

The Field in the FFTB Permanent Dump Magnets

We discuss the expected central field strength, and field profile in the midplane of the permanent dump magnets based on a simple model. We predict that widening the gap by 20% will reduce the peak field in the magnets by only 8%.

The dump magnets we consider are two-dimensional C-magnets. The air gap between the permanent magnets is $\Delta x = 1.25''$ at present, the gap height is $\Delta y = 4''$, and the length of the pole face along the beam is $\Delta z = 36''$. Each pole is made of $T_{\text{mag}} = 6''$ -thick alnico magnets.

The iron of the yoke has a total path length over $50''$, which is sufficiently large that we ignore any H field inside the iron.

1 Central Field Value

In the simplest model we suppose the B field in the magnet gap is the same as the B field inside the permanent magnets, *i.e.*,

$$B_{\text{mag}} = B_{\text{gap}}.$$

Neglecting the H field in the iron, the condition $\oint H = 0$ applied to the line $y = z = 0$ (where the field is maximum) tells us that

$$H_{\text{mag}} = -\frac{\Delta x}{2T} B_{\text{gap}} = -\frac{\Delta x}{2T} B_{\text{mag}} = -0.104 B_{\text{mag}},$$

where the numerical value holds for the present configuration of the magnets.

In the summary of maps of the dump magnets dated 10/4/79, the typical peak field integral is 0.49 T-m. I take the effective length of the magnets to be $\Delta z + \Delta x = 37.25'' = 0.95$ m, so the peak field is actually about 0.52 T.

Figures 1-3 show magnetization curves for eight types of alnico material, taken from the book 'Permanent Magnets and Their Application,' by R.J. Parker and R.J. Studders (Wiley, 1962). I have added lines showing $H = -0.104B$ and $H = -0.125B$. I do not know which type of alnico was used in the dump magnets, but type 7 is perhaps the best guess, especially since a rule of thumb is that a permanent magnets operating point should be chosen where the product BH is a maximum. For type-7 alnico we would then expect a peak field of 0.54 T for the magnet as configured.

Suppose now that the gap is widened to $\Delta x = 1.5''$. Now we expect that $H = -0.125B$, and if the magnet is type-7 alnico, the operating field would drop to 0.50 T, an 8% loss of peak field compared to the present configuration.

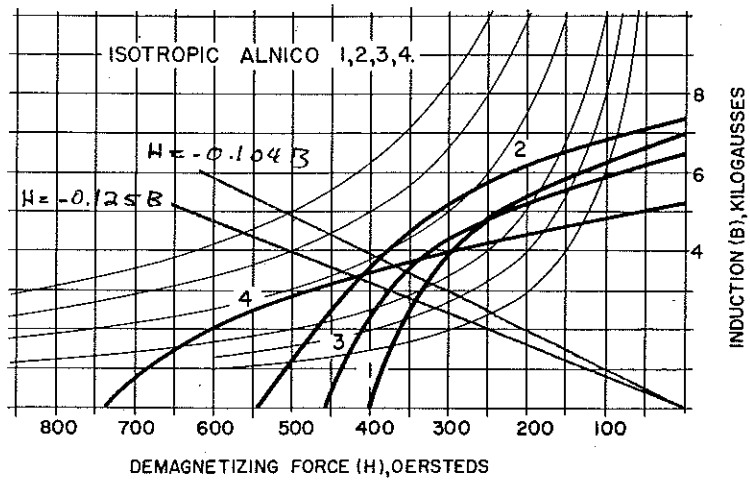


Figure 3-16. Demagnetization curves of isotropic grades of Alnico.

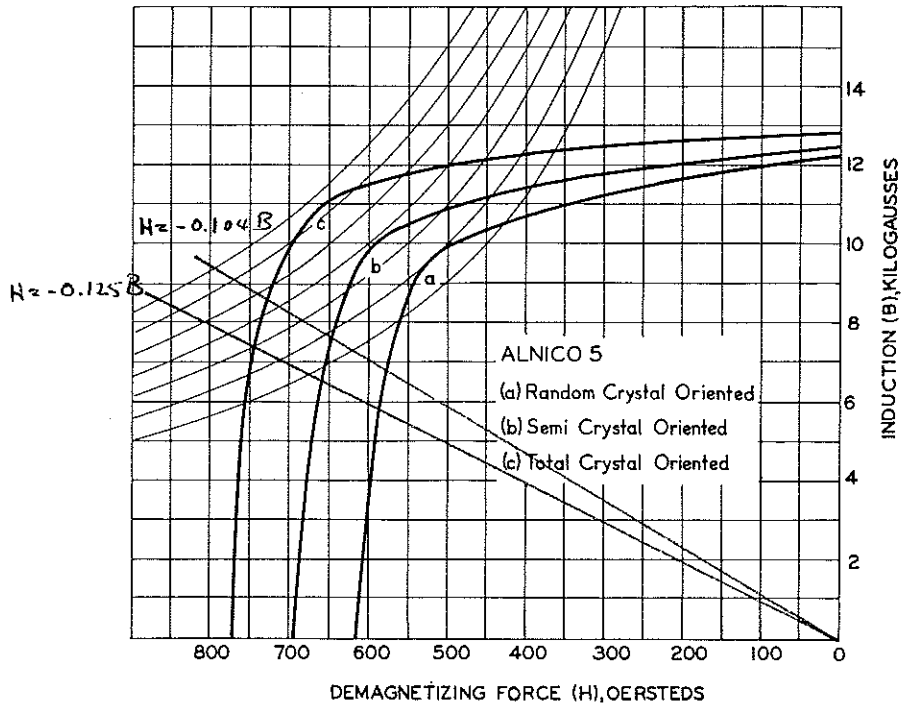


Figure 3-18. Effect of crystal orientation on magnetic characteristics of Alnico 5.

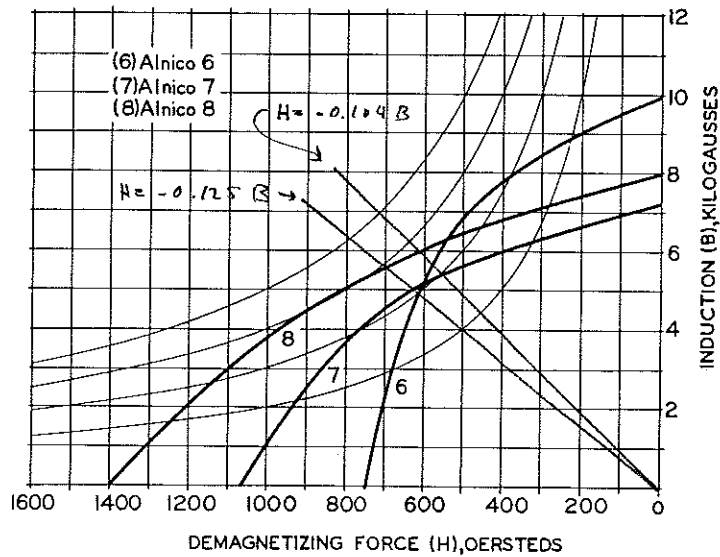


Figure 3-19. Demagnetization curves of high coercive force anisotropic Alnico.

2 Field Profile in y at $x = 0$

We next model $B_x(x, y)$, supposing that the magnetization M inside the alnico is uniform. In this model the source of the magnetic field can be taken as a sheet of magnetic charges of density

$$\sigma = \mathbf{M} \cdot \mathbf{n} = \frac{B_{\text{mag}} - H_{\text{mag}}}{4\pi} = \frac{B_{\text{gap}}}{4\pi} \left(1 + \frac{\Delta x}{2T}\right). \quad (\text{pole face})$$

in cgs units on each pole face of the magnet.

There is also an effective magnetic charge density at the interface between the alnico and the iron yoke. Here the charge density at the surface of the alnico is just the negative of that given above. At the surface of the iron where $H_{\text{iron}} \approx 0$, the magnetic charge density is just $B_{\text{gap}}/4\pi$. The net charge at the interface is then

$$\sigma = -\frac{B_{\text{gap}}}{4\pi} \frac{\Delta x}{2T} \quad (\text{iron-alnico interface}).$$

We now calculate the field due to these effective magnetic charges, assuming the magnet to be two-dimensional. First recall the elementary result that a line charge of density Q per cm at (x', y') leads to the magnetic field

$$\mathbf{B}(x, y) = 2Q \frac{(x - x', y - y')}{(x - x')^2 + (y - y')^2}.$$

Next we consider a surface of (negative) charge density $-\sigma$ per cm^2 at $x' = a$ extending from $y' = -b$ to $+b$. For our magnet, $a = \Delta x/2 = 0.625''$, and $b = \Delta y/2 = 2''$. Integrating over the surface we find

$$\begin{aligned} \mathbf{B}(x, y) &= 2\sigma \int_{-b}^b dy' \frac{(a - x, y' - y)}{(a - x)^2 + (y' - y)^2} \\ &= 2\sigma \left(\tan^{-1} \left(\frac{y + b}{a - x} \right) - \tan^{-1} \left(\frac{y - b}{a - x} \right), \frac{1}{2} \ln \frac{(b + y)^2 + (a - x)^2}{(b - y)^2 + (a - x)^2} \right). \end{aligned}$$

Similarly, a surface charge density $+\sigma$ at $x' = -a$ of the same extent in y' leads to

$$\mathbf{B}(x, y) = 2\sigma \left(\tan^{-1} \left(\frac{y + b}{a + x} \right) - \tan^{-1} \left(\frac{y - b}{a + x} \right), \frac{1}{2} \ln \frac{(b + y)^2 + (a + x)^2}{(b - y)^2 + (a + x)^2} \right).$$

Finally we add the small correction due to the effective charges at the alnico-iron interface:

$$\mathbf{B}(x, y) = \mp 2\sigma \left(\tan^{-1} \left(\frac{y + b}{a + T \mp x} \right) - \tan^{-1} \left(\frac{y - b}{a + T \mp x} \right), \frac{1}{2} \ln \frac{(b + y)^2 + (a + T \mp x)^2}{(b - y)^2 + (a + T \mp x)^2} \right).$$

For our example with $a = 0.625''$, $b = 2''$ and $T = 6''$, we find $B_x(a, 0) = 0.89B_{\text{gap}}$, so the model is not completely self-consistent. However, it may still yield a reasonable estimate of the shape of the profile $B_x(0, y)$. Using the expressions for the effective surface charge density we find

$$\begin{aligned} B_x(0, y) &= \frac{B_{\text{gap}}}{\pi} \left[\left(1 + \frac{a}{T}\right) \left\{ \tan^{-1} \left(\frac{y + b}{a} \right) - \tan^{-1} \left(\frac{y - b}{a} \right) \right\} \right. \\ &\quad \left. - \frac{a}{T} \left\{ \tan^{-1} \left(\frac{y + b}{a + T} \right) - \tan^{-1} \left(\frac{y - b}{a + T} \right) \right\} \right]. \end{aligned}$$

The peak values $B_x(0,0)/B_{\text{gap}}$ are 0.872 and 0.845 for the cases $a = 0.625''$ and $a = 0.75''$, respectively, supposing $b = 2''$ and $T = 6''$. Figure 4 gives plots of $B_x(0,y)/B_x(0,0)$ for the two gaps. The predicted falloff of the field with y is slightly faster than that reported in the magnet maps of 10/4/79.

In both cases we find

$$\int_0^{\infty} dy B_x(x,y) = 2'' \cdot B_{\text{gap}}$$

to good accuracy. This implies that the P_t kick for particles leaving the **top** or **bottom** of the dump magnets will be essentially unchanged when the gap is widened, even though the kick of particles leaving the ends of the magnets is reduced.

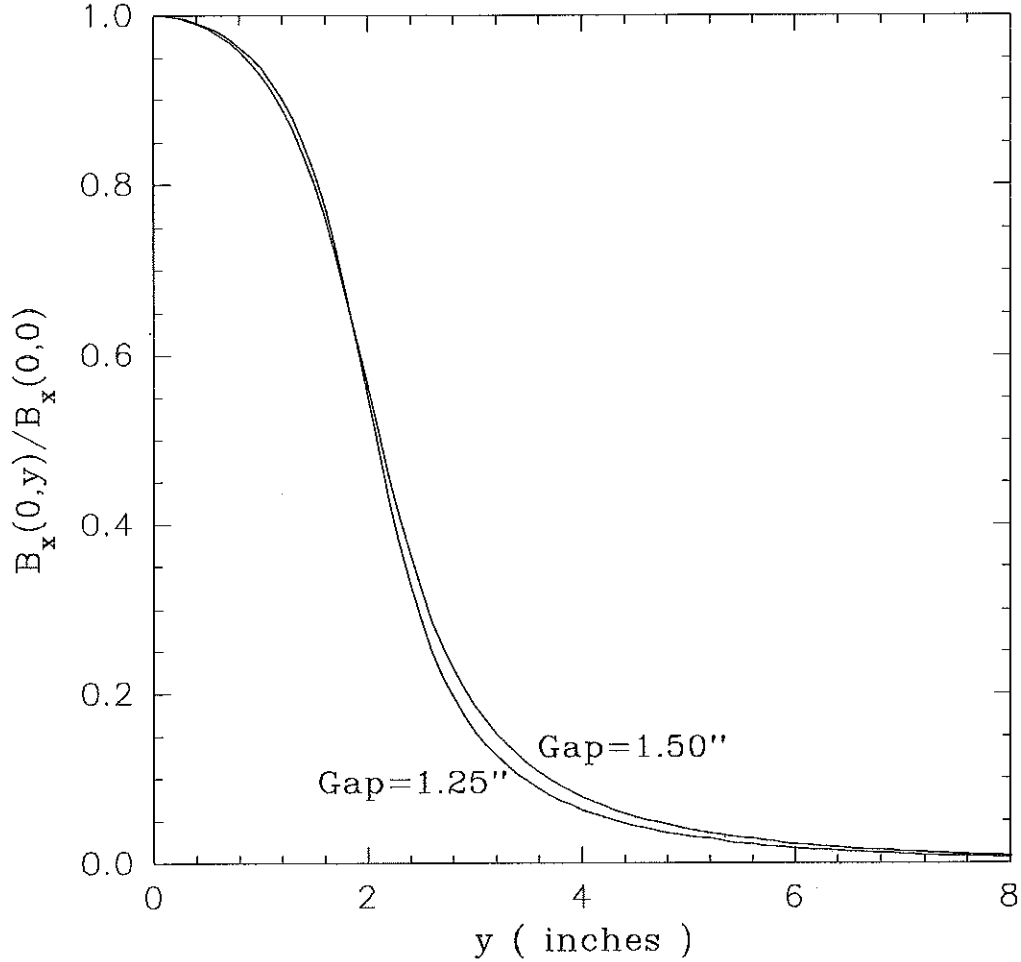


Figure 4: Normalized field profiles calculated for the midplane of the dump magnets for two gap widths.

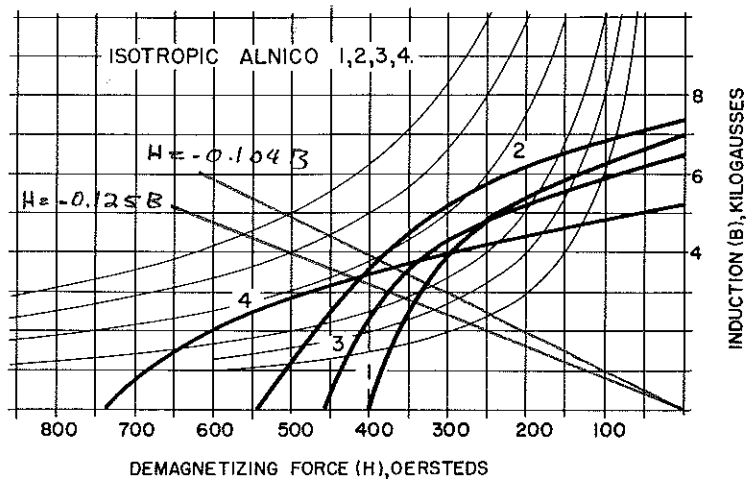


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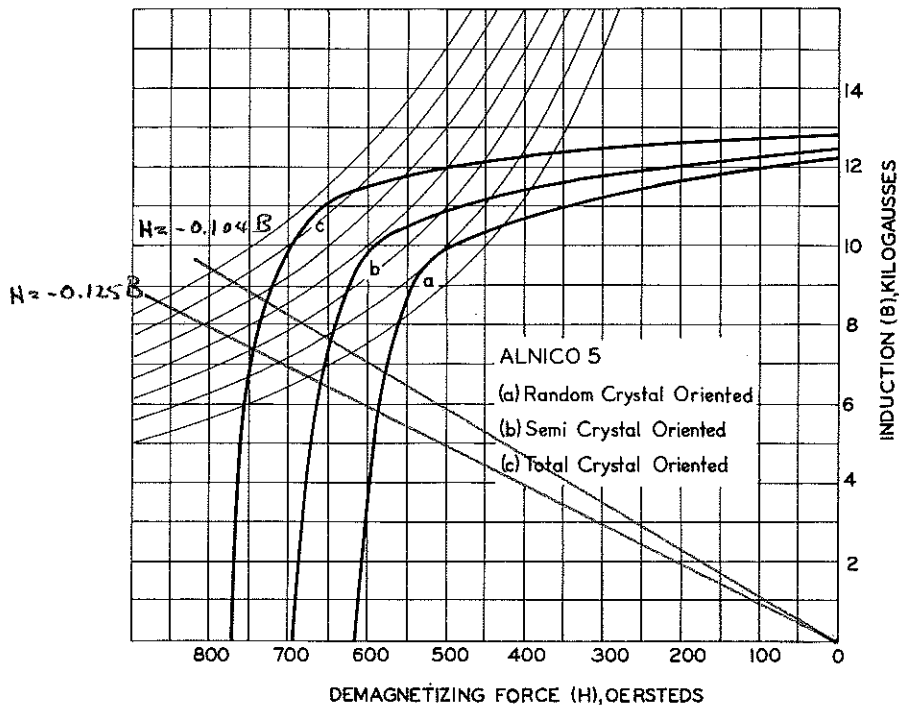


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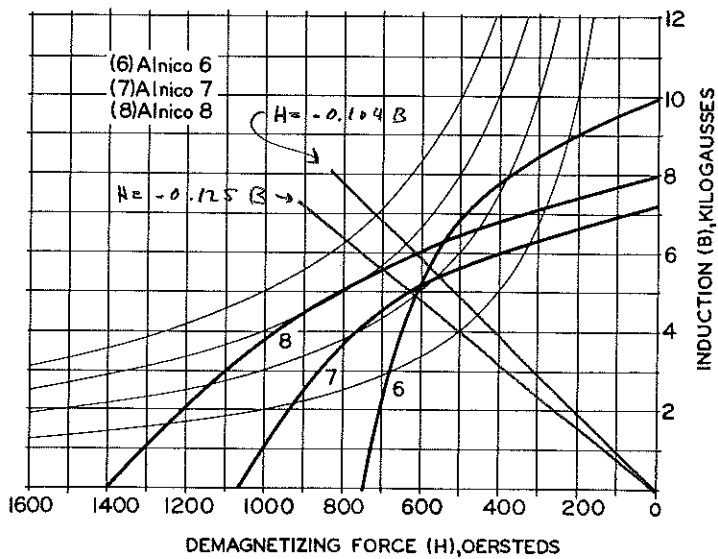


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