Meeting Motor Design Requirements for low Temperatures

Christoph Stuckmann [1]; Michael Weickhmann [2]; Frank Becker [2]
[1] MACCON GmbH, Munich, Germany
[2] VACUUMSCHMELZE GmbH & Co. KG, Hanau, Germany

I. Categories

Digest Categories:
Motors, Valve, Ariane, Pr-Fe-B Magnets, Cryogenic-Application

II. Digest

Most space programs require special motor designs, processes and materials. For these projects, classical industrial motor design approaches are not suitable. The individual design approaches, the material choice and manufacturing processes need to be qualified unless they are already verified by space heritage. To achieve long life and reliability, conservative and proven designs as well as the best possible quality levels of material and workmanship must be used. Further design requirements can be summarized as high efficiency, minimization of losses and heat dissipation by suitable a design architecture in order to reduce the influence of thermal stress on each component. Furthermore, special attention is needed, if a wide thermal operational range is required. In some extreme cases, temperature ranges for cryogenic applications are required. In such applications operating temperatures from around 70K up to a higher level of ambient conditions have to be managed. Therefore, the whole motor design has to be adapted to these extreme conditions by using special design rules. One example of a design rule for motors for cryogenic applications, is that the local coupling and contacting between individual motor phases in the stator winding must be minimized. This rule must be adhered to within the active part of the stator winding, but also within the end-turns, in order to minimize mechanical stress caused by unequal thermal expansion of the copper wiring, as well as to mitigate the effects of stress caused by the high vibration levels typical during a launch event. Furthermore, the choice of the lamination insulation varnish, as well as the wire and slot insulation material must be adapted to these harsh ambient conditions. In addition, the wire impregnating resin material and further stator components must be adjusted to these extreme requirements. For the rotor design special criteria must also be employed. The main issues of a cryogenically specified rotor design are the rotor architecture and the selected, high remanent magnet materials. A design with embedded rotor magnets may be the safest solution with regard to the mechanical stability and the protection of the magnets against demagnetization by strong stator fields. However, this approach is not conducive to maximizing the torque-to-volume ratio i.e. the torque density. A rotor design with surface-mounted magnets has a higher torque density than a design with embedded magnets. However, there are significant risks for the secure mechanical attachment of the magnets to the rotor hub due to thermal expansion stresses, not to mention centrifugal forces at high speed operation.

In this paper, motor design rules and criteria for space applications operating in extremely low temperatures all the way up to higher temperatures are presented. One application example given will be the design for the cryogenic valve actuator components MACCON has designed and built for the FLPP- program on behalf of ArianeGroup GmbH. VACUUMSCHMELZE contributed it's $Pr_2Fe_{14}B$ magnet alloy with an extraordinary high remanence at low temperatures (without spin-reorientation of the magnetic polarization) and it's magnet coating technology (VACCOAT® 20011) as well as dimensioning a glass fiber bandage for fixation of the surface-mounted magnets and the assembly thereof.

The illustration below shows the functional architecture of the FLPP- Expander Technology Integrated Demonstrator (ETID). The rocket engine demonstrator features electrically-driven motor valves at all locations replacing the classical pneumatically-driven valves. Within the FLPP- project a demonstrator valve has been built showing three key electrically-driven valves, which are: the TCV/RGV (thrust-control valve, regulation valve) using a mass flow regulating cone and the OCV (oxygen chamber valve) using a streaming cone. For the HCV (hydrogen chamber valve) the design has been established and the long lead items were procured. The locations of these valves can be seen in Fig. 1.

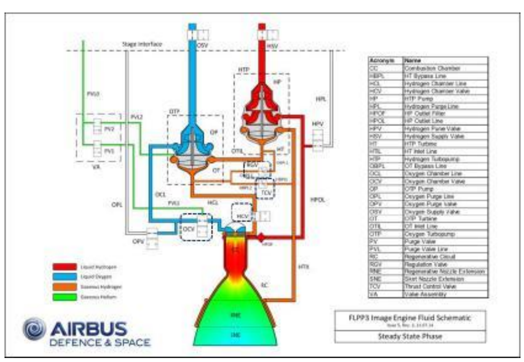

Figure 1. Architecture of the FLPP3 valve structure

An exceptional torque-to-volume ratio has been achieved with VACUUMSCHMELZE's cryogenic VACODYM® 131 DTP alloy, with a remanence significantly higher than traditional SmCo or NdFeB alloys. Hence, both approaches, embedded and surface-mounted magnets, need special magnetic materials. Especially, below 140K (-133 °C) conventional NdFeB magnets experience a reorientation of the main magnetization vector of the c-axis, thus the main flux direction of anisotropic magnets will be turned into a different direction, which reduces the energy density of the motor. Thus, for applications below 140K, special magnetic material is needed. For these extreme ambient in space low temperatures, VACUUMSCHMELZE has developed suitable magnetic materials by substituting the Nd with Pr. Additionally, by applying grain boundary diffusion (GDB) the material type VACODYM® 131 DTP offers even more coercivity keeping the remanence at an exceptional high level refer to Tab 1.

It is well known refer to [1] and [2], however, that the spin-reorientation does not occur for $Pr_2Fe_{14}B$. In former publications [3], it has been shown, that combined alloys of $(Nd_xPr_{1-x})_2Fe_{14}B$ don't show the typical cusp in remanence over temperature caused by the spin-reorientation

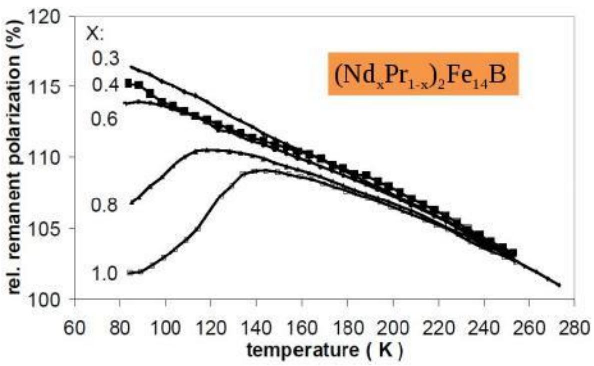

Figure 2. Relative remanent polarization vs. temperature for various compositions of (NdxPr1_x) 2Fe14B -magnets, partially showing the spin-canting phase transition for high values of x.

when x becomes less than 0.3. This has been successfully used in a mini-undulator for HZB refer to [4] with an alloy consisting of $(Nd_{0.2}Pr_{0.8})_2Fe_{14}B$ see Fig. 2. The properties at very low temperatures have been examined by [5] and assuming that the cited thermal coefficients also hold for VACODYM® 131 DTP and VACOMAX® 262 HR one would render the values shown in Tab. 1 below.

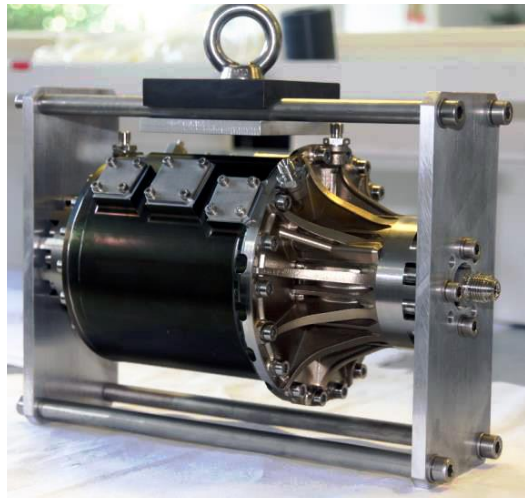

Figure 3. OCV- housing (with inlet flange) [6]

Figure 4. OCV- Campaign test at LN2 temperature conditions (77 K) [6]

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[5] M Hasegawa et al. Rare earth magnets for applications over a wide temperture range. *Jornal of Magnetism and Magnetic Material, 124:325– 329, 199*

[6] .Thomas Fuhrmann, Dr. Bernd Mewes, Felipe Dengra Moya and Markus Horstmann (Airbus Safran Launchers GmbH) *7TH EUROPEAN CONFERENCE FOR AERONAUTICS AND SPACE SCIENCES (EUCASS), DOI: 10.13009/EUCASS2017-13*

Property	VACOMAX® 262 HR	VACODYM® 131 TP	VACODYM® 131 DTP
	Sm_2Co_{17}	$Pr_2Fe_{14}B$	$Pr_2Fe_{14}B$ GBD**)
Br_{typ} @ 20 °C	1.19 T*)	1.41 T	1.41 T
Br_{typ} @ -133 °C	1.24 T*)	1.58 T	1.58 T
Br_{typ} @ -203 °C	1.25 T*)	1.62 T	1.62 T
Hcj_{typ} @ 20 °C	≥1750 kA/m	≥1230 kA/m	≥1640 kA/m
Hcj @ -133 °C	≥2250 kA/m*)	≥ 3185 kA/m	≥ 3185 kA/m
Hcj @ -203 °C	≥2900 kA/m*)	≥2900 kA/m*)	≥2900 kA/m*)

Table I

COMPARISON OF DIFFERENT PERMANENT MAGNET ALLOYS AT VARIOUS TEMPERATURES.

*) expected

**) with Grain Boundary Diffusion

MACCON

MOTION UNDER CONTROL

MACCON Elektroniksysteme GmbH

Aschauer Str. 21 · D-81549 München

Tel.: 089 / 65 12 20-0

Fax: 089 / 65 52 17

http://www.maccon.de