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Fast multi-material discrete topology optimization for the design of electrical machines

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Abstract

This work presents a finite element analysis-based, discrete multi-material topology optimization (TO) methodology for the design of electrical machine cores. Our methodology is based on the Bi-directional Evolutionary Structural Optimization (BESO). The magnetization amplitude can be considered as a discrete variable, we propose to deduce magnetization direction \vec{M} from the distributed flux field lines in the rotor, such as it is normal to its direction. The proposed methodology improves the average torque density while formulating cost function on calculated energy difference in the d-axis (W_d) and q-axis (W_q).

Optimization Problem

The problem $P1$ is initially formulated to increase the saliency of a synchro-reluctant motor. Then it is completed by a second one $P2$ to distribute magnets in the established flux barriers.

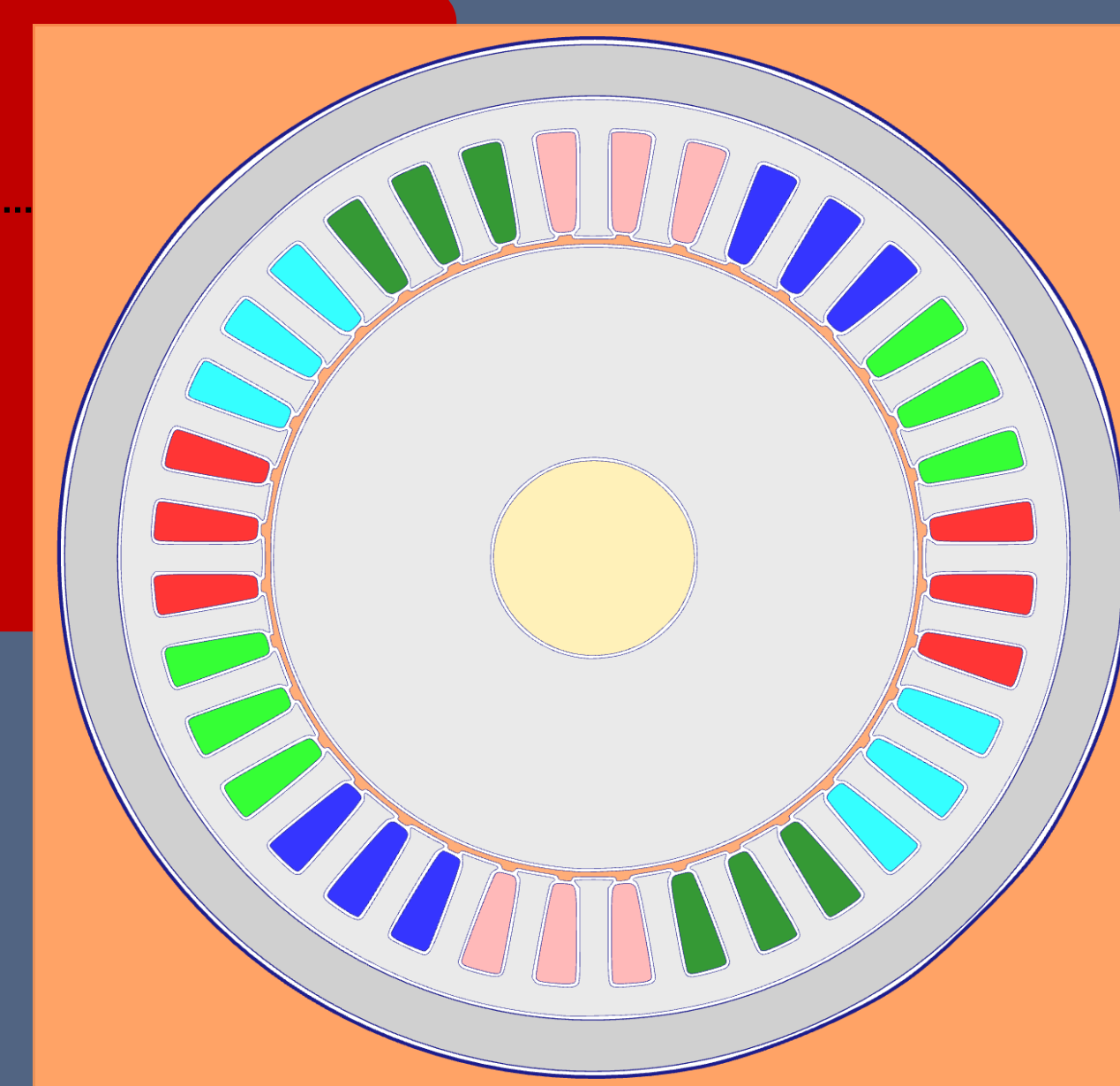
$$P1 \begin{cases} \max_x 1 - W_q/W_d \\ S.t \\ \sum_{i=1}^{N_e} x_i \cdot v_i = V_{iron} \end{cases} \quad P2 \begin{cases} \max_x 1 - W_q/W_d \\ S.t \\ \sum_{j=1}^{N_m} x_j \cdot v_j = V_{magnets} \end{cases}$$

Magnetostatic Problem

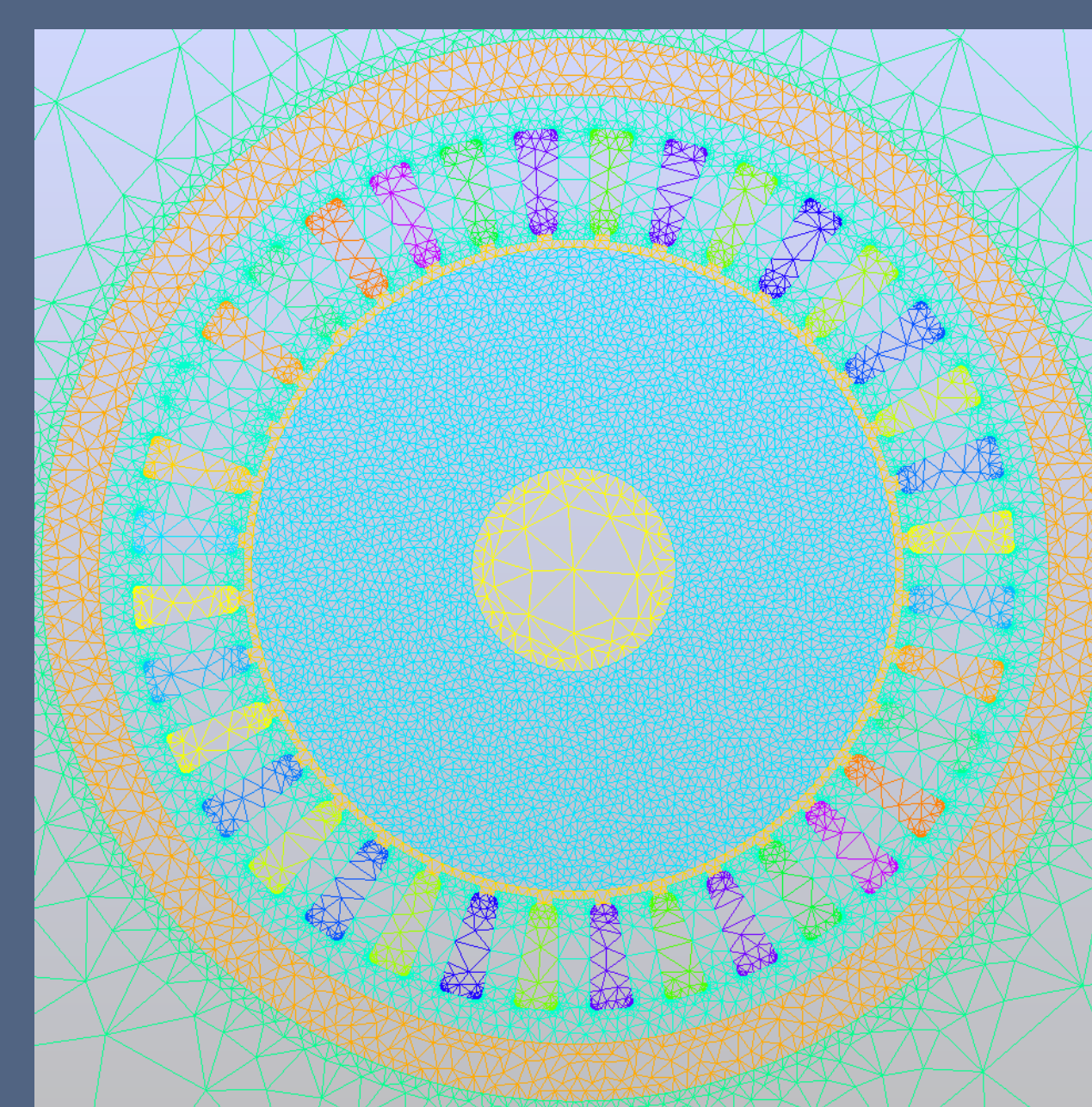
The magnetostatic problem is solved on Matlab. mesh is generated in 2D via Gmsh.

The problem is given by :

$$-\nabla \cdot (\nu \nabla A_z) = J_z + \nabla \cdot \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \cdot M$$



A+
C-
B+
A-
C+
B-



Adapted BESO Algorithm

Discretize domain using Gmsh. Initialize the domain with no material

Determine Energy values in d and q axis by element. Calculate the objective function .

Proposed Modified BESO

$$N_{add} = A_{prec} \cdot fac_{add} \cdot Ratio \cdot N_e$$

$$N_{remove} = R_{prec} \cdot Ratio \cdot N_e$$

$$Ratio = \left| \frac{\left(\sum_{i=1}^{N_e} x_i \cdot v_i \right) - V_{iron}}{V_{iron}} \right|$$

Ratio $\neq 0$

N_{add} : Number of added elements

$N_{removed}$: Number of removed elements

A_{prec} : Adding precision

R_{prec} : Removing precision

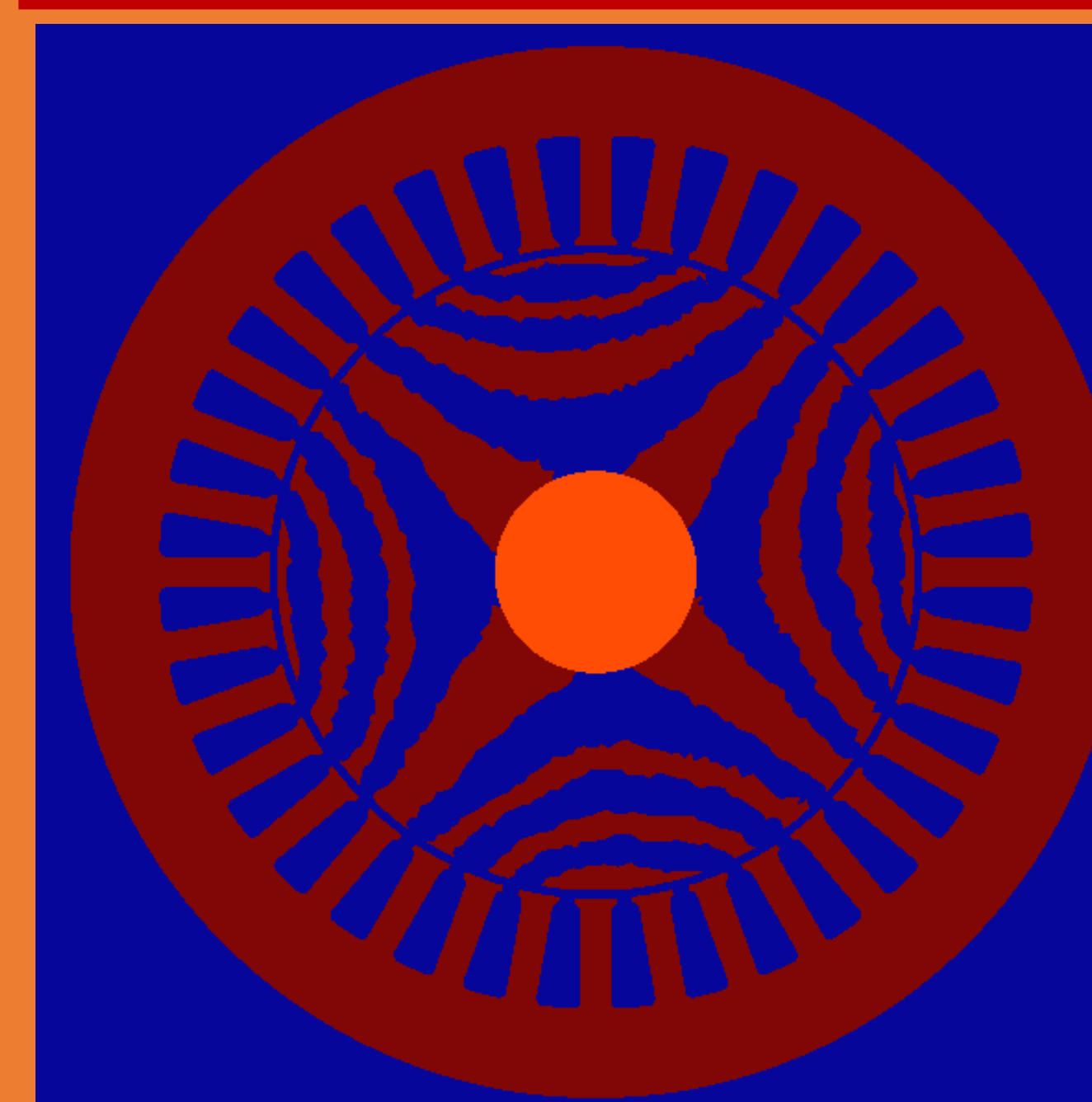
N_e : Number of elements

N_m : Number of elements in the flux barriers

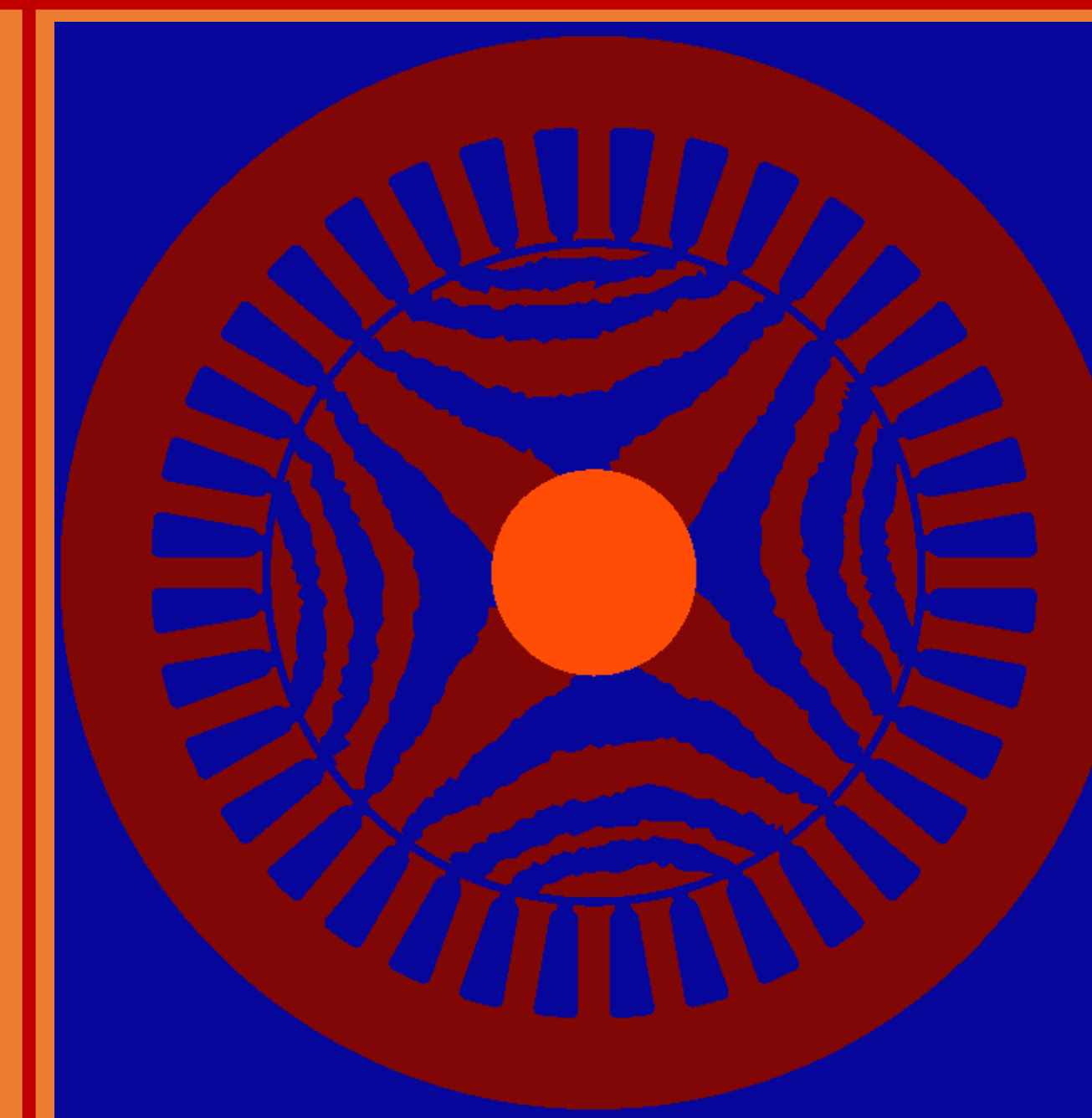
v_i, v_j : Elementary volumes

Results

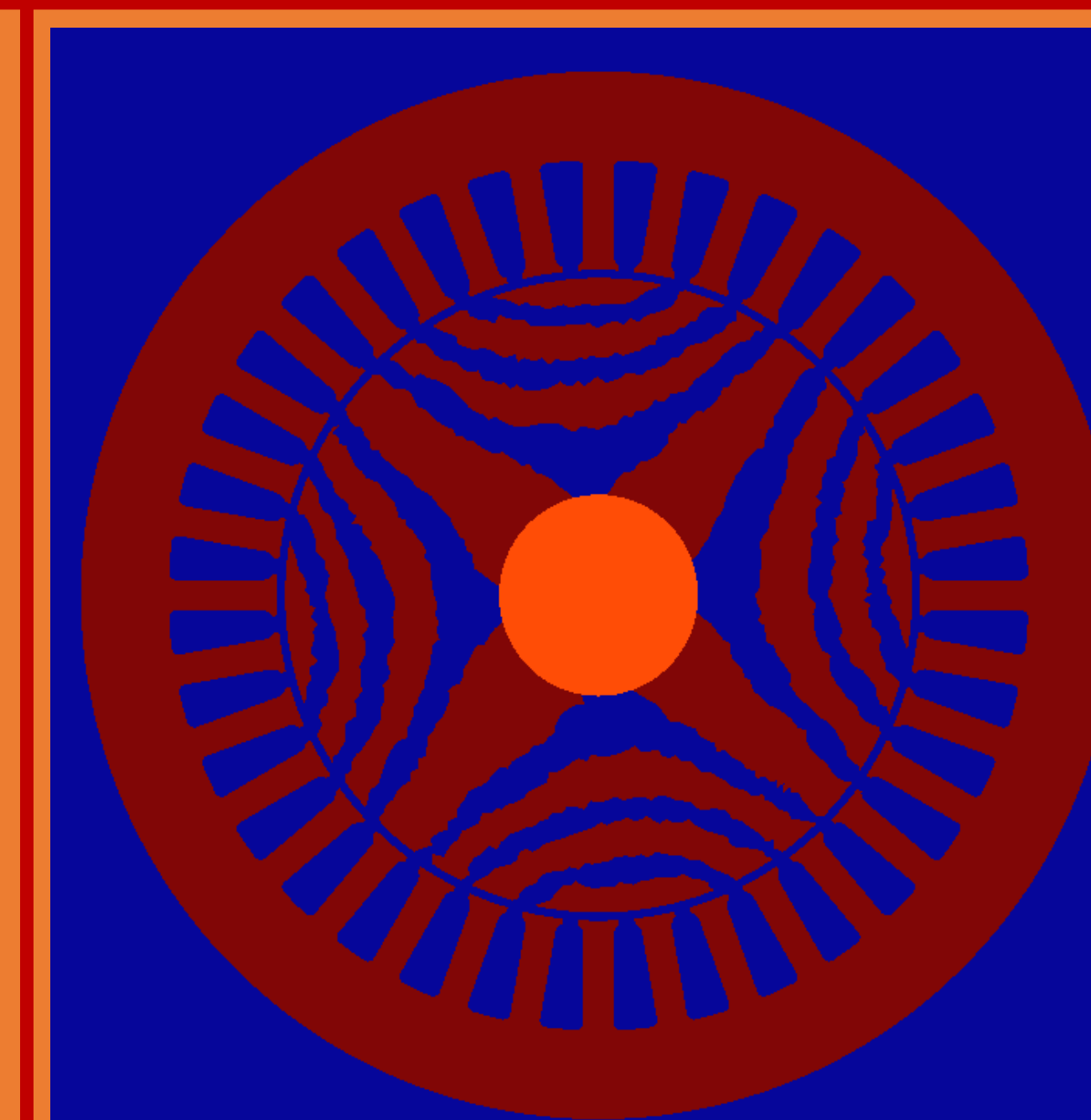
40% iron



50% iron



60% iron



The number of elements in the rotor is **8642**. The convergence is different for each volume. For 60% of iron, the number of iteration is equal to 1000, and the total time is **12min**

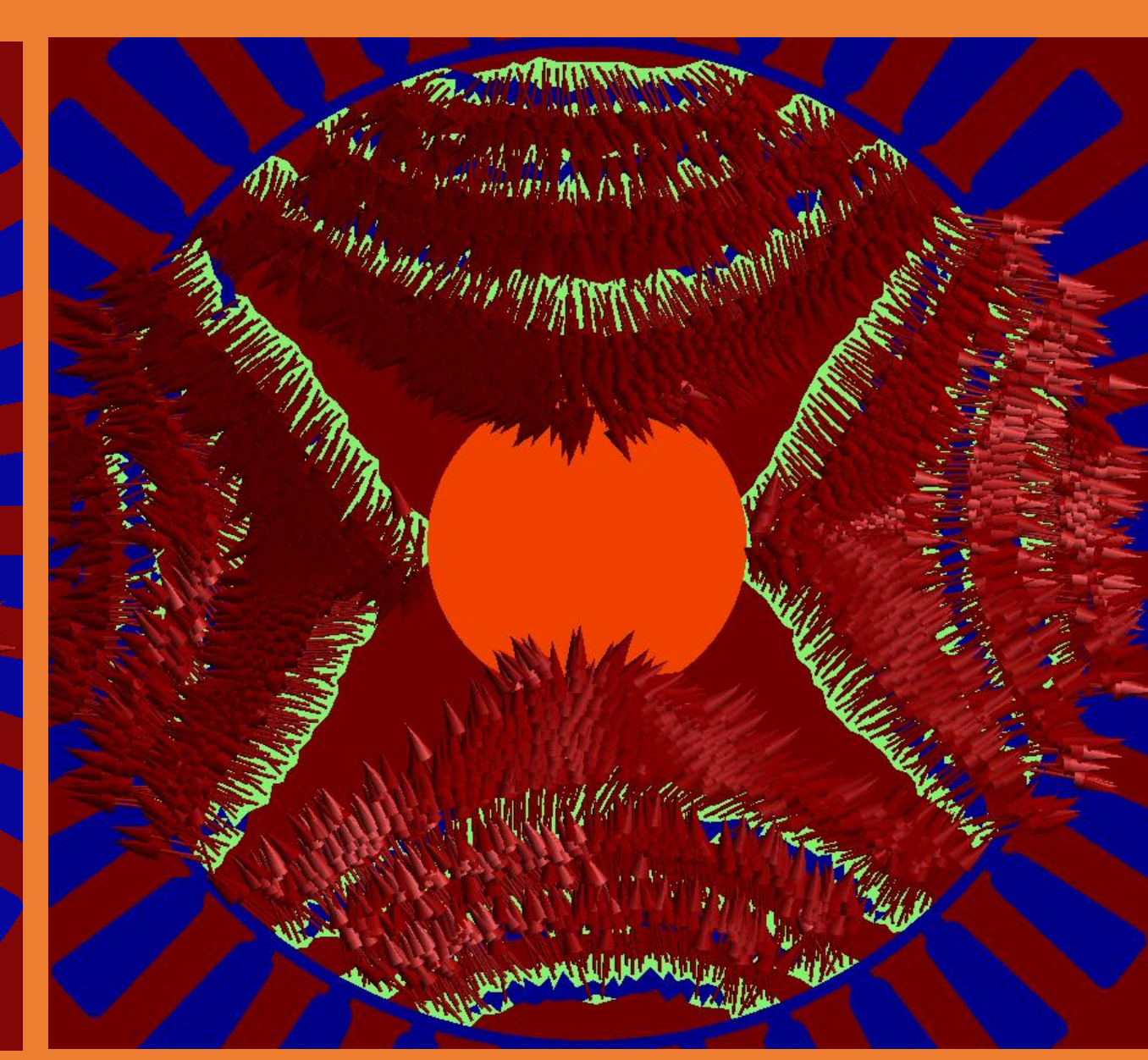
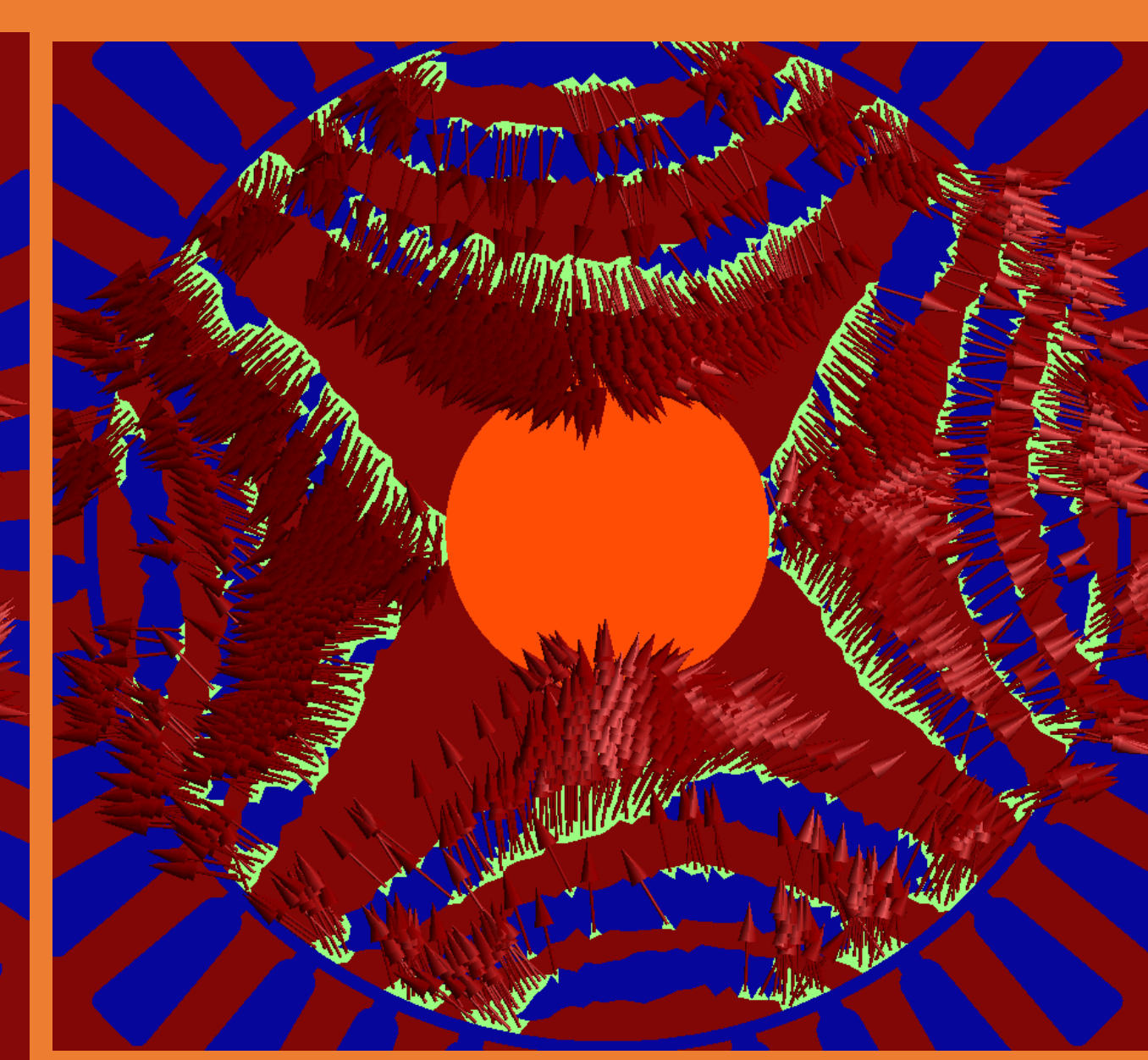
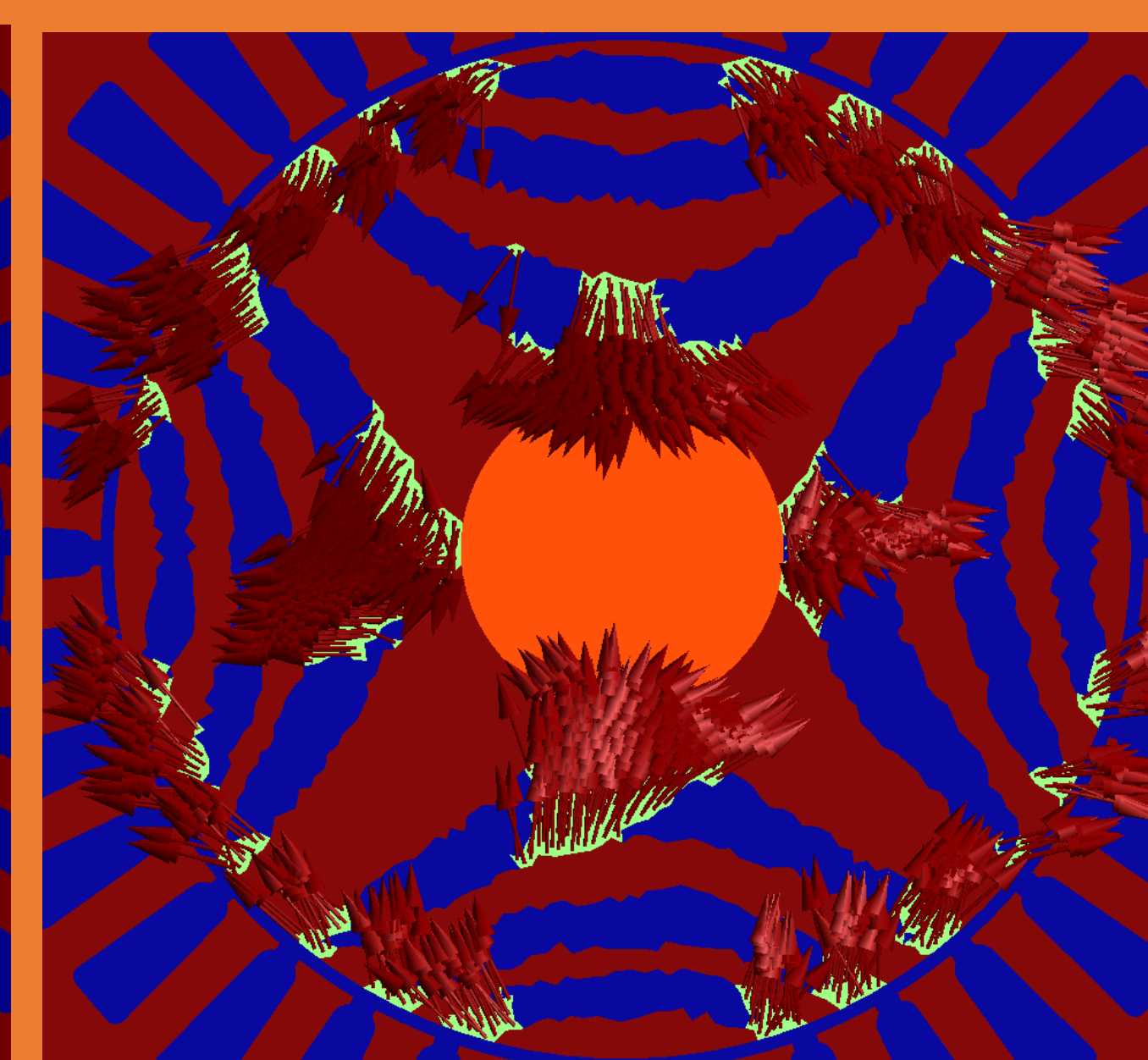
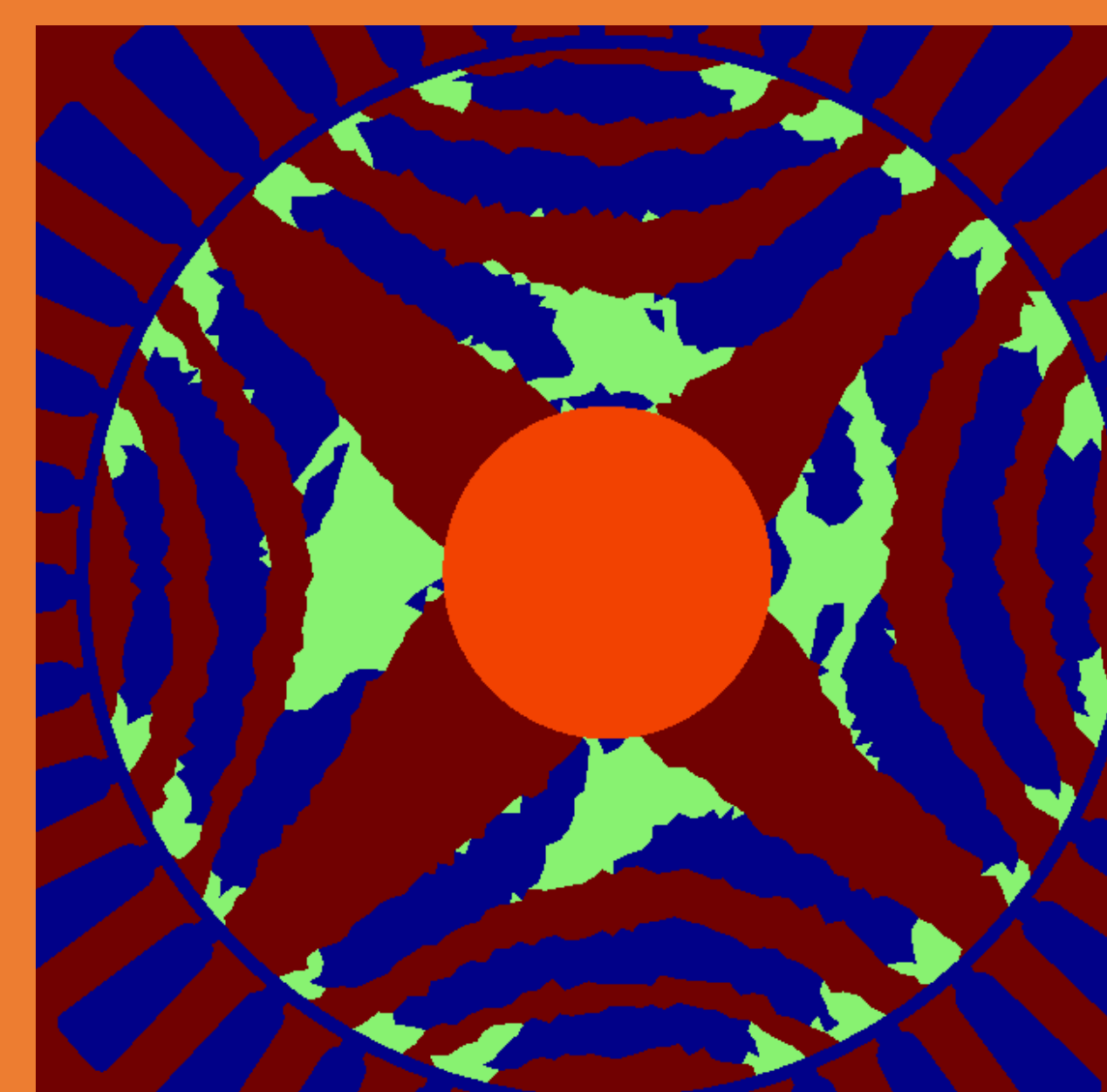
Representation of the rotor for 50% iron and 30% magnets

30% Magnets

50% Iron

50% Magnets

80% Magnets



Conclusion

In this work a modified BESO algorithm for topology optimization of electrical machines is presented. The work is based on a reformulation of the optimization problem to consider first the increase of the machine saliency and then to distribute magnets in the flux barriers. In future work, a coupled magneto-mechanical model will be presented to consider the design of iron bridges based on mechanical constraints.