# Synchronous reluctance machine optimization based on reduced set of geometric parameters with improved convergence and robust geometric feasibility verification


Branko Ban, M.Sc.
(Branko.ban@fer.hr)
Supervisor: Assoc. prof. dr. sc. Stjepan Stipetić,
University of Zagreb Faculty of Electrical Engineering and Computing


## 1. Introduction

Due to the performance characteristics, interior rare earth permanent magnet (PM) synchronous machines are preferred for automotive traction. PM cost volatility poses a considerable risk, so vehicle manufacturers are investigating the use of PM-free electric machines. A possible alternative is a synchronous reluctance machine (SyRM). This poster contains the research related to scientific contribution "Method for SyRM rotor geometry parametrization with the reduced parameter set".

## 2. Problem" Description

When designing a SyRM, the initial step is the selection of rotor barrier type. Literature provides several topologies but does not clearly state which one yields the best performance. The goal of the research is to differentiate the best variant for a 6-pole, 54 slot, 4 rotor barrier machine according to the selected requirements, using a metamodel-based optimization approach. The novelty of the proposed strategy is in the systematic and fair comparison of different rotor topologies.

## 3. Methodology

The Seven rotor barrier topologies have been derived:

1. Circular concentric (CrC), Fig. 1a (red)
2. Circular variable depth (CrVD), Fig. 1a (blue)
3. Hyperbolic, fixed eccentricity (HyFE), Fig. 1b (red)
4. Hyperbolic, variable eccentricity (HyVE), Fig.1b (blue)
5. Original Zhukovsky (Zh), Fig. 1c (red)
6. Modified Zhukovsky variable depth (MZhVD), Fig. 1c (blue)
7. Modified Zhukovsky with equal depth (MZhED), special case of 6.

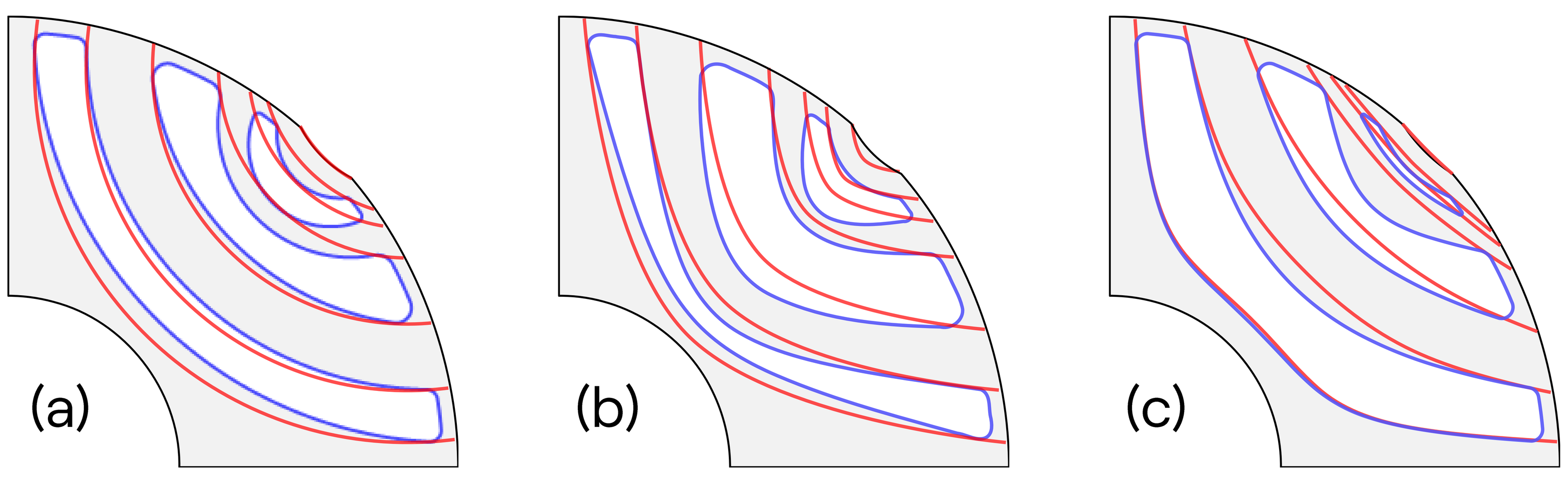


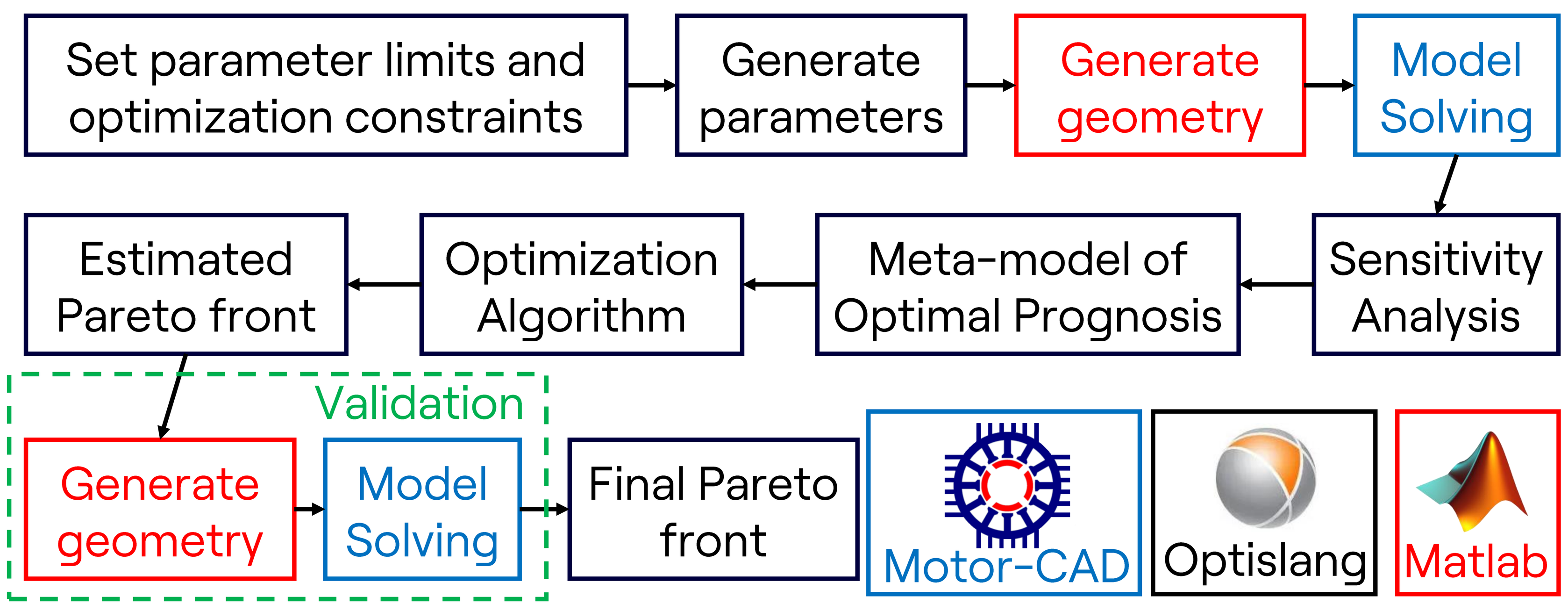

**Figure 1: Illustration of selected SyRM rotor barrier topologies**

The optimization process couples automated geometry generation (Matlab), electromagnetic finite element analysis (Motor-CAD), and metamodel optimization (OptiSlang).

**Table 1: Design requirements**

| Description | Symbol | Value | Unit |
|---|---|---|---|
| Base speed | $n_{base}$ | 1700 | rpm |
| Maximum operating speed | $n_{max}$ | 2500 | rpm |
| Min. avg. torque | $T_{avg\ min}$ | 210 | Nm |
| Battery voltage | $U_{DC}$ | 610.00 | V |
| Maximum phase current | $I_{s\ max}$ | 300 | $A_{rms}$ |

**Figure 2: Optimization workflow with tool-chain components**




## 4. Results

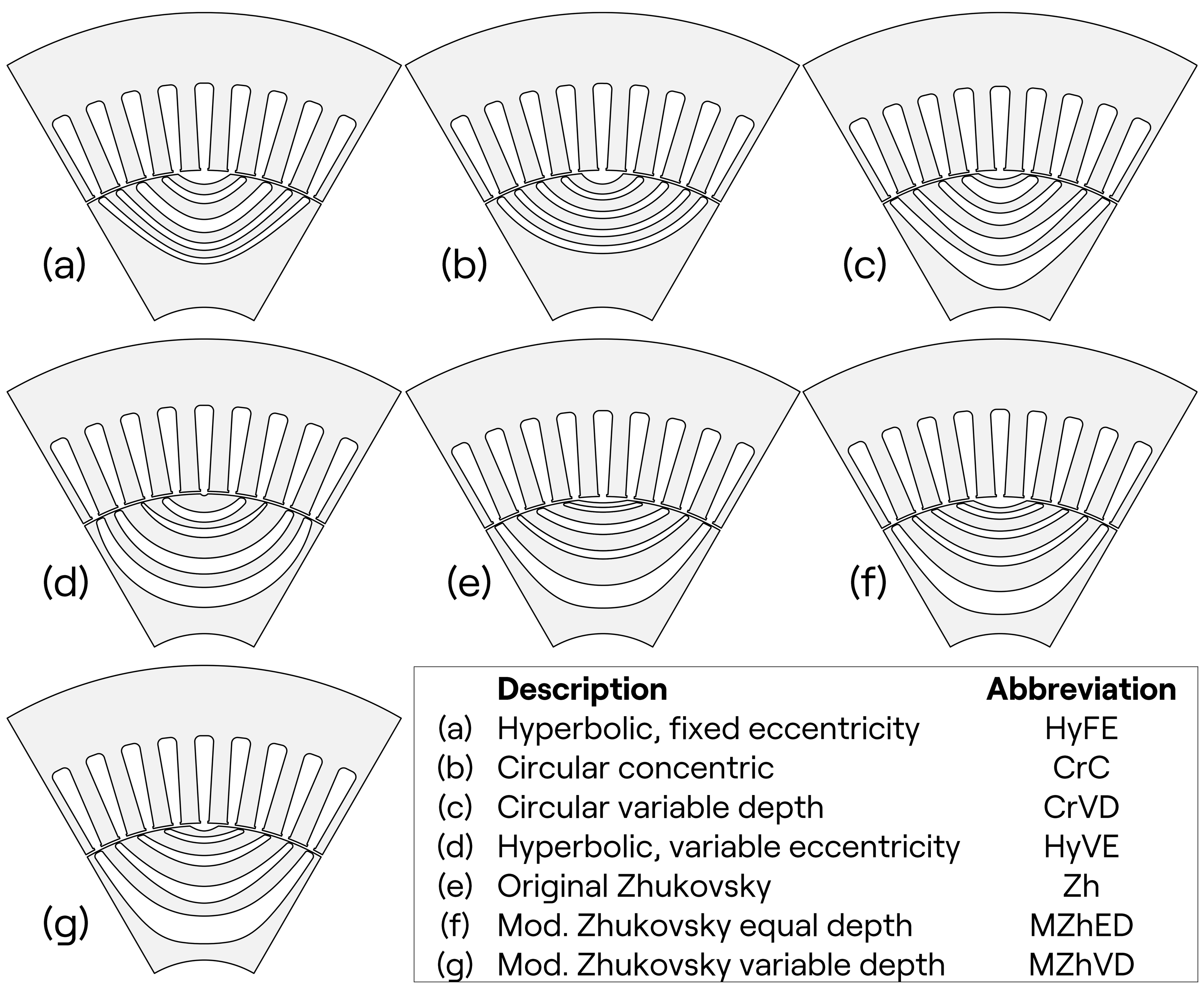
Optimization objectives were to maximize torque per volume and minimize total losses. Designs with approximately the same losses have been selected. Performance at MTPA conditions from the worst (left) to the best topology (right), is listed in Table 2.

**Table 2: Performance summary of the selected designs**

| Name | Unit | HyFE | CrC | HyVE | CrVD | Zh | MZhED | MZhVD |
|---|---|---|---|---|---|---|---|---|
| TPV | $Nm/dm^3$ | 32.5 | 33.1 | 34.3 | 35.4 | 36.2 | 36.4 | 37.3 |
| $V_{active}$ | $dm^3$ | 6.47 | 6.47 | 6.47 | 6.47 | 6.47 | 6.47 | 6.47 |
| $P_{loss}$ | kW | 5188 | 5199 | 5209 | 5182 | 5188 | 5197 | 5184 |
| $P_{mech}$ | kW | 37.4 | 38.1 | 39.5 | 40.8 | 41.7 | 41.9 | 43.0 |
| $T_{avg}$ | Nm | 210.1 | 214.2 | 221.9 | 229.0 | 234.1 | 235.6 | 241.3 |
| $T_{ripple}$ | % | 12.1 | 14.1 | 11.7 | 12.7 | 9.7 | 9.3 | 13.7 |
| n | rpm | 1700 | 1700 | 1700 | 1700 | 1700 | 1700 | 1700 |
| $B_{yoke,\ max}$ | T | 1.53 | 1.53 | 1.39 | 1.60 | 1.52 | 1.54 | 1.56 |
| $B_{tooth,\ max}$ | T | 1.86 | 1.87 | 1.87 | 1.82 | 1.87 | 1.86 | 1.84 |
| $FOS_{mech}$ | - | 8.8 | 9.4 | 7.3 | 6.3 | 3.6 | 5.2 | 6.3 |
| m | kg | 45.6 | 46.0 | 44.2 | 44.3 | 45.0 | 44.8 | 44.1 |
| THL | $MA^2/m^3$ | 1.52 | 1.53 | 1.57 | 1.47 | 1.53 | 1.52 | 1.52 |
| $l_{stack}$ | mm | 180 | 180 | 180 | 180 | 180 | 180 | 180 |
| γ | ° | 57.9 | 60.3 | 61.4 | 62.5 | 61.8 | 61.8 | 62.9 |
| $I_{max}$ | $A_{rms}$ | 95.6 | 95.6 | 94.3 | 94.1 | 95.9 | 95.7 | 95.7 |
| cos φ | - | 0.61 | 0.62 | 0.66 | 0.67 | 0.67 | 0.67 | 0.69 |
| Gain | % | 0.0 | 1.9 | 5.6 | 9.0 | 11.4 | 12.1 | 14.9 |

Performance wise, HyFE yields the worst results (TPV=32.5 $Nm/dm^3$) and will be considered the baseline design (0% gain). Performance gain is calculated via: Gain=$(T_{avg}/T_{HyFE\ avg}-1)\cdot 100$ %. CrC topology is slightly better (2% gain) but still has rather low power factor. Next, HyVE yields better results (5.6% gain) but is superseded by CrVD topology (9% gain). Even better performance results are achieved by standard Zh (11.4% gain) and MZhED topology (12.1% gain) but without any power factor increase. Finally, the best result is obtained for MZhVD topology with full barrier depth variance (14.9% gain).

**Figure 3: Cross sections of the selected optimized machines**




## 5. Conclusion

Nowadays, due to the confidence in modelling tools and rapid product iteration, electric machine designers primarily rely on simulation. The presented approach reduces time and cost and is very useful when comparing different machine topologies. The results prove that SyRM topology selection severely affects the final performance.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