Research on Temperature Rise and Temperature Control for Giant Magnetostrictive Transducer

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ID:#644

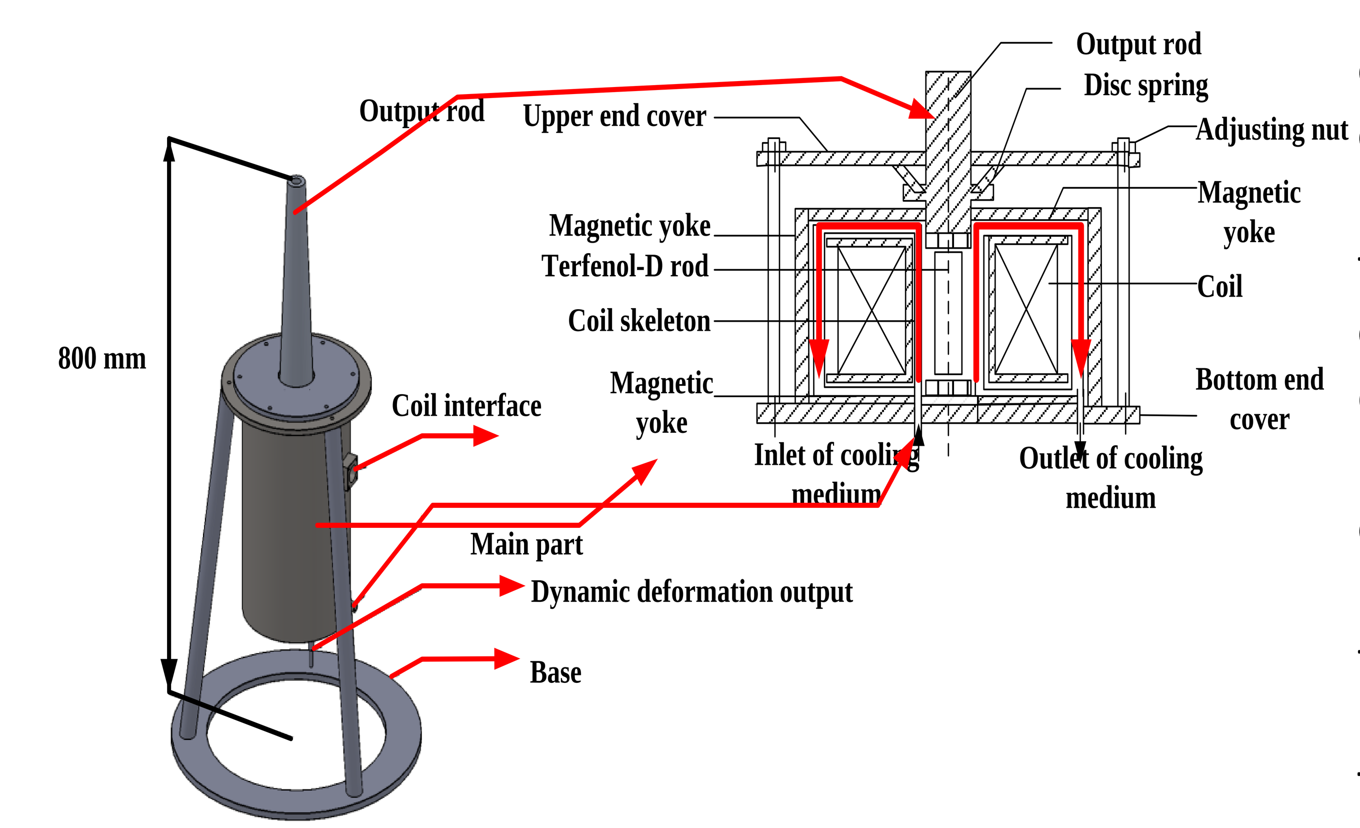
Tue-Af-Po2.10-14

MT25
25th International Conference on Magnet Technology
RAI - Amsterdam
August 27 - September 1, 2017

Introduction

Terfenol-D is a kind of magnetostrictive material, which is an alloy of Terbium, Dysprosium and Iron. The strain of Terfenol-D can reach 2000 ppm. What's more, it has giant energy density (25 kJ/m^3) and relatively high thermal conductivity (13.5 w/(m·k) at 20 °C). It is the core component of giant magnetostrictive transducer (GMT) which has been widely used in the field of ultra-precision machining and precision fluid control technology. However, when GMT operates at 6000Hz high frequency magnetic field, hysteresis loss, eddy current loss and copper loss of excitation coil lead to serious temperature rise. The temperature of Terfenol-D rod can reach above 120 °C without a cooling device. The temperature rise of Terfenol-D rod seriously affects the precision of GMT. So, it is necessary for GMT to analyze temperature rise and temperature control under high frequency.

Temperature control schematic



Temperature control schematic of the GMT is shown in Fig. 1. It consists of output rod, main part and base. The temperature control of the GMT is determined by controlling the cooling medium. The two-dimensional section of the main part is shown in the upper right corner of Fig.1. A Terfenol-D rod is the core component of GMT which produces axial deformation under driving magnetic field. It converts electromagnetic energy into mechanical energy. The Terfenol-D rod is surrounded by exciting coil and bias coil. The magnetic circuit is closed through an annular magnetic yoke. Disc spring and adjusting nut allow the Terfenol-D to be placed under a variable prestress. A cooling medium flow loop is formed between the coil skeleton and the Terfenol-D rod. The temperature rise of the transducer is most serious here. The cooling medium flows from the inlet of cooling medium to the outlet.

Nonlinear Electromagnetic-Mechanical-Thermal Multi-Field Coupled Finite Element Model of Transducer

➢Dynamic Magnetization Model of Terfenol-D

the magnetization model, which considers the effect of pinning loss, eddy current loss and stress, can be calculated by equations.

$$dE = \left(k_0 + k_1 \cdot \left((dM)/(dt)\right)\right)\cdot dM$$

The first one simulates the pinning effect, and the second one simulates the eddy current effect.

$$k_1 = \left(\mu_0{}^2 d^2\right)/\left(2\rho\beta_0\right)$$
$$dM = M_{an} - M$$
$$M = cM_{an} + (1-c)M_{irr}$$
$$M_{an} = M_s f(H_e)$$
$$f(H_e) = M_s \cdot \left((\beta\cdot H_e)/(1+\beta\cdot H_e)\right)$$
$$H_e = H + \alpha M + H_\sigma$$
$$H_\sigma = (3/2)\cdot(\sigma/\mu_0)\cdot(d\lambda/dM)$$

➢Multi-field Coupled Finite Element Model of GMT

Governing equation of electromagnetic field:

$$\int_V H\cdot(\nabla\times\delta A)dV + \int_{\partial V} H\cdot\delta A dS + \int_V \sigma\nabla V\cdot\delta A dV + \int_V \sigma\cdot(\partial A/\partial t)\cdot\delta A dV = \int_V J\cdot\delta A dV$$

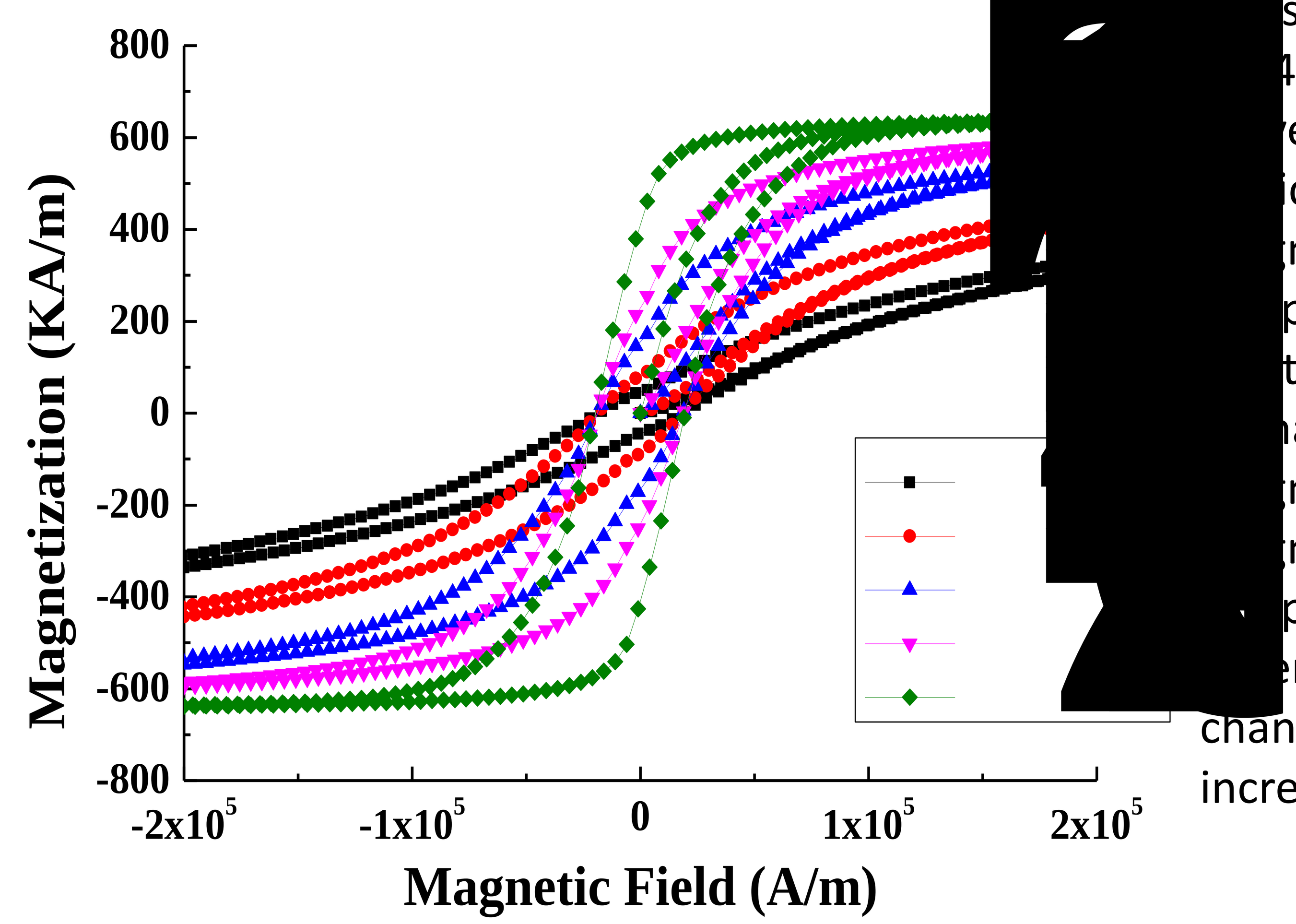
Governing equation of mechanical field :

$$\int_V T\delta u dV + \int_V \rho\ddot{u}\delta u dV = \int_{\partial V} T\delta u dS + \int_V b\delta u dV$$

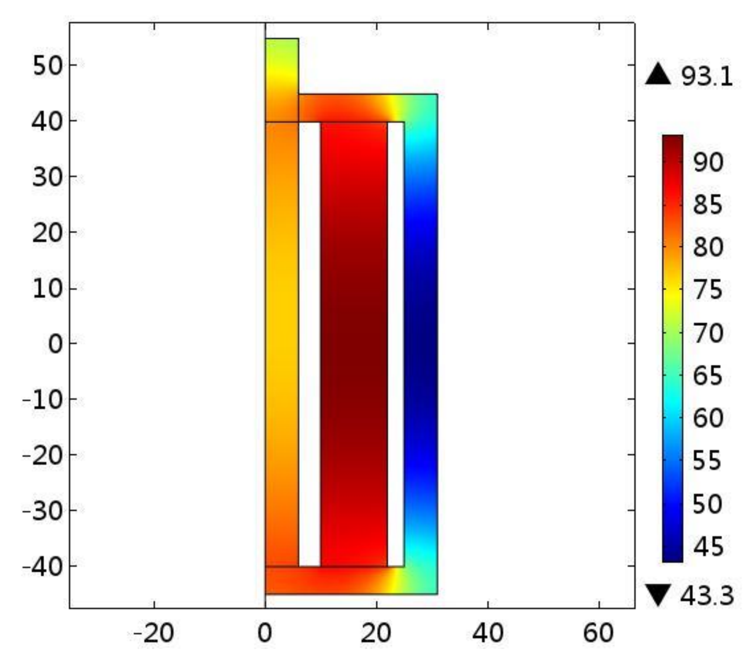
Governing equation of thermal field :

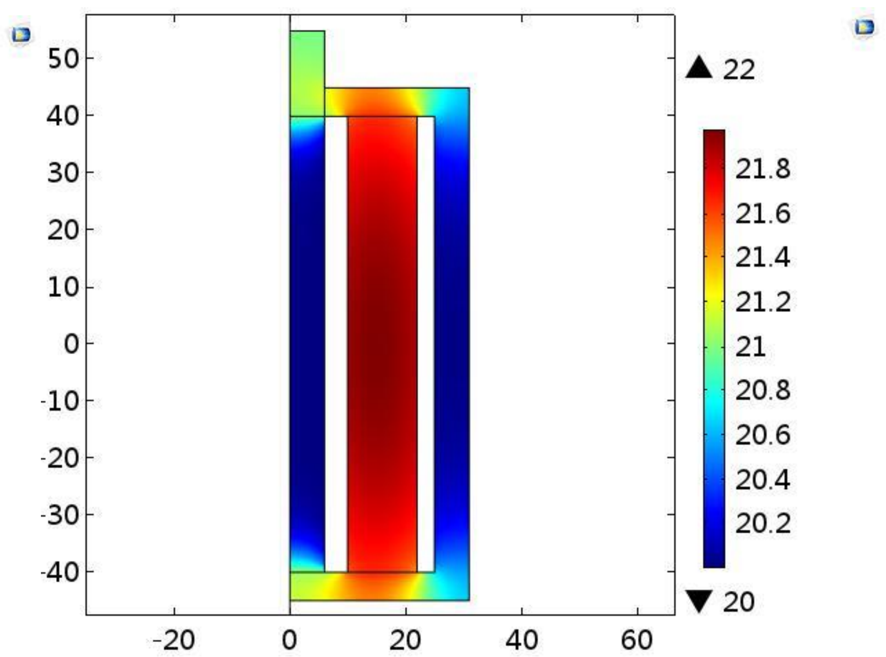
$$\int_V k\nabla T\cdot\nabla V dV + \int_V \rho C_p\cdot(\partial T/\partial t)V dV + \int_V \rho C_p u\cdot\nabla T\cdot V dV = \int_{\partial V} k\nabla T n\cdot V d\partial V + \int_V Q\cdot V dV$$

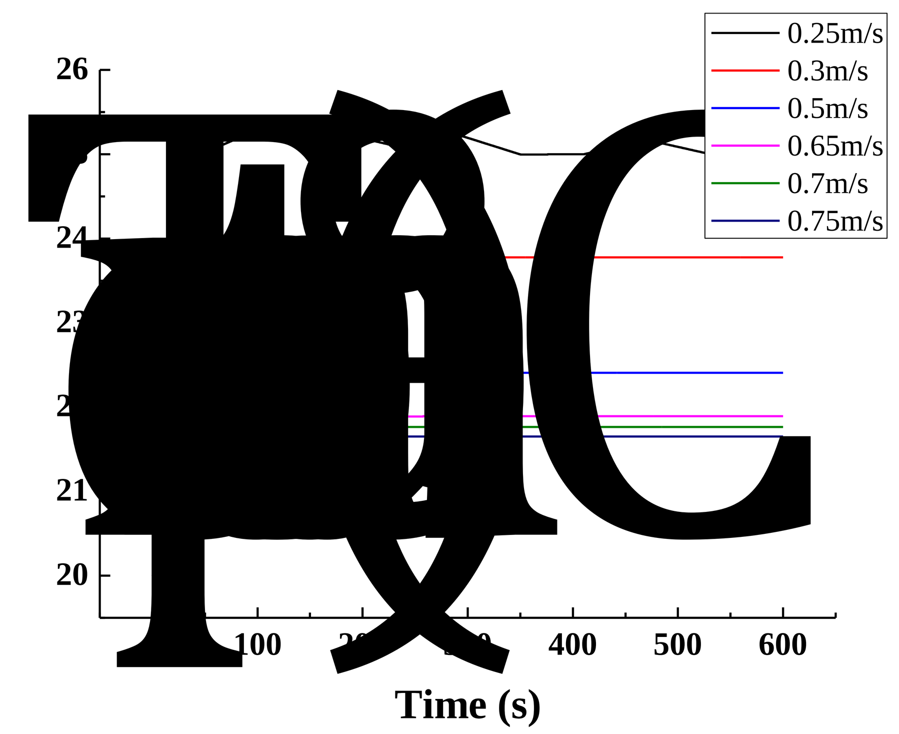
Results



[redacted]sing the model, when the temperature is 20 [redacted]40 °C, 60 °C, 80 °C, and 100 °C, the calculated [redacted]es of magnetic field versus magnetization are [redacted]icted in Fig. 2. It is observed that the [redacted]netization decreases with increasing [redacted]perature. As the temperature raises, the [redacted]tronic order in material is destroyed and the [redacted]ain offset each other, which make the [redacted]netization become weak. That's why the [redacted]netization decreases with increasing [redacted]perature. From the result in Fig. 2, we can [redacted]rmine the coercivity of the material and it changes from 20.5 kA/m to 19 kA/m with increasing temperature from 20 °C to 100 °C.







According to the theoretical and experimental researches, when the velocity of the fluid is greater than 0.5m/s, the temperatures of Terfenol-D rod can be controlled within 21.7 °C under the excitation field of 6000 Hz. The temperature error can be limited below 0.5 °C, and the axial output displacement error by temperature rise can be controlled less than 0.65 μm.