2. POWER ELCTRONICS

C. Characterization of Rare Earth Permanent Magnets for Automotive Applications

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Contractor: Oak Ridge National Laboratory
Prime Contract No.: DE-AC05-00OR22725

Objective

- To determine the effect of thermal cycling on the magnetic and mechanical properties of sintered and bonded rare earth permanent magnets.

Approach

- Develop a test facility with an environmental chamber capable of cycling temperature between –40°C and 300°C.
- Instrument environmental chamber to determine in real-time the magnetic strength of test specimens as a function of temperature and thermal cycling.
- Evaluate the residual mechanical properties of sintered and bonded rare earth permanent magnets after thermal cycling.

Accomplishments

- Developed a test facility capable of cycling temperature between –40°C and 300°C. The test facility is instrumented to determine, real-time, the magnetic strength of sintered and bonded rare earth permanent magnets.

Future Direction

- Utilize test facility to evaluate bonded and sintered NdFeB magnets.

Introduction

Achieving FreedomCAR and Fuel Partnership goals will require the development of new technologies for electric machinery. The new technologies must be compatible with high-volume manufacturing; must ensure

high reliability, efficiency, and ruggedness; and must simultaneously reduce cost, weight, and volume. Key components for hybrid vehicles include motors, sensors, and control systems [1].

Permanent magnet motors have the highest power density; but they don't have a sufficient constant power speed range, and their cost is too high. The unacceptably high cost of permanent magnet motors is due to the high cost of magnet materials, magnet manufacturing, and rotor fabrication. Sintered and polymer-bonded particulate magnets are being developed with the objectives of increasing their useful operating temperature to 150ºC and decreasing the cost to about 25% of the current price of approximately $90/kg. Furthermore, these magnets should be rugged and reliable enough to operate in harsh environments including extreme temperatures, humidity and thermal cycling for 150,000 miles or 15 years. The objective of this project is to determine the resistance of sintered and bonded permanent rare earth magnets to thermal cycling between –40°C and 150°C.

Approach and Results

A test facility was designed and fabricated to evaluate the resistance of sintered and bonded rare earth permanent magnets to thermal cycling. The test facility consists of a chamber, which is shown in Figures 1 and 2, capable of cycling temperature between –40°C and 300°C. Cooling is achieved using liquid nitrogen, compressed air and a solenoid valve, while heating is achieved using compressed air and two cartridge heaters. The interior of the chamber, which has dimensions of 61 cm X 30 cm X 30 cm, is lined with one layer of insulating material. Temperature measurements obtained with type K-thermocouples placed at various locations inside the chamber demonstrated that it is possible to attain a very uniform temperature distribution inside the chamber. Figure 3 shows the temperature history recorded by seven thermocouples during heating/cooling. Results from these tests also provided information on the time required to achieve thermal equilibrium.

A computer-based system was assembled for controlling the operation of the test facility and for data acquisition. The system consists of a personal computer, a high-speed A/D data acquisition system, customized software using the commercially available package LabView and a digital temperature controller. Inside the box an array of sixteen 6.5-mm diameter rods is attached to a frame, which at the same time, is connected to a pneumatic actuator. The permanent magnets under evaluation, which are shaped in the form of prismatic beams, are placed at various locations along the rods. The reciprocating motion induced by the pneumatic actuator will slide the permanent magnets through coils, which are placed around plastic tubes that are concentric to the rods as illustrated in Figure 4. The motion of the magnets through the coils will induce a voltage in the coils. According to Faraday's law [2], the voltage induced in the coil will be proportional to the change in the magnetic flux through the coil (□), according to:

$$V = -\frac{d\Phi}{dt} \tag{1}$$

where the magnetic flux through the coil is given by:

$$\Phi(t) = B(t)\, N\, A \tag{2}$$

B(t) is the magnetic field of the magnet, N is the number of turns in the coil and A is the cross-sectional area of the coil.

The voltage induced across the terminals of the coil is recorded as a function of temperature and number of thermal cycles. Figure 5 shows a photograph of voltage traces resulting from the displacement of a bonded permanent NdFeB magnet sample through the coils, while Figure 6 illustrates the effect of temperature on the magnitude of the voltage and therefore, on the magnitude of the magnetic field of the test specimen.

After a prescribed number of thermal cycles test specimens are removed from the chamber and evaluated in 4-pt bending to assess the effect of thermal cycling on their mechanical strength. During FY05, the effect of thermal cycling on the magnetic and mechanical properties of bonded NdFeB magnets, received from IAP (Columbus, OH) will be evaluated.

Summary

A test facility was designed and fabricated to evaluate the effect of thermal cycling on the magnetic and mechanical properties of sintered and bonded permanent magnets. The test facility is capable of operating between –40°C and 300°C and of providing real-time measurement of the magnetic strength of test specimens. The effect of thermal cycling on the mechanical strength of sintered and bonded permanent magnets is determined by 4-pt bending after subjecting test specimens to a prescribed number of thermal cycles.

References

1. *2002 Annual Progress Report, Automotive Propulsion Materials*, U. S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Office of FreedomCar and Vehicle Technologies, Washington, D.C.
2. J.D. Jackson, *Classical Electrodynamics*, John Wiley & Sons, New York, 1967

FY 2004 Publications/Presentations

None.

Figure 1. Environmental chamber for thermal cycling

Figure 2. Detail of environmental chamber showing pneumatic actuator and frame with sixteen 6.5-mm diameter rods.

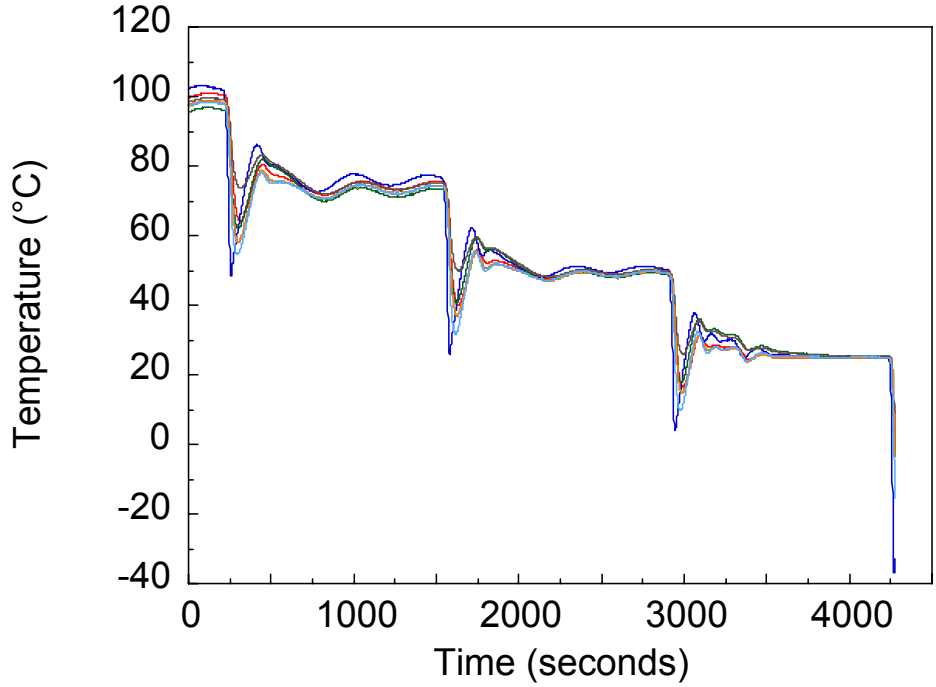

Figure 3. Temperature history recorded with seven thermocouples located at different locations within the environmental chamber. These results demonstrate that it is possible to achieve nearly isothermal conditions within the chamber. These tests also provided information on the time needed to reach thermal equilibrium.

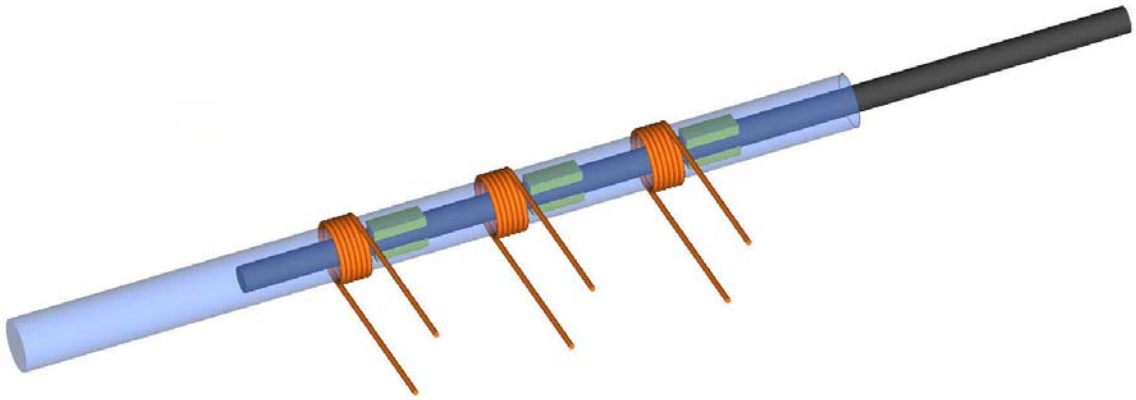

Figure 4. Schematic of test configuration illustrating the relative location of the coils with respect to the supporting rods and the permanent magnet test specimens.

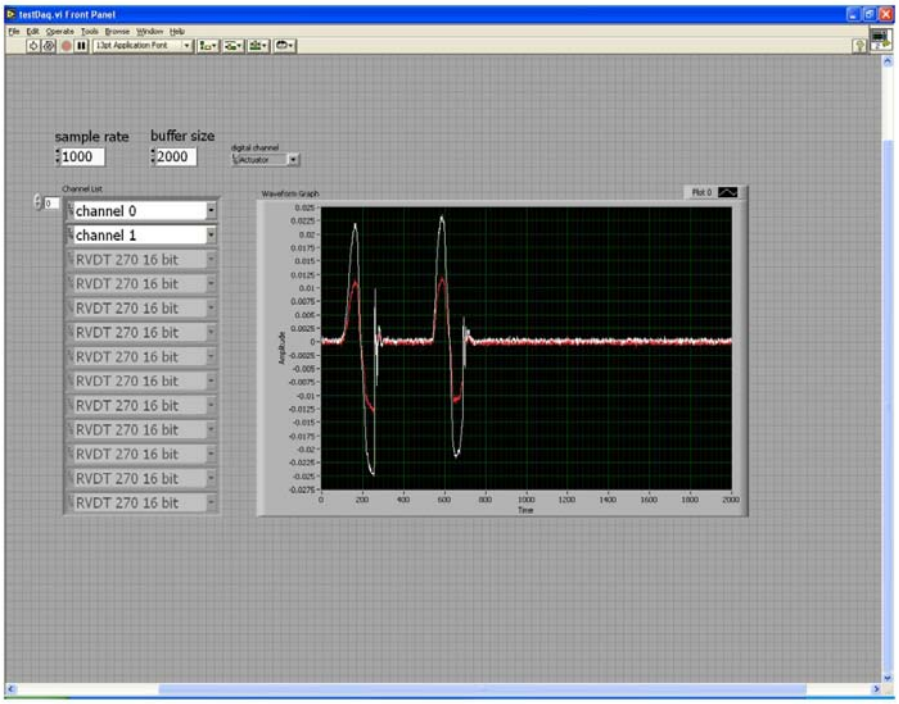

Figure 5. Voltage trace associated with the motion of magnet through coil.

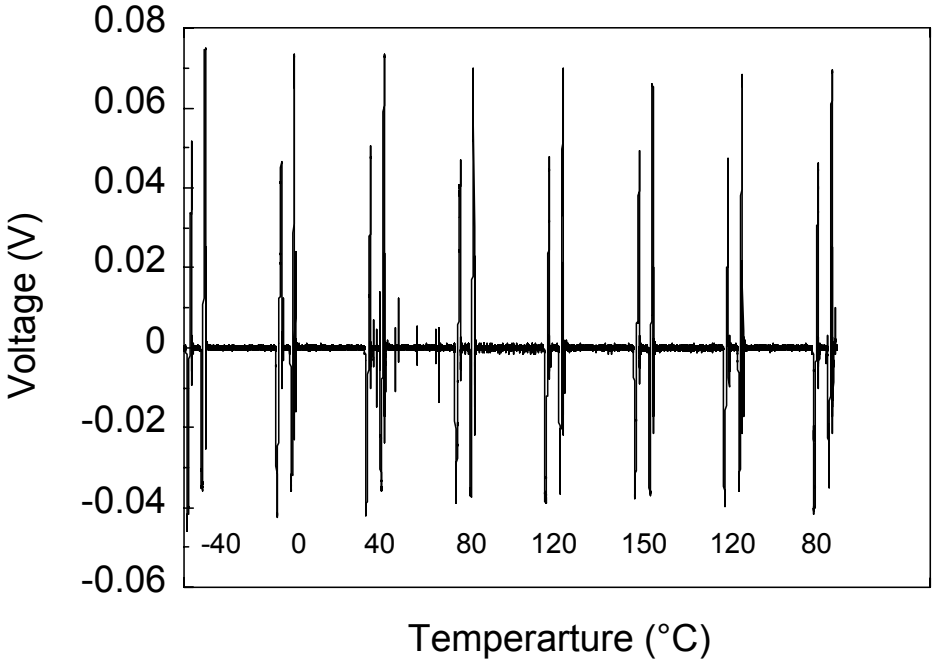

Figure 6. Voltage traces associated with the motion of magnet through coil as a function of temperature. Changes in voltage are proportional to changes in magnetic strength.