THE EFFECT OF TEMPERATURE VARIATIONS ON THE MAGNETIC PERFORMANCE OF PERMANENT MAGNETS

All permanent magnet materials are temperature sensitive and it is important to take this into consideration when designing magnetic circuits where a high degree of temperature stability is necessary or where high maximum temperatures are likely to be reached in operation.

The four main material groups, ***Ferrite, Alnico, Samarium Cobalt*** and ***Neodymium-Iron-Boron***, all have their own distinctive temperature coefficients, but also have variations with different grades within the main groups.

Temperature changes have an effect on the demagnetisation curves with different coefficients of both remanence and coercivity. As can be seen from the typical example below Fig. 1, the general shape of the curve remains the same but has varying values of remanence and coercivity with temperature changes. The material grade shown in Fig. 1 is **N40M**.

To minimise the effect of temperature on the field produced by a permanent magnet, it is advisable to operate above the ‘knee’ in the demagnetisation curves, and in the example shown, a working point of -2.0 would be considered a minimum.

However the temperature effects are of two types. The reversible changes where the initial flux is restored when the magnet returns to the original temperature; and the irreversible changes where the losses are permanent, but can be restored by remagnetising.

The reversible changes are usually only dependant upon the material composition, whereas the irreversible losses are largely dependant on the working point and intrinsic coercivity of the material grade.

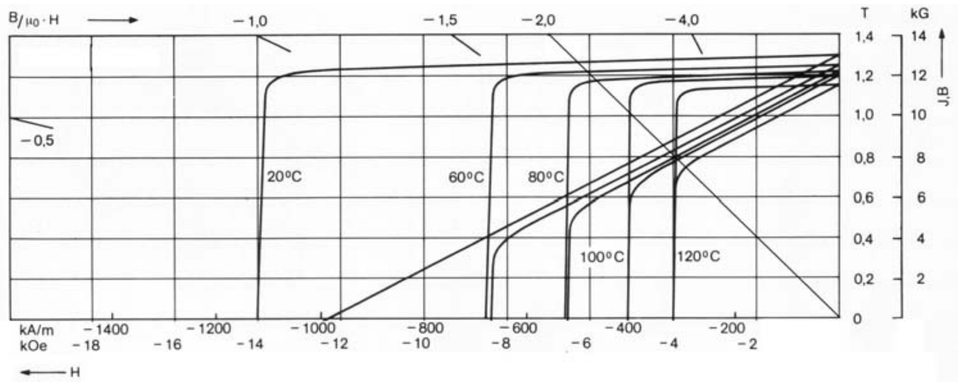


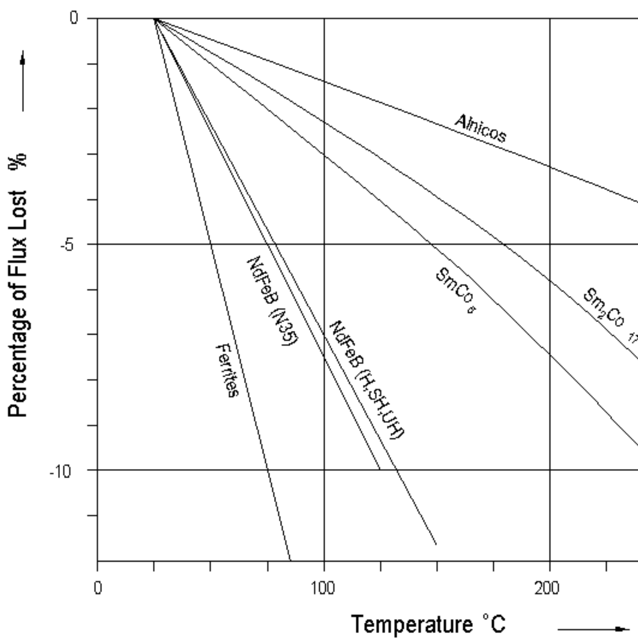
Fig 1

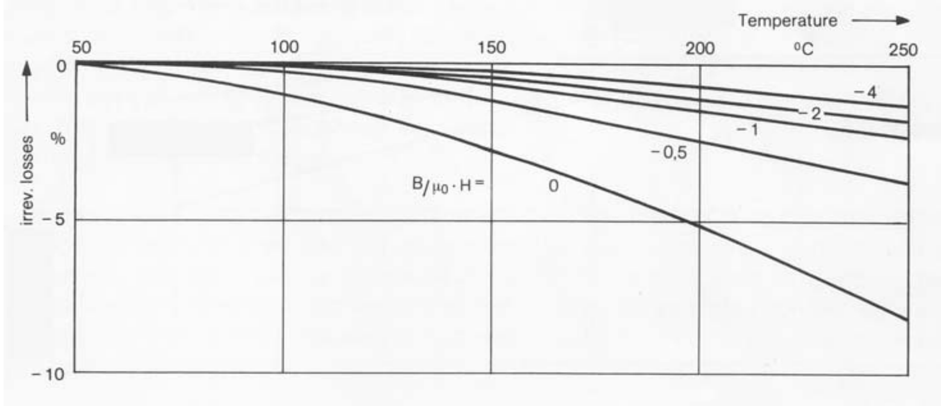
Typical changes of remanence Tk(Br) in the temperature range 20-100ºC are shown in the following table, together with the normal maximum working and approximate Curie temperatures for five major material groups:

Material	Tk(Br)	Maximum working Temp.	Approximate Curie Temp.
FERRITE	-0.19%/ºC	250ºC	450ºC
ALNICO	-0.02%/ºC	550ºC	760ºC
SmCo (1:5)	-0.04%/ºC	250ºC	720ºC
SmCo (2:17)	-0.03%/ºC	300ºC	800ºC
NdFeB (N35)	-0.11%/ºC	80ºC	310ºC
NdFeB (N35M)	-0.11%/ºC	100ºC	310ºC
NdFeB (N35H)	-0.11%/ºC	120ºC	310ºC
NdFeB (N35SH)	-0.11%/ºC	150ºC	320ºC
NdFeB (N35UH)	-0.11%/ºC	180ºC	330ºC

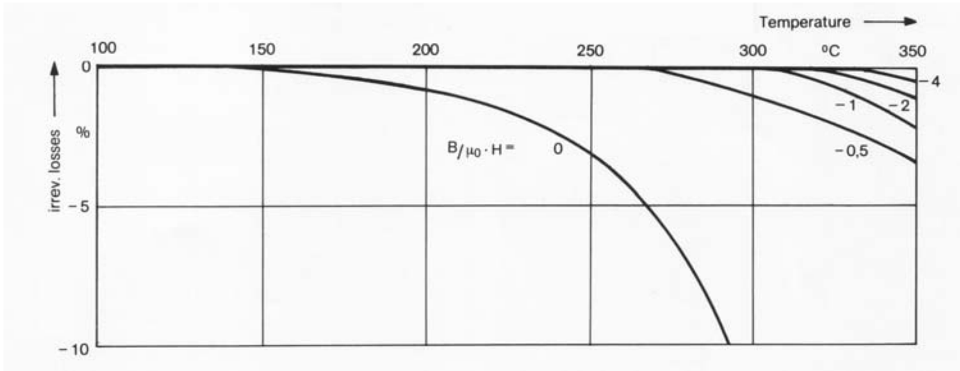
TABLE 1

These reversible changes of remanence are graphically represented in Fig. 2

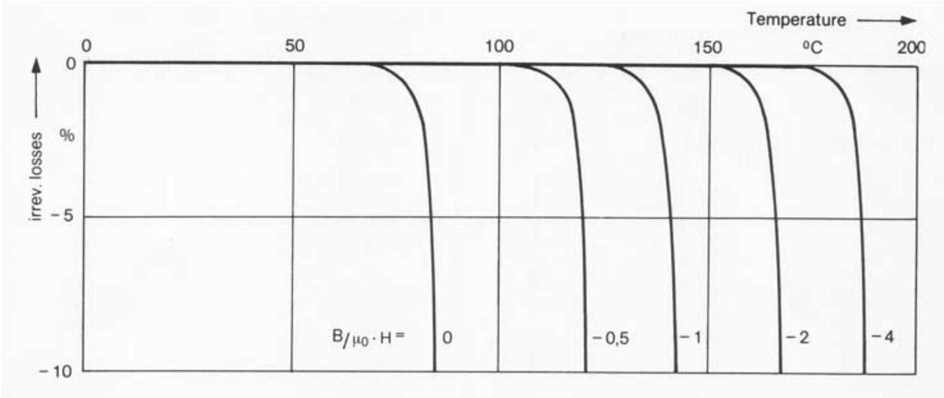




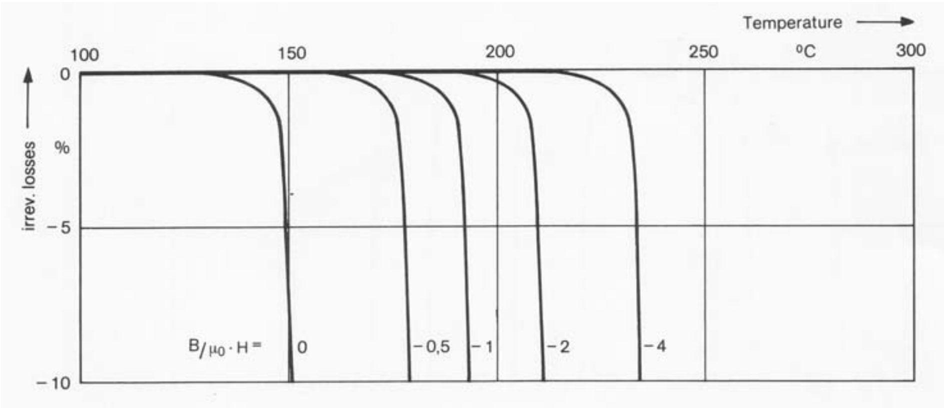
SmCo 1:5



SmCo 2:17

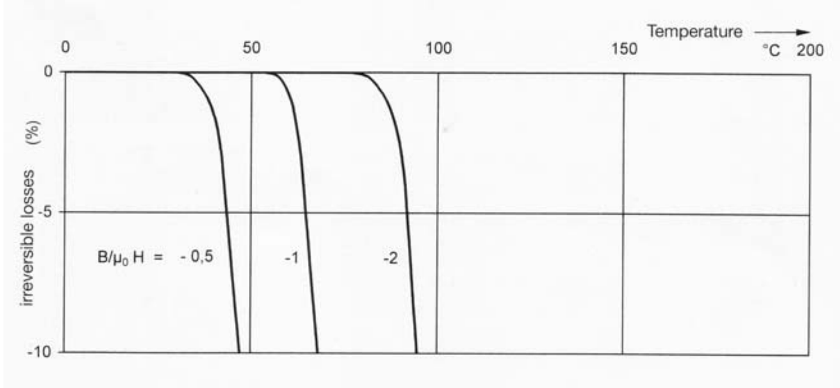


N35SH



N35UH

Irreversible Losses



N 35 (Fig 3)

As previously stated, to achieve the minimum effect from temperature changes in a magnetic circuit, it is necessary to establish as accurately as possible, the working point of the magnet to be used. A simple curve showing the irreversible losses for N35 grade NdFeB at various working points is shown in Fig. 3. The working point (B/μ_o-H) for high coercive materials can be calculated by using the following method for a single discrete magnet with no iron circuit.

(1) Establish the L/D ratio of the magnet to be used, i.e. the magnetic length of the magnet divided by the diameter, or if a square or rectangular magnet is being used, $D=\sqrt{4Am/\pi}$ where Am is the magnet area.

(2) Using this ratio, read across in Table 2 to arrive at the working point B/μ_o-H.

The L/D ratio and therefore the working point may be increased by either using a longer magnet assuming that the diameter is fixed, or by placing a ferrous body on the rear magnetic pole surface. This also has the effect of doubling the L dimension. (Thus a 10 mm diameter x 5 mm thick magnet with a ferrous backing plate will have the same working point and therefore provide the same flux as a magnet 10 mm diameter by 10 mm long).

As can be seen from Fig. 3, the higher the working point, the lower will be the irreversible losses at elevated temperatures. Irreversible loss curves for other NdFeB and SmCo grades are shown on pages 5,6 & 7. Note that for NdFeB, these curves are similar for all energy grades within a temperature grade (H,SH, etc), i.e. the percentage loss for N40H will be the same as for N30H. The upper temperature limit for NdFeB grades is quoted for a working point of 1.4 (L/D ratio of 0.7).

L/D	B/μ_o-H	L/D	B/μ_o-H
0.1	0.3	1.1	2.1
0.2	0.5	1.2	2.4
0.3	0.7	1.3	2.6
0.4	0.9	1.4	2.9
0.5	1.1	1.5	3.2
0.6	1.2	1.6	3.6
0.7	1.4	1.7	4.0
0.8	1.6	1.8	4.4
0.9	1.7	1.9	4.8
1.0	1.9	2.0	5.3

TABLE 2

Example:

(1) Magnet size:.............10 mm diameter x 3 mm thick (axis).
Material: ....**Sintered NdFeB N35H grade**
Temperature range: .20-100ºC
L/D = 0.3 so working point = 0.7 from Table 2.
From Neo 2 curves Irreversible loss = 4.5%
80º x 0.11 = reversible change of 8.8%
So total loss at 100ºC = 13.3%.
When the magnet returns to 20ºC, the only loss will be 8.8%, and no further permanent loss will occur when recycling up to 100ºC.

(2) Magnet size:.............10 mm diameter x 3 mm thick (axis).
Material: ....**Sintered SmCo 2:17 grade**.
Temperature range: .20-100ºC.
L/D = 0.3 so working point = 0.7 from Table 2.
From Sm_2Co_{17} curves Irreversible loss = 0.2%
80ºC x 0.03 = reversible change of 2.4%.
So total loss at 100ºC = 2.6%.

However, as the pole face flux density of the NdFeB magnet = 3000 gauss @ 20ºC the actual flux density @ 100ºC = 3000 - 13.3% = 2600 Gauss, and for the SmCo magnet @ 20ºC = 2400 Gauss so at 100ºC the pole face flux density will be 2400 - 2.6% = 2338 Gauss.

So, unless a low temperature coefficient is required between 20ºC and 100ºC, the NdFeB magnet will still provide a higher flux.

So, generally, if the only concern is the degree of loss at a maximum operating temperature, raise the whole device including the magnet to the highest temperature to which it may be subjected and the magnet will lose a percentage dependant on the material used and the magnet size. No further losses will be encountered provided that the subjected temperature is not exceeded. However, the device will still be subject to the reversible changes of the magnetic material being used.

If the magnets are taken to temperatures above the maximum working temperatures shown on Table 1, metallurgical changes may occur and the original level of magnetisation not restored by re-magnetisation.

Sub-Zero Temperatures

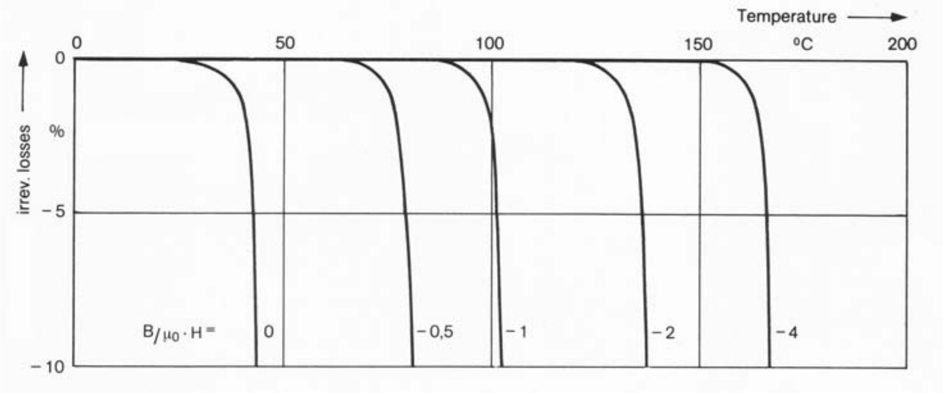
This is a much more complex area, and the following points should be considered for each of the material groups. Losses are still basically dependant on the L/D ratio, i.e. Working Point related.

Ferrite Serious irreversible losses will occur below -60ºC especially if the L/D ratio falls below 0.5.

Alnico L/D dependant, but permanent losses of no more than 10% are to be expected even down to 4K.

Samarium cobalt Minimal losses down to 4K.

Neodymium-Iron-Boron Our experience has shown that there are virtually no irreversible losses down to 77K.



N35H