e+000   1.262487e+003
  8.000000e+000   1.324692e+003
  9.000000e+000   1.484989e+003
  1.000000e+001   1.626085e+003
  1.100000e+001   1.647429e+003
  1.200000e+001   1.692789e+003
  1.300000e+001   1.793034e+003
  1.400000e+001   1.795375e+003
```

Agenda

Goal and nomenclature

Model setup

Modal Analysis loadcases varying the BCs:

- Free-free
- Fixed-fixed
- **Fixed-axial rotation free**
- Fixed-displacement and rotation free

Harmonic loadcases:

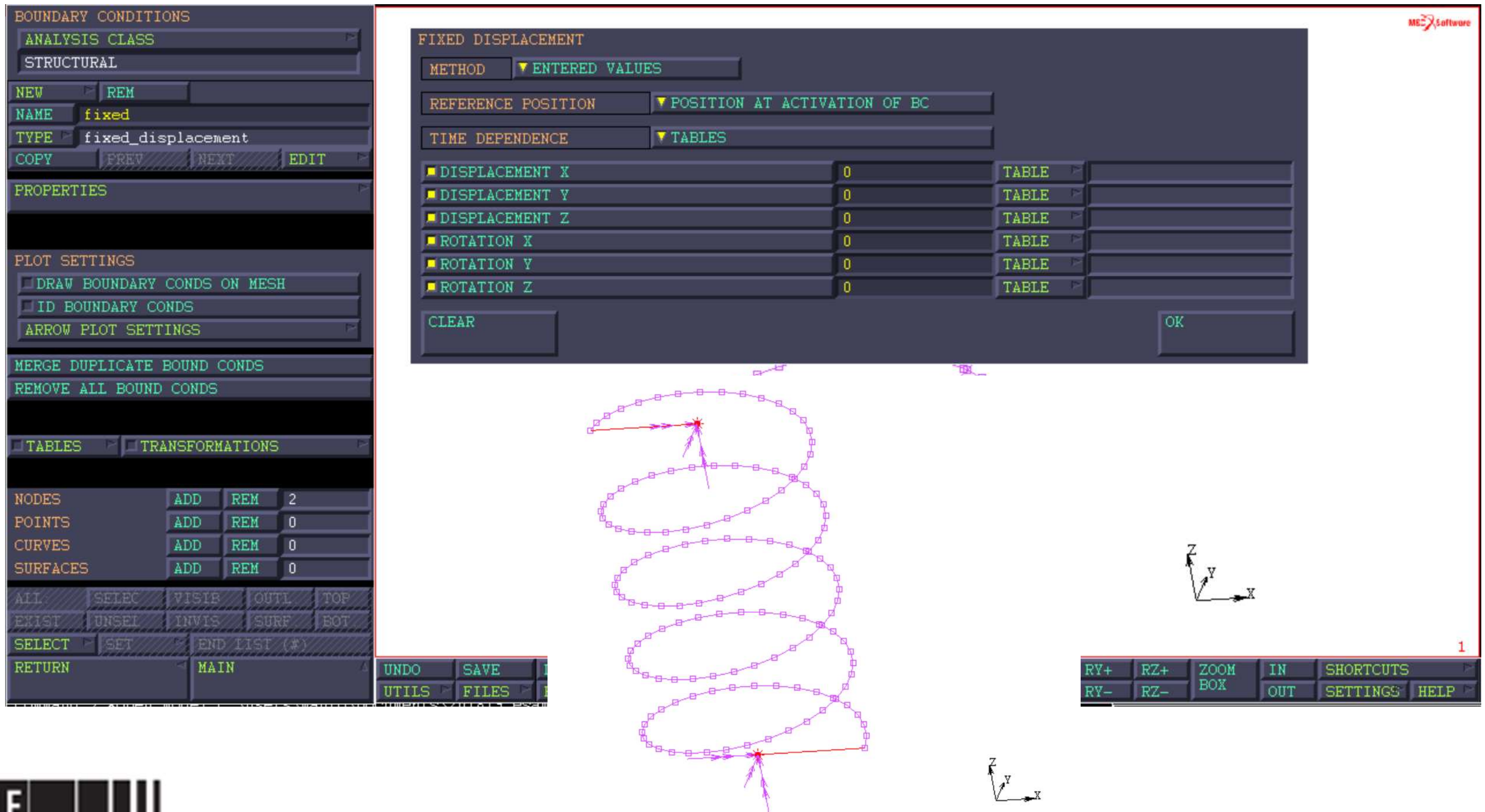
- Neglecting damping effect
- Considering damping effect

References

BCs

Upper extremity fixed – lower extremity rot$_z$ free

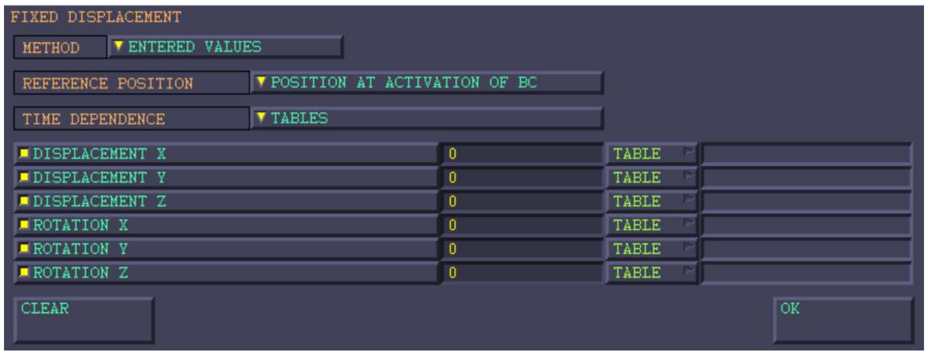
Moving from a free-free modal analysis to a fixed-fixed modal analysis, the natural frequencies of the coil are evaluated. The natural frequency involves the modes proper of the wire preventing the movent of the extremity of the component.

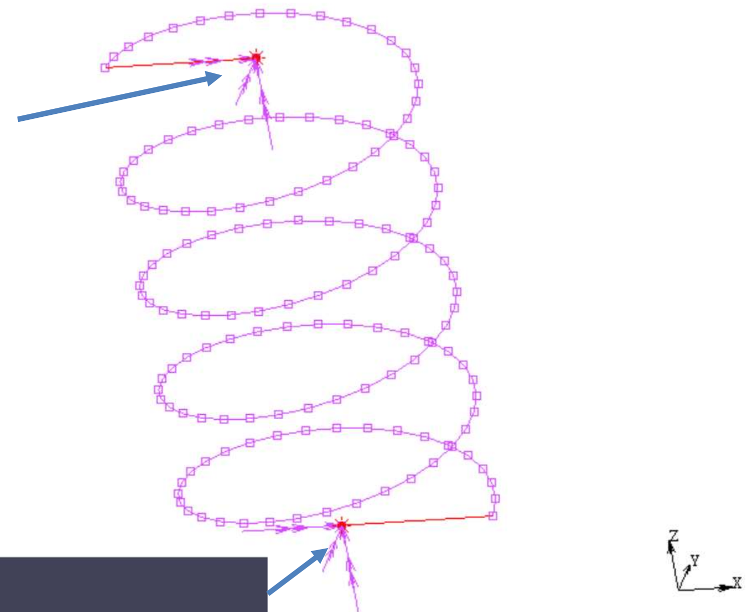


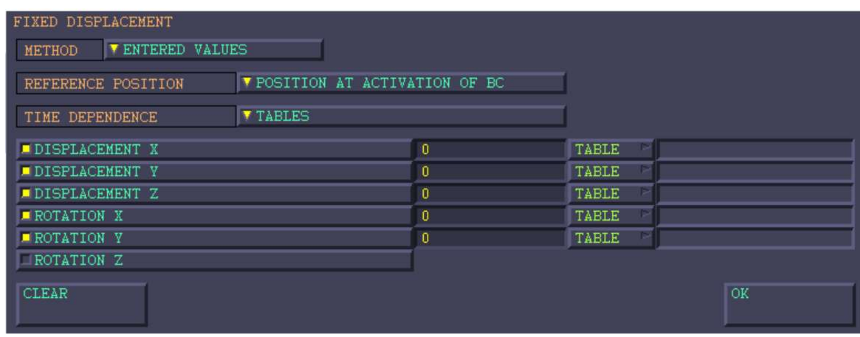
BCs

Upper extremity fixed – lower extremity rot$_z$ free

The natural frequencies of the coil are evaluated, considering the upper extremity of the coila as fixed, and the lower one as free to rotate along Z direction. Therefore, the BCS are named *fixed* and *rotz_free.*



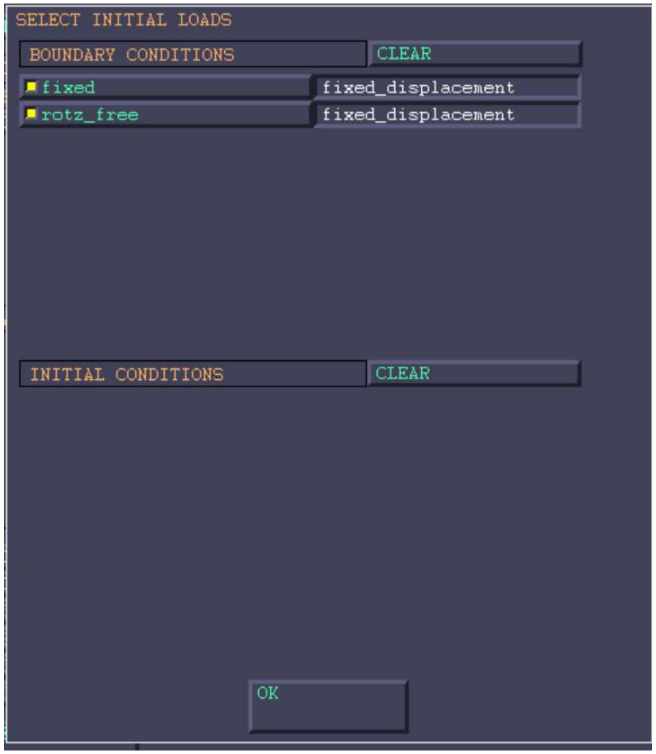




Loadcase

Upper extremity fixed – lower extremity rot$_z$ free

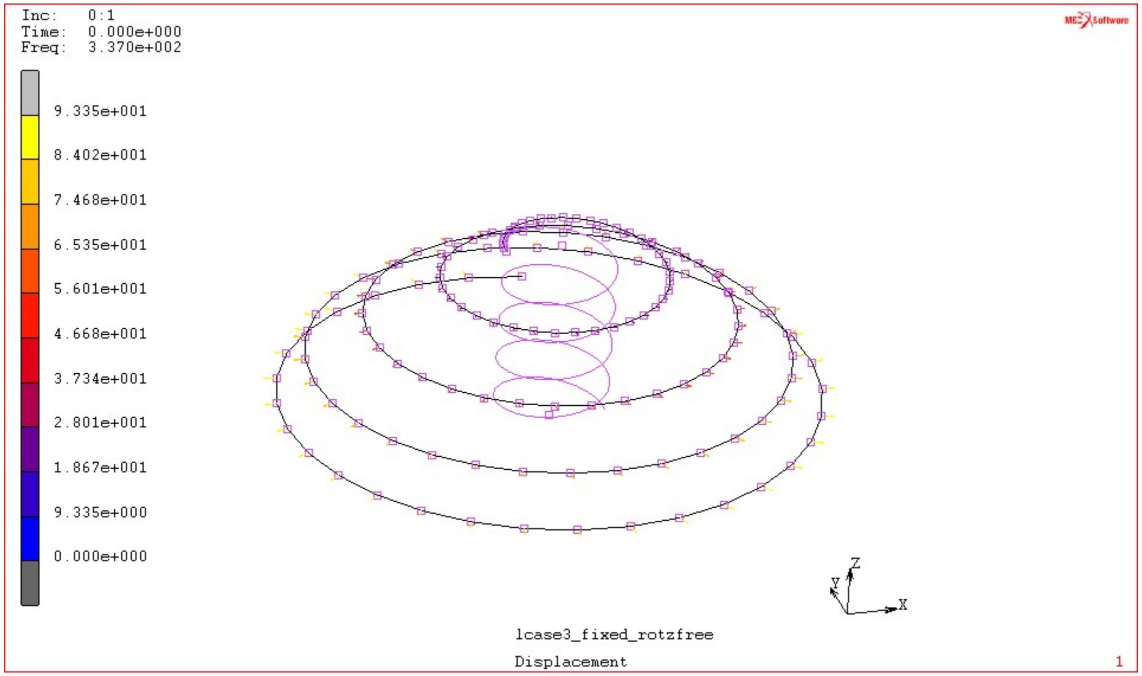
Remember to update the INITIAL LOAD condition at the JOBS menu, then submit the model to the evaluation.



Results

Natural frequencies of the coil (#1 mode)

Check the deformation mode of the model in comparison with the undeformed condition.
The scaled factor applied to compare the deformation is set equal to 1.0
In addition, the displacement field is plot by vectors from the RESULT MORE menu.

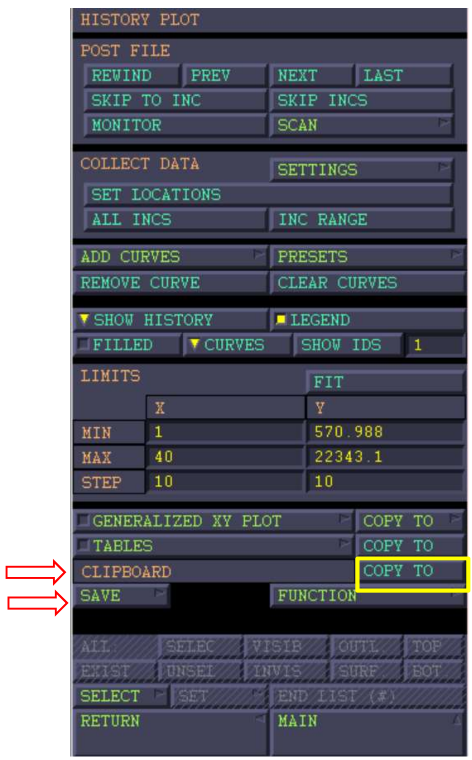


1 mode
Circumferential Expantion of the wire
Freq: 337.0 Hz

Results

Natural frequencies: Hystory plot

The automatic collection of natural frequencies of the coil (#40 modes) can be done by using HYSTORY PLOT option. These data can usually exported to make the post-processing in a Spreadsheet file, *e.g.* .xls, .xlsx, .ods, … files.



CLIPBOARD:
copy and paste the data from MARC to the Excel file only for Windows.

SAVE:
Save the data in a text file in a defined directory, The .txt file formatting is presented beside.

```
HISTORY PLOT
job3_fixed_rotzfree

Curve 1
X : Sub Increment
Y : Frequency

      X              Y
------------------------------
  1.000000e+000  3.369980e+002
  2.000000e+000  5.921451e+002
  3.000000e+000  7.263797e+002
  4.000000e+000  7.325867e+002
  5.000000e+000  9.684847e+002
  6.000000e+000  1.131105e+003
  7.000000e+000  1.217419e+003
  8.000000e+000  1.262912e+003
  9.000000e+000  1.460717e+003
  1.000000e+001  1.535286e+003
  1.100000e+001  1.638096e+003
  1.200000e+001  1.647432e+003
  1.300000e+001  1.762460e+003
  1.400000e+001  1.793168e+003
```

Agenda

Goal and nomenclature

Model setup

Modal Analysis loadcases varying the BCs:

- Free-free
- Fixed-fixed
- Fixed-axial rotation free
- **Fixed-axial displacement and rotation free**

Harmonic loadcases:

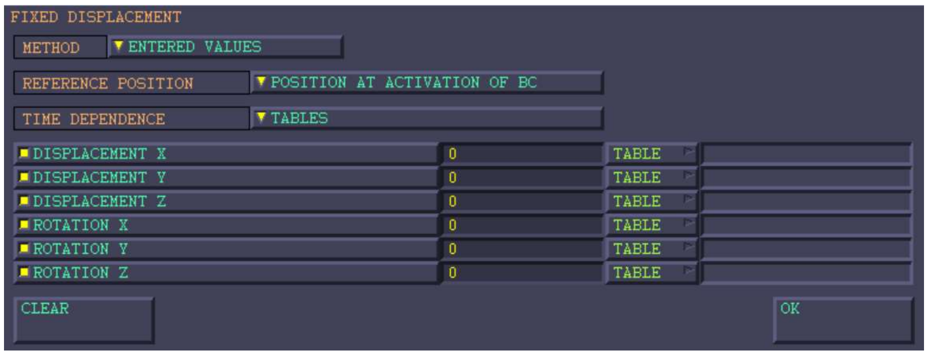
- Neglecting damping effect
- Considering damping effect

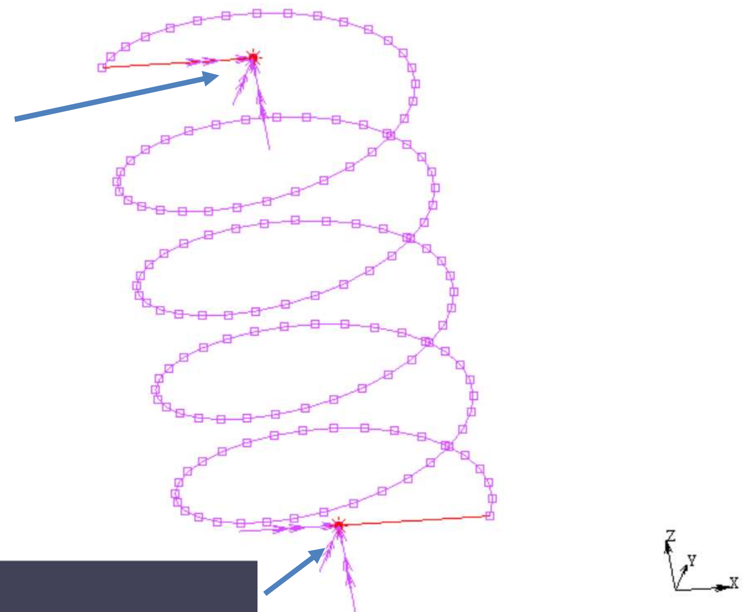
References

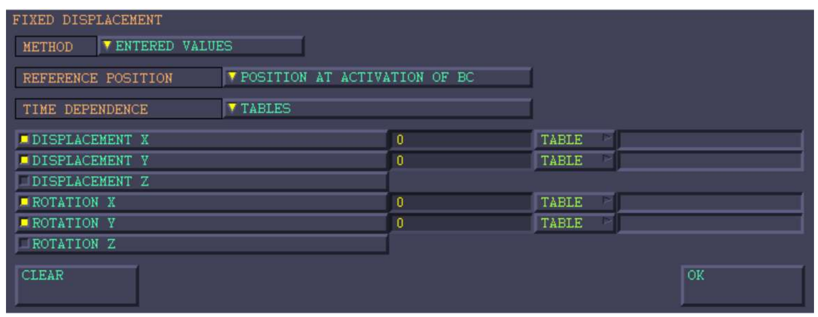
BCs

Upper extremity fixed – lower extremity displ$_z$ and rot$_z$ free

The natural frequencies of the coil are evaluated, considering the upper extremity of the coila as fixed, and the lower one as free to move and to rotate along Z direction. Therefore, the BCS are two named *fixed* and *displrotz_free.*



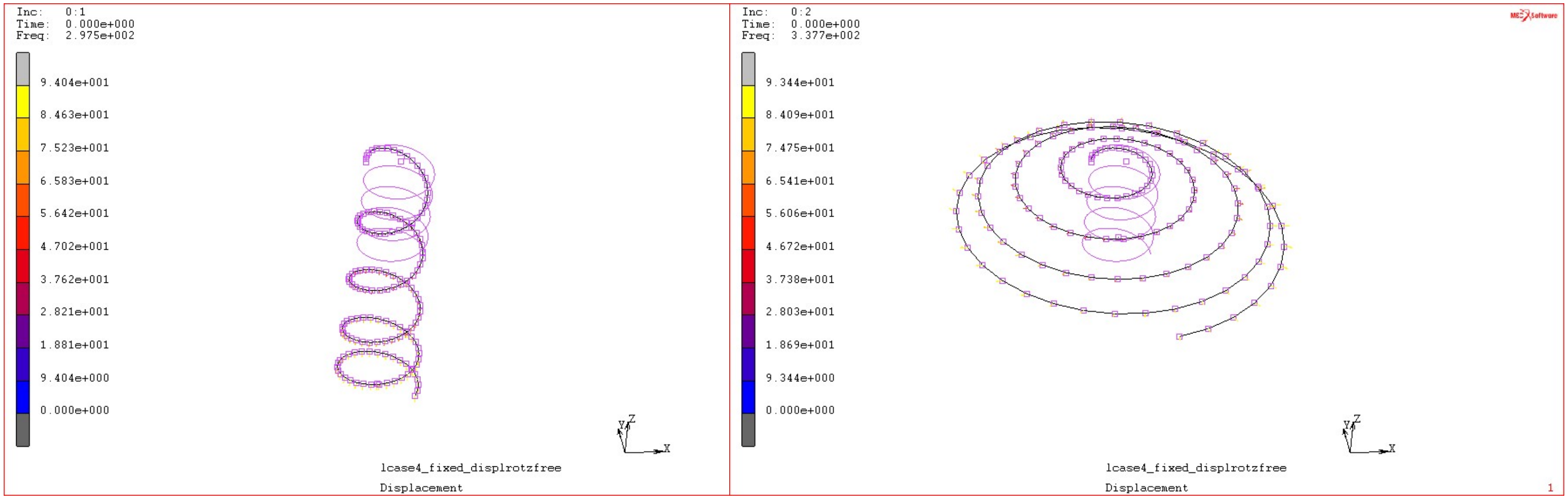




Results

Natural frequencies of the coil (#1 and #2 mode)

Check the deformation mode of the model in comparison with the undeformed condition.
The scaled factor applied to compare the deformation is set equal to 1.0
In addition, the displacement field is plotted by vectors from the RESULT MORE menu.



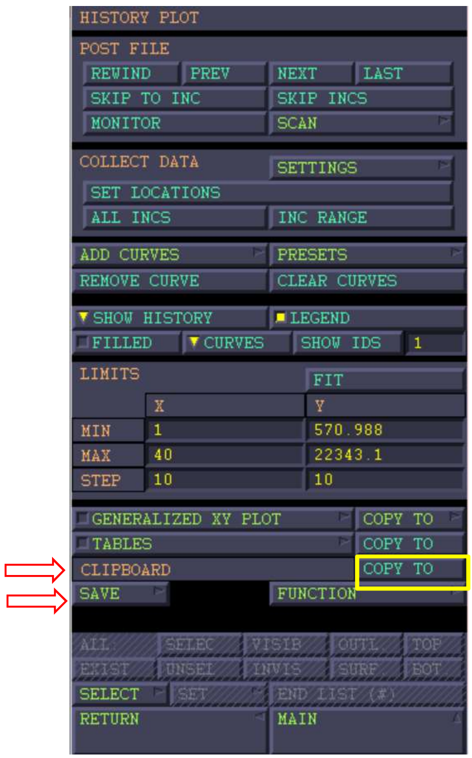
1 mode
Axial displacement
Freq: 297.5 Hz

2 mode
Circumferential Expantion of the wire
Freq: 337.7 Hz

Results

Natural frequencies: Hystory plot

The automatic collection of natural frequencies of the coil (#40 modes) can be done by using HYSTORY PLOT option. These data can usually exported to make the post-processing in a Spreadsheet file, *e.g.* .xls, .xlsx, .ods, … files.



CLIPBOARD:
copy and paste directly the data form MARC to the Excel file only for Windows.

SAVE:
Save the data in a text file in a defined directory, The .txt file formatting is presented beside.

```
HISTORY PLOT
lcase4_fixed_displrotzfree

Curve 1
X : Sub Increment
Y : Frequency

       X              Y
------------------------------
  1.000000e+000  2.975393e+002
  2.000000e+000  3.377146e+002
  3.000000e+000  7.263588e+002
  4.000000e+000  7.320267e+002
  5.000000e+000  8.665751e+002
  6.000000e+000  9.744045e+002
  7.000000e+000  1.216291e+003
  8.000000e+000  1.262441e+003
  9.000000e+000  1.328036e+003
  1.000000e+001  1.504377e+003
  1.100000e+001  1.625996e+003
  1.200000e+001  1.640287e+003
  1.300000e+001  1.669783e+003
  1.400000e+001  1.768155e+003
```

Agenda

Goal and nomenclature

Model setup

Modal Analysis loadcases varying the BCs:

- Free-free
- Fixed-fixed
- Fixed-axial rotation free
- Fixed-axial displacement and rotation free

Harmonic loadcases:

- **Neglecting damping effect**
- Considering damping effect

References

Frequency responce

Considerations

When a system is being excited by know oscillatory frequencies, it may not be feasible to design its natural frequencies out of this operating range. In cases of this nature, evaluating the system in the presence of this enforced vibration proves necessary. When the excitation does not change with time, the solution is a steady state responce at the operating frequeny of interest. This is know as *frequency responce analysis*. The relevant results of this analysis are typically displacements, velocities, and accelerations of the system, which can be used to calculated forces and stress in the structure.

The presence of an harmonic force (F) or displacement (u) is defined as follows: $u = u_0 \cos(\omega t + \varphi)$ or $F = F_0 \cos(\omega t + \varphi)$

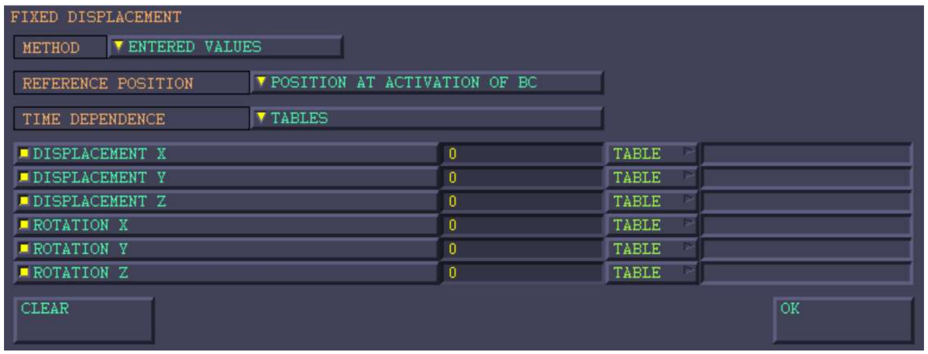
Where
ω is the angular frequency
u_0 and F_0 are the amplitude of the displacement or force

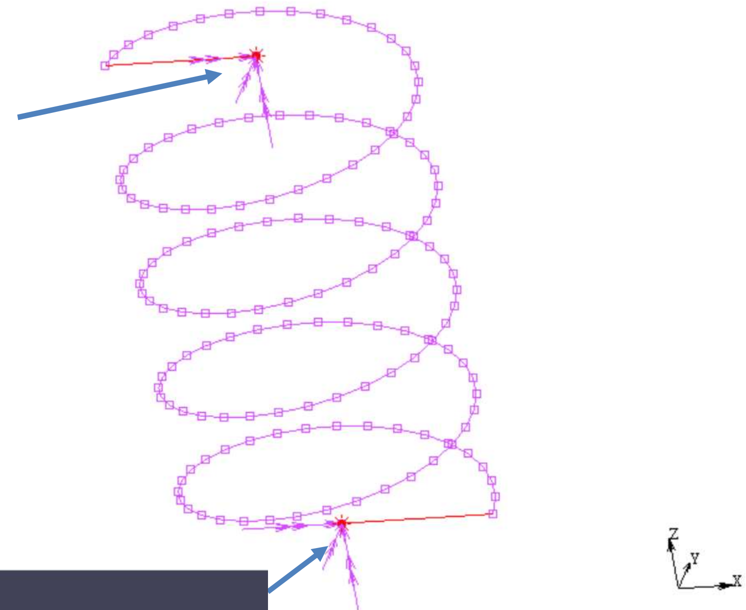
The resonance is defined as the condition when the $\omega/\omega_n = 1$ in other words when the operating frequency corresponds to the natural frequency (ω_n) of the structure.

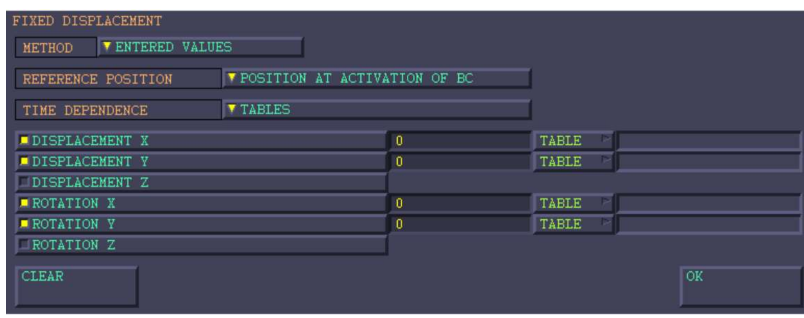
BCs

Upper extremity fixed – lower extremity displ$_z$ and rot$_z$ free

The natural frequencies of the coil are evaluated, considering the upper extremity of the coila as fixed, and the lower one as free to move and to rotate along Z direction. Therefore, the BCS are three and named *fixed, displrotz_free and harmonic_displz.*



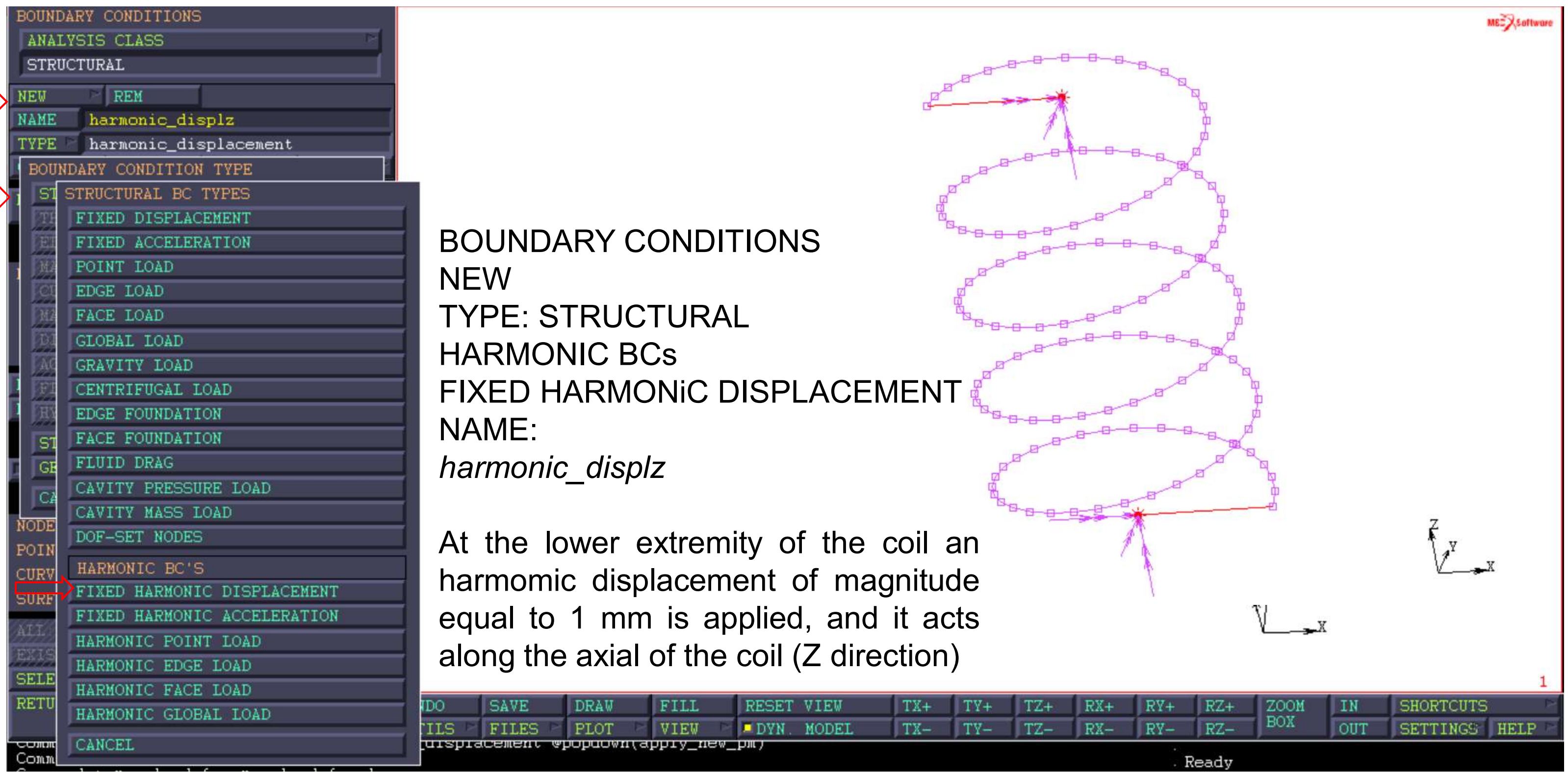




BCs

Upper extremity fixed – lower extremity harmonic displ$_z$

The natural frequencies of the coil are evaluated, considering the upper extremity of the coila as fixed, and the lower one as free to move and to rotate along Z direction. Therefore, the BCS are three and named *fixed, displrotz_free and harmonic_displz.*



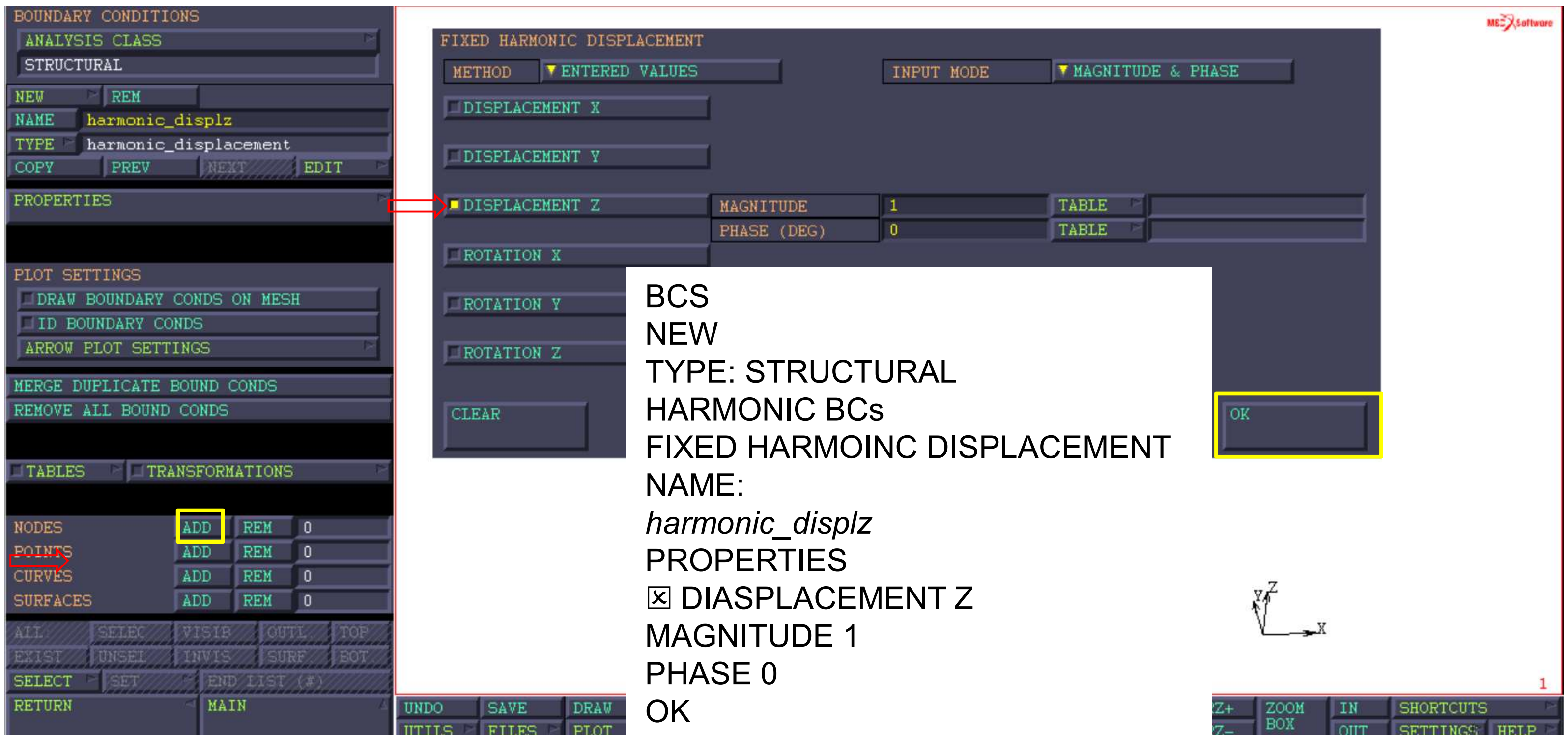
BOUNDARY CONDITIONS
NEW
TYPE: STRUCTURAL
HARMONIC BCs
FIXED HARMONiC DISPLACEMENT
NAME:
harmonic_displz

At the lower extremity of the coil an harmomic displacement of magnitude equal to 1 mm is applied, and it acts along the axial of the coil (Z direction)

BCs

Upper extremity fixed – lower extremity harmonic displ$_z$

The natural frequencies of the coil are evaluated, considering the upper extremity of the coila as fixed, and the lower one as free to move and to rotate along Z direction. Therefore, the BCS are three and named *fixed, displrotz_free and harmonic_displz.*



BCS
NEW
TYPE: STRUCTURAL
HARMONIC BCs
FIXED HARMOINC DISPLACEMENT
NAME:
harmonic_displz
PROPERTIES
☒ DIASPLACEMENT Z
MAGNITUDE 1
PHASE 0
OK
NODES: ADD
Select the retained node of the *rbe2_z0*.

Loadcase

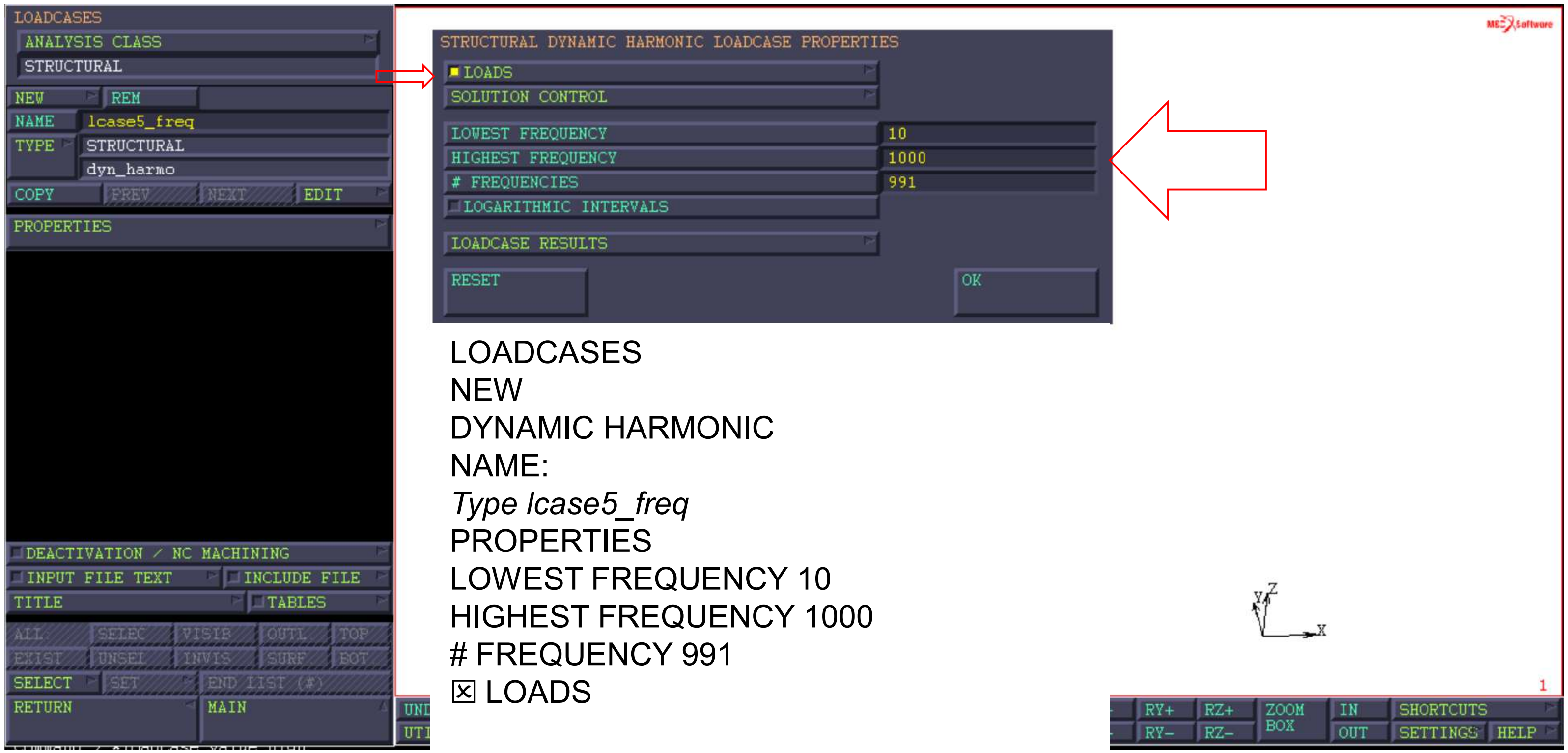
Frequency responce

The evalution of the responce of the structure is evaluated with a LOADCASE of DYNAMIC HARMONIC type.

Loadcase

Frequency responce

Remember to update the INITIAL LOAD conditions at the LOADCASE menu, then submit the model to the evaluation.



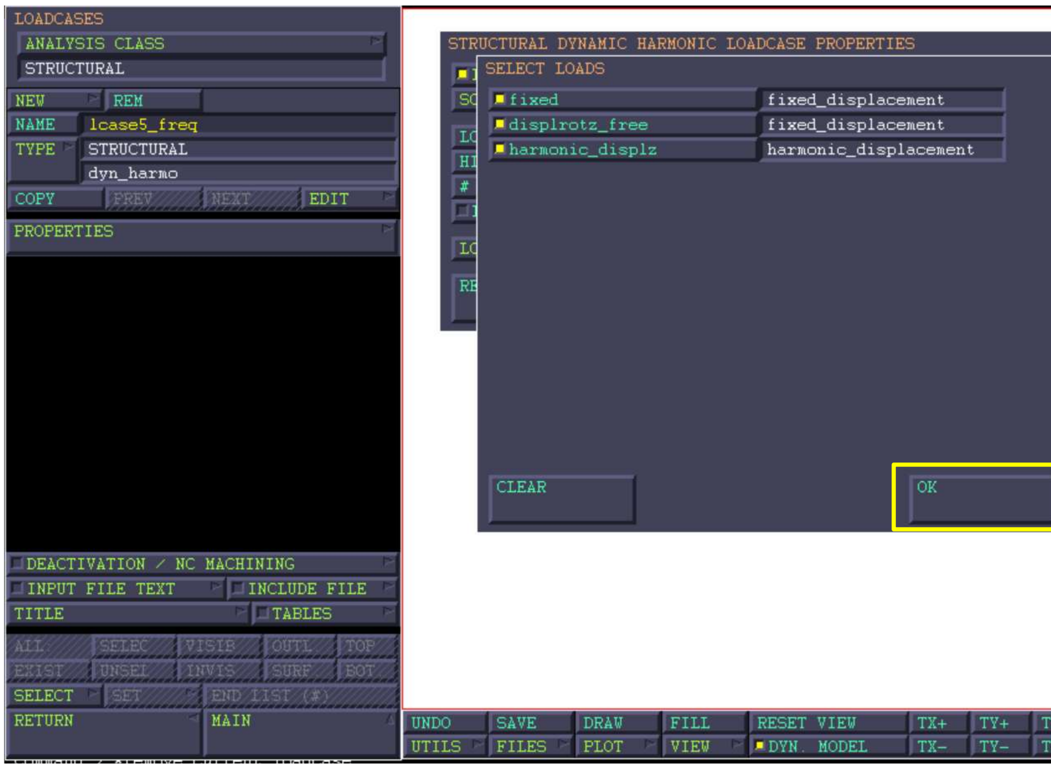
LOADCASES
NEW
DYNAMIC HARMONIC
NAME:
Type lcase5_freq
PROPERTIES
LOWEST FREQUENCY 10
HIGHEST FREQUENCY 1000
FREQUENCY 991
☒ LOADS

The frequency range that is investigated starts from 10 to 1000 Hz with a discrete step equal to 1 Hz.

Loadcase

Frequency responce

Remember to update the INITIAL LOAD conditions at the LOADCASE menu.

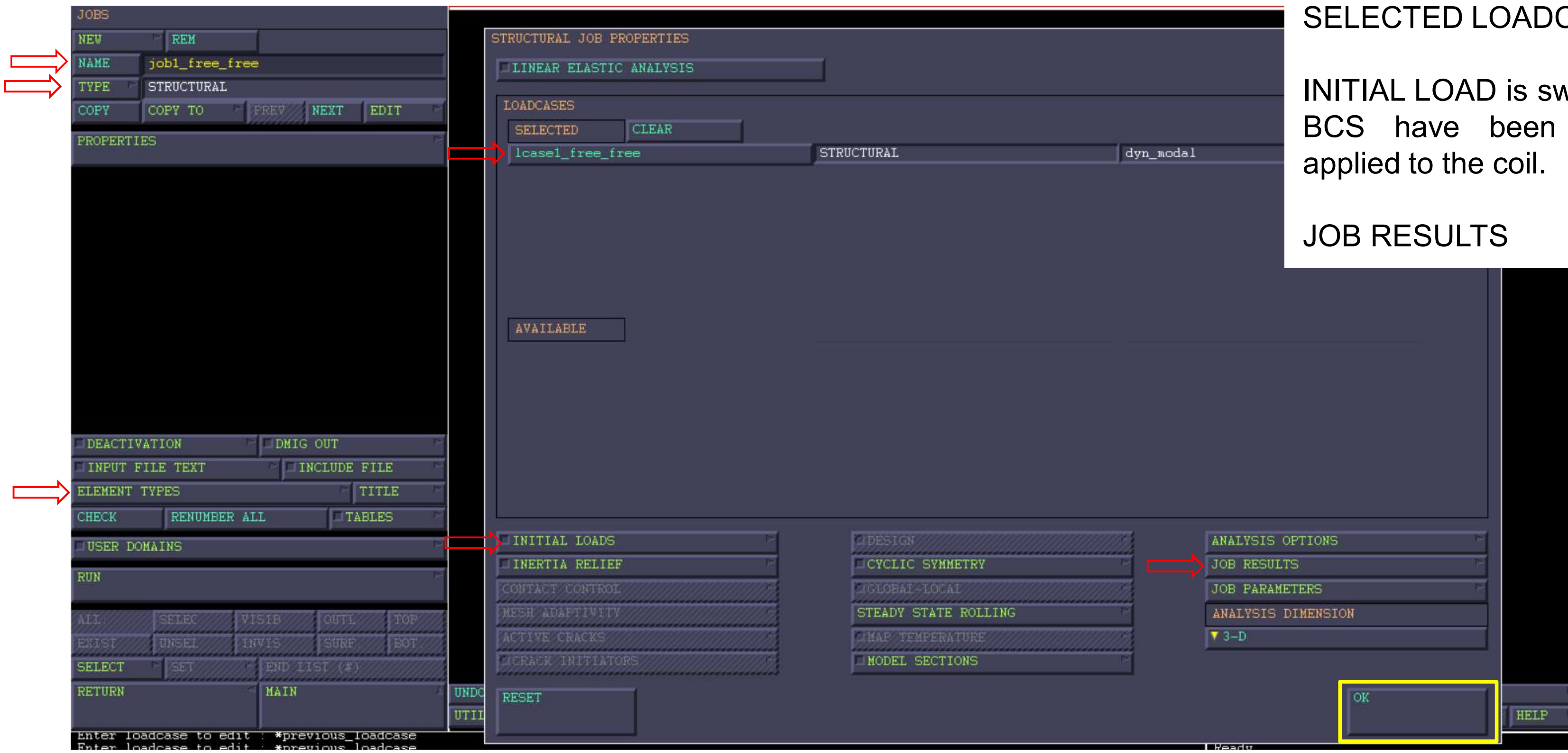


LOADCASES
NEW
DYNAMIC HARMONIC
NAME:
Type lcase5_freq
PROPERTIES
LOWEST FREQUENCY 10
HIGHEST FREQUENCY 1000
FREQUENCY 991
☒ LOADS
☒ fixed
☒ displrotz_free
☒ harmonic_displz
OK

And finally press OK on the previous shell.

Jobs

Job results



JOBS
NEW
TYPE: STRUCTURAL
NAME: job5_freq
PROPERTIES

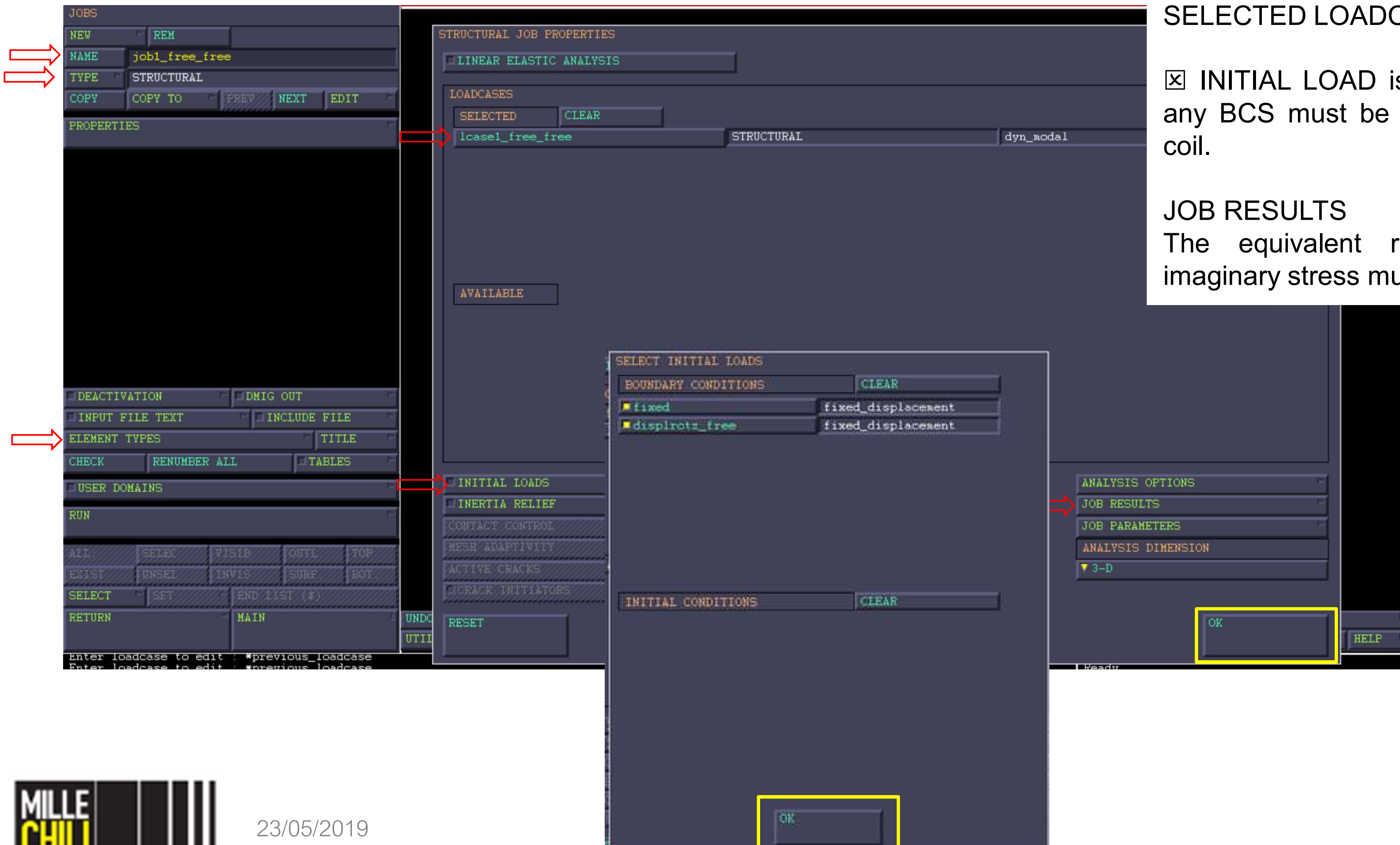
The *lcase5_freq* must be updated from the AVAILABLE to the SELECTED LOADCASES option.

INITIAL LOAD is switched off, any BCS have been defined and applied to the coil.

JOB RESULTS

Jobs

Job results



JOBS
NEW
TYPE: STRUCTURAL
NAME: job5_freq
PROPERTIES

The *lcase5_freq* must be updated from the AVAILABLE to the SELECTED LOADCASES option.

☒ INITIAL LOAD is switched on, any BCS must be applied to the coil.

JOB RESULTS
The equivalent real and the imaginary stress must be added

Jobs

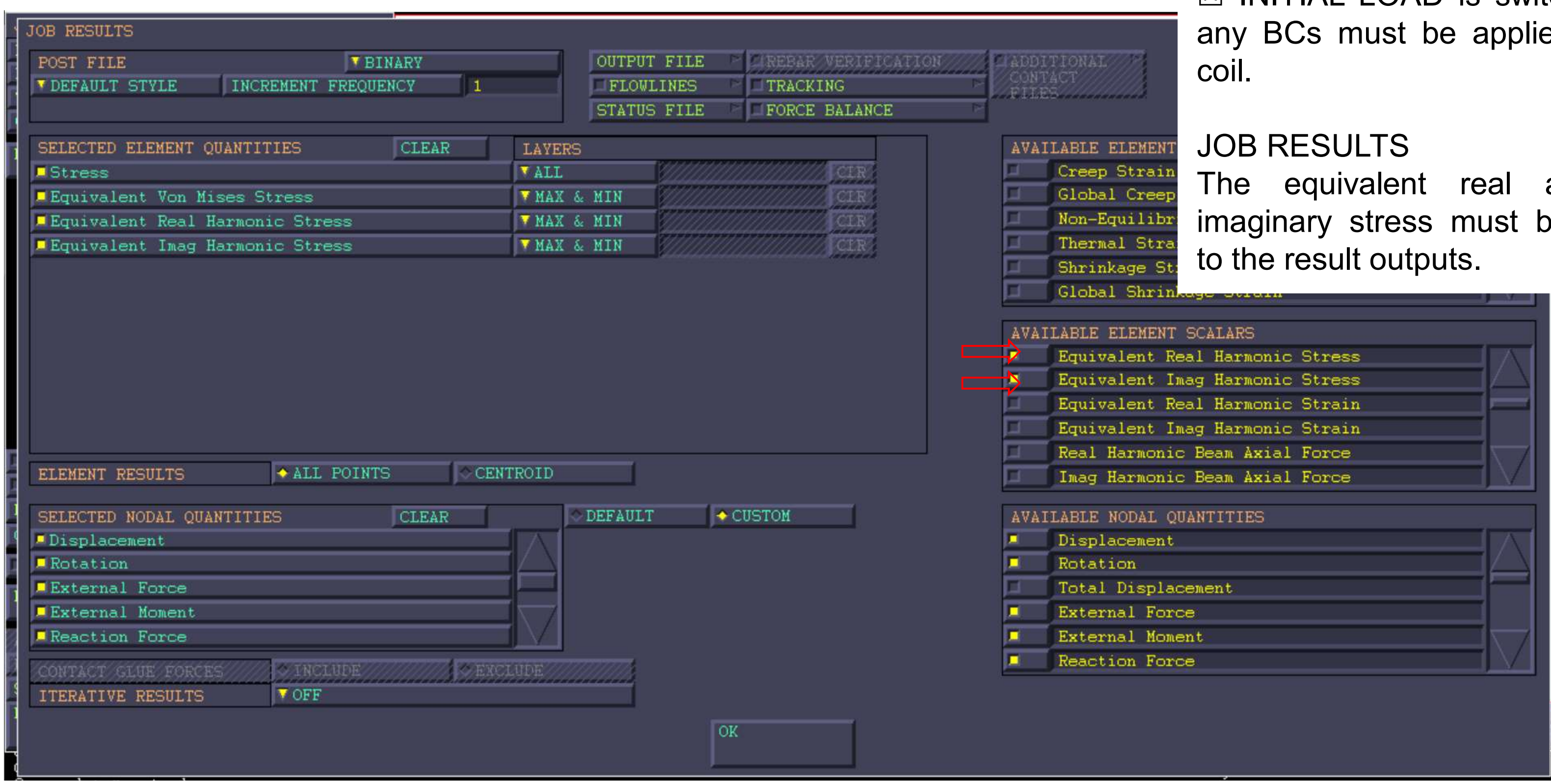
Job results

JOBS
NEW
TYPE: STRUCTURAL
NAME: job5_freq
PROPERTIES

The *lcase5_freq* must be updated from the AVAILABLE to the SELECTED LOADCASES option.

☒ INITIAL LOAD is switched on, any BCs must be applied to the coil.

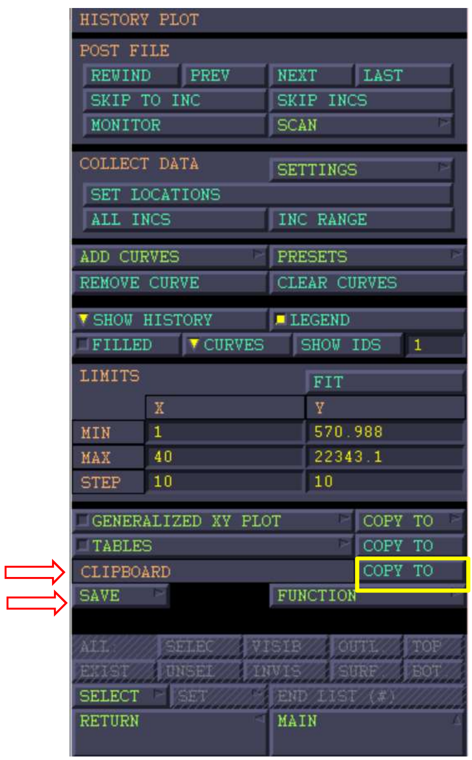
JOB RESULTS
The equivalent real and the imaginary stress must be added to the result outputs.

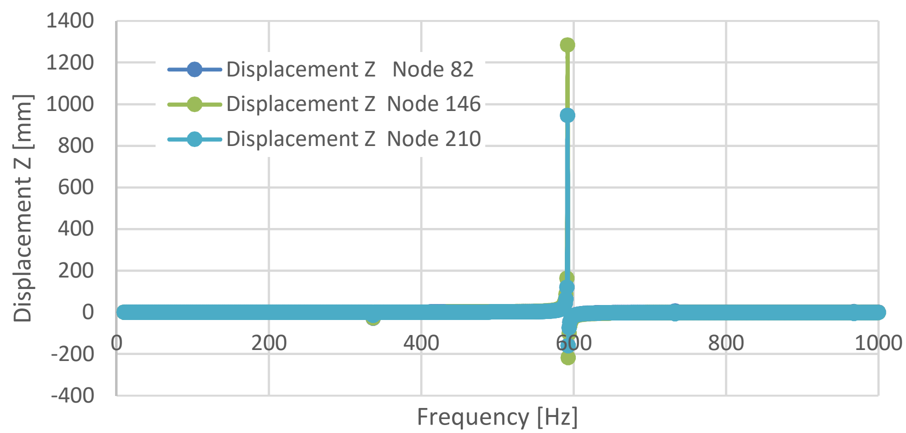


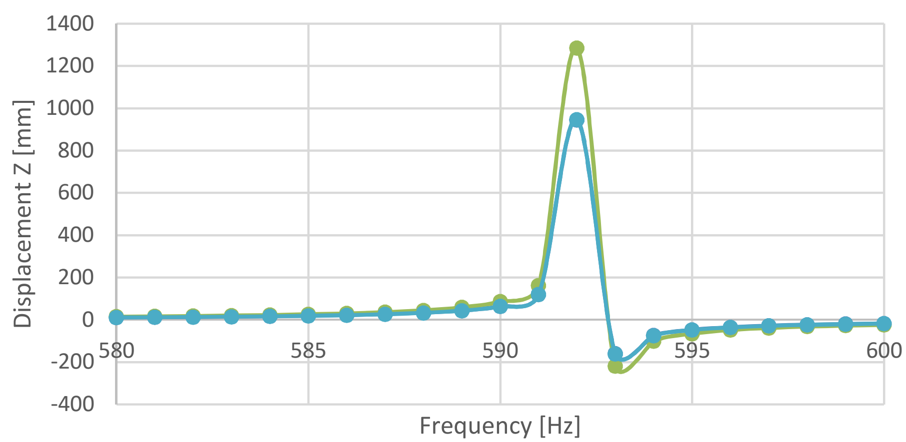
Results

Frequency responce: Hystory plot

The automatic collection of the frequencies of the coil (#991 frequencies) can be done by using HYSTORY PLOT option. These data can usually exported to make the post-processing in a Spreadsheet file, *e.g.* .xls, .xlsx, .ods, … files. The node of interest is the 82, 146 and 201 nodes, and the displacement Z is plotted on the frequency range under investigation [10-1000] Hz.







Agenda

Goal and nomenclature

Mesh generation

Modal Analysis loadcases varying the BCs:

- Free-free
- Fixed-fixed
- Fixed-axial rotation free
- Fixed-axial displacement and rotation free

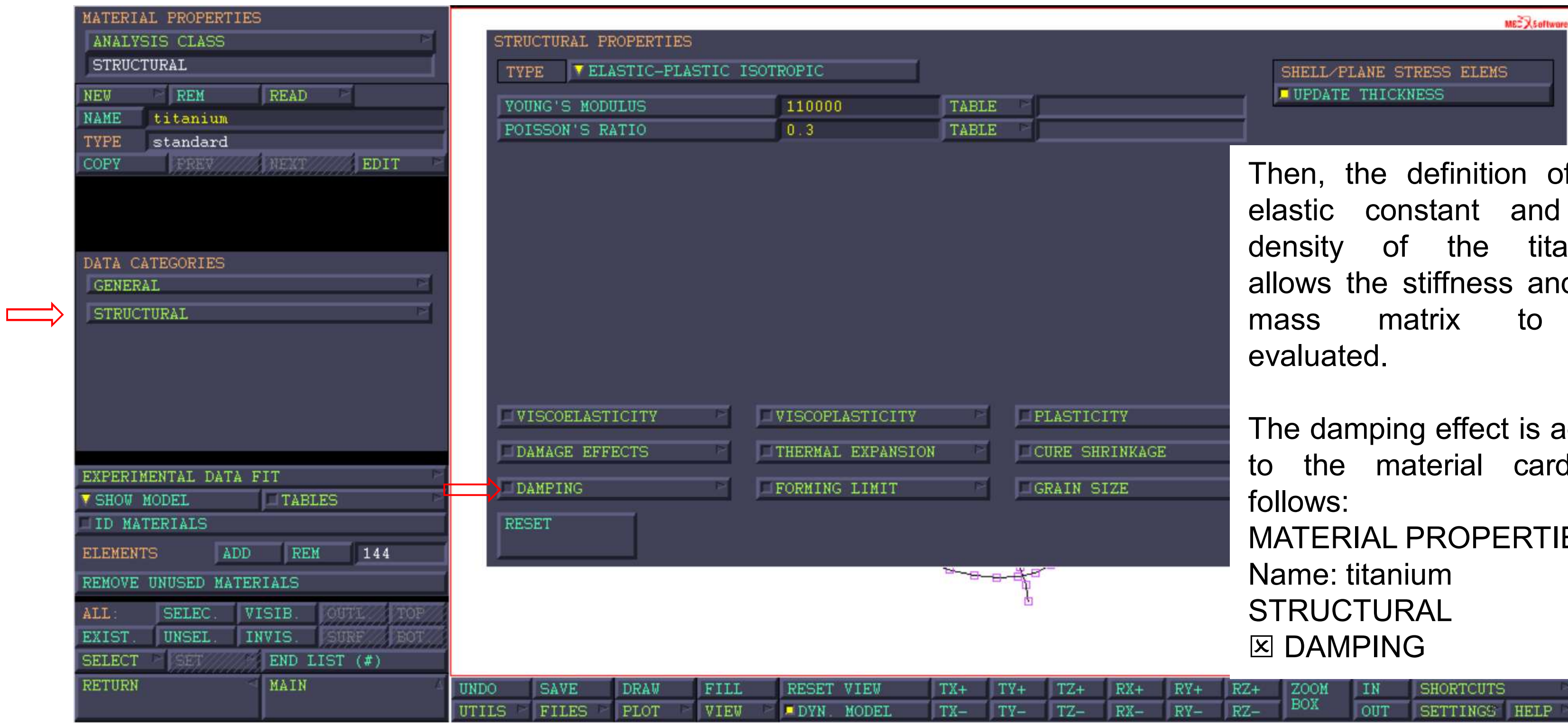
Harmonic loadcases:

- Neglecting damping effect
- **Considering damping effect**

References

Material properties

Isotropic and homogeneous with damping

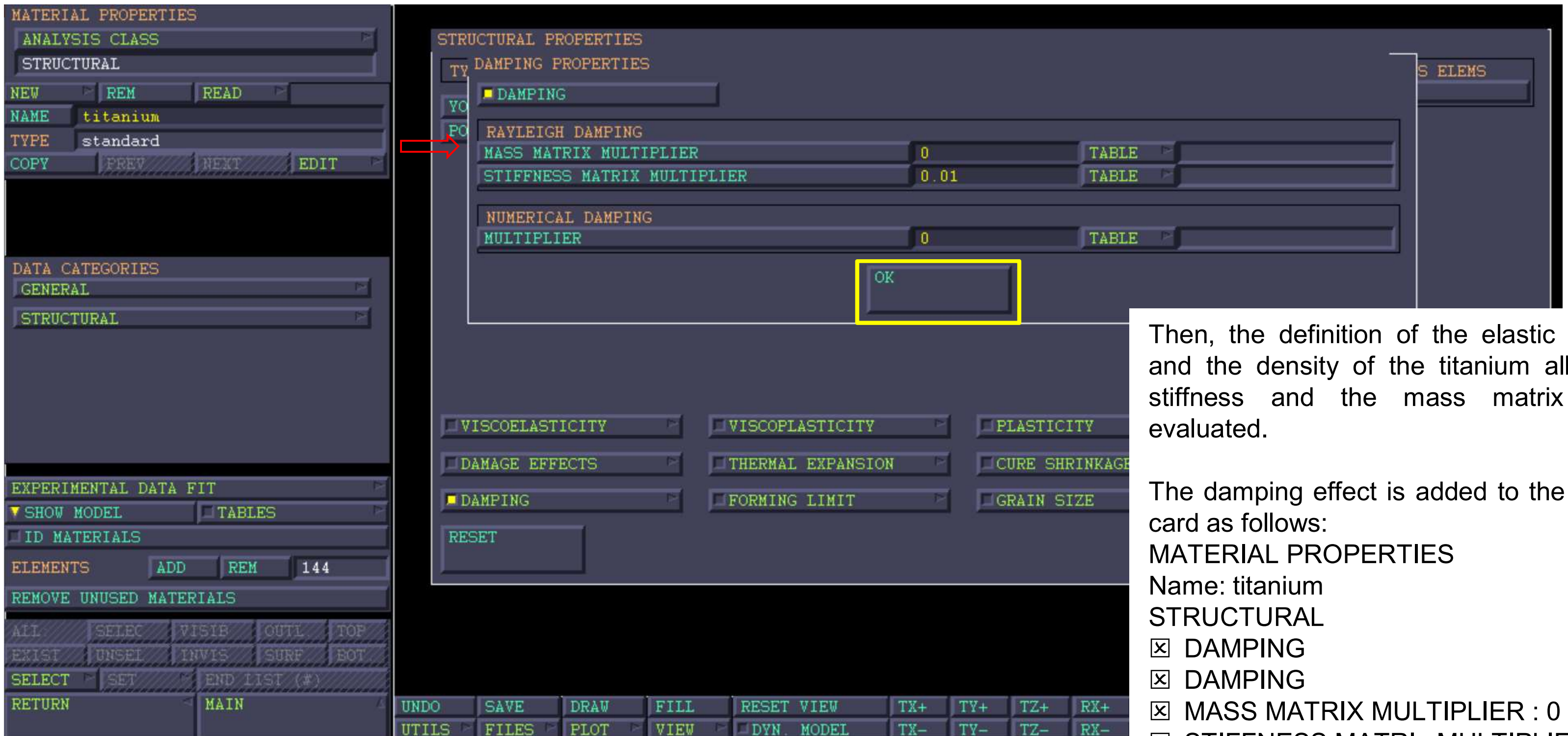


Then, the definition of the elastic constant and the density of the titanium allows the stiffness and the mass matrix to be evaluated.

The damping effect is added to the material card as follows:
MATERIAL PROPERTIES
Name: titanium
STRUCTURAL
☒ DAMPING

Material properties

Isotropic and homogeneous



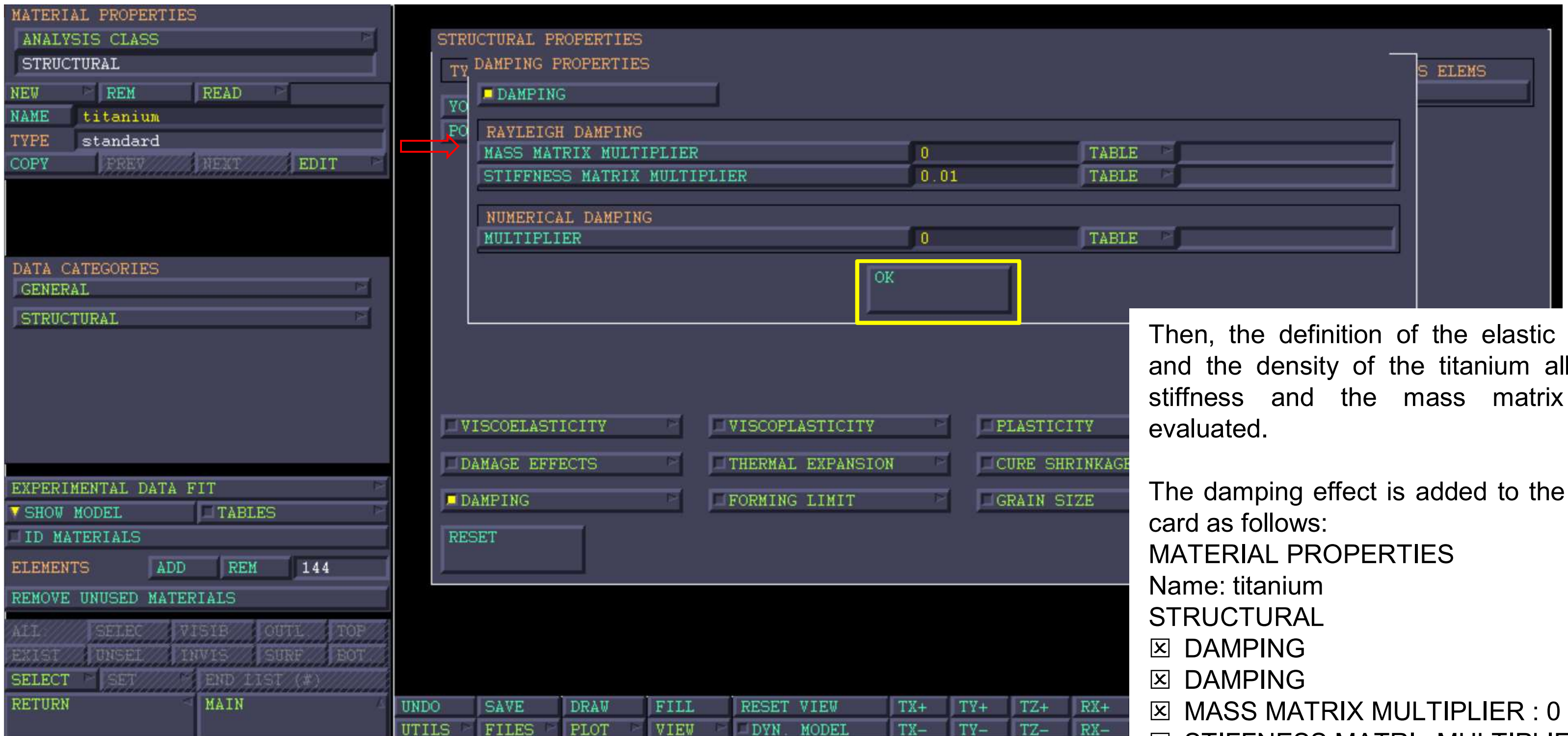
Then, the definition of the elastic constant and the density of the titanium allows the stiffness and the mass matrix to be evaluated.

The damping effect is added to the material card as follows:
MATERIAL PROPERTIES
Name: titanium
STRUCTURAL
☒ DAMPING
☒ DAMPING
☒ MASS MATRIX MULTIPLIER : 0
☒ STIFFNESS MATRIx MULTIPLIER : 0.01
OK

The damping effect is consider fraction of the crtically damper factor (ζ) adopting the Raileigh definition and assuming null the mass matrix multiplier (α) and equal to 1 per cent the stiffness matrix multiplier (β).

Material properties

Isotropic and homogeneous with damping



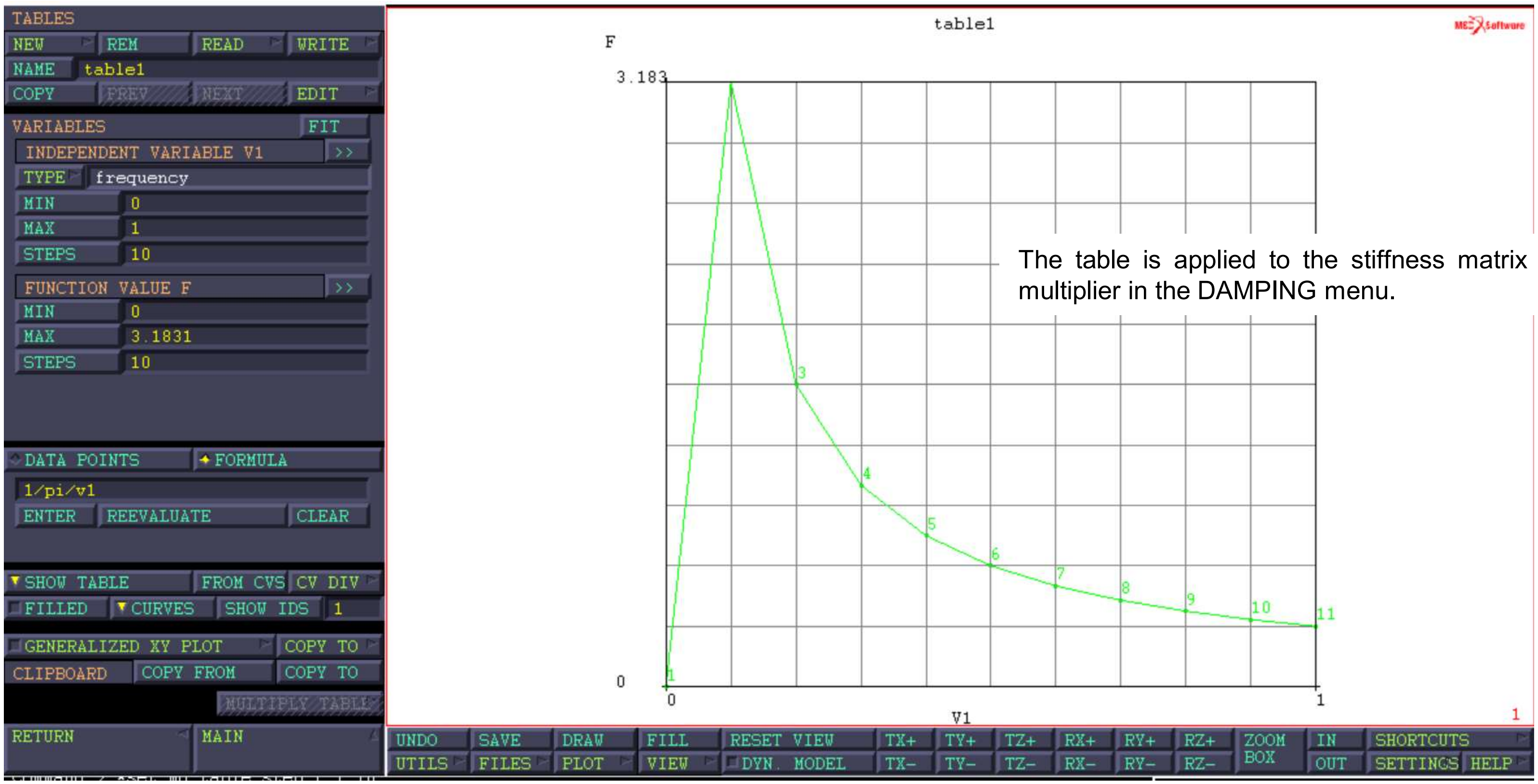
Then, the definition of the elastic constant and the density of the titanium allows the stiffness and the mass matrix to be evaluated.

The damping effect is added to the material card as follows:
MATERIAL PROPERTIES
Name: titanium
STRUCTURAL
☒ DAMPING
☒ DAMPING
☒ MASS MATRIX MULTIPLIER : 0
☒ STIFFNESS MATRIx MULTIPLIER : 0.01
OK

The damping effect is consider fraction of the crtically damper factor (ζ) adopting the Raileigh definition and assuming null the mass matrix multiplier (α) and equal to 1 per cent the stiffness matrix multiplier (β).

Material properties

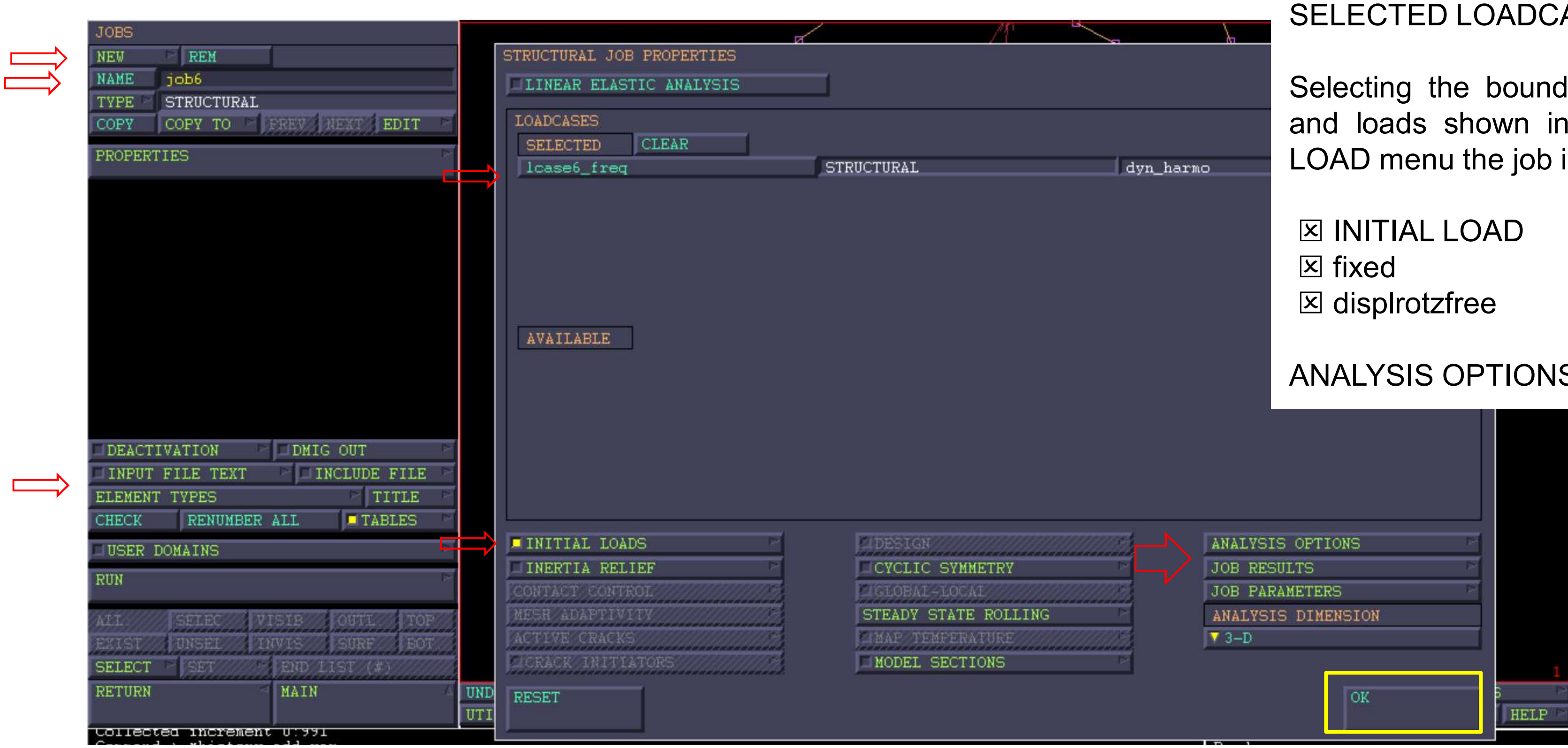
Isotropic and homogeneous with damping



The table is applied to the stiffness matrix multiplier in the DAMPING menu.

Jobs

Job results



JOBS
NEW
TYPE: STRUCTURAL
NAME: job2_fixed_fixed
PROPERTIES

The *lcase6_freq* must be updated from the AVAILABLE to the SELECTED LOADCASES option.

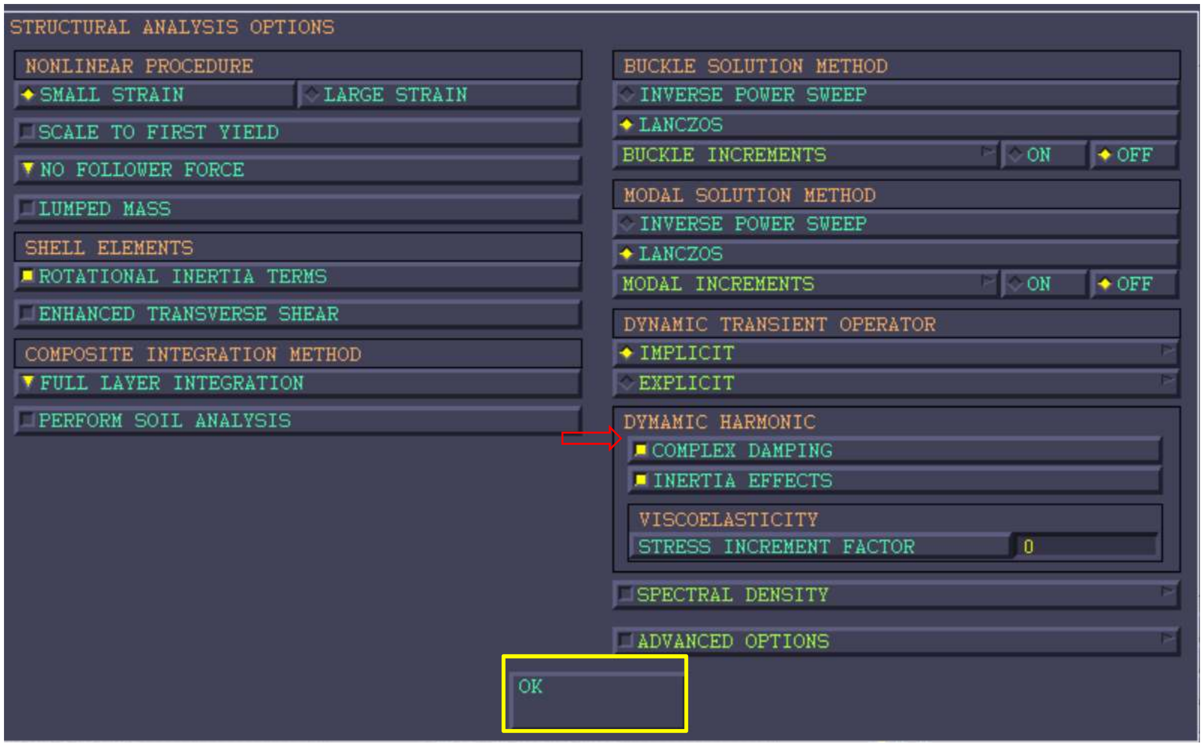
Selecting the boundary condition and loads shown in the INITIAL LOAD menu the job is defined.

☒ INITIAL LOAD
☒ fixed
☒ displrotzfree

ANALYSIS OPTIONS

Jobs

Job results



ANALYSIS OPTION
☒ COMPLEX DAMPING

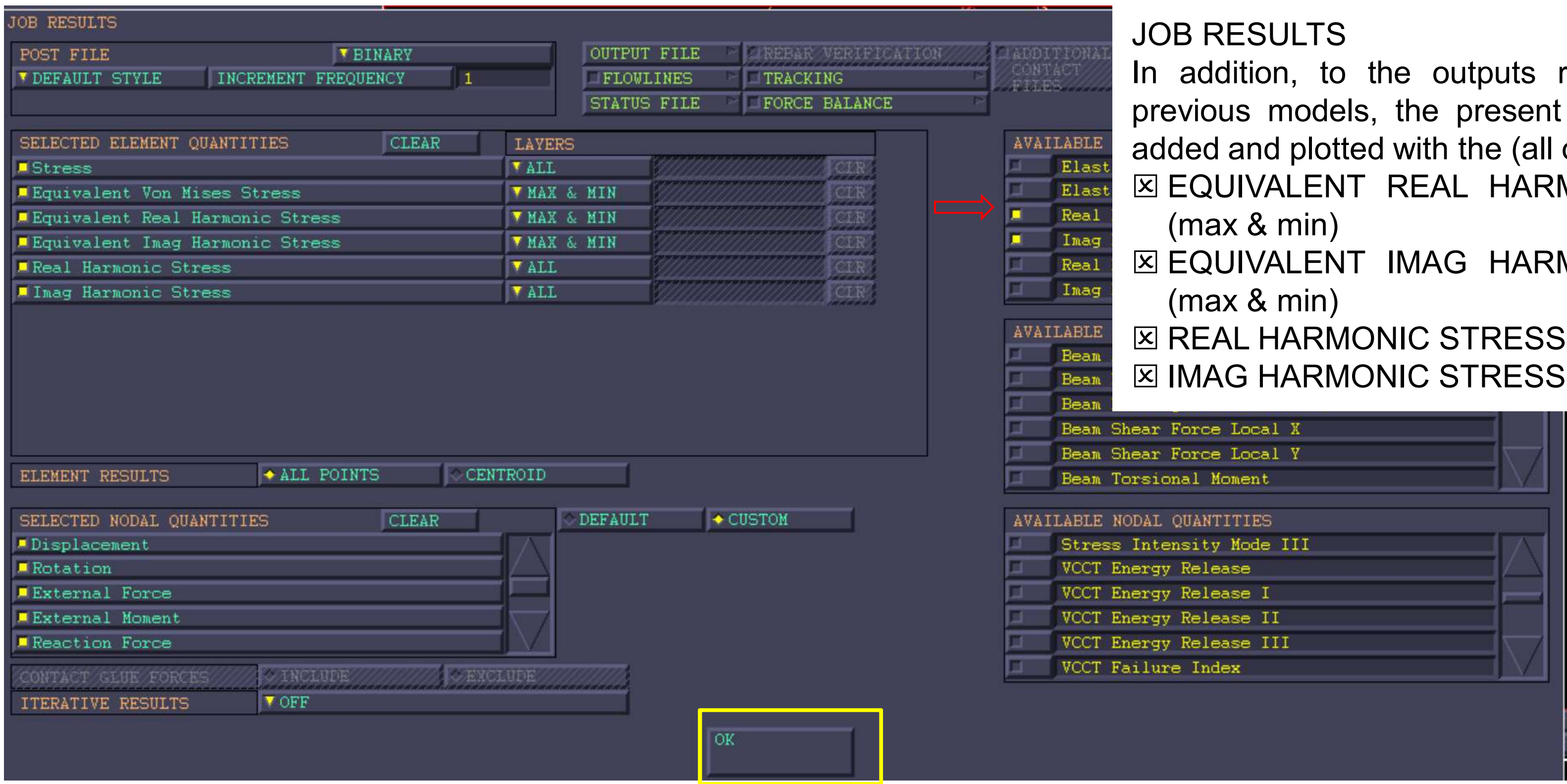
OK

We enable the complex damping effects in the solution of the dynamic problem.

JOB RESULTS .

Jobs

Job results



ANALYSIS OPTION
☒ COMPLEX DAMPING

OK

We enable the complex damping effects in the solution of the dynamic problem.

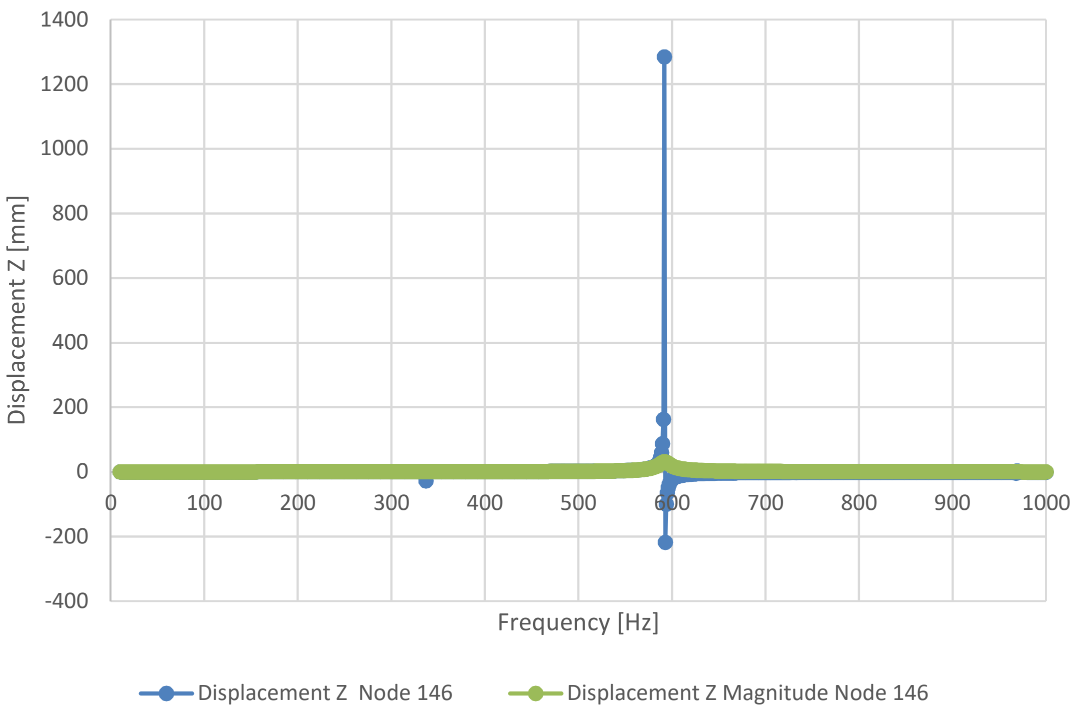
JOB RESULTS
In addition, to the outputs requested in the previous models, the present results must be added and plotted with the (all or max & min):

☒ EQUIVALENT REAL HARMONIC STRESS (max & min)
☒ EQUIVALENT IMAG HARMONIC STRESS (max & min)
☒ REAL HARMONIC STRESS (all)
☒ IMAG HARMONIC STRESS (all)

Results

Frequency responce: Hystory plot

The automatic collection of the frequencies of the coil (#991 frequencies) can be done by using HYSTORY PLOT option. These data can usually exported to make the post-processing in a Spreadsheet file, *e.g.* .xls, .xlsx, .ods, … files. The node of interest is the 146 node, and the displacement Z is plotted on the frequency range under investigation [10-1000] Hz.



Without damping

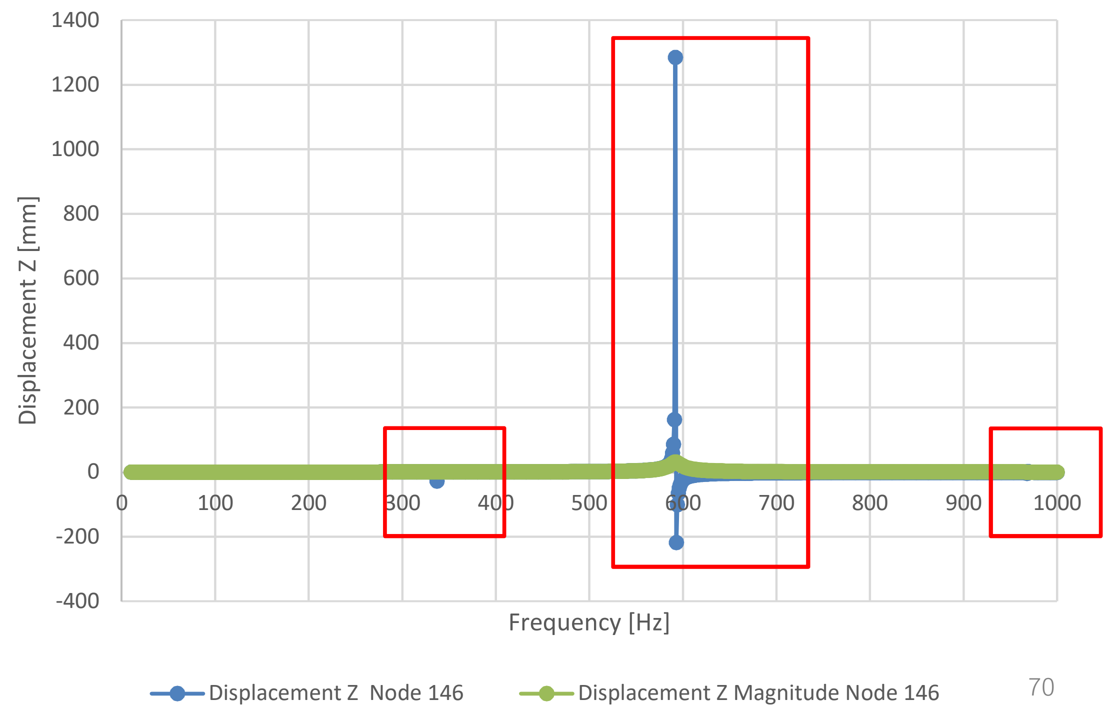
With damping

Results

Frequency responce: Hystory plot

At the natural frequencies collected by the modal analysis (*3_modal_fixed_rotzfree.mud*), the frequency responce analysis evidences a fluctuation of the Z-displacement in sign.
Comparing the two models that consider or neglect the damping, the frequency responce amplitude becomes finite, *e.g.* at 592 Hz the peak is 31.5 Hz (see Excel file).
Considering damping the #3 and #4 natural modes collected in the model *3_modal_fixed_rotzfree.mud* are covered by the #2 mode. The damping affects the frequency responce by mitigating some peaks.

3_modal_fixed_rotzfree.mud	
Sub Increment	Frequency
1	337.0
2	592.1
3	726.4
4	732.6
5	968.5



Without damping With damping

Agenda

Goal and nomenclature

Mesh generation

Modal Analysis loadcases varying the BCs:

- Free-free
- Fixed-fixed
- Fixed-axial rotation free
- Fixed-axial displacement and rotation free

Harmonic loadcases:

- Neglecting damping effect
- Considering damping effect

References

References

Books:
Garro A. Progettazione strutturale del motore, Levrotto & Bella, Torino, 1992. pp. 464-465
Gugliotta A. Elementi Finiti, progetto didattica in rete, Otto Editore, 2002. parte IV

FE models and procedures:
mesh_geom_mat_link.mud (.proc)
→ Using the present .proc the starting model is defined and recalled for setting the further analyses.

For modal analysis:
1_modal_free_free.mud (.proc)
2_modal_fixed_fixed.mud (.proc)
3_modal_fixed_rotzfree.mud (.proc)
4_modal_fixed_displrotzfree.mud (.proc)

For frequency responce analysis:
5_freq_fixed_displrotzfree.mud (.proc)
6_freq_fixed_displrotzfree_damping.mud (.proc)

Excel file:
modal_frequency_analysis_coil.xlsx
→ post-processing result

References

Video:

Engine valve distribution
https://vehiclecue.it/fasatura-variabile-descrizione-e-funzionamento/9552/

Bridge
https://www.youtube.com/watch?reload=9&v=3mclp9QmCGs

Helicopter
https://www.youtube.com/watch?v=-LFLV47VAbI