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Techniques for Reducing Eddy Current Losses in Permanent Magnet

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INTRODUCTION & AIM

The primary goal of this work is to investigate two methods for minimizing eddy power loss in a surface-mounted Permanent Magnet Synchronous Machine (PMSM).
The first one is about magnet segmentation, where the optimal segmentation parameters are identified using genetic algorithm method.
The second technique uses a conductive shielding cylinder around the magnets.
The 2D finite element method is used to analyze the eddy power loss.

Eddy power loss analysis

2D magnetodynamic electromagnetic field formulation :

Neglecting end efects; Infinite permeability of the rotor and stator; iron relative permeability of the shielding cylinder, permanent magnet and stator slots μ_r =1; zero conductivity of the rotor and stator iron; no induced currents in the slots.

In harmonic case :

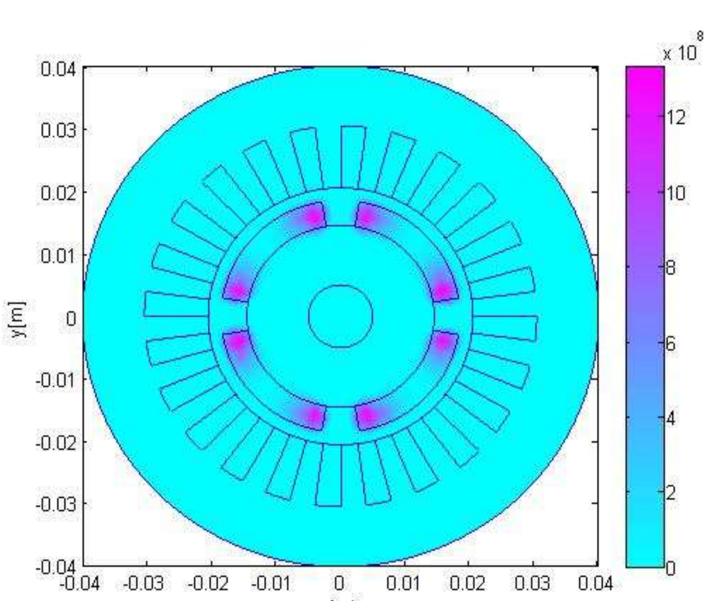
$$\begin{cases} \nabla \frac{1}{\mu} \nabla A + \sigma(j\omega A + \nabla V) = J_S + \mu \nabla \times \overrightarrow{B_r} \\ J = -\sigma(j\omega A + \nabla V) \end{cases}$$

Power loss in magnet : $P = \frac{1}{\sigma} \int_V J J^* dV_m$

Application of 2D FEA for power loss analysis in a PMSM

Main design parameters of the studied PMSM

Parameter	Value
Rotor yoke radius	14.5[mm]
Air gap outer radius	20.5[mm]
Slot outer radius	30.4[m]
Nd-Fe-B magnet's conductivity	7.10^5 [Ω/m]$^{-1}$
Machine outer radius	40[mm]
Magnet height and span (h_p and α_m)	4[mm] and 0.8π/2[rad]



Magnet eddy losses in the studied PMSM [W/m^3] at 1 kHz.

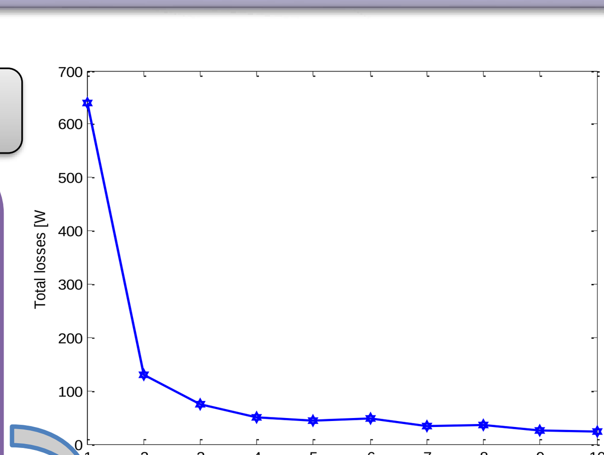
Techniques for eddy power loss reduction

1. Magnet's segmentation technique

- Magnet divide to **Ns** segments
- Elementary magnet's span :

$$\alpha_{me} = (\alpha_m - (N_s - 1) \cdot \beta)/N_s$$

- Angular space between two elementary magnets : $\beta = \pi/180$

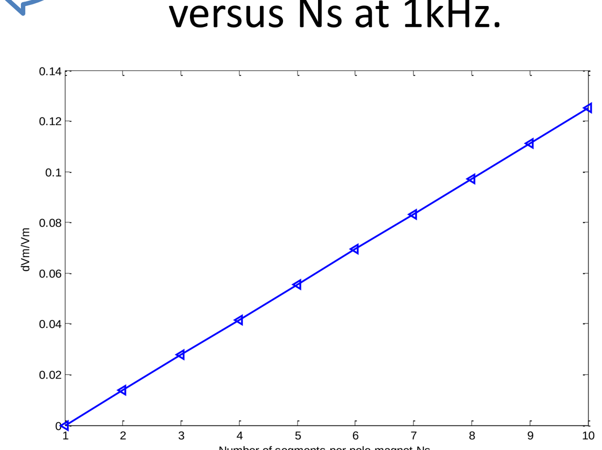


Variation of magnet's loss versus Ns at 1kHz.

dVm : magnet's volume loss with segmentation
Vm : Total magnet's volume

Segmentation reduces also the magnet's volume

Decrease of energy efficiency of the magnet



Variation of ration dV_m/V_m with segmentation

Optimization with GA of segmentation's parameters

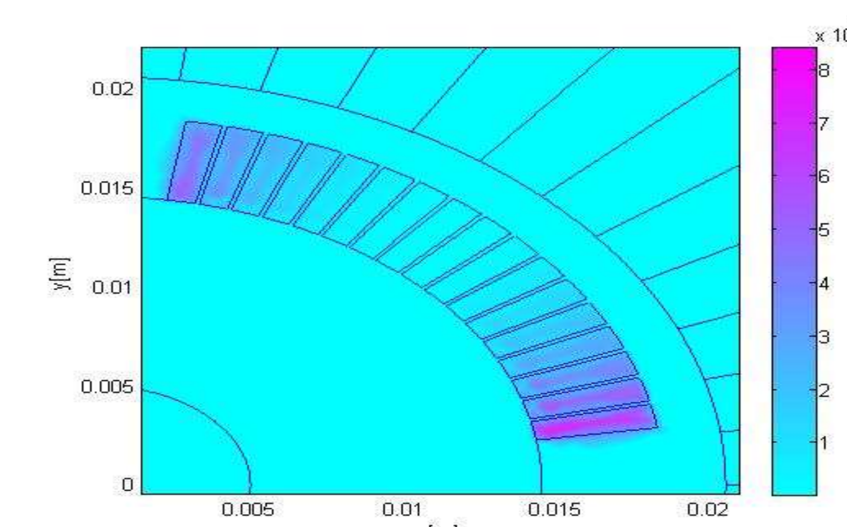
Problem formulation :

$$\begin{cases} F = \min(P(x)) \\ dV_m \le 0.01 V_m \end{cases}$$

Design parameters

parameter	Lower bound	Upper bound
Ns/pole	2	20
β	π/360[rad]	π/140 [rad]

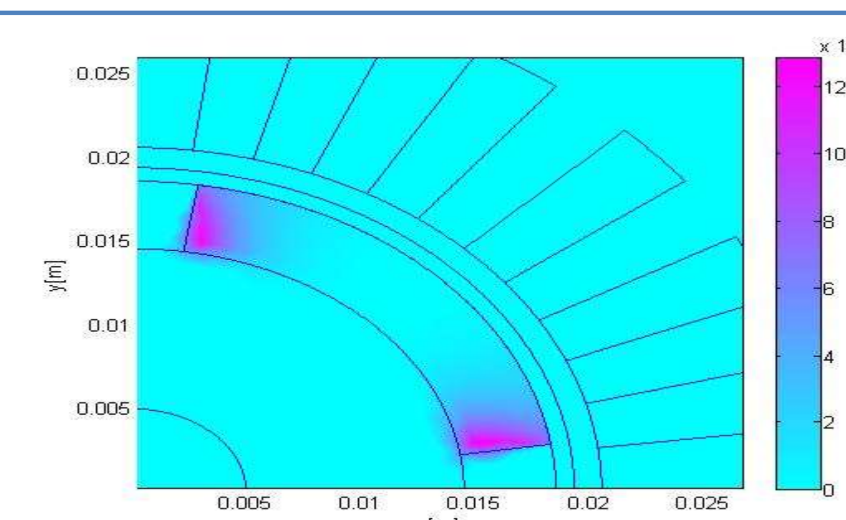
Best parameters		Best objective function
N_s	17	11.64 [W]
β	π/329[rad]	



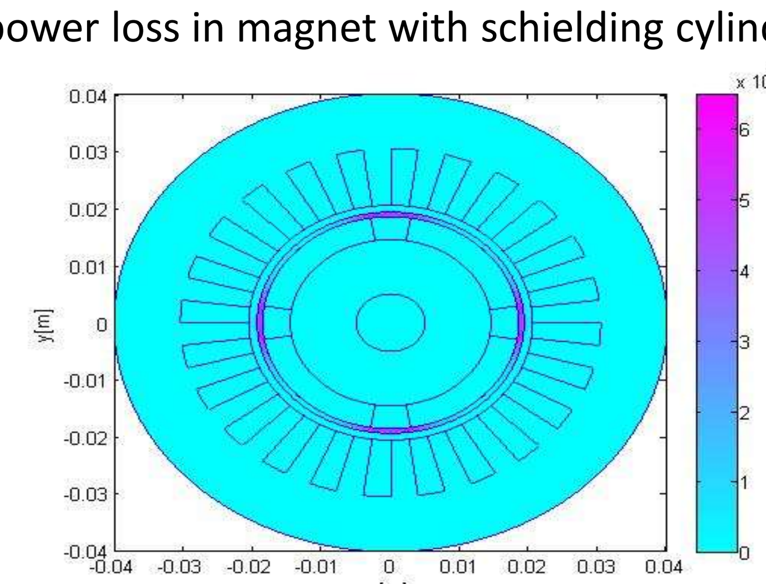
Density of power loss in the Best PMSM configuration

2. Shielding cylinder around the magnet

Electrical conductivity of the shielding cylinder : 5.9510^7 [Ω/m]$^{-1}$.



Eddy power loss in magnet with schielding cylinder at 1 kHz.



Eddypower loss in conductive schielding cylinder at 1 kHz.

CONCLUSION

The shielding conductive cylinder appears to be a more effective method of reducing eddy current loss. However, the presence of significant induced eddy currents in the cylinder can result in significant power loss and magnet heating. Selecting the best magnet segmentation parameters enhances the technique's performance and efficiency.

REFERENCES

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2. Y. Zhang, S. Mcloone, W. Cao, F. Qui and C. Geroda, "Power Loss and Thermal Analysis of a MW High Speed Permanent Magnet Synchronous Machine," IEEE Trans. Energy Conversion, vol. 32, no 4, 2017.