PMAG Database Handbook

Properties of Magnets

Version 3

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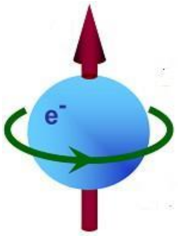

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ABSTRACT

Whether you are designing an automotive traction motor, wind power generator, washing machine motor, or loudspeaker, your product is only as good as the Permanent Magnet Material that you employ. To gain a competitive edge for your product, you need to identify the best grade of magnet that suits your specific requirements. This requires access to their magnetic properties, called *demagnetization curves*. It is hoped that this *PMAG* user manual will help you access them through MagWeb's PMAG Visualizer on the web.

So far, the demagnetization curves were available only as picture files such pdf, jpg, etc. But you cannot superpose them to *discover* the best grade. You cannot input picture files into your design software. You cannot easily locate the maximum energy point to minimize the cost. You cannot read values of the residual flux density precisely. What is more, with pdf files, you cannot precisely estimate a key metric for demagnetization onset, called *Demag Flux Density* (see Chapter 2,3). It is the flux density at the knee point beyond which irreversible losses are excessive. All these issues made the selection, design, or safe operation of magnets a non-trivial, and extremely difficult task. To address these issues, MagWeb prepared this *PMAG database* of a curated compilation of thousands of digital demagnetization curves of all magnet grades produced by major manufacturers worldwide. The *Digital* B(H) curves represent properties as a set of carefully digitized and equispaced data points.

With *PMAG,* the key metric *Demag Flux Density is automatically included in the digital data*. The *PMAG* Database can save you time in discovering the right magnet (and its manufacturer) that meets your specific requirements. You can use it to compare various properties of magnets. You can use it to minimize the cost of a magnet by identifying the maximum energy product point as well as the knee point. You can input the digital B(H) data into your design software. You can use it to simplify your magnet sizing calculations.

Magnet grades have several similarities but subtly differ with manufacturers. Different manufacturers use their secret recipes of ingredients, manufacturing techniques, and purity control methods to fabricate the magnets. So even if two magnets are stamped with the 'same grade label', their demag curves differ subtly. *PMAG* database lists properties of grades by their manufacturers so that you can better understand these subtle differences and select the right manufacturer.

***PMAG* hopes it will help you to discover an optimal permanent magnet and integrate it into your product, thereby gain a competitive advantage.**

DISCLAIMER

The ***PMAG*** database is the result of a multi-decade effort to digitize and compile hard-to-find magnetic property data from open sources/ publications. They include scientific literature, manuals, handbooks, textbooks, websites, federal databases, university records, old archives, manufacturer's catalogs, etc. MagWeb believes digitized data to be accurate and reliable. It is intended to support the user in making informed decisions on magnetic materials. MagWeb does not provide any warranty or support. MagWeb is not liable for any damages caused by using its database whether explicitly or implicitly. The sources and methods used to digitize the curves are confidential and proprietary. MagWeb reserves the right to change the data without notice.

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1. INTRODUCTION

Permanent Magnets are those that can attract iron[1]. They store energy (as in a pre-compressed spring). You use them in your daily life: in your computer disc drives, smartphones, TVs, loudspeakers, automobiles, washing machines, and refrigerators. Industry uses them in Traction Motors for electric vehicles, Wind Power Generators, Flight Control Systems, MRI Machines, Maglev Trains, Magnetic Clutches, Brakes, Solenoids, etc.

A magnet is made of fine powders of rare-earths and metals. Manufacturers use several methods (sintering, molding, casting, pressing, etc.) to make them. They measure its magnetic properties as Demagnetization Curve per IEC 60404-5. Major applications need high-grade magnets that can withstand high temperatures. So ***PMAG*** database centers and lists only those manufacturers who provide temperature-dependent demag curves.

1.1. B(H) Curve

Fig. 1 shows the B(H) curve of a typical magnet, at a particular temperature. It shows how flux density B [tesla] in a magnet varies with demagnetizing field aka magnetic field strength H [kA/m]). It contains a knee that smoothly joins 'reversible' (green) and 'irreversible' (red') segments. In the reversible segment, increasing H decreases B linearly; removing H returns the magnet to its initial state. The irreversible segment is waterfall-like[2] and nonlinear and indicates a demagnetized state that damages the magnet forever. A knee point k within the knee signals onset of demagnetization[3].

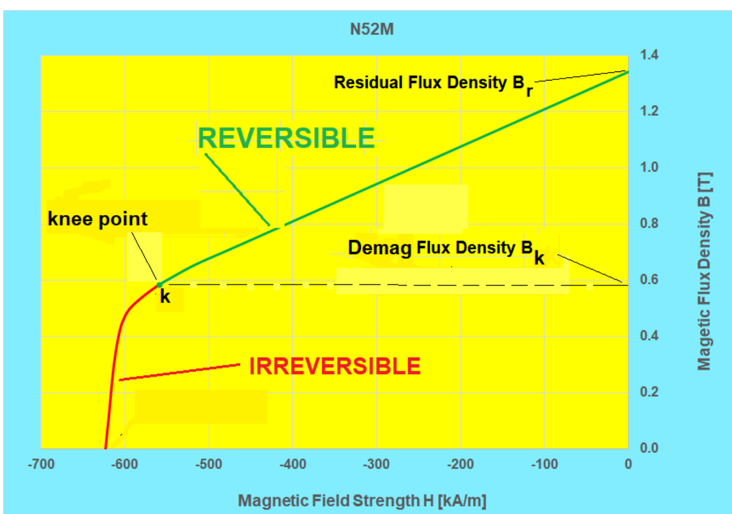


Figure 1. B(H) Curve of a Magnet. PMAG database furnishes the two key properties (B_r, B_k) that define the usable segment of a magnet.

[1] Electromagnets also attract iron, but only if energized.
[2] In this segment, the magnet transitions from 'hard' to 'soft'. It also has an inflection point of numerical instability.
[3] For most magnets operating at high temperatures, it will be in the 2nd quadrant. However it can also fall in the 3rd quadrant.

Residual Flux Density B_r quantifies a magnet's ability to create flux. It controls the torque capacity of a motor. It is the intercept of the B(H) curve with the B-axis. It defines the grade of a magnet. The 'knee point k' defines the point in the knee beyond which excessive and unacceptable demagnetization occurs. At k, on removing H, it returns to a point which reduces its B_r reduces by an *irreversible loss* δB_r that equals 1%·B_r.

Demag Flux Density B_k (aka knee flux density) is the flux density at the knee point k. It is the point where the magnet will lose 1% of B_r. Operating above the knee point prevents the magnet from degenerating to a lower grade forever[4]. Thus the ability of a magnet to create flux and simultaneously resist its demagnetization is quantified by the pair (B_r, B_k). Both properties are needed to design a magnet such that it produces the needed torque, yet will not demagnetize and degrade to a lower grade.

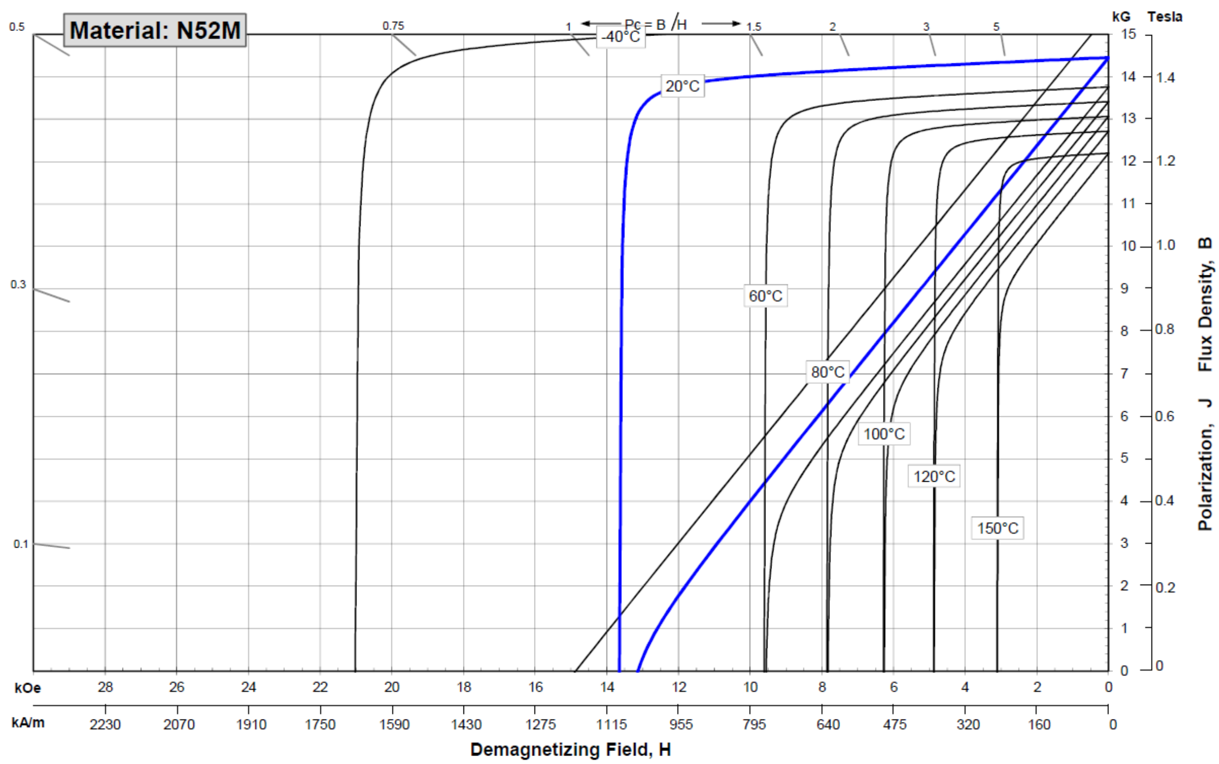


Figure 2. Typical Demagnetization Chart. It clutters J(H) curves with B(H) curves, obscuring the knee point of the magnet.

[4] Rao, D.K. and Bagianathan, M., Selection of Optimal magnets for Traction Motors to prevent Demagnetization, Machines, 2021, Vol.No.24, Paper No. 9060124, 2021.

1.2. *Demag Flux Density (aka Knee Flux Density)*

Fig. 2 shows a typical demagnetization chart provided by manufacturers, over a wide temperature range. It shows both B(H) mixed up with the J(H) curve. But these curves intersect each other at umpteen places. All such intersection points obscure the key knee point k beyond which the magnet cannot be used.

Fig. 3 shows MagWeb's alternative representation. It contains only B(H) curves and highlights the key ***Demag Flux Density*** $\boldsymbol{B_k}$ demarking the usable or Safe Operating Area (green) from the useless or demagnetized segment (red). The value of B_k reflects a magnet's vulnerability to demagnetization as temperature increases. Higher the B_k, the poorer the demagnetization resistance.

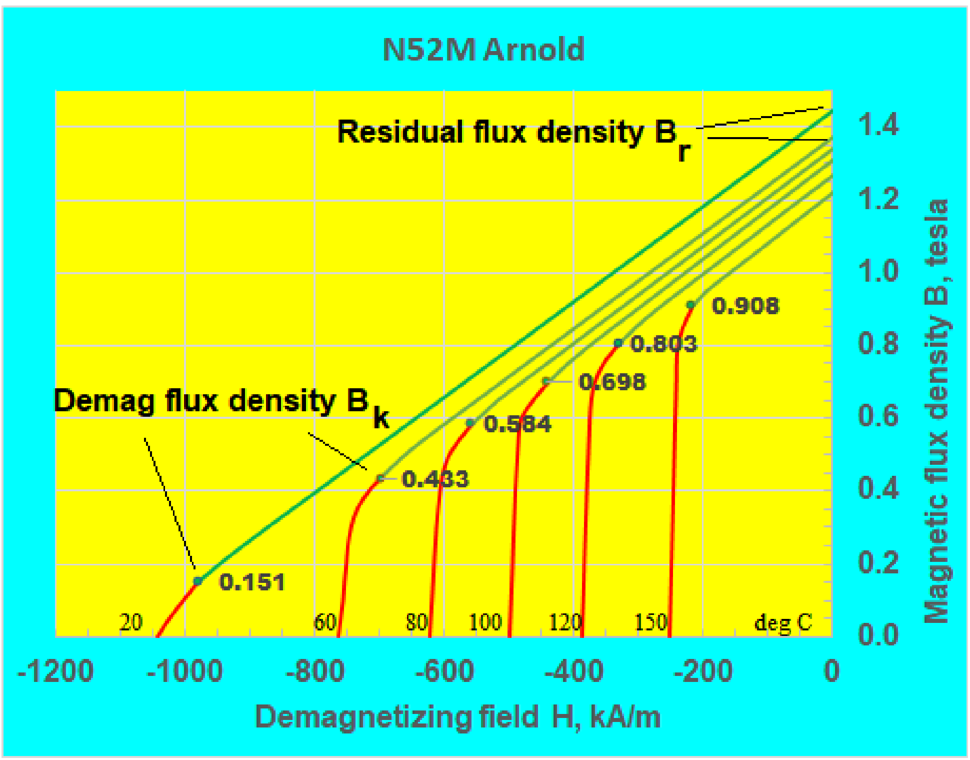


Figure 3. PMAG's B(H) Demagnetization Curves include Demag flux density $\boldsymbol{B_k}$

For example, consider a PM motor using Arnold N52M grade. At 100C, its SOR is (B_r, B_k) = (1.312,0.698)T = 1.005 ±0.307 T. If its temperature rises to 150C, its SOR shifts to (1.22,0.908)T = 1.064 ± 0.156 T. So increasing magnet's temperature from 100C to 150C halves the dynamic load capacity (from ±0.307 to ± 0.156T).

The ***PMAG*** Database stores the B(H) data points in excel files. Appendix A, Fig. 14 describes the format used by MagWeb to store the B(H) data.

1.3. Significance

MagWeb's ***PMAG*** database is a large and unique compilation of digital demagnetization curves. It contains about 5000 temperature-dependent digital demagnetization curves of hundreds of grades that are made by dozens of manufacturers. It puts the vital magnet properties of all permanent magnets at your fingertips. Typical benefits of using the ***PMAG*** database are:

- Improve Performance:
  - Compare properties of same-grade magnets by various manufacturers
  - Discover Optimal Grade that best suits your requirements.
  - Determine BH_{max} of any grade
  - Save on cost by choosing the right operating point
- Improve Demagnetization Resistance or heat resistance:
  - Limit irreversible loss and develop optimal fault diagnostics.
  - Identify B_r of a magnet at your machine temperature.
  - Superpose B(H) Curves to compare the same grades.
  - Input digital B(H) data into your Computer software.
  - Assist in reliable design against short-circuit fault.

Largest Database. Different manufacturers offer magnets at various grades. Some of these grades are deemed 'equivalent' and assigned the same label, viz. N40UH. But their actual magnetic properties depend on several factors e.g. impurities, particle sizes, shapes, composition, quality control practices[5, 6, 7, 8, 9] so they differ. ***PMAG*** database lists manufacturer-dependent B(H) data of each grade. With it, the users can determine how the magnetic properties of a magnet can differ from the manufacturer, even though they carry the same grade label.

Demag Flux Density $\boldsymbol{B_k}$**.** It quantifies the resistance of a magnet to demagnetization. ***PMAG*** database lists the Demag Flux Density of any grade. Operating a magnet beyond its knee point k produces excessive irreversible demagnetization loss. (see Ch. 2, 3).

Computer Input. Demag curves supplied by manufacturers as picture files. They cannot be inputted into computer software. MagWeb's (H_i, B_i) digital data tables can be inputted into simulation software. The demag flux density data is built-in, so the software can

[5] See section 2.2 on how B(H) curves of same-grade Neo magnets vary with manufacturers.
[6] Benecki, W. T., What the heck happened to the Magnet industry?, *Magnetics Magazine*, Oct. 2015, http://www.magneticsmagazine.com/main/articles/what-the-heck-happened-to-the-magnet-industry/
[7] Mildrum H.F. et al, High Speed PM Generator Magnet Investigation - Rare Earth Magnets, AFWAL-TR-81-2096, http://www.dtic.mil/dtic/tr/fulltext/u2/a108550.pdf
[8] Strnat, K. L., Study of sintered magnets of Nd-Fe-B type, Report No. SLCET-TR-84-0458-F, 1989, http://www.dtic.mil/dtic/tr/fulltext/u2/a209185.pdf
[9] Quality Control, Magfine Corp., https://www.magfine.co.jp/eng/magnet/quality.html

display the precise demagnetized volume fractions of magnets thereby providing reliable protection against severe duties such as short-circuit [10],[11].

Superpose B(H) Curves. In the past, demag curves were created in diverse units, scales, and formats. This made it very difficult to discover which manufacturer offers a better grade. The digital demag curves in ***PMAG*** Database are created in standard SI units. This enables one to superpose of B(H) curves from different manufacturers. PMAG visualizer can provide such superposed plots which can help you to identify a better quality grade (see sec. 2.1).

Discover Best Grade. The designer uses several parameters (such as B_r, B_k, BH_{max}) to select a grade that suits his specific requirements. The ***PMAG*** Database can thus be used to investigate how various grades compare from such diverse perspectives.

Residual Flux Density B_r. It varies nonlinearly with temperature. Operating magnets require a precise value of residual flux density B_r at the continuous duty and overload duty temperatures. The ***PMAG*** allows you to determine B_r precisely at any temperature.

Demag Flux Density B_k. It defines the point beyond which a magnet will get demagnetized excessively. Operating above B_k prevents degradation of magnet to a lower grade. The ***PMAG*** database allows you to locate a grade that matches the specification of your machine.

Maximum Energy Product BH_{max}. This is useful in minimizing the volume and hence the cost of a magnet. The PMAG database can determine its location and how it changes with temperature. This allows you to minimize the cost of magnets.

In summary, this ***PMAG*** Database allows you to prevent the magnet from degrading to a lower grade during severe duty, to determine its usable range, to compare B(H) curves, to minimize their cost. All these benefits simplify your task of discovering the best grade that suits your requirements. This helps you to gain a competitive edge for your product.

[10] Kim, Y. H. et al, Study on optimal design of 210 kW IPMSM considering thermal demagnetization, *AIP Advances,* No. 8, 2018, https://aip.scitation.org/doi/pdf/10.1063/1.4994160。
[11] Sundaramahalingam, S., Finite element modeling and simulation of composite magnetic materials using ANSYS, IJITEE, Vol.8, June 2019, https://www.ijitee.org/wp-content/uploads/papers/v8i8/H6637068819.pdf

2. IMPROVE PERFORMANCE

This section describes how the ***PMAG*** database can be used to improve the performance of your machine. It shows how to discover an optimal magnet that best suits your specific requirements, thereby improving the performance of your machine.

In traction motors that drive electric vehicles, magnets operate at elevated temperatures that range from 100º C to 200º C. The primary requirement for a magnet is that it should produce the largest possible torque with the least potential for demagnetization. This amounts to saying that it should have the widest possible safe operating range at rated temperatures. That is, they should offer the highest B_r and lowest B_k. So designing traction motors needs accurate (B_r, B_k) at the rated temperatures. ***PMAG*** provides such data.

2.1. Manufacturer

In the early 1990s, the quality of Neo magnets produced by China used to vary widely. But over the past 10 years, the Chinese magnet industry has come of age. Today, many Chinese firms offer grades with very consistent properties at competitive prices. So the motor designers that employ these magnets in say traction motors have come to 'expect' that the same grade magnets, procured from different manufacturers, have the consistent properties within published tolerances. For example, recently, Vacuumschmelz achieved the aerospace and defense standard EN 9100 for consistent quality certification for its permanent magnets.

Till 2012, manufacturers used Dysprosium (Dy) up to 12% to improve the heat resistance or demagnetization resistance (i.e. Demag Flux Density) of UH, EH, and AH grades (that are used widely in EV motors). But at ~$300/kg, Dy is very expensive. Recently, to combat its high cost, different manufacturers developed different methods to lower the Dy to 7.5%.

These methods include grain boundary diffusion[12], grain size refinement, solid solution strengthening, etc. As result manufacturers use different % Dy to produce the same grade.

So the magnetic properties of a grade do vary with its manufacturers. This is hidden in their demagnetization curves. For example (in magnets that carry the same 'grade label') even if their residual flux density B_r is the same, their demag flux density B_k can differ. That is, the heat resistance of magnets from some manufacturers can be better than that of others carrying the same grade label.

Demag Flux Density Differs with manufacturer

[12] BJMT, Grain Boundary Diffusion, https://idealmagnetsolutions.com/knowledge-base/grain-boundary-diffusion/

For example, Fig. 4 compares the Demag Flux Density of the same N40UH grade at 180° C from 3 different manufacturers – TDK, Arnold, and HPMG. It shows that TDK's N40UH grade has a B_k of 0.291T, while HPMG's N40UH grade has a B_k of 0.393T.

This shows that HPMG's N40UH grade has 35% lower demagnetization resistance than TDK's N40UH grade. It demonstrates that even if manufacturers use the same grade label, one of them will have higher demagnetization resistance, so is the preferable choice. Thus one can use the Demag Flux Density B_k listed in the ***PMAG*** in this fashion to discover the manufacturer that offers a higher quality grade.

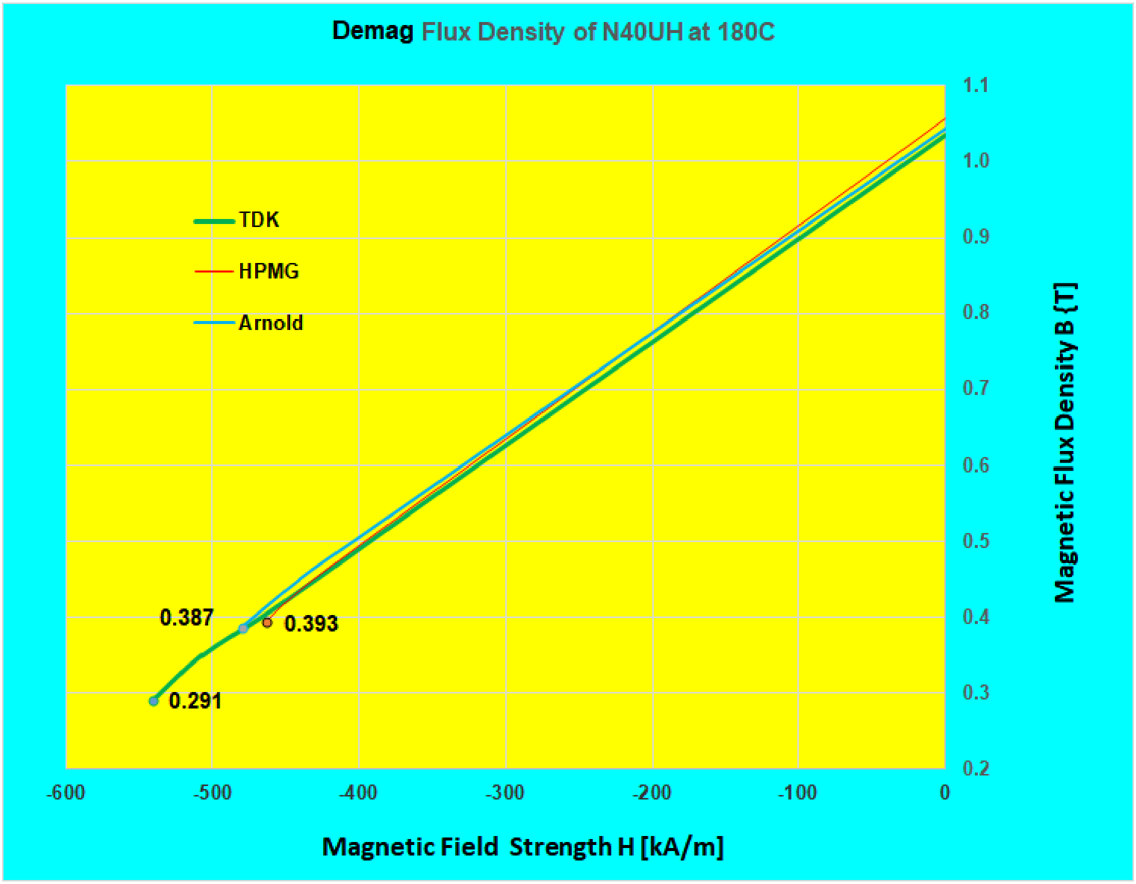


Figure 4. Demag Flux Density B_k varies significantly with its manufacturer.

2.2. Grade

PMAG database reveals that the energy product BH_{max} varies by as much as 20% in the same grade magnets produced by different manufacturers. That is, there will be a manufacturer whose grade offers 20% higher energy than others. Discovering such a manufacturer (without changing the grade) can lower the cost of a magnet.

Fig. 5 shows how the demag flux density of a magnet varies with a grade temperature rating. N40 denotes that all carry the same energy. But M, H, etc. indicate that they have different temperature capabilities. It shows that for N40, N40M grades (with ~100C capability) B_k clusters around ~ 0.65T. In contrast, that for N40H, N40SH (with higher ~150C capability) B_k clusters around ~0.3T. Thus it shows that using these high-temperature grades doubles the demagnetization resistance.

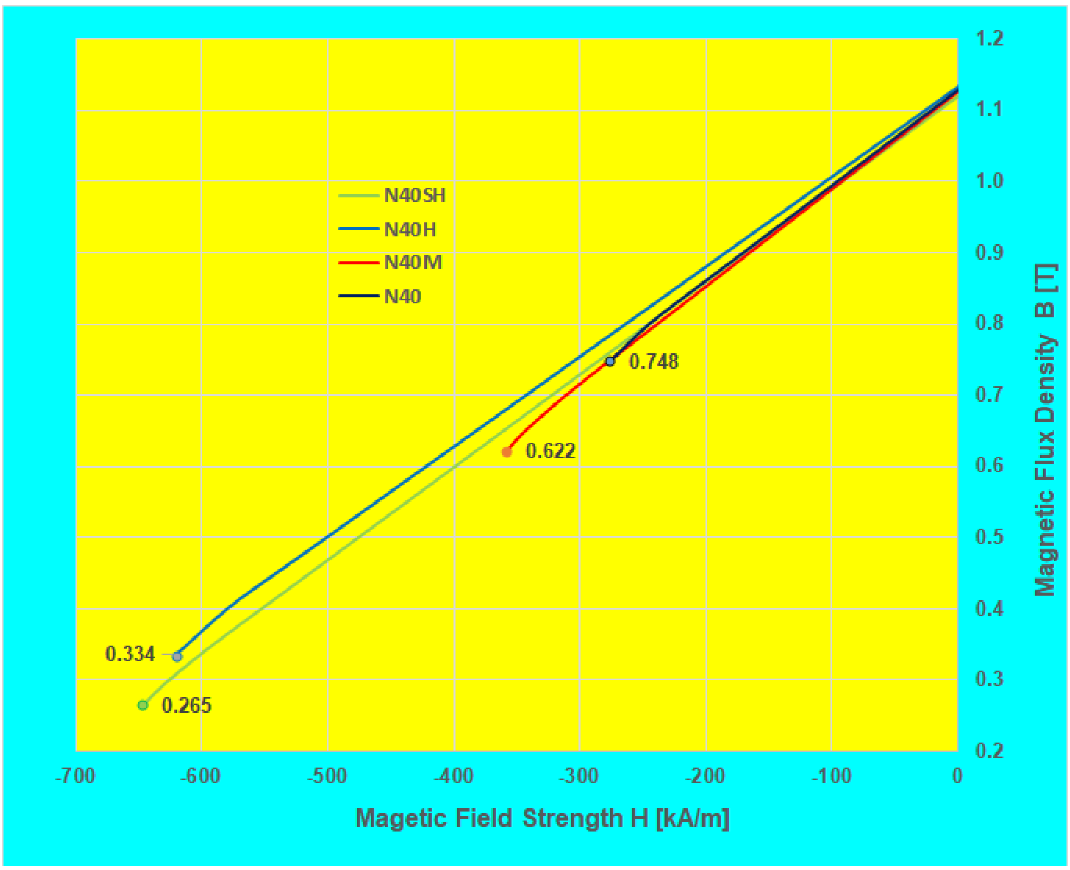


Figure 5. Demag Flux Density variation with a temperature rating of Grade.

Fig. 6 shows the effect of the energy of magnets (with different temperature ratings) on the Demag Flux Density. It shows that an increase in energy stored increases both residual flux density and demag flux density proportionately.

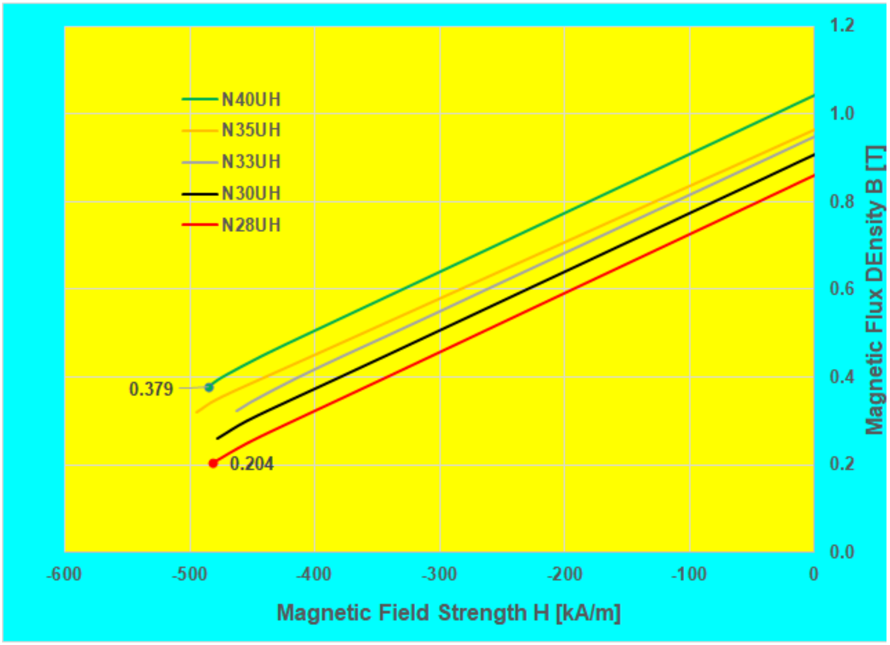


Figure 6. Demag Flux Density dependency on the Grade.

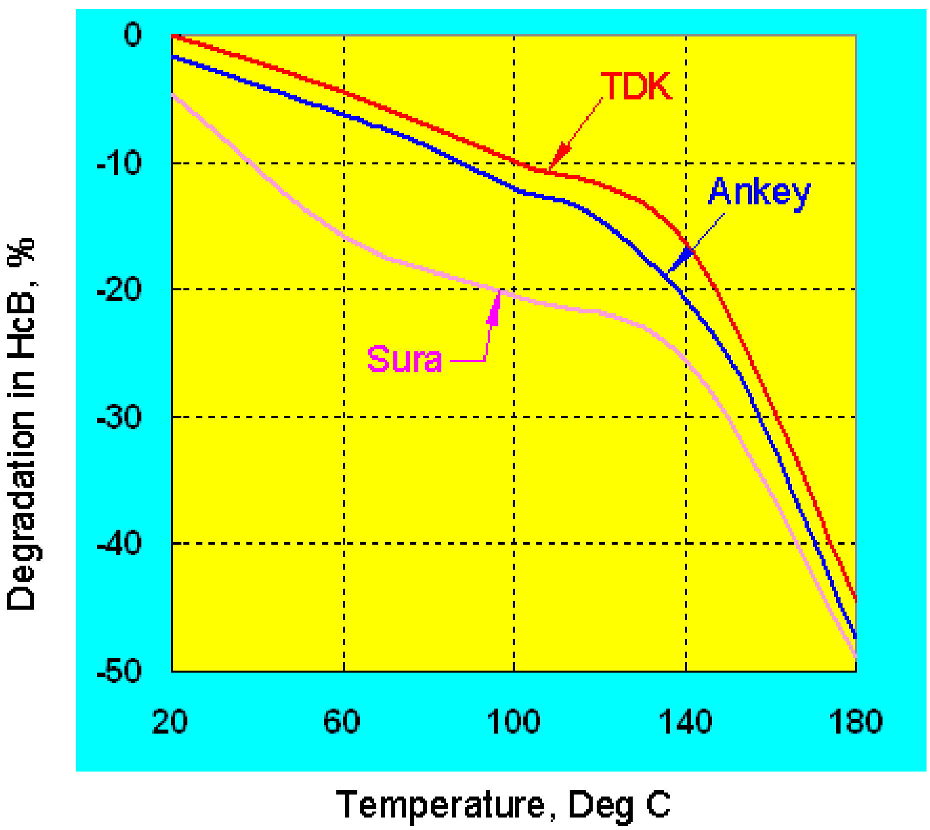


Figure 7. Coercivity Degradation of a Magnet Grade varies with the manufacturer.

Fig. 7 shows the effect of a manufacturer on the H_{cB} temperature coefficient. The y-axis shows the percentage degradation relative to a reference H_{cB} (-1000 kA/m for TDK at 20ºC). Thus ***PMAG*** database indicates that a H_{cB} temperature coefficient is highly nonlinear. The nonlinearity varies with the manufacturer. It reveals that using the linear temperature coefficients (that is usually provided by manufacturers) can produce misleading results.

2.3. Energy Product

BH Energy Product is the product of B [G] and H [Oersted]). It is expressed in MGOe; 1 MGOe equals 7.958 kJ/m^3. It characterizes energy density (the energy stored per unit volume) at a given H. A high BH_{max} indicates a smaller volume of the magnet is needed to store the same energy.

In a PM motor, the energy product BH of a magnet at its rated temperature determines its size[13] . To minimize the magnet cost, discover the manufacturer and grade of a magnet that needs the smallest volume to store the required maximum energy using the ***PMAG*** database. Then operate it close to this max. energy BH_{max} point [14].

A review of BH(H) Curves of hundreds of magnets revealed that magnets from only a handful of reputed manufacturers meet their maximum energy product specification. The ***PMAG*** database will help you spot such reliable manufacturers.

Most manufacturers do not publish the maximum energy product BH_{max} at elevated temperatures. So you can use the digital (B_i, H_i) data in ***PMAG*** to calculate BH at any temperature. ***The PMAG is the only database that helps you calculate BH_{max} for any magnet and any manufacturer at a specific temperature.***

[13] Todorov, G., and Stoev, B., Analytical model for sizing the magnets of permanent magnet synchronous machines, J Elec. Engg., Vol. 3, 2015, pp. 134-141.
[14] Krishnan, R., *Electric motor drives, modeling, analysis and control,* p. 518. Prentice-Hall, 2001.

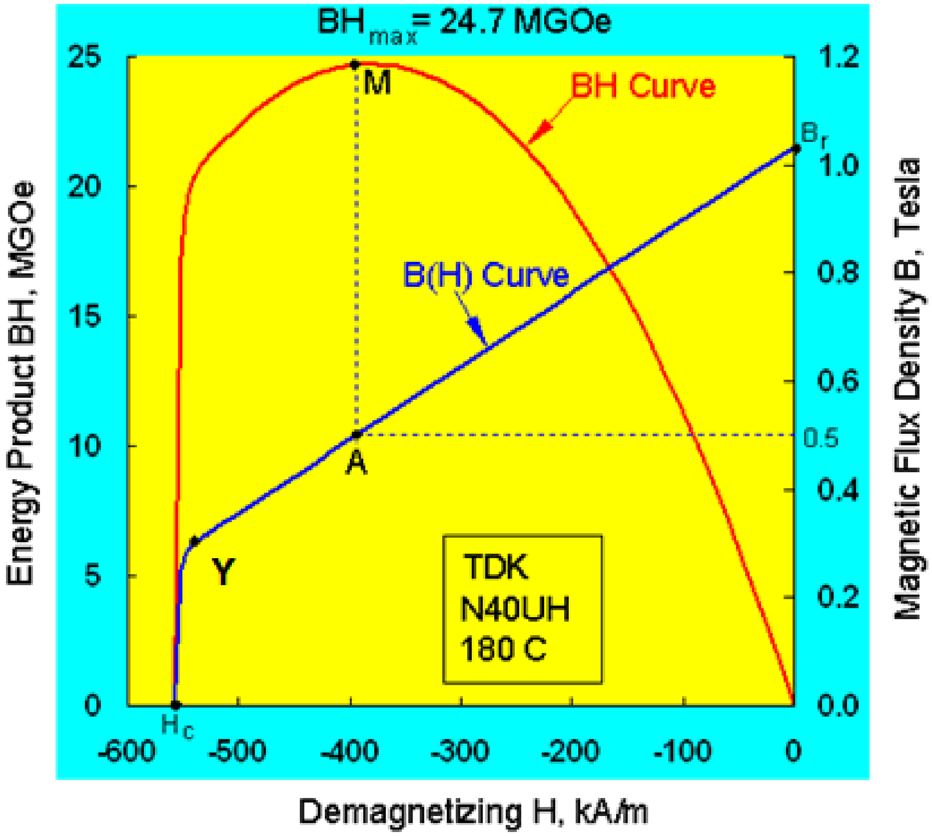


Figure 8. Energy Product Curve BH(H) indicates the point at which the magnet stores maximum energy. Operating it at the BH_{max} point minimizes the cost.

The BH can also be plotted against H. Fig. 8 shows the BH(H) curve for the N40UH magnet from TDK at 180º C. At point M the magnet attains maximum energy product. It corresponds to P on B(H) curve. This BH_{max} reduces with the temperature. An N40UH magnet at room temperature has BHmax = 40 MGOe. It also shows that the same magnet at 180C reduces to BH_{max} = 24.7 MGOe. Thus the magnet degrades energy-wise by ~40% when the temperature increases from 25 C to 180 C.

2.4. Cost

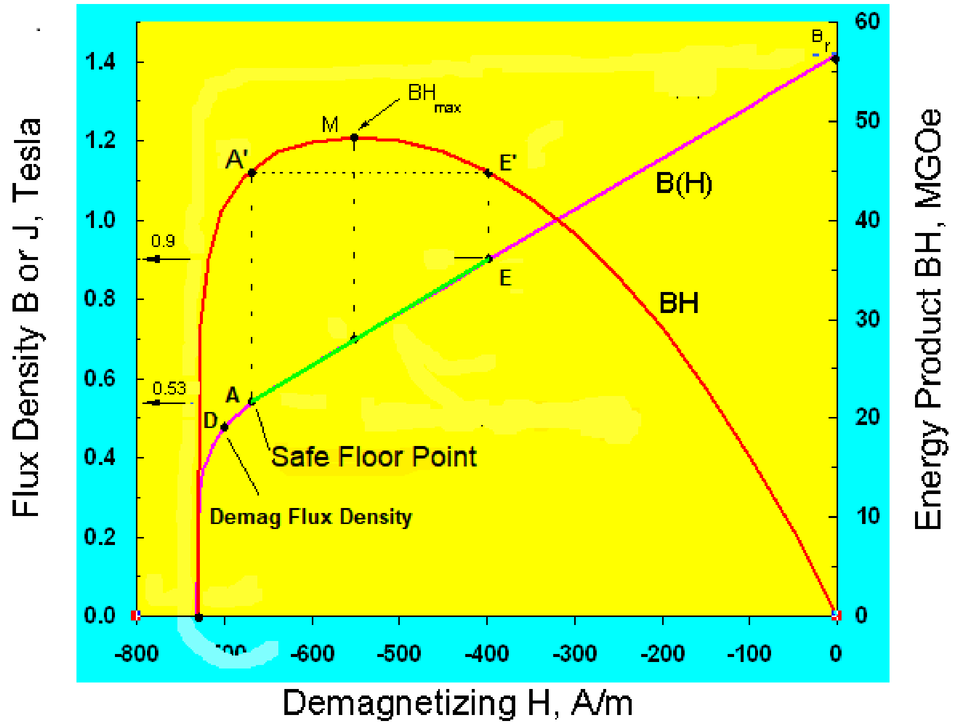


Figure 9. The energy product curve can be used to minimize the cost of a magnet.

A BH(H) curve can help you achieve a minimal magnet cost design. Fig. 9 shows BH(H) curve for an N52 magnet at 40 C. What working point E minimizes its cost without demagnetization?

Fig. 9's BH(H) curve shows max energy BH_{max} = 48.4 MGOe occurs at M. Its B(H) curve shows that its Demag Flux Density B_k = 0.44 T. Allowing a 20% safety margin establishes a ***Safe Floor Point A (0.53T)***. The magnet should always operate above point A to prevent demagnetization.

One can use the ***PMAG*** database to locate the working point E that minimizes the cost as follows:

- Draw a vertical line from point A(0.53T). It intersects the BH curve at point A' (45MGOe).
- Draw a horizontal line from A'. It intersects the BH curve again at point E' (45MGOe).
- Draw a vertical line from E'. Its intersection with B(H) curve locates point E (0.9T).

Then extreme loads can demagnetize the magnet from E (0.9T) to A(0.53T) – causing a 70% drop in B. But the energy in it fluctuates from E' (45 MGOe) to M (48.4 MGOe), i.e. energy stored drops only 7%. Thus the magnet operates near its maximum energy product point M, thereby needs minimal volume. The ***PMAG*** database can be used this way to minimize the cost of a magnet without demagnetization.

3. IMPROVE DEMAGNETIZATION RESISTANCE

3.1. Manufacturer

In section 2.1 we have shown that there will be some manufacturers whose grade offers a higher demagnetization resistance. How high this advantage is, depends on the operating temperature.

Fig. 10 compares the variation of Demag Flux Density $B_k(T)$ for N40M grade produced by 3 firms (Ankey, Arnold, and K&J). It shows that Ankey's N40M grade offers the highest demag resistance compared to that of K&J. But such a comparison between those of Ankey and Arnold is more complex. It shows that magnets from Ankey have superior demag resistance only at either low or higher temperatures. This shows the need to compare $B_k(T)$ plots of same-grade magnets from different manufacturers to locate the manufacturer with a superior demag resistance advantage.

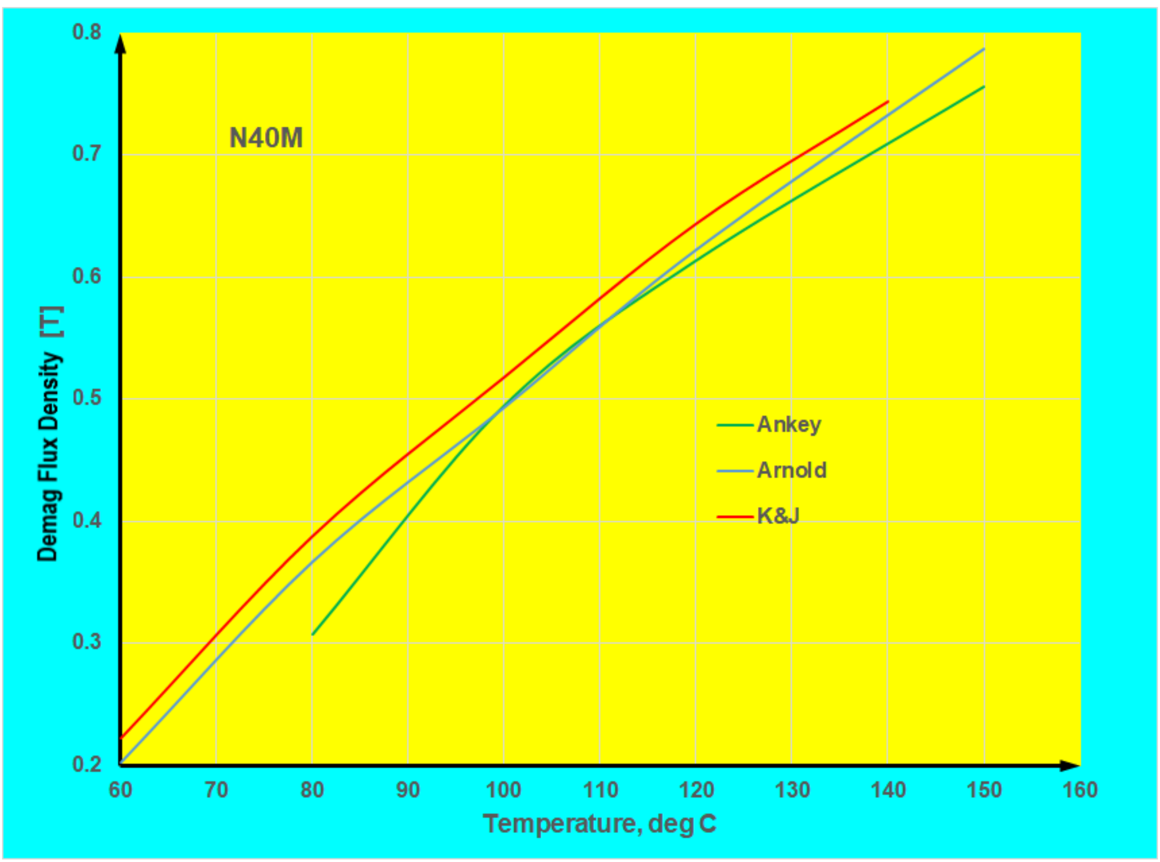


Figure 10 Demag Flux Density varies nonlinearly with temperature. Such nonlinearity depends on the manufacturer

3.2. Grade

Fig. 11 plots the variation of $B_k(T)$ with the temperature. It shows that both N40 can be operated above 0.5T without demagnetization only up to 80C. In contrast, N40H extends the demag-free range to 140C. This figure shows that the variation of B_k with temperature is highly nonlinear, and this nonlinearity depends on the grade.

Design of permanent magnets often require demag flux densities at a specific operating temperature T. We estimate it by fitting a quadratic model

$$B_k(T) = B_k(T_o)[1 + \alpha_1(T - T_o) + \alpha_2(T - T_o)^2] \equiv B_k(T_o)P(T)$$

Where T_o is a reference room temperature. The coefficients α_1, α_2 are obtained by fitting the model to the data.

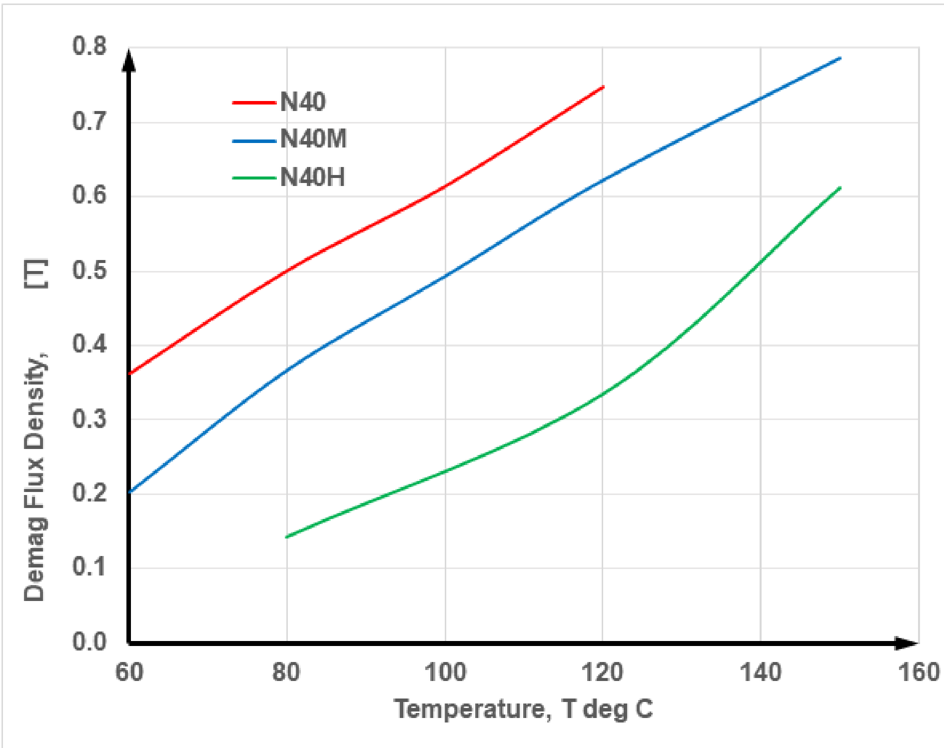


Figure 11. Demag Flux Density varies nonlinearly with temperature. Such nonlinearity depends on the grade.

Similarly, a plot showing how H_k varies with temperature (for several grades) will be useful to determine the grade required to operate a magnet at a rated temperature up to a given demag field.

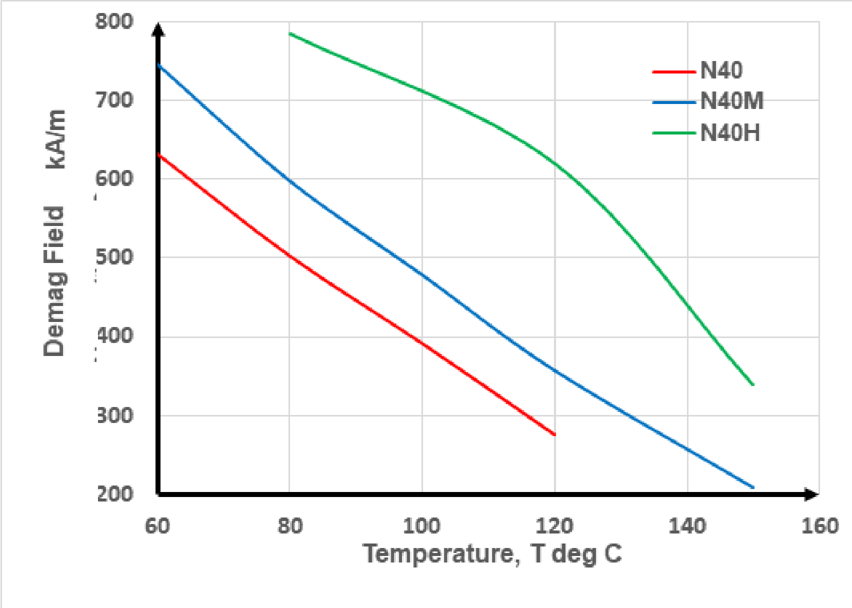


Figure 12. Demag field H_k varies nonlinearly with temperature.

Fig. 12 shows how H_k typically varies with the temperature [57]. It shows that H_k decreases linearly with temperature for some grades, but is highly nonlinear with other grades. For example, for a required demag field of 500 kA/m at 100º C, this figure shows that N40M is the most suitable grade. It also shows that N40H grade can also withstand similar operating conditions, but will also protect it at far higher temperatures of 130º C, so might be overkill.

3.3. Neo vs SmCo

At present most engineers believe[15] [16] that Neo magnets max out and are preferable for operation below 150º C. Both Neo and Samarium magnets are usable in the 140º C to 250º C range. The choice depends on which one offers a better demag flux density. If a Neo grade with a better B_k is preferable as it lowers the cost.

Fig. 13 compares the demag flux density B_k of Neo Grade Vac 992TP with Samarium Cobalt Vacomax 240 over a 200-250º C temperature range. It shows that even though Samarium magnets suffer from a substantially poorer Demag Flux Density – they have lower heat resistance. Specifically, demag flux densities are:

- at 210C: Neo = 0.113T; Samarium = 0.425T – so Neo has a 73% higher demag resistance.
- At 240C: Neo = 0.320T; Samarium = 0.489T - so Neo has a 35% higher demag resistance.

Thus, for a 240º C application, the higher demagnetization resistance of Neo grade (921TP) makes it a better choice than the samarium magnet Vacmax 240.

[15] Constantinedis, S., Magnet Selection, https://www.arnoldmagnetics.com/wp-content/uploads/2017/10/Magnet-Selection-Constantinides-Gorham-2003-psn-hi-res.pdf
[16] Williams, A., High Performance Machine Design Considerations, https://www.arnoldmagnetics.com/wp-content/uploads/2017/10/ArnoldWP_-Automotive_FINAL-1.pdf

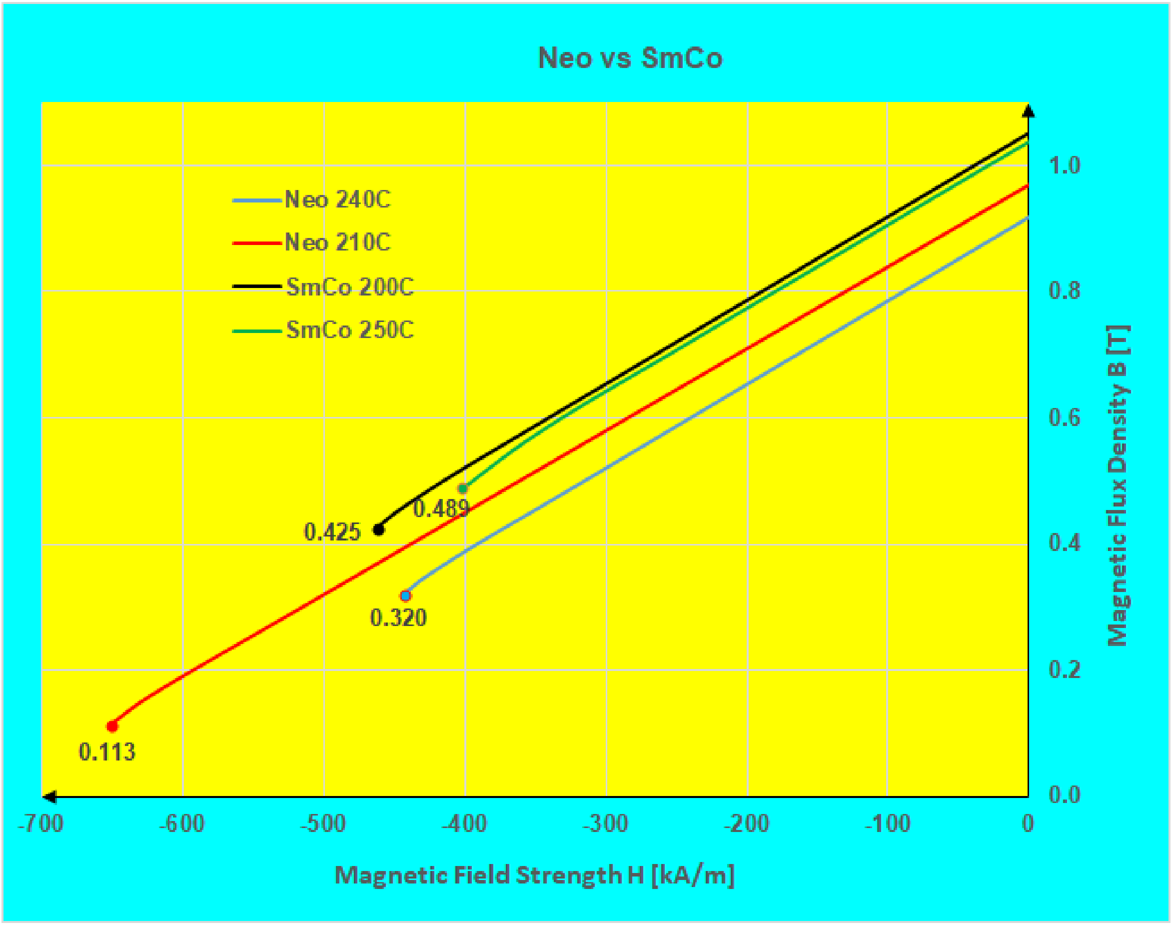


Figure 12. At 240º C, the Neo magnet offers higher demagnetization resistance than the SmCo magnet, making it a better choice.

4. NEODYMIUM MAGNETS

PMAG Database Folder AM for Neodymium Magnets lists 3351 B(H) Demagnetization Curves of 707 grades, produced by more than 35 manufacturers worldwide. For names of all these grades, please click on *PMAG, Materials*.

Neo magnets were initially developed by Hitachi in the 1980s. They are also called Neo or NdFeB magnets. They are produced by sintering ~4µm size fine powders[17]. They can be made only in simple blocks, rings, or arc shapes. They are made of ~66% Fe, 30% Neo, 1% B,0.7% Nb, 0.3% Al. 7 to 12% dysprosium is added to improve high-temperature performance, but it increases their cost[18]. Different manufacturers use different recipes, so magnets from some manufacturers may have higher demagnetization withstand capability.

Neo magnets have poorer thermal stability than SmCo magnets (~0.1%/C). So currently most engineers prefer to use them below 150C. Their energy product ranges from 28 to 54 MGOe. Their residual flux density ranges from 1 to 1.45T. Their maximum service temperature ranges from 80 to 250^o C.

4.1. Grades

Manufacturers identify the Neo magnets by "N". They offer them in several "grades" which follow Chinese conventions. 64 of them are called "standard" grades, with two codes:

- A *letter* code, which refers to their Maximum Service Temperature T_{max}.
- A *numeral* code, which prescribes their Max. Energy Product BH_{max} (MGOe).

Table 1 lists these grades, their maximum service temperatures, maximum energy product. (It excludes the more recent dysprosium-free 'case hardened' magnets[19] which concentrate neodymium on the surface and refine the grain to reduce cost). It shows that Br of Neo magnets spans 1T to 1.45T. Grades between 30 to 40MGOe are spaced at 0.05T, while those between 40 to 55 are spaced at ~0.025T.

[17] *How Neo magnets are made*, e-magnetsuk.com

[18] Kramers, M.J et al. *Prospects for non-rare earth PM magnets for traction motors and generators*, JOM, Vol. 12, 2012, https://link.springer.com/article/10.1007/s11837-012-0351-z

[19] Anonymous, Toyota develops Neodymim reduced magnet for electric motors, Magetics Business Technology, https://magneticsmag.com/toyota-develops-neodymium-reduced-magnet-for-electric-motors/

Table 1. "Standard" Grades of Neodymium Magnets

Br Tesla		1.05	1.10	1.15	1.20	1.25	1.29	1.32	1.35	1.38	1.40	1.42	1.45
BHmax MGOe		28	30	33	35	38	40	42	45	48	50	52	54
Code	Max Temp C												
AH	230	28AH	30AH	33AH	35AH	38AH	40AH						
EH	200	28EH	30EH	33EH	35EH	38EH	40EH	42EH	45EH				
UH	180		30UH	33UH	35UH	38UH	40UH	42UH	45UH	48UH	50UH		
SH	150		30SH	33SH	35SH	38SH	40SH	42SH	45SH	48SH	50SH	52SH	
H	120		30H	33H	35H	38H	40H	42H	45H	48H	50H	52H	
M	100		30M	33M	35M	38M	40M	42M	45M	48M	50M	52M	
none	80		N30	N33	N35	N38	N40	N42	N45	N48	N50	N52	N54

Of these, UH, EH, and AH grades are used primarily in traction motors for electric vehicles, wigglers, and wind power generators.

American standards identify a grade as xx/yy where xx refers to maximum energy product BH_{max} in MGOe and yy refers to intrinsic coercivity H_{cJ} in Oe. European standard IEC 60404-8-1 uses the same symbols, but with xx for BH_{max} in kJ/m^3 and yy for H_{cJ} in 10kA/m. European and Japanese firms do not follow the Chinese naming conventions, so it is difficult to identify their equivalent grades. Unfortunately, none specify the key B_k

Coating. Neo magnets need coating as their corrosion resistance is poor. All manufacturers offer a wide variety of coatings[20]. The thickness of such coating varies from 7 to 28 μm. Electrolytic nickel coating is a common choice as it is the least expensive and provides a hermetic seal against, air, moisture, and gases. The user should select the coating that best suits his application. The thickness of the uncoated magnet should be considered in design software (instead of its nominal thickness) for a more accurate design of a machine.

4.2. Major Manufacturers

Neo magnets are offered in several grades. Fig. 14 ranks some of these major manufacturers by the number of grades they produce. It shows that ***Arnold Magnetic Technology*** offers the largest number (79) of grades, followed by Dexter Magnetics (60). Three European firms - Sura Magnets (51), Neorem (48), and Vacuumschmelze (44) - also offer more than 40 grades. One Chinese firm Ankey offers ~ 50 grades.

[20]For comparison of various coatings, see for example e-magnetsuk.com.

Few reputed firms such as Hitachi, Shin-Etsu, TDK produce a smaller number of higher grades. So producing a large number of grades need not necessarily imply that it is a source of high-quality grades.

Highest Temperature Magnets: 230-240º C class Neo magnets are offered by Vaccumschmelze, Arnold Magnetics, and Integrated Magnetics with demag curves. They are also offered by Schramberg and Ningbo Yinzhou UpMagnet but without demagnetization curves. 220º C classes are offered by Sura Magnets, Arnold Magnetics, Eclipse Magnetics, Hitachi, etc.

Strongest Magnets: 55 MGOe grade Neo magnets are produced by Arnold Magnetics, Dexter Magnetics, Smart Magnet, and Yantai Shougang Magnetic. Their residual flux density can be as high as 1.49T.

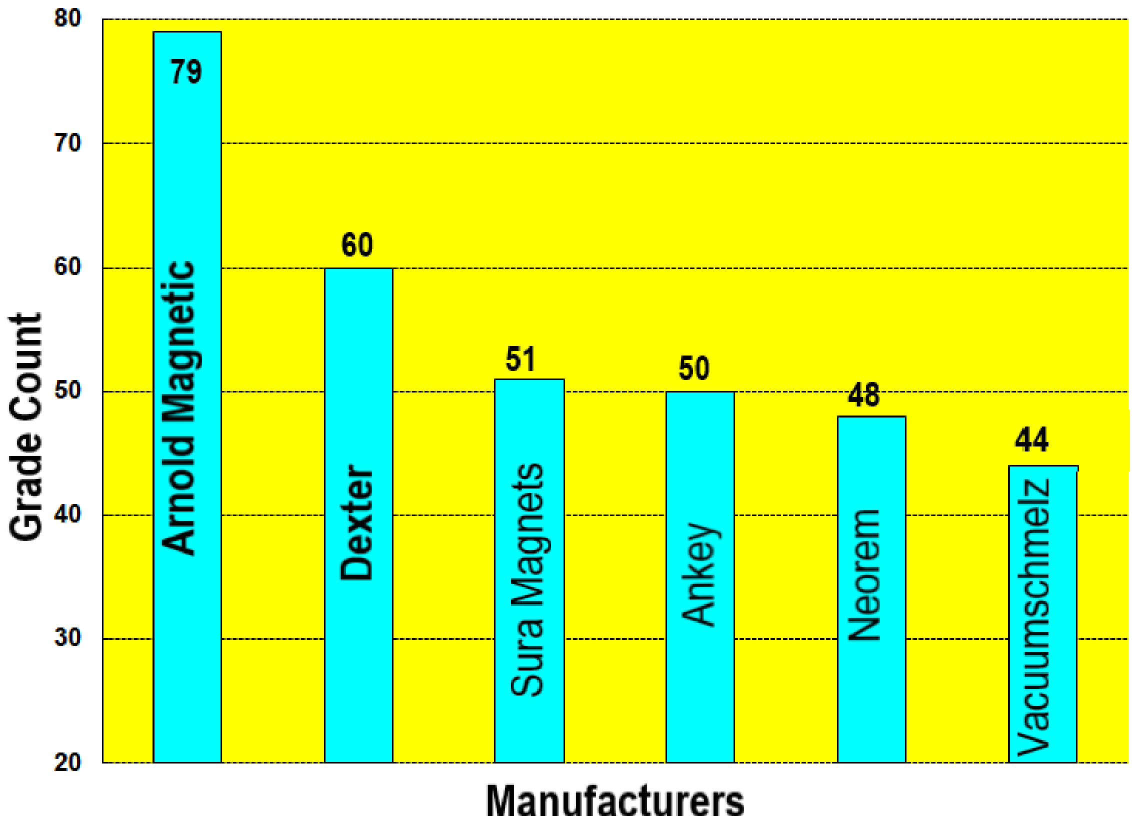


Figure 13. Number of Grades Produced by Major Manufacturers.

5. SAMARIUM COBALT MAGNETS

PMAG Database Folder BM lists 694 B(H) Demagnetization Curves of their 159 grades, produced by 23 manufacturers worldwide. For names of all these grades, please click on *PMAG, Materials*.

Samarium Cobalt Magnets were developed for US Air Force by the University of Dayton Research Institute (UDRI) in the 1970s. They are also called Samarium or SmCo Magnets. They are composed of Sm, Co, balance Cu, Zi, and Fe. The powders are pressed, sintered, machined, and magnetized. They can be only made in simple shapes. SmCo magnets can easily 'chip' and create dirty magnets with sharp edges. To prevent such chipping, customers should tumble them which rounds their edges to a 0.005-inch radius. They are expensive, so mainly used in applications that demand exemplary performance at high temperatures. Their energy product ranges from 15 to 32 MGOe. Their residual flux density ranges from 0.9 to 1.2 T. It is the preferred choice for operation above 150ºC, up to 550ºC.

Electron Energy Corp (EEC) produces SMCO magnets that can operate at 550º C. Both EEC, Dexter, and Arnold Magnetic offer the strongest SMCO magnets (BH_{max} = 33 MGOe, B_r = 1.19T). ***Tianhe Magnets*** offers 52 grades without demag curves. Dexter Magnetic offers 38 grades with demag curves. Ningbo Ningang Permanent Magnet also offers 33 grades but without demag curves. Two subcategories:

Sm1Co5: Also called 1:5. It has one Samarium atom per 5 Cobalt atoms. It has a 35% Samarium. It has no iron, so does not corrode with water. Its Energy Product ranges 15 – 25 MGOe. In the ***PMAG*** database, they can be identified by their T_{max} of 250°C and lower electrical resistance of 55 μΩcm.

Sm2Co17: Also called 2:17. It has two Samarium atoms for 14 – 17 Cobalt atoms. It is less expensive (has only 25% Samarium) and carries more energy (21-32 MGOe). Its B_r ranges 0.9 to 1.16T. So most new designs use 2:17 magnets as it is less expensive and reduces the size of magnets. But it uses iron, so may corrode slightly in water. It has high demag resistance. It comes in three styles:

- *Normal*. Their T_{max} ranges 350º C. They offer higher resistivity of 85 μΩcm.
- *Ultra-High Temperature (UHT)*. Their T_{max} ranges from 400 to 550º C. ***PMAG*** database contains their hard-to-find demag curves. They should be plated, however.
- *Low-Temperature Coefficient* (LTC). They offer near-zero thermal temperature coefficients. So their thermal stability is very high.

SMCO stores less energy than Neo and is more expensive. But:

- Cooling restores its magnetic properties (reversible thermal degradation).
- Above 180º C their B_r is higher than Neo – so they are the preferred choice[21].
- It can operate up to 550º C (but its B_r falls to 0.54T) Neo is limited to 250º C.
- Its demag resistance is higher than Neo.
- It degrades less with temperature (.035%/ ºC).
- It is more resistant to corrosion.
- It can be abrasively machined only with coolant.
- Its abrasive machining does not degrade its properties.
- But it is more brittle than Neo magnets.

[21] Arnold Magnetics, Temperature effects on magnetic output, http://www.arnoldmagnetics.com/wp-content/uploads/2017/10/TN_0303_rev_150715.pdf

6. MOLDED/BONDED MAGNETS

PMAG Database Folder CM for Molded magnets lists 554 B(H) Demagnetization Curves of 49 grades, produced by 19 manufacturers worldwide. For names of all these grades, please click on *PMAG, Materials*.

Also called plastic magnets or polymer magnets, the molded/bonded magnets are made by mixing magnetic powders with nonmagnetic binders. They are made into intricate shapes by either injection molding or compression bonding. Molding avoids additional machining and assembly cost. It reduced per part cost in large volumes but needs high tooling cost investment. They use Neo, Samarium, or Ferrite magnetic powders. Those made of Ferrite are inferior to others. Their magnetic strength is reduced by the binding agent. Injection Molded magnets are limited to 6 MGOe. Bonded magnets can go up to 13 MGOe. Their residual flux density ranges from 0.6 to 1T. Their service temperature ranges from 100 to 220^o C.

Aichi Steel's bonded magnets can reach 21 MGOe (B_r ~ 1T). They are generally small (< 125 gm). Their density is less than 6 gm/cc.

Arnold Magnetic Technology offers 40 grades, followed by Kollektor and Schramberg (~30). Schramberg and Max Baerman also make ones that can operate up to 220^o C. Magnequench has the largest number of patents. Their names do not follow any standard conventions. MagWeb's magnetization curves can help you to find the best grade vendor that matches your specific needs.

Injection molding mix ~65% magnetic powders with ~35% *thermoplastic* "resin". It squeezes the heated cavity into a cavity, applying pressure in multiple directions. They can produce complex intricate shapes (compression bonding produces only blocks, rings). Insert injection molding can mold magnets over pre-manufactured parts. They can produce shafts for micromotors with multipole magnets to be mass-produced inexpensively. They are less dense than compression molded ones, so store less energy.

Their maximum service temperature T_{max} is limited by that of the binders. PPS resins can offer T_{max} up to 220^o C. They also offer better resistance against oils, grease. Other popular resins are Nylon 6, 12, PA6, PA12, and Polyamide; their T_{max} 150^o C or 180^o C.

Compression bonding mix ~80% magnet powders with ~20% *thermoset* "epoxy". The mix is fed into a die cavity and compacted punches; the green part is then cured. This process applies pressure in one direction, so they can produce only rings, blocks, or segments. They are best suited to make thin wall rings. But the height is limited by the compression pressure. Its tooling is less complex and hence less expensive than injection molding. So their energy product ranges from 7 to 13 MGOe (B_r <0.8T).

7. FERRITE CERAMIC MAGNETS

PMAG Database DM lists 430 B(H) Demagnetization Curves of 134 grades, produced by 19 manufacturers worldwide. For names of all these grades, please click on *PMAG, Materials.*

Ferrite Magnets were first engineered by Philips, Netherland in the late ’50s. They are made of 85% iron oxide plus oxides of Barium or Strontium Ferrites. They are mixed with a ceramic binder which is compressed and sintered. Dry-pressing results in isotropic magnets. Wet pressing results in anisotropic magnets which store far more energy. Ferrite magnets are the cheapest magnets. But they are a lot weaker. They are very hard but brittle. They are resistant to water, salt, petrol, but not to acids. They are used in toys, speakers, and motors. They suffer from low energy (1 to 5 MGOe) and low flux density (B_r ~ 0.25 to 0.4 T). Their maximum service temperature is 350^o C.

Most Ferrite magnets are produced in China, so the Chinese standard SJ-285-77, T10410 is increasingly popular. It lists 27 Y grades. US’s MMPA lists 7 C grades. European IEC404-8-1 lists 18 HF grades. HF20/19 refers to a ferrite magnet with a minimum energy product of 20 kJ/m^3 and a minimum HcJ of 190 kA/m. Japanese (TDK) lists FB. Typically C5, HF 26/18 are ‘treated’ equivalent to Y30.

But their properties depend on the temperature. At higher temperatures, they vary with the manufacturer. So equivalent tables are necessary but not sufficient. ***PMAG’s*** manufacturer-dependent demagnetization curves help you to identify the best grade.

Dexing Magnetics offers 63 grades, followed by Kaiven Magnets (52). Alliance Magnetics makes ferrite magnets with a T_{max} of 350^o C. Kaiven Magnets make the strongest magnets (B_r~0.88T).

Properties. Ferrites are valued for their low cost, high resistivity (>10MΩcm), and high corrosion resistance. Their demagnetization resistance is moderate (~250 kA/m).

Most Ferrite magnets can operate up to 250^o C. But some firms that produce ferrite magnets that can operate up to 400^o C. Hc of Ferrites need not decrease monotonically with temperature; in some, it may be limited to ~-60^o C. Their thermal stability is an order of magnitude worse than Alnico (0.2%/ ^{o}C). For anisotropic materials, coercivity decreases at +0.35 %/^{o}C. Their thermal conductivity is ~ 12 w/mK.

8. ALNICO MAGNETS

PMAG Database contains 82 B(H) Demagnetization Curves of 75 Alnico Magnets grades, produced by 12 manufacturers worldwide. For names of all these grades, please click on *PMAG, Materials*.

Alnico Magnets were first developed for the USA military in the 1940s. Alnico magnets are composed of Al (8-12%), Ni (13-20%), Co (3 -24%), Cu (3 -6%), balance Fe, plus trace elements such as Ti, Si, Zi. Different grades are obtained by combing them into different strengths. They are formed by casting or sintering. Alnico is best in long pencil-shaped magnet applications. They are very hard and brittle. Their energy product is limited to 10MGOe. Their B_r varies from 0.55 to 1.37 tesla. They can operate up to 600C. They are valued for their high-temperature stability (0.02%/ºC).

PMAG database lists their properties by each manufacturer as their properties differ. Alnico magnets exhibit a 'knee' beyond which irreversible demagnetization occurs. So great care must be used in using them beyond their knee point. This sort of demag can occur during assembly or startup of motors causing it to run below the 'virgin' B(H) curve, so great care must be taken for proper design and handling. They suffer from low resistance to demagnetization (HcB ~ 40-150 kA/m). They also can leak significant flux. USA, Europe, and China use different ways to name "standard" grades as listed in Table 3.

Table 2. Equivalent Grades of Alnico Magnets.

CHINA	USA	Europe	Br, tesla
	MMPA 0100-	IEC 60404-8-1[23]	
LN10	Alnico 3	Alnico 9/3	0.65
LNG11	Alnico 1	Alnico 8/4	0.72
LNG13	Alnico 2	Alnico 12/6	0.7
LNGT18	Alnico 8	Alnico 17/9	0.58
LNG16	Alnico 4		0.8
LNG34	Alnico 5C		1.18
LNG37	Alnico 5C	Alnico 37/5	1.18
LNG40	Alnico 5		1.22
LNG44	Alnico 5	Alnico 44/5	1.22
LNG52	Alnico 5 DG	Alnico 52/6	1.25
LNG60	Alnico 5-7		1.3
LNGT28	Alnico 6	Alnico 26/6	1.05
LNGT32	Alnico 8	Alnico 38/11	0.8
LNGT38	Alnico 8	Alnico 38/11	0.82
LNGT44	Alnico 8		0.88
LNGT60	Alnico 8	Alnico 60/11	0.9
LNGT72	Alnico 9		1.05
LNGT36J	Alnico 8 HC	Alnico 36/15	0.7

Datayo Magnet, Dexing Magnet offers the largest number of grades (32) Magnets from AIC Magnetics can operate up to 550º C. Thomas Skinner, Arnold, and AIC Magnetics make Alnico magnets with the highest B_r of 1.37 T.

[22] MMPA, Standard Spec. of Permanent Magnet Materials, MMPA 0100-00, https://www.allianceorg.com/pdfs/MMPA_0100-00.pdf
[23] IEC 60404-8-1, Magnetic Materials – Magnetically Hard Materials, https://webstore.iec.ch/preview/info_iec60404-8-1%7Bed3.0%7Db.pdf

9. APPENDIX A. PMAG DATABASE FORMAT

9.1. Category Folders

PMAG Database groups all permanent magnets into ***5 Category Folders, labeled AM to EM***. For example, AM Folder stores B(H) digital demagnetization curves of all Neodymium Magnets types.

Table 1 shows these 5 category folders. Col. 3 lists the maximum energy product (in MGOe) while the rest list the number of firms, grades, and demagnetization curves in each folder. It shows that the ***PMAG*** database comprises nearly 5000 digital demagnetization curves.

Example: Category AM Folder contains 3351 digital demagnetization curves. This data is stored in 696 excel files, each file corresponding to a specific grade produced by 35 firms worldwide.

These magnets operate over a wide temperature range of -40º C to 550º C. Neo magnets can operate between -125º C to 250º C. The Samarium magnets can operate up to 550º C but are expensive. The molded/bonded magnets can withstand 180º C. The weaker Alnico and Ceramic magnets can go up to 520º C and 400º C respectively.

Table 3. Demagnetization Digital Curves in the PMAG Database (5111)

CC	Category Folder Name	MGOe	Firms	Grades	Curves
L	Neodymium Magnets	55	35	696	3351
M	Samarium Cobalt Magnets	34	23	165	694
N	Molded/Bonded Magnets	12	19	145	554
O	Ferrite Ceramic Magnets	4	18	126	430
P	Alnico Magnets	4	12	75	82
	Total		62	1207	5111

9.2. Manufacturer Subfolders

Each Category Folder comprises several *Manufacturer Subfolders.* Its label refers to a specific *manufacturer. E*xample: 'Hitachi' subfolder contains data files of all the grades produced by Hitachi Metals Ltd. If a Manufacturer furnishes J(H) curves it is converted into B(H) curves using B = J -

$\mu_o H$. ***PMAG*** stores all data with 8-decimal digits. But it displays only 3 decimal digits. One can use excel format to display more digits if desired.

9.3. Grade Files

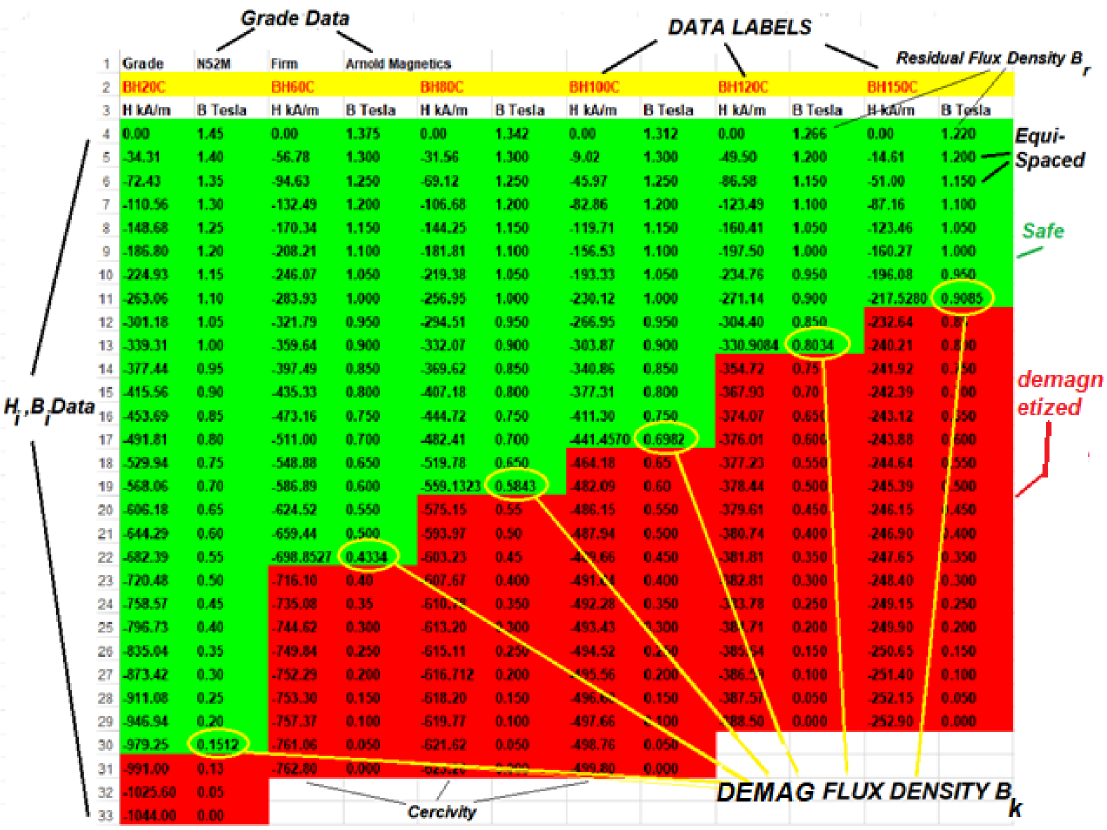
Each Manufacturer subfolder comprises several Grade Files. Each Grade File is an excel file that contains the B(H) and Core Loss datasets (at several frequencies and temperatures) for a particular Grade. For example, the 'N2717' excel grade file contains demagnetization datasets of grade N2717.

Format of Grade Files

Fig. 15 shows the format of datasets in a Grade File. In each Grade File,

- Header Row 1: Grade in col. 2, its Manufacturer in col. 4.
- Header Row 2: Data Labels
- Header Row 3: Units, H kA/m, B tesla.

Remaining rows stores the demagnetization datasets in H and B columns.



1	Grade	N52M	Firm	Arnold Magnetics								
2	BH20C		BH60C		BH80C		BH100C		BH120C		BH150C	
3	H kA/m	B Tesla	H kA/m	B Tesla	H kA/m	B Tesla	H kA/m	B Tesla	H kA/m	B Tesla	H kA/m	B Tesla
4	0.00	1.45	0.00	1.375	0.00	1.342	0.00	1.312	0.00	1.266	0.00	1.220
5	-34.31	1.40	-56.78	1.300	-31.56	1.300	-9.02	1.300	-49.50	1.200	-14.61	1.200
6	-72.43	1.35	-94.63	1.250	-69.12	1.250	-45.97	1.250	-86.58	1.150	-51.00	1.150
7	-110.56	1.30	-132.49	1.200	-106.68	1.200	-82.86	1.200	-123.49	1.100	-87.16	1.100
8	-148.68	1.25	-170.34	1.150	-144.25	1.150	-119.71	1.150	-160.41	1.050	-123.46	1.050
9	-186.80	1.20	-208.21	1.100	-181.81	1.100	-156.53	1.100	-197.50	1.000	-160.27	1.000
10	-224.93	1.15	-246.07	1.050	-219.38	1.050	-193.33	1.050	-234.76	0.950	-196.08	0.950
11	-263.06	1.10	-283.93	1.000	-256.95	1.000	-230.12	1.000	-271.14	0.900	-217.5280	0.9085
12	-301.18	1.05	-321.79	0.950	-294.51	0.950	-266.95	0.950	-304.40	0.850	-232.64	[illegible]
13	-339.31	1.00	-359.64	0.900	-332.07	0.900	-303.87	0.900	-330.9084	0.8034	-240.21	[illegible]
14	-377.44	0.95	-397.49	0.850	-369.62	0.850	-340.86	0.850	-354.72	0.75	-241.92	[illegible]
15	-415.56	0.90	-435.33	0.800	-407.18	0.800	-377.31	0.800	-367.93	0.70	-242.39	[illegible]
16	-453.69	0.85	-473.16	0.750	-444.72	0.750	-411.30	0.750	-374.07	[illegible]	-243.12	[illegible]
17	-491.81	0.80	-511.00	0.700	-482.41	0.700	-441.4570	0.6982	-376.01	[illegible]	-243.88	0.600
18	-529.94	0.75	-548.88	0.650	-519.78	0.650	-464.18	0.65	-377.23	0.550	-244.64	0.550
19	-568.06	0.70	-586.89	0.600	-559.1323	0.5843	-482.09	0.60	-378.44	0.500	-245.39	[illegible]
20	-606.18	0.65	-624.52	0.550	-575.15	0.55	-486.15	0.550	-379.61	0.450	-246.15	[illegible]
21	-644.29	0.60	-659.44	0.500	-593.97	0.50	-487.94	0.500	-380.74	0.400	-246.90	[illegible]
22	-682.39	0.55	-698.8527	0.4334	-603.23	0.45	[illegible]	0.450	-381.81	0.350	-247.65	0.350
23	-720.48	0.50	-716.10	0.40	-607.67	0.400	[illegible]	0.400	[illegible]	0.300	-248.40	0.300
24	-758.57	0.45	-735.08	0.35	[illegible]	0.350	-492.28	0.350	[illegible]	0.250	-249.15	0.250
25	-796.73	0.40	-744.62	0.300	-613.20	[illegible]	-493.43	[illegible]	[illegible]	0.200	-249.90	0.200
26	-835.04	0.35	-749.84	0.250	-615.11	0.250	-494.52	[illegible]	[illegible]	0.150	-250.65	0.150
27	-873.42	0.30	-752.29	0.200	-616.712	0.200	[illegible]	0.200	[illegible]	0.100	-251.40	0.100
28	-911.08	0.25	-753.30	0.150	-618.20	0.150	[illegible]	0.150	-387.57	0.050	-252.15	0.050
29	-946.94	0.20	-757.37	0.100	-619.77	0.100	-497.66	[illegible]	[illegible]	0.000	-252.90	0.000
30	-979.25	0.1512	-761.06	0.050	-621.62	0.050	-498.76	0.050				
31	-991.00	0.13	-762.80	0.000	[illegible]	[illegible]	-499.80	0.000				
32	-1025.60	0.05										
33	-1044.00	0.00										

Figure 14. *Format of **PMAG** database. Header Row2 lists Data Labels. Header Row 3 lists Units. Within the Data Label, BH denotes B(H) Data, 20C denotes data at 20 °C. Data in the green Zone refers to Safe*

Operating Range. Operating a Magnet in this Range will protect it from degenerating to a lower grade permanently.

Data Labels

The Data Label defines the type of curve plus the temperature at which it is measured. It is highlighted yellow. Its format is:

BHttC

where

BH = B(H) demagnetization Curve

ttC = Temperature numerals ttt followed by ' C'

Example: **BH50C**- B(H) demagnetization data at 50^{o} C.

Data

It equi-spaces all data at 0.05T. It shows points in the reversible segment (viz. Safe Operating Range) in green color. **knee point k** (H_k, B_k) **is the last point in this green segment; it has 4 decimal data.** It stores other points to 3 decimals. It also shows those in unsafe operating range in red color.

DIGEST Files

Each Category Folder also contains a **DIGEST** file. It is a single searchable excel file that lists discrete properties of most grades at room temperature. For example, the DIGEST AM for Neo Magnet Folder AM lists the magnetic properties of 1379 Neo magnet grades, out of which only 633 contain temperature-dependent demagnetization curves.

In it, the 5 columns (A to D, L) contain magnet/manufacturer descriptors. These include Manufacturer, Country, Material Category, Material Name (Grade) and Source) as shown in Table 1.

Table 1. DIGEST File - Manufacturers, Grade, and Source

	A	B	C	D	L
1	***Manufacturer***	***Country***	***Material Category***	***Material Name***	***Source***
2					
3	AIC Magnetic	China	Alnico, Cast	CLNG12	http://www.aicmag.com/wp-
4	AIC Magnetic	China	Alnico, Cast	CLNGT82	http://www.aicmag.com/wp-
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The balance columns (E to K) contain 7 searchable magnetic properties listed below.

Table 4. DIGEST File – Discrete Properties of Magnets.

	E	F	G	H	I	J	K
1	***Max. Service Temperature***	***Max. Energy Product***	***Remanant Flux Density***	***Normal Coercivity***	***Intrinsic Coercivity***	***Resistivity***	***Density***
2	***T_{max} [°C]***	***BH_{max} [MGOe] @ 20C***	***B_r [tesla] @ 20C***	***H_{cB} [kA/m] @ 20C***	***H_{cJ} [kA/m] @ 20C***	***ρ [$\mu\Omega$cm]***	***γ [gm/cc]***
3	80	48	1.413	1000	1036	114	7.3
4	120	42	1.359	997	1497	114	7.3
5	100	38	1.346	908	1182	114	7.3

Column	***Symbol***	***Property***
E	T_{max}	Maximum Service Temperature [°C]
F	BH_{max}	Maximum Energy Product [MGOe]
G	B_r	Remnant Flux Density [T]
H	H_{cB}	Normal Coercivity [kA/m]
I	H_{cJ}	Intrinsic Coercivity [kA/m]
J	ρ	Resistivity [μΩ cm]
K	γ	Density (gm/cm^3)

T_{max} can be that temperature beyond which B(H) shows curvature (a “knee”) in the second quadrant, but this definition is not adapted as a standard. With the DIGEST file, you can search or compare the magnetic properties of same-grade magnets from different manufacturers. You can also shortlist those magnets which can withstand your specific service temperature.

The magnetic properties in the DIGEST refer mostly to “typical” values listed by manufacturers. But manufacturers list mostly minimum values of H_{cB} and H_{cJ} to be listed instead of a typical value. So the magnetic data in the digest should not be used for design. In contrast, the temperature-dependent B(H) curves in the ***PMAG*** database consistently refer to typical values. In most machines, magnets operate between 50 to 150^o C. So for consistency, they should be used in designing magnets.

Properties of magnets vary slightly from batch to batch, grade, and firm. Reputed firms offer magnets with ±2 % tolerance on B_r. Others offer with ±5% tolerance.

Free Magnet B(H) Data

The MagWeb website also furnishes 10 sample B(H) data files (2 from each of the 5 categories of magnets). You can review them to get a ‘feel ‘for the diverse capabilities of the ***PMAG*** database.