

# Parametric Design Optimization with Genetic Algorithm for Internal Permanent Magnet Synchronous Motors

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A novel parametric-design methodology is proposed for optimizing the performance of asymmetric rotors in Internal Permanent Magnet Synchronous Motors (IPMSMs). Implemented within a genetic algorithm (GA), the method systematically adjusts the variation range of the geometric parameters to accommodate boundaries on the flux barriers and magnets. The results show an efficient exploration of the high-dimensional design spaces, reducing the rotor's Total Harmonic Distortion (THD). The proposed approach provides a robust and scalable tool for the development of IPMSMs, allowing designers to explore and optimize complex designs.

**Index Terms**—Genetic algorithms, Permanent magnet motors, Design optimization

## I. INTRODUCTION

THE demand for sustainable electric machines is driving research into eco-friendly motor solutions [1] and the deployment of efficient charging infrastructure [2]. To address these challenges, collaborative research was conducted between the Department of Energy of the Politecnico di Milano and the Italian company Mavel EDT, which specializes in the development of electric motors and inverters for high-performance premium traction applications.

This research focuses on Internal Permanent Magnet Synchronous Motors (IPMSMs) designed to operate at speeds up to 20,000 rpm. To balance electromagnetic performance with the consumption of rare-earth materials, researchers commonly rely on advanced global optimization algorithms, most notably Genetic Algorithms (GA) [3] and Particle Swarm Optimization (PSO) [4].

This paper introduces a novel parametric-design function specifically developed for asymmetric rotor topologies. The function enforces manufacturability restrictions while allowing exploration of a 52-parameter design space. Although this high dimensionality complicates geometry definition and constraint handling, it allows the optimizer to reach regions of the solution space that remain inaccessible to conventional symmetric-rotor models. The parametric-design function is embedded in a custom GA-based optimization framework fully implemented in MATLAB.

## II. CASE STUDY

The reference machine is a three-phase IPMSM equipped with a double-layer V-shaped magnet rotor topology (see Table I and Fig. 1). The optimization targets two conflicting objectives: (i) minimization of Total Harmonic Distortion (THD) and (ii) maximization of the total magnet area  $A_t$ . THD is chosen as the primary electromagnetic metric because it can be evaluated rapidly in no-load finite element analyses, making it well suited to iterative optimization. As a contrasting design objective, the maximization of  $A_t$  increases the available magnetic flux and thus the achievable torque, but also introduces harmonic distortion.

TABLE I  
MOTOR DIMENSIONS AND INITIAL TARGET PERFORMANCE

| Name                      | Value | UOM             |
|---------------------------|-------|-----------------|
| Poles                     | 6     | n.              |
| Slots                     | 36    | n.              |
| Motor Active Length       | 60    | mm              |
| Stator Diameter           | 160   | mm              |
| Rotor Diameter            | 100   | mm              |
| Initial rotor THD         | 17    | %               |
| Initial Magnet Area $A_t$ | 440   | mm <sup>2</sup> |
| Initial magnet weight     | 0.9   | kg              |

## III. METHODS

The proposed motor parametrization facilitates compliance with rotor geometric boundaries and manufacturability constraints by expressing rotor parameters in polar coordinates (see Table II and Fig. 1). To accommodate rotor asymmetry, each pole pair is parameterized and checked independently. The resulting description includes 52 independent parameters, accounting for four magnet layers and two barriers per magnet. Consequently, every candidate rotor is encoded as a chromosome array of 52 elements, each normalized to the interval [0, 1]. During optimization, the parametric-design function dynamically rescales these values to satisfy the rotor's geometric boundaries. Although this approach ensures that the magnets remain within admissible boundaries, magnets in

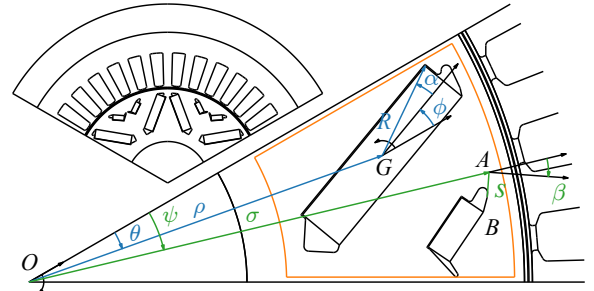


Fig. 1. Top: two motor poles. Bottom: half a pole, showing the magnet parameters (blue), barrier parameters (green), and boundaries (orange).

TABLE II  
ROTOR PARAMETRIZATION DESCRIPTION

| Parameter | Description                                                                      |
|-----------|----------------------------------------------------------------------------------|
| $\rho$    | radial position of the magnet center G [mm]                                      |
| $\theta$  | angular position of the magnet center G [rad]                                    |
| $\phi$    | orientation of the magnet [rad]                                                  |
| $\alpha$  | angle whose tangent is the ratio between width and thickness of the magnet [rad] |
| $R$       | half of the diagonal of the magnet [mm]                                          |
| $\sigma$  | radial position of barrier point A [mm]                                          |
| $\psi$    | angular position of barrier point A [rad]                                        |
| $\beta$   | direction normal to barrier segment $\overline{AB}$ [rad]                        |
| $s$       | length of barrier segment $\overline{AB}$ [mm]                                   |

different layers can still overlap. The cost function penalizes this condition by a factor proportional to the overlapping area. A second penalty is applied if the total mass of the magnet exceeds the maximum limit of 1.15 kg.

A single-objective GA is used to minimize the following cost function:

$$F = \text{THD}/\text{THD}^{\text{prec}} - A_t/A_t^{\text{prec}}, \quad (1)$$

with  $A_t^{\text{prec}}$  and  $\text{THD}^{\text{prec}}$  denote, respectively, the magnet area and THD of the initial symmetric precursor rotor. To evaluate THD for any trial geometry, the stator is replaced by a homogeneous iron ring so that only the rotor harmonics are captured. The normal component of the air-gap flux density is sampled and decomposed via a Fourier series. Finally, the rotor THD is computed using the RMS of the ratio of the higher-order harmonics to the fundamental.

The GA is executed with a population size of 100 and a limit of 5000 calls to the cost function (50 generations). The initial population follows a Gaussian distribution centered on the chromosome representing the symmetric precursor. To ensure reproducibility, ten independent runs of the optimizer are performed.

#### IV. RESULTS

Figure 2 follows the evolution of the cost function  $F$  over 50 generations, demonstrating robust optimization capabilities. During the first 20 iterations, the algorithm achieves a steep reduction in  $F$ , driven by simultaneous improvements in both THD and magnet area  $A_t$ . Later generations produce smaller but significant improvements until  $A_t$  converges to a value of approximately 560 mm<sup>2</sup> due to the weight limit.

The exploration behavior of the parametric-design function is represented in Fig. 3, along with the final rotor geometry. Darker regions correspond to frequently explored design configurations associated with the high-ranked individuals. The asymmetry of these regions reflects the independent optimization of the four magnet layers, which allows each pole pair to contribute differently to the suppression of rotor harmonics. This observation aligns with the findings of [5], where asymmetric rotors were shown to mitigate harmonic content and torque ripple.

#### V. CONCLUSION AND FUTURE WORK

The asymmetric parametric-design function successfully achieves optimization objectives through efficient exploration

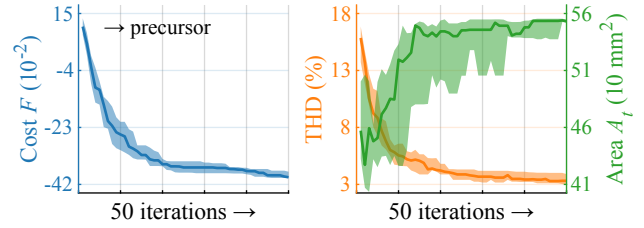


Fig. 2. Cost function  $F$  (left), THD and  $A_t$  (right) over 50 generation starting from the precursor. Solid lines represent median values over ten optimizations; shaded areas indicate the region between the 1st and 3rd quartiles. Average runtime per optimization run was 1.52 h on an Intel Core i9-14900K @ 3.2 GHz, 64 GB DDR5-4000 RAM (4 × 16 GB), and a 512 GB Samsung PCIe NVMe M.2 SSD.

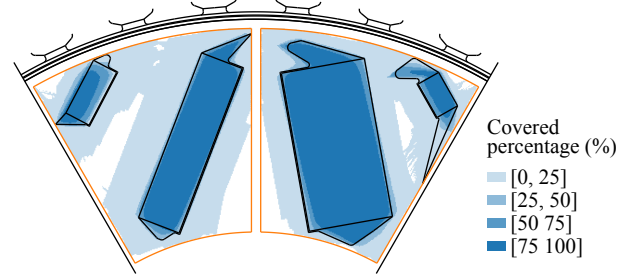


Fig. 3. Optimized rotor geometry shown in black lines. Colored regions represent the design space explored by the algorithm; darker colors indicate regions where the magnets are more frequently positioned. Percentages are based on all motor designs generated during a single optimization run.

of the design space. Future work will extend this methodology to a multi-objective framework that explicitly accounts for torque, torque ripple, electromagnetic losses, and mechanical stresses due to centrifugal loads. Integrating these additional physics will yield a more comprehensive optimization process capable of resolving the inherent multiphysics trade-offs.

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