PERMANENT MAGNET STABILITY
(REV 1)

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MOTIVATION

To minimize costs and increase reliability, the new Recycler Ring will be constructed using magnets driven by bricks of permanently magnetized ferrite. Concerns are often expressed about the decrease in magnetization of the ferrite with time. To avoid operational problems, the magnetization should not vary by more than 1 part in 1000 over a period on the order of 20 years. The purpose of this note is to document what is known about the nature of the phenomenon.

EXPERIMENTAL OBSERVATIONS

In a paper published in 1960, Kronenberg and Bohlmann [1] reported measurements of the remanent induction B_d in Alnico and Barrium Ferrite samples at 25 C for times up to 10,000 hours (1 year). Various grades of material and various length/diameter ratios of the samples (i.e. demagnetizing fields) were studied. Kronenberg and Bohlmann observed a decrease in B_d of up to 0.4 % in Barrium Ferrite and established that B_d decreased logarithmically in accordance to

$$\Delta M = aT \log t/t_0 \qquad (1)$$

where a is a parameter which depends on the material and the demagnetization field, t is the time and T is the absolute temperature. The logarithmic time dependence means that:

- **stability improves with time after demagnetization (1/2 of the total change in the first 100 hours).**
- **measured data can be extrapolated to fairly long times ($\simeq$ 20 years) with reasonable confidence.**

THEORY

The phenomenon of decrease in magnetization with time, often and **incorrectly** referred to as "aging" is well understood. The theory was developed by Louis Néel [3] and by Street and Wooley [2]. It was initially applied to "conventional" magnets (i.e. Alnico), but was later shown to apply to ferrites as well.

The arrangement of magnetic domains or regions is disturbed constantly by randomly distributed influences from within and without. They provoke rearrangements to lower-energy configurations which result generally in a decrease of remanence. The decrease depends on many parameters concerning the magnet as well as its environment.

Néel assumes that disturbance influencing the magnetic situation at a certain location in a magnet can be represented by a fictitious magnetic field. This local field represents the effect of thermal fluctuations, mechanical shocks, external fields, rotations in the earth's field etc. Under constant environmental conditions, the fictitious field occurs randomly with the passage of time. **Each occurrence provokes an adjustment, stabilizing against all ensuing occurrences of equal or smaller sizes; only a larger one initiates a new adjustment.**

Street and Wooley adopt a slightly different –but essentially equivalent – point of view and ascribe the magnetic adjustment effect to fluctuations in thermal energy sufficient to cause irreversible rotations in small volumes of the material. The probability that the magnetization of a small volume will fluctuate by an amount δM due to a fluctuation in energy δQ is

$$\delta M \sim \exp -\delta Q/kT \tag{2}$$

One would expect the change ΔM in bulk magnetization of ferrite brick to vary in the same way, whereas it is found to vary **linearly** with T. This can be explained by assuming that the activation energy Q does not have a single value, but rather a **continuous range of values from** 0 **to** Q_m (this statement is equivalent to the statement that each grain has a slightly different coercivity).

In the same manner, one would naively expect the rate of the magnetization adjustment $d(\Delta M)/dt$ to be

$$\frac{d(\Delta M)}{dt} \sim \exp \frac{-t}{\tau} \tag{3}$$

whereas it is found to vary **linearly** with $1/t$. Street and Wooley show that the relaxation time τ is related to the activation energy Q in the following manner

$$\tau = \tau_0 \exp Q/kT \tag{4}$$

To the extent that the activation energy $0 < Q < Q_m$, one also has $\tau_0 < \tau < \tau_m$; this leads to relation (1).

STABILIZATION

Kronenberg and Bohlmann report that a magnet can be stabilized "completely" by "slow" partial demagnetization; **excessive or rather sudden demagnetization results in erratic behavior.** The proper demagnetization level is found to be between 5% and 15%. Incompletely magnetized magnets have a more stable remanence than fully magnetized magnets. **However, they are not as stable as those which are fully magnetized and subsequently demagnetized.**

References

[1] Kronenberg K.J. and Bohlmann M.A., Long Term stability of Alnico and Barium Ferrite Magnets, *J. of Applied Physics 31, 82S-84S (1960)*

[2] Street R. and Wooley, J.C., A Study of Magnetic Viscosity, *Proc. Phys. Soc.* **A62**, *562-572, (1949)*

[3] Néel Louis, Théorie du Trainage Magnétique des Substances Massives dans le Domaine de Rayleigh, *J. de Phys. et Radium, 11,49-61 (1950)*