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CADFEM CONFERENCE RAPPERSWIL 2024

Combining PyANSYS and APDL to optimize the dynamic behavior of large electric motors using the NSGA-II algorithm

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Optimization of large electric motors using the NSGA-II algorithm

Topics

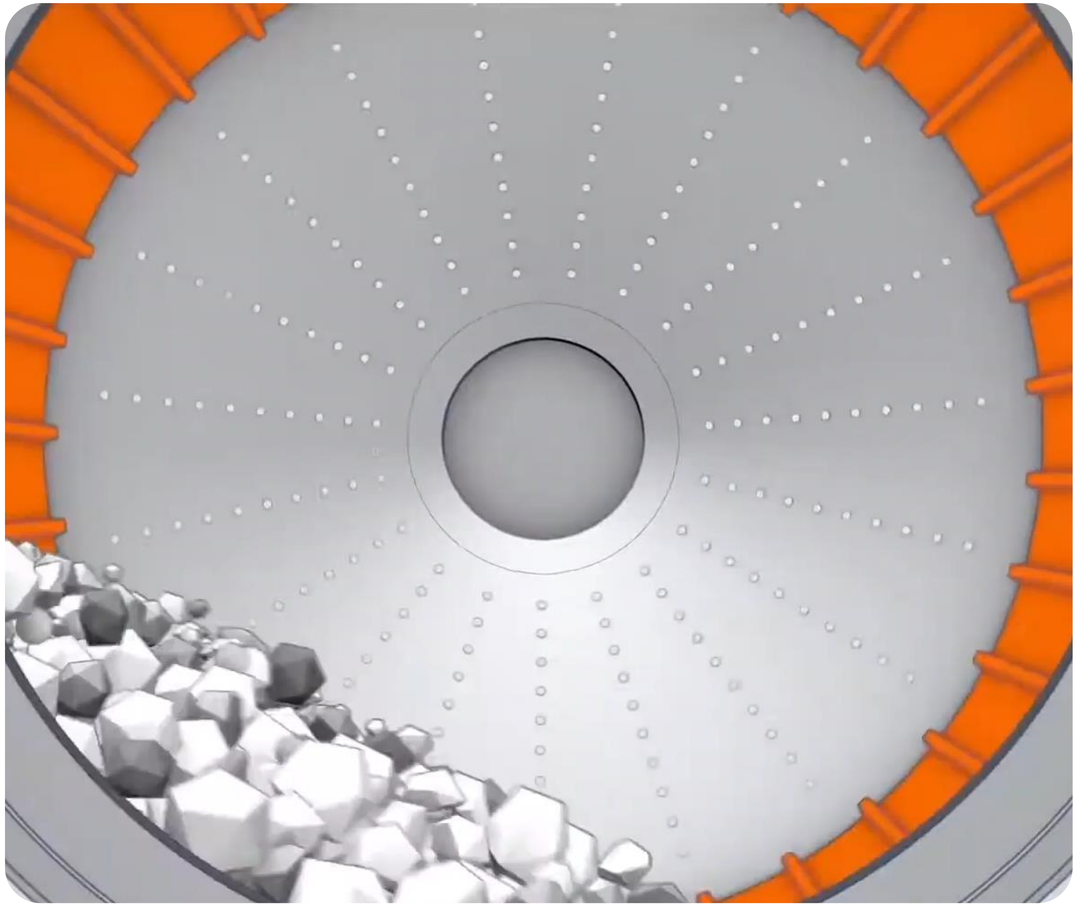
- ❑ What is a Gearless Mill Drive (GMD)?
- ❑ What is typically modeled in ANSYS?
- ❑ Current state-of-the-art APDL macros
- ❑ Optimization of ring motor for GMD
- ❑ Non-dominated Sorting Genetic Algorithm – NSGA-II
- ❑ Example of optimization parameters and goals
- ❑ Implementation using PyMAPDL
- ❑ Outcome of the optimization process
- ❑ Future PyMAPDL implementation tasks

ABB

Optimization of large electric motors using the NSGA-II algorithm

What is a Gearless Mill Drive (GMD)?

- ❑ A rotating mill drum throws larger rocks of ore in a cascading motion which causes impact breakage of larger rocks
- ❑ Rotor poles wrapped around mill drum using the drum as a rotor which is held by bearings at both ends.
- ❑ Stator core held by motor frame which is fixed to concreate foundation.
- ❑ Ring motor for GMD:
  - Power up to approx. 28 MW.
  - Bore diameter up to approx. 15 m.
  - Up to 70+ poles each of which weighs approx. 4 tons.



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What is typically modeled in ANSYS?

- ❑ Static structural analysis
  - – Magnetic forces
  - – Gravity
  - – Thermal expansion
  - – Soil properties
- ❑ Modal analysis
- ❑ Harmonic analysis
- ❑ Seismic analysis
- ❑ Thermal analysis
- ❑ Transient structural analysis

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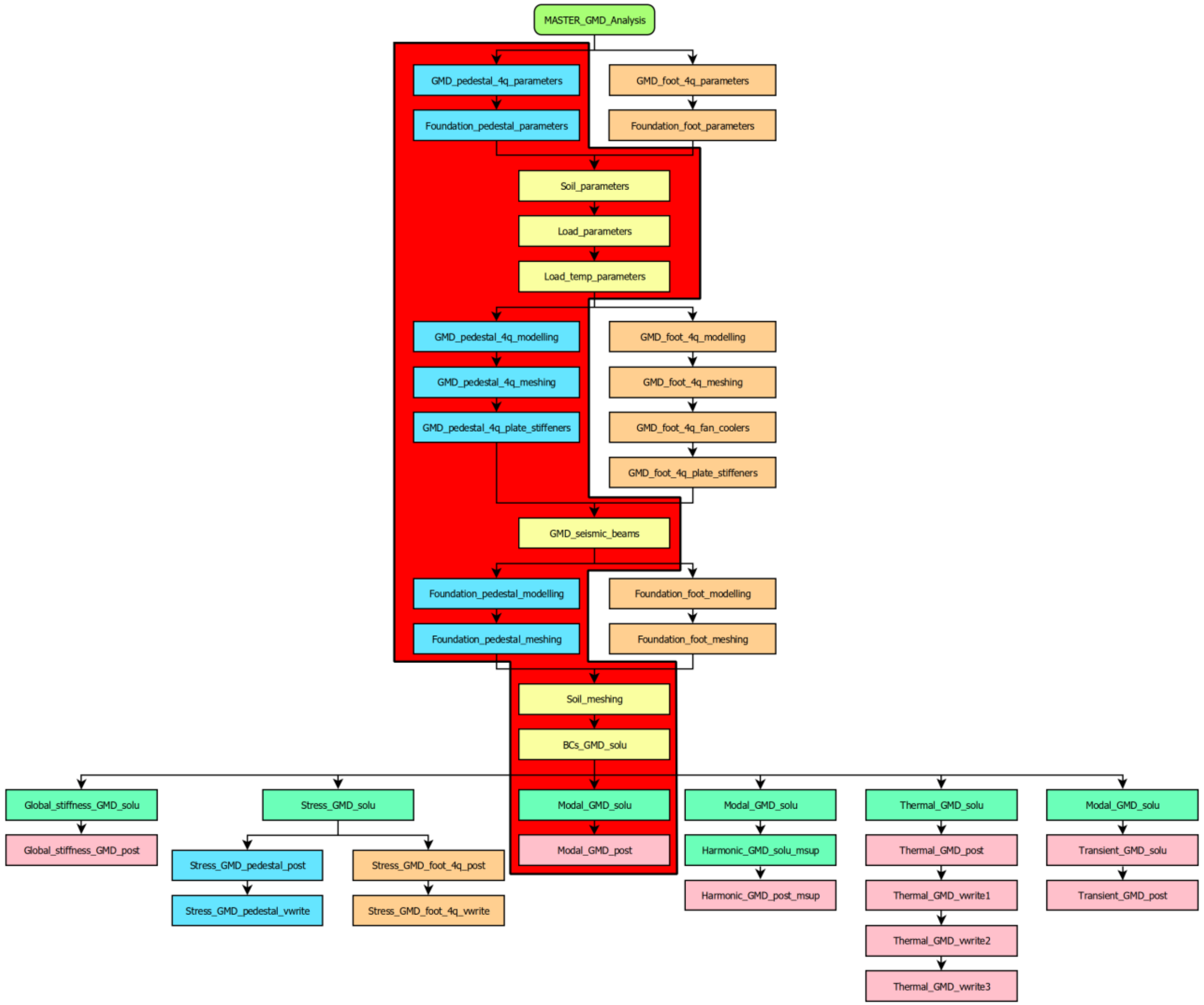

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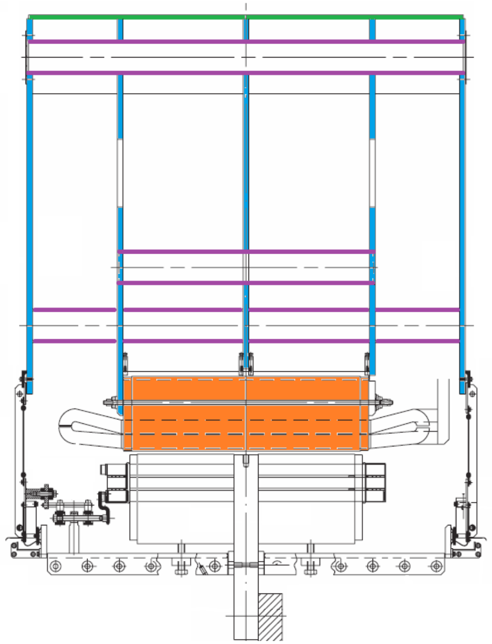
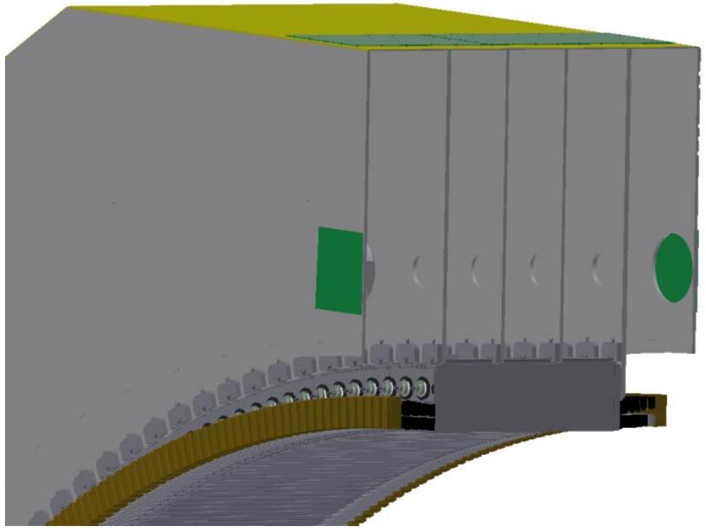
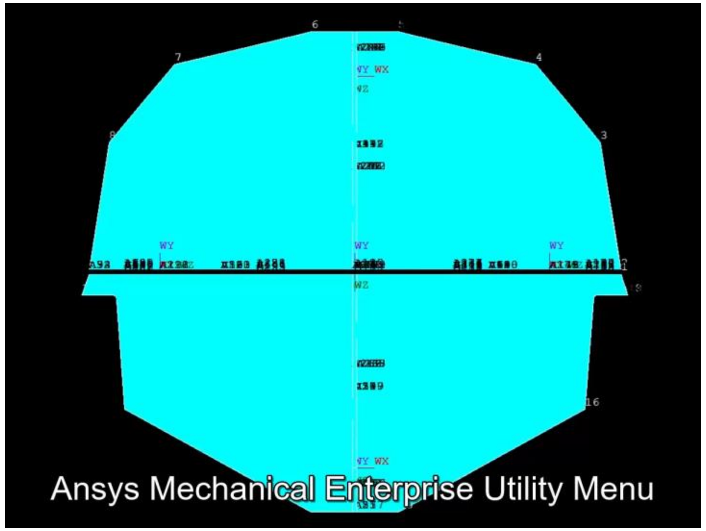
Current state-of-the-art APDL macros

Extent of model:

- ❑ Frame
  - 5 or 6 plates spaced in axial direction
  - Multiple perimeter plates
  - Multiple internal stiffener tubes and plates
- ❑ Stator
  - 4 solid ring quarters attached to internal frame plates through key bar connections
- ❑ Foundation
  - One solid block with soil springs and which carry the frame







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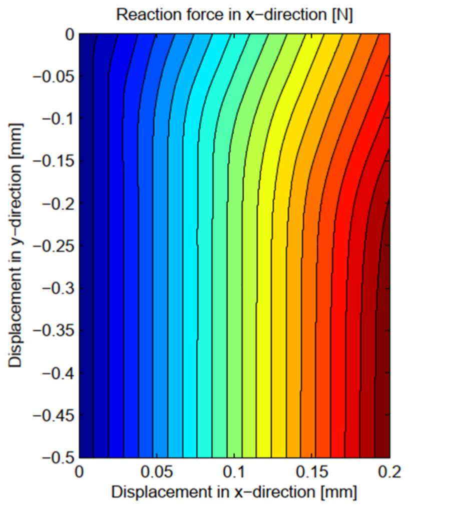
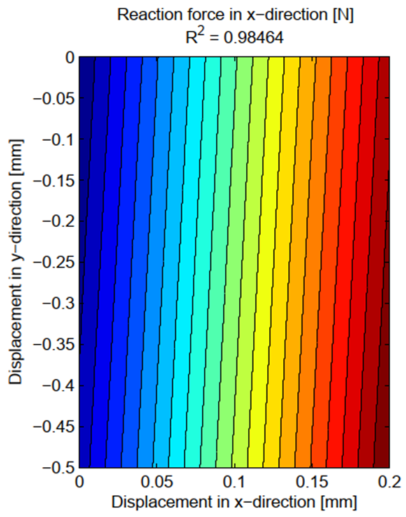
Current state-of-the-art APDL macros

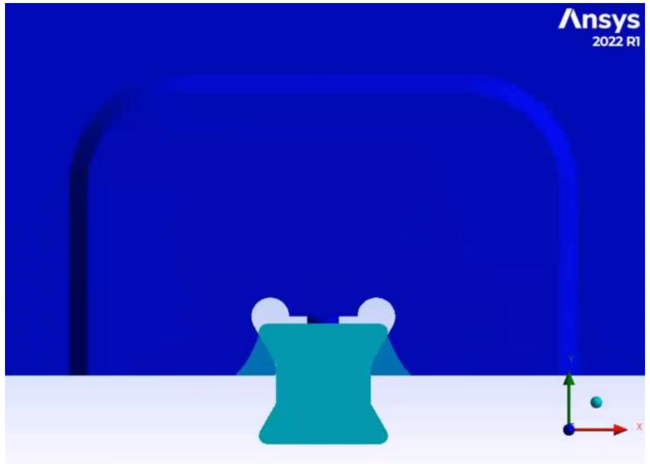
- ❑ Characterization of core to frame connection.
- ❑ Spring stiffness matrix based on static models.
- ❑ Element types:
  - Frame plates (shell181)
  - Core and foundation (solid185)
  - Key bar connection and magnetic pull (combin14)



Reaction force in x-direction - ANSYS values



Reaction force in x-direction - Least square best fit



$$\begin{bmatrix} K_{xx} & K_{yx} \\ K_{xy} & K_{yy} \\ K_{xz} & K_{yz} \\ K_{x\theta} & K_{y\theta} \\ K_{x\phi} & K_{y\phi} \\ K_{x\psi} & K_{y\psi} \end{bmatrix} \cdot \begin{Bmatrix} x \\ y \end{Bmatrix} = \begin{Bmatrix} F_x \\ F_y \\ F_z \\ M_\theta \\ M_\phi \\ M_\psi \end{Bmatrix}$$

Optimization of large electric motors using the NSGA-II algorithm

Optimization of ring motor for GMD

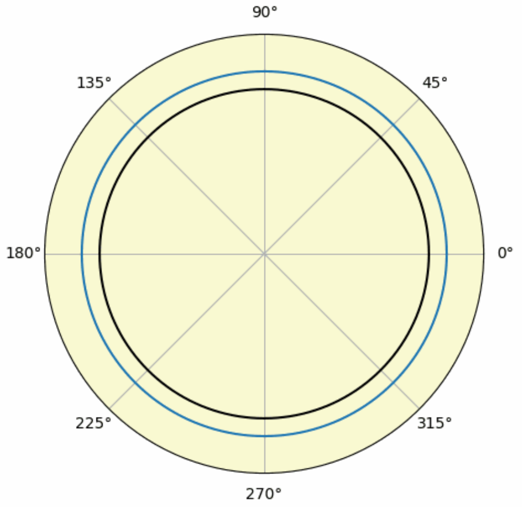
Mode shapes of the core can be represented as a superposition of modes of a perfect circle (here called R spatial orders).

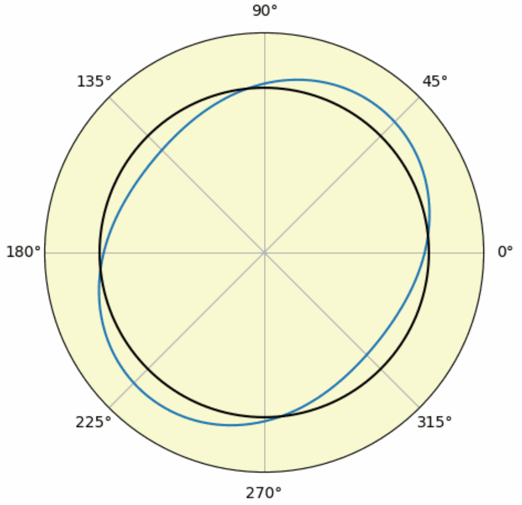
The optimization goals could be individual R spatial orders:

- ❑ Increase frequency of R0 breathing (top right)
- ❑ Increase frequency of R2 4-node (bottom right)

Why are these goals important?

- ❑ Distort the air gap
- ❑ Easier to excite





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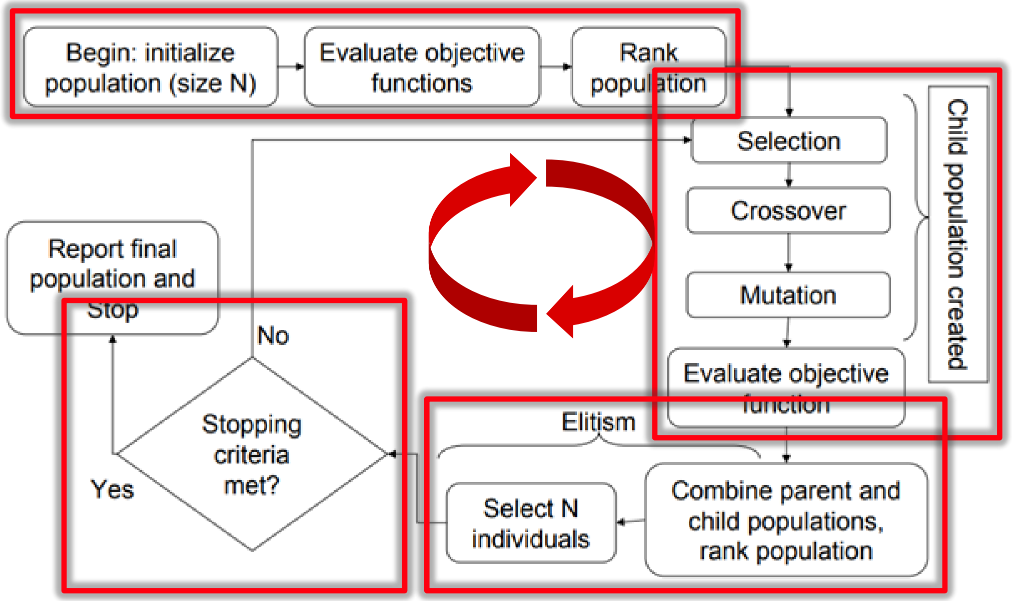
Non-dominated Sorting Genetic Algorithm – NSGA-II

- ❑ NSGA-II belongs to the metaheuristics optimization algorithms
- ❑ What are the pros and cons?
  - – Good for problems which are too large or too complex for traditional methods
  - – Easy to implement
  - – Can be computationally expensive
  - – May not always find the best solution
- ❑ Single and multi objective algorithms (goals)



IEEE : *A Fast and Elitist Multiobjective Genetic Algorithm: NSGA-II*

Optimization of large electric motors using the NSGA-II algorithm

Example of optimization parameters and goals

Objective parameters (variables):

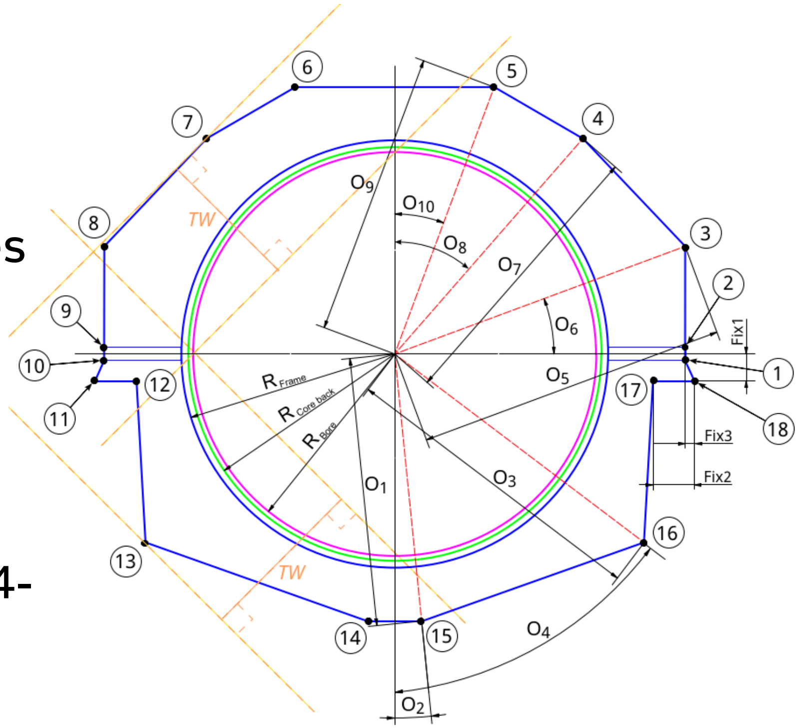
- ❑ 10 geometry parameters defining the 18 nodes which define the perimeter of the stator frame.
- ❑ 10 geometry parameters defining the thicknesses of the frame plates.

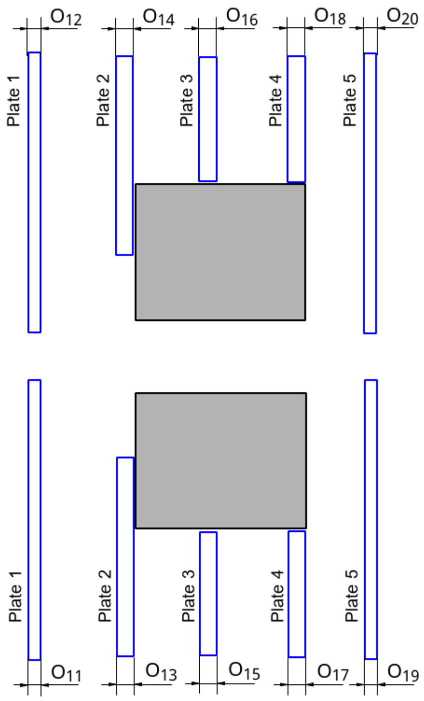
Objectives (goals):

- ❑ Maximization of the frequency @ max. R0 peak (breathing spatial order)
- ❑ Maximization of the frequency @ max. R2 peak (4-node spatial order)

Constrains:

- ❑ Transport width (TW) can't exceed TW of ref. motor
- ❑ Total mass can't exceed total mass of ref. motor





Optimization of large electric motors using the NSGA-II algorithm

The Python code – General structure

- ❑ Using pyMAPDL Python site package.
- ❑ Using NSGA-II algorithm from pymoo Python site package.
- ❑ Python (NSGA-II) send objective parameters (geometric parameters) to ANSYS using pyMAPDL interface.

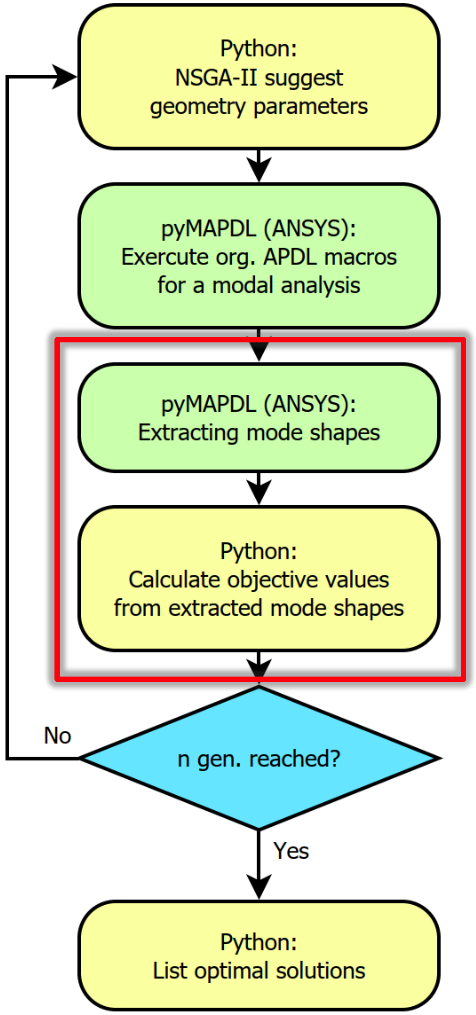
```
mapdl.parameters['st_frame_perimeter'] = st_frame_perimeter
```

- ❑ Python execute the original APDL macros for a modal analysis in non-interactive mode using pyMAPDL interface.

```
with mapdl.non_interactive:
    mapdl.run("/input,00001_220510_GMD_pedestal_4q_parameters,txt")
```

- ❑ Python is extracting results from ANSYS for post-processing using pyMAPDL interface.

```
for i in range(post_modes_total_num):
    mapdl.set(1, i + 1)
    mapdl.rsys(1)
    ux[i, :] = mapdl.get_array("NODE", "", "U", "X")[sc_pilot_node_rpole_num - 1]
```



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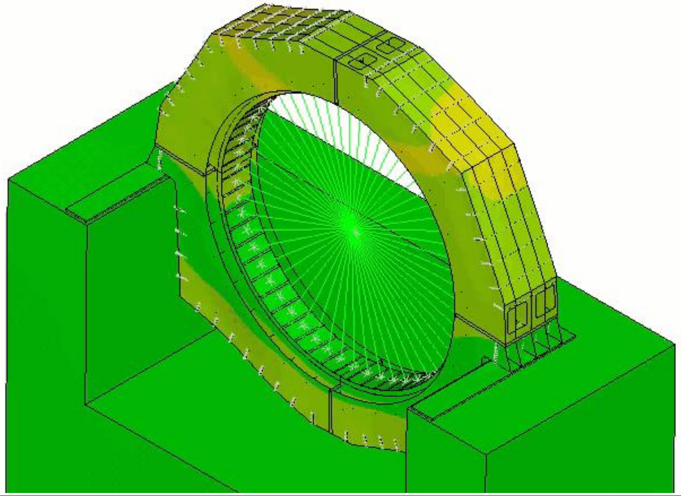
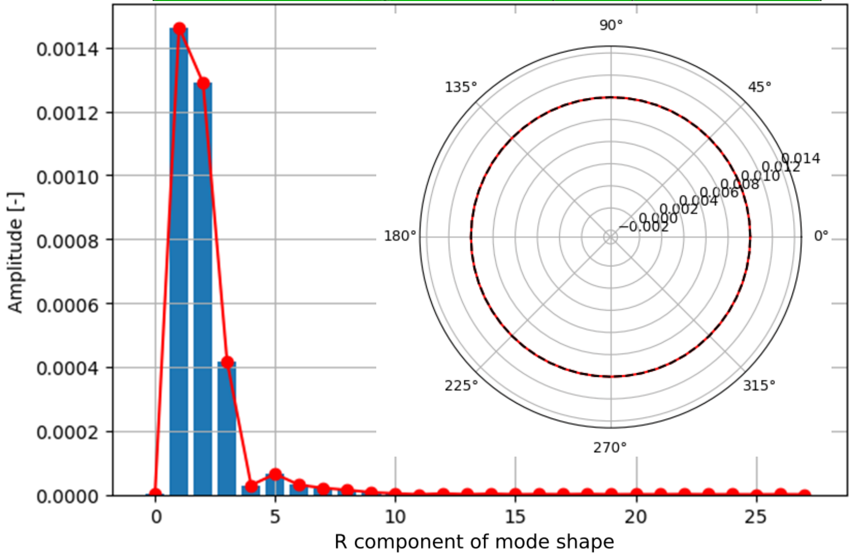
The Python code – Fitness values (goals)

- ❑ Post-processing of modal results.
- ❑ Extracting radial displacement around bore diameter for each natural frequency of the modal model.
- ❑ Perform FFT on the extracted displacements for each mode.
- ❑ Determine the frequency of the highest R0 and R2 spatial orders peak from the FFTs (the two optimization goals).





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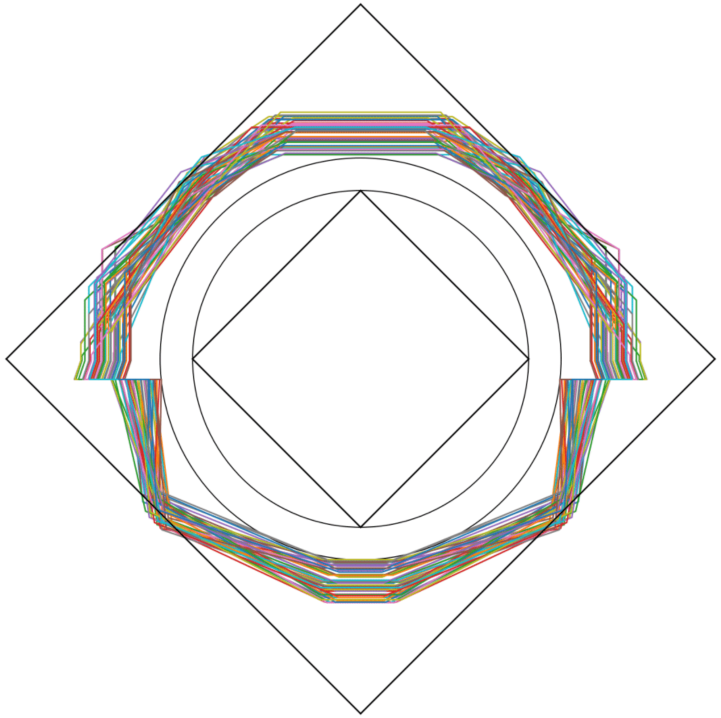
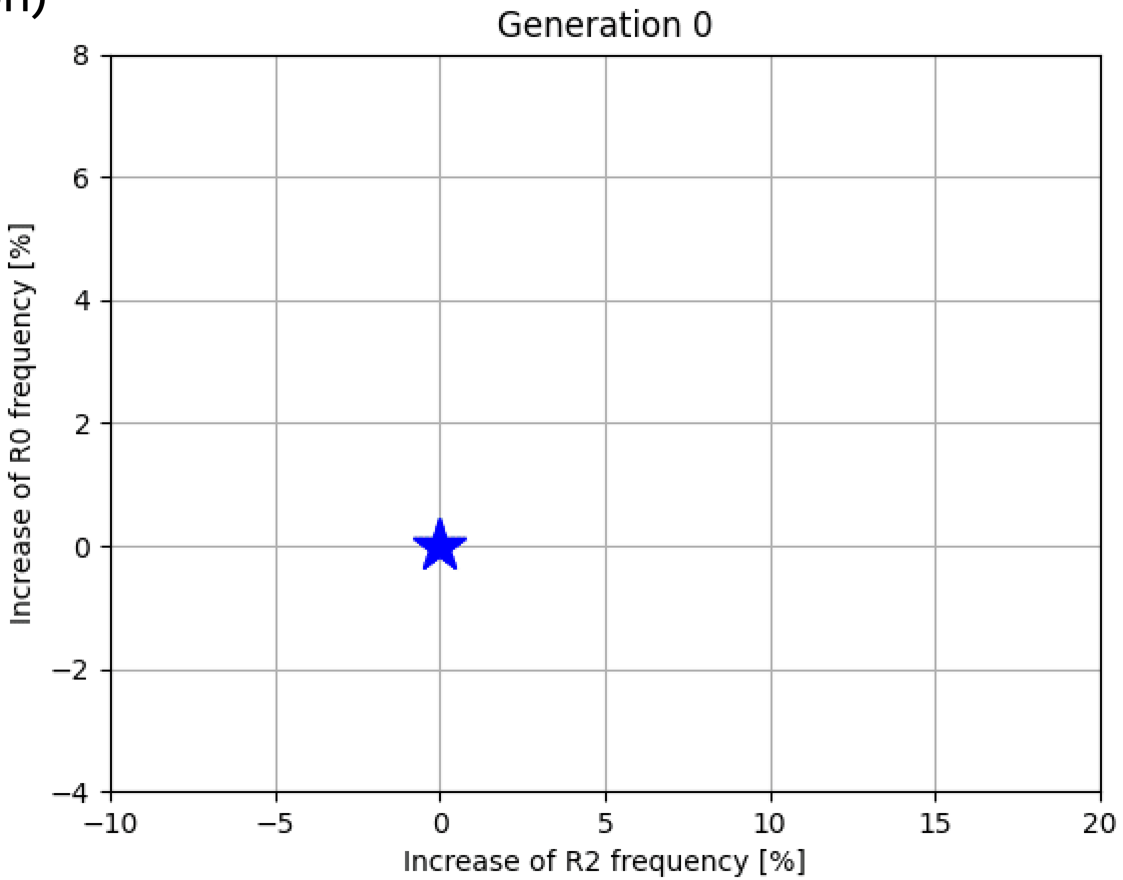
Optimization evolution

- ❑ Population size = 50 (no. of solutions per iteration)
- ❑ No. generations = 75 (no. of iterations)
- ❑ Total calculated models = 50 x 75 = 3750





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Outcome of the optimization process

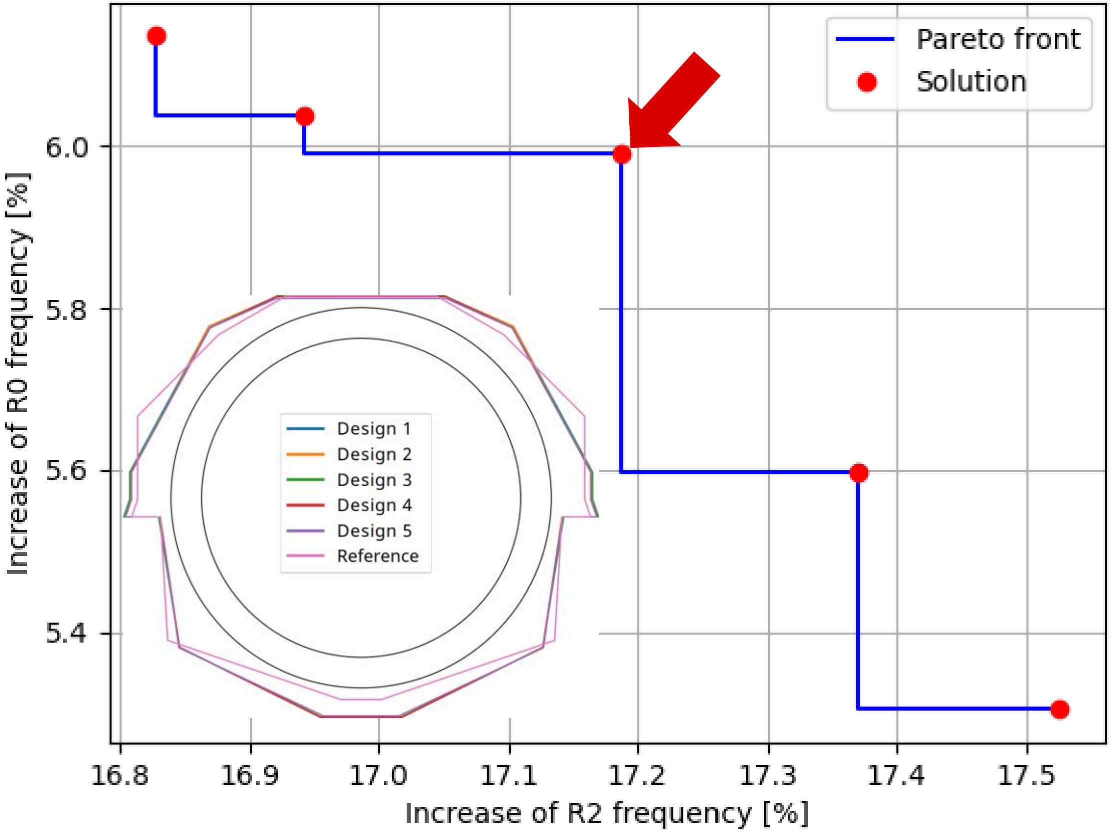
In this example, the two goals are not that conflicting as the optimization converged to more or less one solution.

The found optimal designs increased the frequency of:

- ❑ The R2 peak by 16.8% to 17.5%
- ❑ The R0 peak by 5.3% to 6.1%

compared to the reference ring motor.

It is up to the designer to decide which of the optimal solutions has the best trade off between the two conflicting goals.



ABB

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Future PyMAPDL implementation tasks

What has been shown here is just one of the benefits of being able to combine Python and ANSYS in order to create more complex analysis which could not easily have been achieved in either tool on its own. Another benefit is the ability to wrap a Python GUI around the previously mentioned APDL macros thereby creating a customized design tool for more automated calculation processes of components, in this case a ring motor for gearless mill drives.

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Questions

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