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Nickel-Iron Alloys (NiFe)-
An Overview of the NiFe Alloys for Sensor Applications

Dr. Manuel Demper, Dr. Niklas Volbers, VACUUMSCHMELZE GmbH & Co KG, Germany,
manuel.demper@vacuumschmelze.com

Abstract— For several applications it is important to choose an appropriate magnetic alloy to achieve highest accuracy in case of magnetic sensing. The class of nickel iron alloys in the range of 40% to 80% Ni-content is often used for sensor applications because of highest permeability and lowest coercivity. To give an overview of the different materials this paper will highlight various high permeability NiFe-alloys and their magnetic properties. The aim is to provide a guideline in order to select the appropriate soft magnetic material for magnetic sensors.

I. Introduction

Prominent examples of detecting devices where NiFe finds its application are inductive current sensors for battery management in cars, so called torque sensors [1] for electric power steering and displacement sensors (e.g. PLC-D-Sensors [2]).

All these types of sensing devices place highest demands on the magnetic performance of the used soft magnetic materials regarding sensor accuracy and sensitivity.

The availability of materials with saturation inductions ($B_s$) from 0.6 to 1.5T and $H_C$-values from 1 to 10 A/m (s. Fig 1) allows to find suitable NiFe-alloys to build sensors with a large range of sensitivity.

VAC’s portfolio of NiFe-materials ranges from 30% to 80% Nickel-content. The following chapter describes the main differences and benefits of the various NiFe-alloys with regard to sensor applications.

All shown data are obtained from annealed ring samples made from 0.35 mm thick strip material. The heat treatment was performed under optimum conditions in dry hydrogen atmosphere.

II. Properties of VAC’s NiFe-Alloys

A. 80% NiFe-alloys

80% NiFe alloys represent the class of crystalline soft magnetic materials with highest permeability and lowest coercivity. Hence, these alloys are used for shielding applications and flux guiding parts or for sensing lowest magnetic changes (e.g. current sensors for battery management).

Two important material parameters the crystalline anisotropy $K_1$ and the magnetostriiction $\lambda$ are nearly zero because of the material composition of 70 to 80% Nickel, 3 to 6% Mo and/or 4 to 5% Cu, which leads to the outstanding magnetic properties (s. e.g. [3, pp. 218]). Within the mentioned component boundaries of Ni, Mo and Cu one can define two classes of alloys. (i) The Cu and Mo containing alloys like MUMETALL® (Ni77%Cu3%Mo3%Febal) and VACOPERM® 100 (Ni77%Cu4%Mo3%Febal), which fulfil the international standard IEC 60404-8-6 and (ii) the (only) Mo containing materials like ULTRAVAC® 80 (Ni80%Mo5%Febal), and ULTRAVAC® 816 (Ni81%Mo9%Febal), which additionally meet the specifications of the US-Standard ASTM 753.

Table 1 Typical DC-values for $B_s$, $B_r$ and $H_C$

<table>
<thead>
<tr>
<th>Material</th>
<th>$B_s$ (T)</th>
<th>$B_r$ (T)</th>
<th>$H_C$ (A/m)</th>
<th>$\mu_{max}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mumetall</td>
<td>0.78</td>
<td>0.45-0.55</td>
<td>≤ 1.5</td>
<td>500,000</td>
</tr>
<tr>
<td>Ultravac 80</td>
<td>0.73</td>
<td>0.30-0.40</td>
<td>≤ 1.5</td>
<td>250,000</td>
</tr>
<tr>
<td>Ultravac 816</td>
<td>0.65</td>
<td>0.20-0.30</td>
<td>≤ 1.5</td>
<td>190,000</td>
</tr>
</tbody>
</table>

Figure 1 Survey of VAC's magnetic Alloy

Hence, NiFe-alloys with lowest coercivity ($H_C$) and highest permeability ($\mu$) are often used for such applications.
Since VACOPERM 100 is the Cu-containing corresponding material to ULTRAVAC 80 with slightly lower initial but higher maximum permeability, for reasons of clarity the following summarized data are from three selected 80% NiFe alloys with typical hysteresis characteristics.

Fig. 2 shows exemplarily three DC-hysteresis loops of 80% NiFe-alloys. Due to small differences in the chemical composition of the main elements a change in the hysteresis loop occurs. In comparison the samples made from MUMETALL show a Z-shaped curve whereas the annealed rings of ULTRAVAC 80 and ULTRAVAC 816 have more round to flat hysteresis loops. Typical DC-values of the saturation induction, the remanence (B_r), the coercivity and the maximum permeability (µ_max) for theses alloys are summarized in Tab 1.

As shown in Fig. 3 the characteristic of the hysteresis loop is directly linked to the permeability of those alloys. While MUMETALL has the highest maximum µ-values, ULTRAVAC 80 and ULTRAVAC 816 show the highest initial permeability (µ_i) in the range below 0.1 A/m.

ULTRAVAC 816 combines a high initial permeability and a high stability in case of disturbing magnetic stray fields, due to its low remanence and round hysteresis loop.

Typical µ-values for the different alloys are summarized in Tab 2.

The 80% NiFe-alloys are ideal soft magnetic materials for detecting lowest field strengths, due to their outstanding magnetic properties concerning coercivity and permeability.

**Table 2 Typical DC-values for static initial and maximum permeability**

<table>
<thead>
<tr>
<th>Material</th>
<th>µ_i</th>
<th>µ_max</th>
</tr>
</thead>
<tbody>
<tr>
<td>MUMETALL</td>
<td>50,000 – 60,000</td>
<td>500,000</td>
</tr>
<tr>
<td>Ultravac 80</td>
<td>70,000 – 90,000</td>
<td>250,000</td>
</tr>
<tr>
<td>Ultravac 816</td>
<td>70,000 – 90,000</td>
<td>190,000</td>
</tr>
</tbody>
</table>

B. 40 to 50% NiFe-Alloys

The field of application of 80% NiFe-materials reaches its limits at higher field strengths because of the low saturation induction.

To detect high currents or for guiding the magnetic flux of hard magnets (e.g. in a torque sensor) a good choice are 40-50% NiFe-alloys. This class of materials is characterized by saturation inductions of about 1.3 to 1.5 T, a coercivity between 3.5 and 10 A/m (s. Fig. 1) as well as high permeability.

Two important alloys of VAC’s 40-50% NiFe-materials are the binary PERMENORM® 5000 V5 (Ni_{44}Fe_{56}) and the ternary ULTRAVAC 44 V6 (Ni_{44}Mo_{3}Fe_{56}). While PERMENORM 5000 V5 has a coercivity of about 4 A/m and the highest saturation induction of 1.55 T, ULTRAVAC 44 V6 shows a lower H_c-value of about 3.5 A/m. However due to additions of Molybdenum (3%) and the reduced Ni-content, the saturation induction of this alloy is also lowered to 1.35 T.

**Figure 2** DC hysteresis loops of 80% NiFe-alloys measured on stamped rings (strip thickness: 0.35 mm; annealing: 5h 1150°C, dry H_2)

**Figure 3** DC initial magnetic curve of 80% NiFe-Alloys measured on stamped rings (strip thickness: 0.35 mm; annealing: 5h 1150°C, dry H_2)

**Figure 4** DC initial magnetic curve of 50% NiFe-Alloys measured on stamped rings (strip thickness: 0.35 mm; annealing: 5h 1150°C, dry H_2)
as well as maximum permeability, the latter has advantages in applications with alternating magnetic fields due to the substantially higher electrical resistivity of $\rho_{\text{el}} = 0.80 \mu\Omega\text{m}$ ($\rho_{\text{el, Permenorm}} = 0.45 \mu\Omega\text{m}$, s. Fig. 5).

However in comparison to the 80% NiFe alloys the sensor accuracy and sensitivity at low magnetic fields is reduced due to the higher coercivity field strengths and the lowered permeability (s. Tab. 4).

### III. Conclusion

NiFe-alloys are often used for magnetic sensing techniques because of outstanding magnetic properties concerning saturation induction, coercivity and permeability. By varying the Ni-Content, as shown in Fig. 6, a large range of saturation inductions between 0.65 to 1.55 T is covered, which allows to build sensors for a large field of application.

In VACs portfolio of NiFe-alloys MUMETALL, VACOPERM 100, ULTRAVAC 80 and ULTRAVAC 816 belong to the 80% NiFe-materials. With additions of Mo and/or Cu these alloys have the lowest coercivity and highest permeability. In case of accurate detecting of lowest magnetic fields this material class will be the best choice. However 80% NiFe-materials reach their limits at higher magnetic field strengths because of the low saturation induction. For such applications suitable materials can be found in the class of 50% NiFe-alloys with $B_s$-values from 0.75 to 1.55 T and a coercivity from 3.5 to 10 A/m. Beside binary materials like PERMENORM 5000 V5, alloys with additional Mo (ULTRAVAC 44 V6) and Cr (CHRONOPERM 36) are available with increased electrical resistivity and lower coercivity.

All these alloys are available in various strip thicknesses and as solid materials like rods, wire etc.

### IV. References