

# Stabilization and Calibration of Permanent Magnets

Presented by  
Steve Constantinides, Director of Technology  
Arnold Magnetic Technologies

at the



Our world touches your world every day...

1

- Dependable magnetic output is defined as all the flux desired, where you need it and at the full range of temperature of the application.
- To achieve these goals often requires pre-conditioning a magnet so subsequent loss in flux is minimal or in treating the magnet so that its output falls in a narrow range.

## Definitions - 1

- Thermal Stabilization
  - The exposure of magnets to elevated (or, for ferrite, low) temperatures such that subsequent exposure to the same temperature results in negligible additional change in (flux) output
- Magnetic Calibration
  - The partial knockdown of each magnet within a batch of magnets such that the entire batch exhibits similar magnetic (flux) output



- The reasons for performing these procedures are evident in the definitions.

### THERMAL STABILIZATION

- Where magnets will be exposed to elevated temperatures, or low temperatures in the case of ferrites, as a pre-treatment to stabilize the magnet. This pre-treatment reduces in-use performance drop to a minimum.

### MAGNETIC CALIBRATION

- Batches of magnets, either a single shipment, shipments over a few weeks or shipments over several years, should perform similarly. To do so requires conformance to an acceptable range of magnetic (flux) output.
- Generally accepted ranges in output for a specific grade vary between +/-3 to +/-5% for Br and +/-7 to 10% for flux.
- When an application requires a tighter tolerance in output, it is necessary to perform some type of selection or treatment process. Because the materials are quite costly, a treatment process is most often more desirable than the selecting-and-rejecting alternative.
- Magnetic calibration can reduce the variation in flux output to as low as +/-1/2% though +/-2% is much more common.
- Magnetic calibration has the added benefit of being able to reduce out-of-spec high product to an acceptable output flux level.

## Definitions - 2

- Reversible Magnetic (Flux) Output
  - That portion of the change in output due to the intrinsic characteristics of the material and is characterized by Reversible Temperature Coefficient of Induction
- Irreversible Magnetic (Flux) Output
  - Loss in output caused by exceeding critical operating parameters or by structural change in the magnetic material



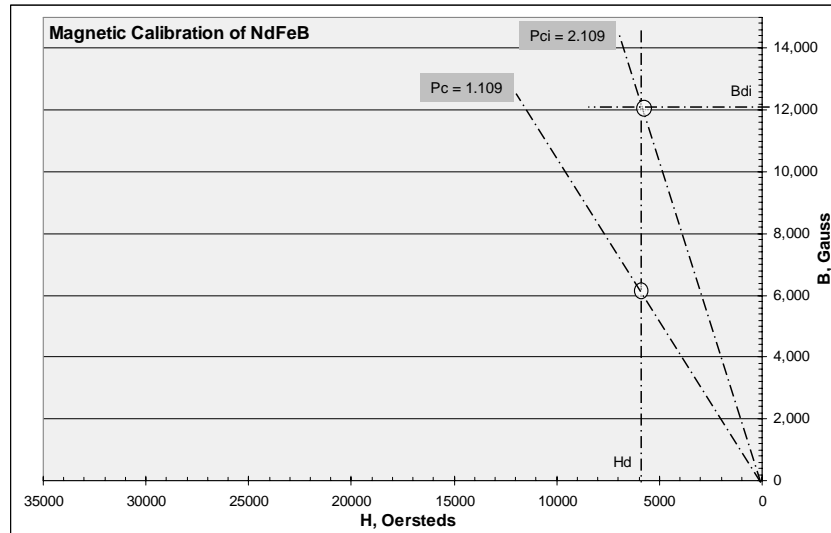
- Stabilizing a magnet reduces or eliminates the irreversible portion of flux loss.
- The reversible portion is due to fundamental material characteristics defined by the Reversible Temperature Coefficient of Induction

## Magnetic Calibration

- Magnetic Calibration is achieved by applying a reverse field to the magnet sufficient to reduce the (flux) output to an acceptable range.
  - This implies the magnet must be measured after the reverse field application
  - It may be necessary to repeat the field application and measurement multiple times
  - This process is often automated and controlled by sophisticated computer algorithms
  - Output tolerance is limited by numerous factors such as magnet field measurement technique, speed of operation, ambient temperature controls, magnetic noise, variability of input material, etc



## Method – 1



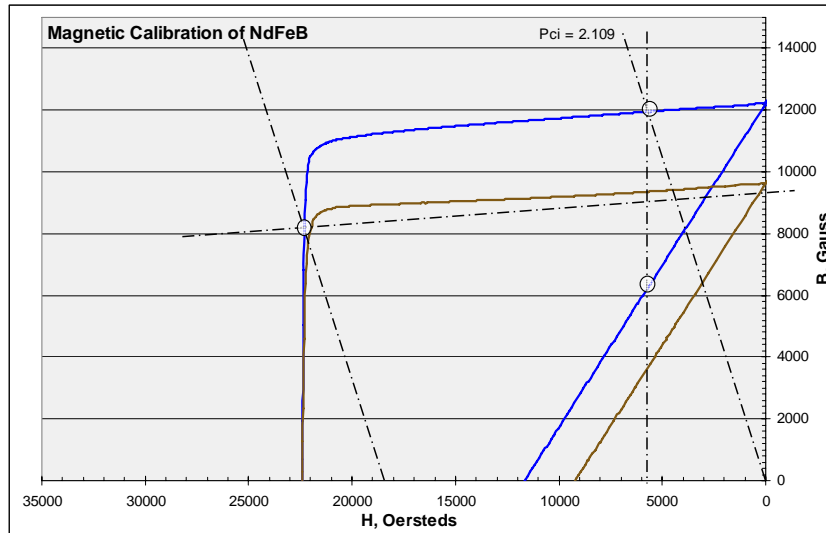
Our world touches your world every day...

5

- Here we will build the explanation for how it works. We start by identifying a magnet, measuring it dimensionally, making select calculations and finally by performing a hysteresisgraph measurement.
- The first measurements are for dimensions and Helmholtz flux.
- The first calculations are for  $P_c$ ,  $P_{ci}$ ,  $B_{di}$  and  $H_d$ .
- $P_c$  is the Permeance Coefficient. It is the slope of the dashed line. The slope is  $B/H$  (CGS). While it is a negative slope, we generally ignore the sign.
- $P_{ci}$  is the Intrinsic Permeance Coefficient, abbreviated  $P_{ci}$  and is  $1+ B/H$  in the CGS system. Both  $B$  and  $H$  can be converted to SI units for slopes consistent with SI demagnetization graphs.
- These values can be represented on a blank hysteresisgraph chart as shown here.



## Method – 3



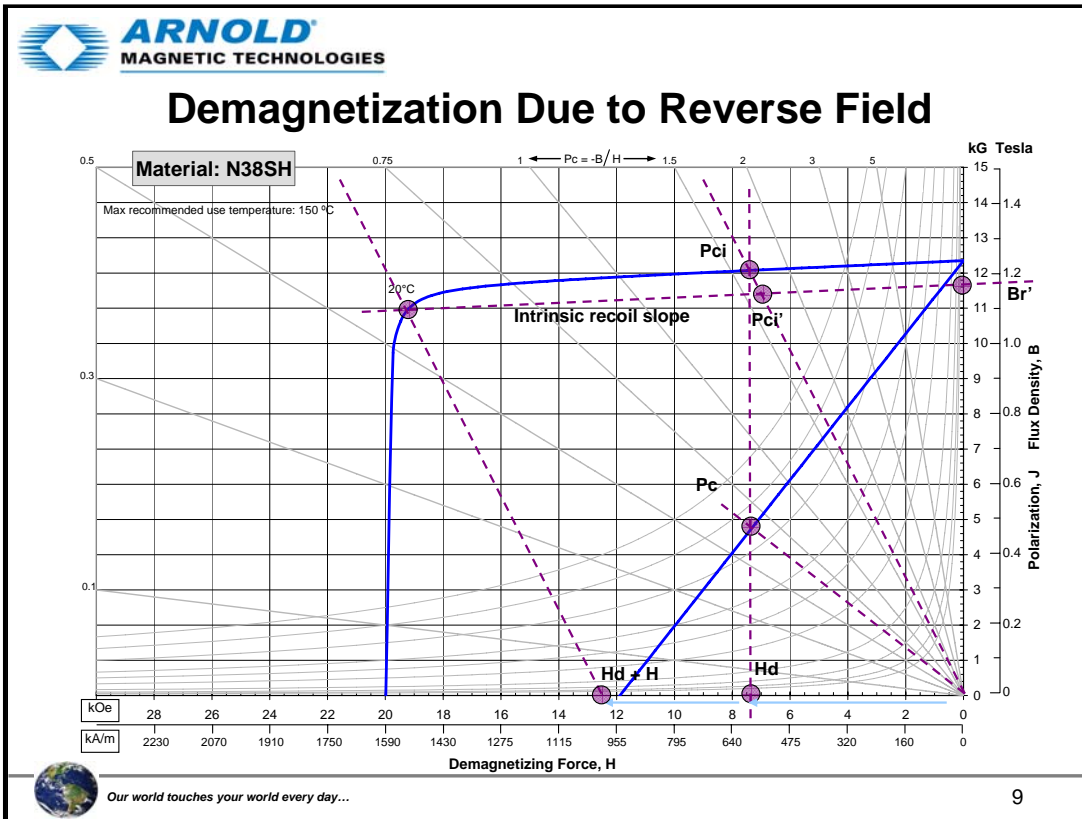
Our world touches your world every day...

- After the magnet has been knocked down with a reverse field of 18,400 oersteds, it is re-measured in the hysteresisgraph and plotted. It is represented here by the dark brown line and shows the measured  $B_r$  to be 9,600 gauss.
- The net result is that this magnet, in free space, can be exposed to any field up to 18,400 and not see additional reduction in flux output.

## Method Reviewed and Expanded

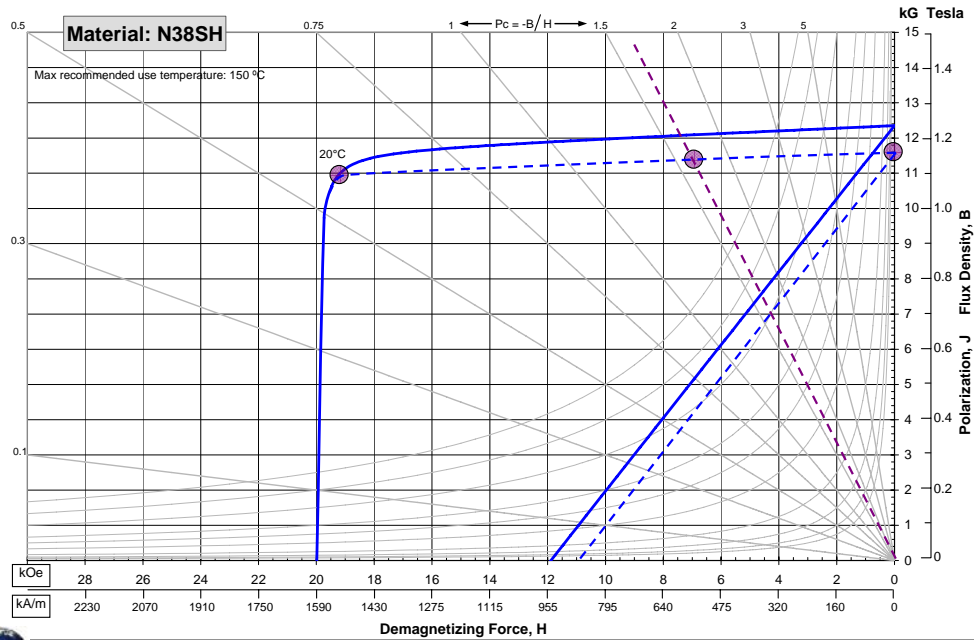
- In the next several slides, we'll start with a group of magnets and show what happens when the calibration method is applied





- $P_c$ : The Permeance Coefficient is calculated. In our example it has a value (slope) of about 0.65. (We ignore the negative sign).
- $P_{ci}$ : The Intrinsic Permeance Coefficient is  $P_c + 1$  or about 1.65. Where these Operating Lines intersect the Normal and the Intrinsic curves, we have the Normal and the Intrinsic Operating Points. The slope of the  $P_{ci}$  line is due strictly to the geometry of the magnet (or magnetic circuit).
- $H_d$ : The internal (self) demagnetizing stress is approximately 7.3 kOe. Both the Normal and the Intrinsic Operating Points fall on the vertical line above this value.
- $H_d + H$ : When an external field is applied, the magnitude of that field is added to the internal demag stress. Since the geometry of the magnet has not changed, the  $P_{ci}$  slope remains unchanged. We draw a line with the same slope but with the origin shifted to the  $H_d + H$  point on the H axis.
- The intersection of this new  $P_{ci}$  line with the Intrinsic curve is intentionally selected to be just over the knee of the curve.
- When a line is drawn from this point back to the B axis, it is drawn with a slope equal to the Recoil Permeability minus 1 (called Intrinsic Recoil slope). For Neo magnets, this Intrinsic Recoil Slope is typically  $\sim 0.05$ .
- $Br'$ : Where this line intersects the B axis we have a new Remanant Induction point.
- $P_{ci}'$ : Where the recoil line intersects the  $P_{ci}$  line, we have a new Intrinsic Operating Point. Note that the  $H_d$  value for this point is lower than the original value. That is, when a magnet becomes partially demagnetized, the internal demagnetizing force is also reduced.

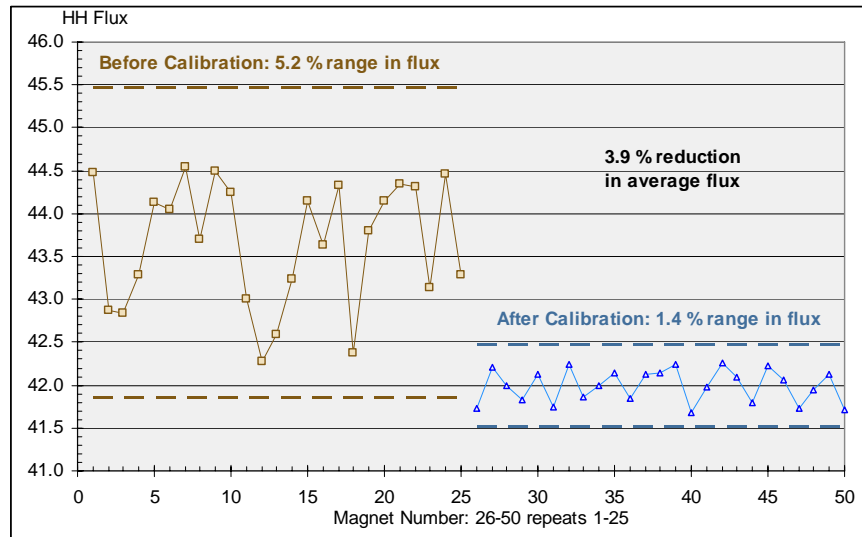
## Result of Calibration Treatment



Our world touches your world every day...

- As a result of the Calibration treatment, the material will exhibit a new demagnetization curve represented by the dashed line.

## Comparison of Before to After Calibration



- 25 magnets calibrated to a tighter distribution.
- Dashed lines are + and – 2.5 standard deviations.

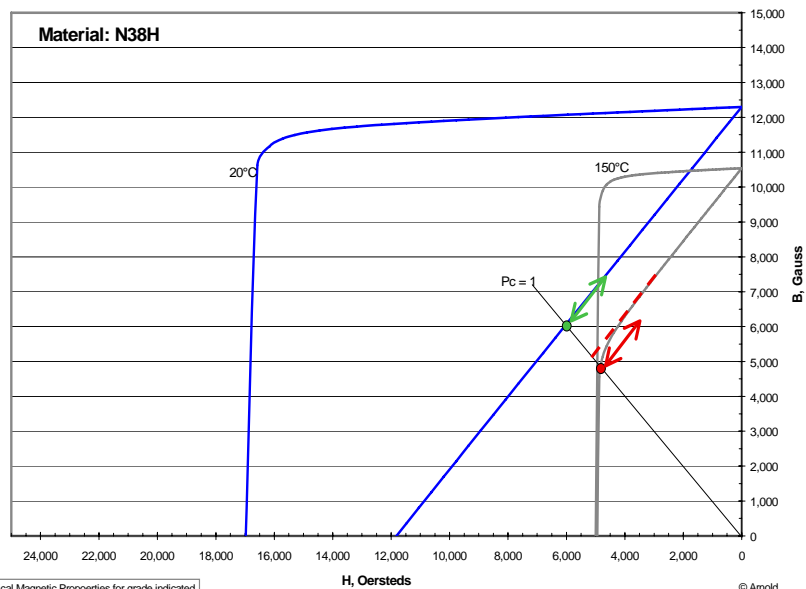
## Thermal Stabilization

- Thermal Stabilization is achieved by exposing a magnet or an assembly containing one or more magnets to temperatures at or slightly above the most extreme temperature expected in the application
- The length of time for exposure is dependent upon material and may also be affected by crystallization of plastics, curing of coatings or adhesives.
  - Exposure times are generally 1 to 2 hours with some situations requiring 8 or more hours treatment
  - Treatment temperature is usually 5 to 15 °C greater than the application extreme temperature
- Magnetic and Thermal treatments affect materials differently
  - While the treatments are not analogous of each other, a combination of magnetic and thermal knockdown can be used to achieve thermal stabilization.



- Selected treatment temperature is most often due to risk assessment.

## Demagnetization Due to Temperature

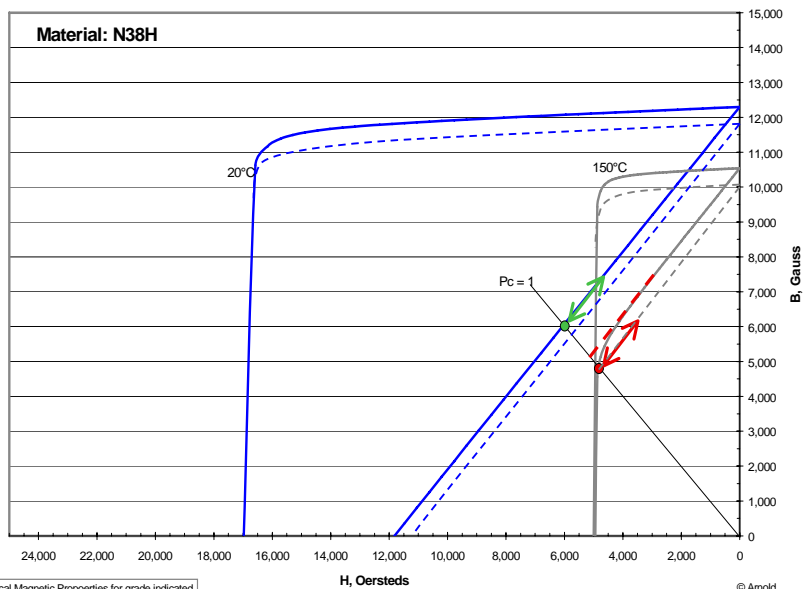


Our world touches your world every day...

13

- When no external magnetic field is applied, we can use either the Intrinsic or the Normal curve to show the affects of temperature - - most often the Normal curve is used.
- If, for example, a  $P_c = 1$  line is drawn on this plot of N38H NdFeB, the intersection with the Normal curves for 20 and 150 degrees would represent the Operating Points at each of those temperatures. They are indicated by the small green and red circles.
- In the application, when the  $P_c$  increases above 1, we see the Operating Point for 20 degrees move back and forth at the slope of Recoil Permeability, approximately along the Normal curve.
- At 150 degrees, however, the Operating Point moves along a line at a slope of the Recoil Permeability which is substantially below the Normal curve.
- There has been Irreversible Loss in magnetic output due to “exceeding the Knee” of the Normal curve.

## Demagnetization Due to Temperature



- If, after exposure to 150 degrees, the magnet is cooled to room temperature and re-measured, it will exhibit properties similar to the dashed blue lines.
- When the magnet is heated and measured at 150 degrees, the curve will look like the dashed gray lines.
- However, after the first drop from the solid blue to the dashed gray lines, additional losses due to exposure to temperatures at or below 150 degrees will be negligible.
- (The exception to this is structural change over time due to metallurgy or corrosion).

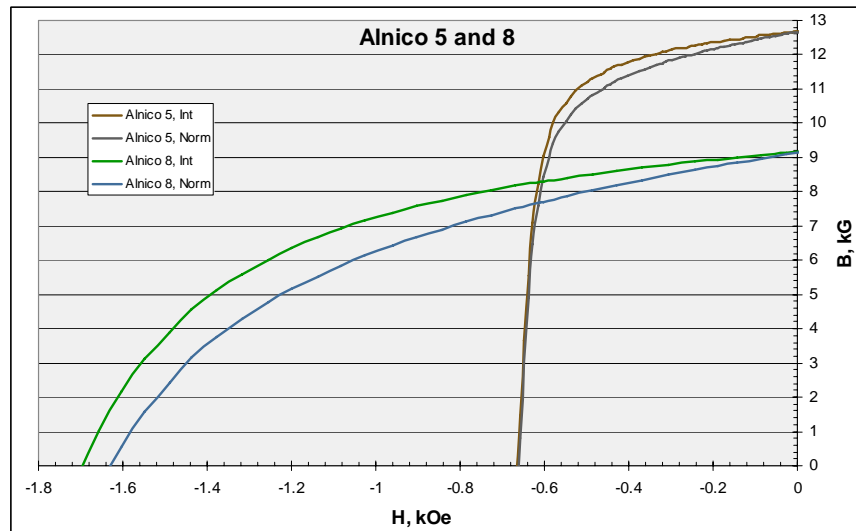
## Method

- Magnets (Individual)
  - Open Circuit
  - On ferromagnetic substrate
- Assemblies
  - Held in fixture or supported on a non-magnetic substrate



- Individual magnets are magnetized to saturation then placed on either a non-magnetic or a ferromagnetic substrate.
- In either case, spacing between magnets must be controlled and consistent.
- For (near) open circuit treatment magnets must be spaced far enough apart so they have minimal affect upon neighboring magnets. Spacing is typically 3 to 5 times the largest magnet dimension.
- It is impractical to space magnets so that nil affect is present. That distance is approximately 20 times the largest magnet dimension.
- The interior of the treatment oven should be constructed of non-magnetic stainless steel (300 series). Racks should also be non-magnetic stainless.
- When testing is performed by placing magnets on a ferromagnetic substrate, it is necessary to use material of consistent magnetic properties and size, especially thickness.
- To prevent damage (chipping) of the magnets a pad is frequently used between the substrate and the magnets. The pad thickness will affect the permeance coefficient and the degree of stabilization so must be selected carefully and remain consistent through all testing.
- Testing of assemblies is usually accomplished by supporting the assembly by a mechanical member, not by the magnets. Assemblies demonstrate their own operating characteristics of permeance coefficient requiring wide spacing between assemblies or one-per-oven treatment. Testing is almost always performed in the absence of adjacent ferromagnetic materials.
- Whatever test conditions are finally agreed to between vendor and customer, appropriate in-use evaluation should be performed and the procedures “locked-down.”

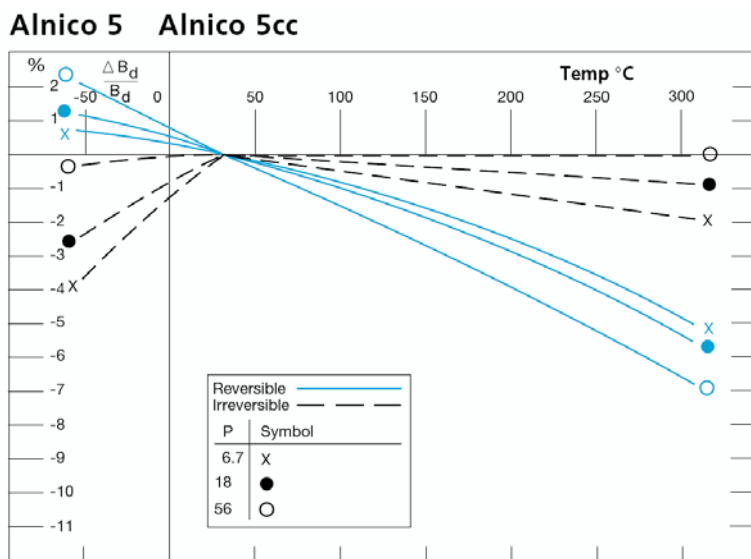
## The Special Case of Alnico



Our world touches your world every day...

- Alnico HcB and HcJ is almost the same for Alnico 5 and fairly close for alnico 8.
- Worded differently, the Normal and Intrinsic curves are similar.
- It has been the ordinary case to ignore the Intrinsic curve and make all measurements and calculations based on the Normal curve.
- Since alnico is not a square loop (or straight line) material, exposure to any demagnetizing field will result in both reversible AND irreversible loss.
- Arnold has for decades presented both quantities in its product literature as follows.

## Change in Alnico Flux with Temperature



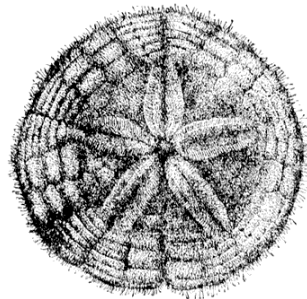
Our world touches your world every day...

17

- Confusing at first, the chart is quite straight forward.
- Once a temperature is selected and a permeance coefficient known, the chart can be consulted.
- Following down from the specified temperature, one can read both the percentage irreversible loss and the percentage reversible loss.
- Subsequent exposure to this same temperature will result in only the reversible loss.
- The example permeance coefficients are high at 6.7, 18 and 56 since alnico's are generally used at high Pc's.
- Note that the percentages shown are total percents. For example, Pc = 6.7 and temperature = 300 degrees C: irreversible loss is 2% (-0.007% per °C) and reversible loss is 5% (-0.018% per °C).



**Thank you !**



FEA from Permanent Magnet Motor Technology: Design and Applications, Jacek Gieras and Mitchell Wing, p.200



Our world touches your world every day...