

Post-Assembly Magnetization with Induction Heating for Large-Sized Permanent Magnet Electrical Machines

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Post-assembly magnetization (PAM) simplifies the manufacturing of permanent magnet electrical machines, but faces challenges in large-sized machines due to the limited magnetizer power. This paper proposes a PAM method with induction heating to reduce the required magnetizing field intensity, utilizing the temperature-dependent property of the Nd-Fe-B magnets. The same coils are used for both magnetization and heating by adjusting the power supply. The method can achieve full magnetization in large machines with limited magnetizer power, demonstrating its practicality and effectiveness.

Index Terms—Post-assembly magnetization, induction heating, permanent magnet electrical machine, full magnetization.

I. INTRODUCTION

POST-ASSEMBLY magnetization (PAM) is a widely employed technique for permanent magnet (PM) electrical machines manufacturing. It allows assembling the machines with unmagnetized PMs, which generate little electromagnetic force, thus significantly simplifying the assembling process. PAM can be particularly helpful for large-sized machine manufacturing [1]-[2], however, the required magnetizing power is usually too high to achieve. To address this challenge, it is proposed to heat the magnets with induced eddy current so as to lower the required magnetizing field and consequently the magnetizing power, with the magnetizing coils being reused as induction heating coils.

II. MACHINE STRUCTURE AND POST-ASSEMBLY MAGNETIZATION PRINCIPLE

A 400 kW, 140 rpm low-speed high-torque (LSHT) Nd-Fe-B PM machine is taken as an example for investigating the PAM. Its cross-sectional view is illustrated in Fig. 1. The machine is so large (see Table I) that it is not possible to use the stator armature windings to magnetize the spoke-type PMs after assembly. Therefore, additional magnetizing coils are arranged around the rotor nonmagnetic spacers, and a pole-by-pole magnetization method is adopted to minimize the required power for each magnetization. In this method, two adjacent magnetizing coils corresponding to a single pole are energized by a pulse power supply magnetizer, generating a tangential magnetic field to fully magnetize the PM of the pole.

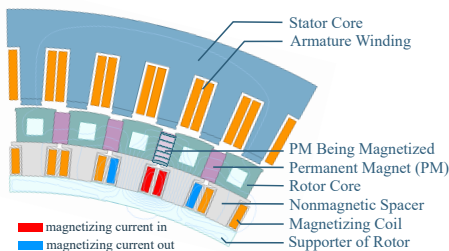


Fig. 1: Cross section diagram of LSHT machine with magnetizing coils.

TABLE I: LSHT Machine Specific Parameters

Parameter	Value	Parameter	Value
Stator core outer diameter	1.61 m	Stator core axial length	0.3 m
Stator slot number	72	Rotor pole number	60
PM thickness	20 mm	PM width	40 mm
PM axial length	50 mm×6	PM grade	N38SH

III. TEMPERATURE-DEPENDENT PM MAGNETIZATION

The Nd-Fe-B PMs require a strong magnetizing field to achieve full magnetization. However, its coercivity H_{cj} decreases almost linearly with rising temperature due to thermal activation [3]. Therefore, the Nd-Fe-B PMs need a lower magnetizing field to achieve full magnetization at higher temperatures [4]. To validate this observation, N38SH PMs are processed with a commercial magnetization device under various magnetizing fields B_m and temperatures, with their demagnetization curves measured, as depicted in Fig. 2. The magnetic flux density B and field intensity H are normalized by the nominal remanence B_{r-pre} and coercivity H_{cj-pre} of a fully magnetized PM to illustrate its magnetization degree clearly. While a magnetizing field of 2 T is insufficient at the temperature 293 K, a lower field of 1.5 T can achieve full magnetization at 373 K. With further measurements, the magnetizing field B_{m-ful} required for full magnetization at different temperatures T can be derived as:

$$B_{m-ful}(T) = 9.19 - 0.0228 \cdot T \quad (1)$$

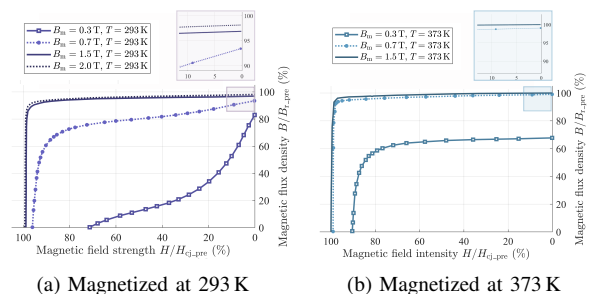


Fig. 2: $B - H$ curves for PMs under various magnetizing fields and temperatures.

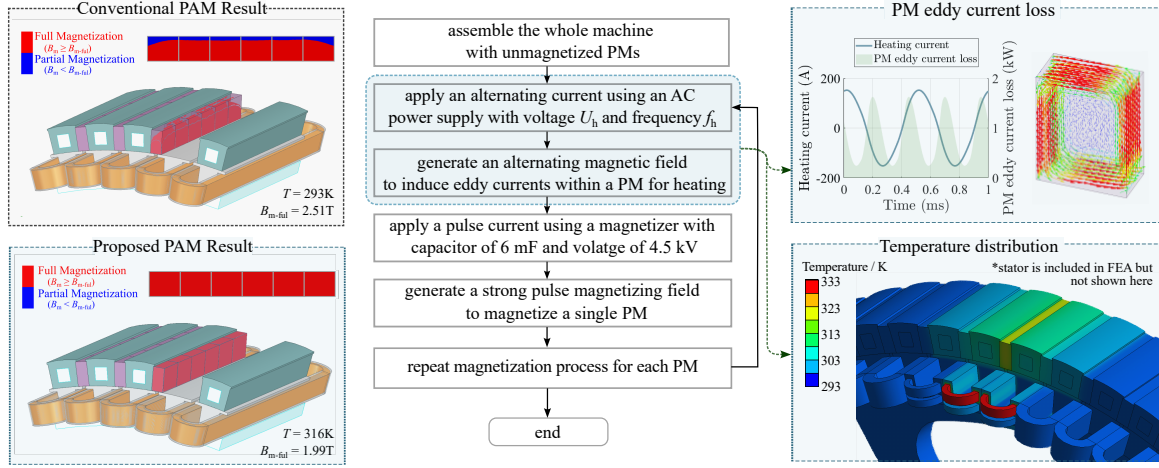


Fig. 3: Proposed PAM method with pre-heating process

IV. PROPOSED PAM METHOD

The proposed PAM method is illustrated in Fig. 3. In the conventional PAM method where the shaded process in the flowchart is not applied, the generated magnetizing field is insufficient using a magnetizer with a maximum capacitor of 6 mF and DC voltage of 4.5 kV, resulting in partial magnetization of the top region of the PM. This incomplete magnetization adversely impacts the machine performance and reduces the PMs' resistance to demagnetization.

To achieve full magnetization, the proposed PAM introduces a pre-induction-heating stage for the PM to be magnetized, i.e., the shaded process in the flowchart of Fig. 3. Eddy current is induced in the six pieces of the PM using the magnetizing coils, which generate an alternating magnetic field for heating. In this stage, the voltage U_h and frequency f_h of the AC power supply are optimized to maximize the heating efficiency.

By way of example, when the PM temperature reaches 316 K, a magnetizing field of 2 T becomes sufficient to ensure full magnetization according to (1). On the other hand, FEA confirms that the 2 T field can be realized by the 6 mF, 4.5 kV magnetizer. Thus, the proposed PAM method enables full magnetization for the large-sized PM machines with limited magnetizing power.

Selection of the AC power supply voltage U_h and frequency f_h during the heating stage considers factors such as time required for heating t_h , temperature rise of the magnetizing coil ΔT_{cu} , and efficiency of the magnetizer η . Due to the short time interval of induction heating, heat transfer from the coils and PM to the outside components is neglected. To heat the PM from room temperature (273K) to 316 K, the required eddy current heating energy P_{pm-pre} can be calculated as (2), while the temperature rise of the magnetizing coils ΔT_{cu} and the magnetization efficiency η can be calculated as (3) and (4),

$$P_{pm-pre} = \Delta T_{pm} c_{pm} m_{pm} \approx 19.31 \text{ kJ} \quad (2)$$

$$\Delta T_{cu} = \frac{P_{cu}}{2c_{cu}m_{cu}} \approx \frac{P_{cu}}{839.3 \text{ J/K}} \quad (3)$$

$$\eta = \frac{P_{pm-pre}}{P_{pm-pre} + P_{cu} + P_{fe}} \quad (4)$$

where $c_{pm}=460 \text{ J/(kg}\cdot\text{K)}$ and $c_{cu}=385 \text{ J/(kg}\cdot\text{K)}$ are the specific heat capacities of the PM and coils, $m_{pm}=1.82 \text{ kg}$ and $m_{cu}=1.09 \text{ kg}$ represent their masses, while P_{cu} and P_{fe} refer to the copper loss in the coils and eddy current loss in ferromagnetic components, such as the rotor core and the support.

Using FEA and (2) (4), the related results with different combinations of U_h and f_h are shown in Fig. 4. To minimize both t_h and ΔT_{cu} while maintain a high η , the optimal values are determined as $U_h=700 \text{ V}$ and $f_h=2 \text{ kHz}$. Consequently, the heating process can be completed in around 20 seconds, enabling localized and rapid induction heating of the PM to 316 K. And, full magnetization can then be realized with a single stronger current pulse generated by the 6 mF 4.5 kV magnetizer.

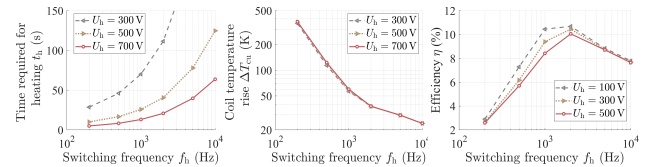


Fig. 4: Induction heating performance with different AC power supply voltages and frequencies.

V. ACKNOWLEDGMENT

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