синтезувати САК напруги АГ, оцінюючи ступінь її інваріантності до збурень

1. Торопцев Н.Д. Асинхронные генераторы автономных систем. – М., 1998. 2. Wajs K. Wlasciwosci dynamiczne elementow napendowych elektrowni wiatrowych, Przeglad Electro-techniczny. – 3/98. – S. 64–65. 3. Шехтер Я.И. Использование энергии ветра. – М., 1983. 4. Farmer E.D.; Newman V.G., Ashmole P.H.: Economie and operational implications of a complex of wind-driven generators on a power system // Proc.-I.E.E. – 1980. – Vol. 127; pt. A;№ 5. 5. Schlueter R.A. Simulation and assessment of wind array power variation based on simultaneous wind speed measure ment // I.E.E.E. – Trans. Vol. P.A.S. – 103; – 1984. – № 5. 6. Chan S.M., Cresap R.L., Curtice D.H. Wind turbine cluster model // I.E.E.E. – Trans. Vol.P.A.S. – 103; – 1984. – № 7. 7. Dessaint L., Nakra H., Mukhedar D. Probagation and elimination of torque ripple in wind energy conversion systems // I.E.E.E. – Trans. vol.EC – 1. – 1986. – № 2. 8. Михайлов О.П. Автоматизированный электропривод станков и промышленных роботов: Учеб. для вузов. – М., 1990. – 304 с. 9. Ткачук В.І., Копчак Б.Л. Асинхронний генератор з самозбудженням як ланка системи автоматичного керування // Вісн. Нац. ун-ту "Львівська політехніка". – 2002. – Вип. 449. – С. 170–177.

Milan Krasl, Rostislav Vlk*

University of West Bohemia, Department of Electromechanics and Power Electronics,
Universitni 8, Pilsen, Czech Republic
* University of West Bohemia, Faculty of Electrical Engineering,
Universitni 8, Pilsen, Czech Republic

PERMANENT MAGNETS AND THEIRS DEPENDENCE ON TEMPERATURE

This article deals with usage of permanent magnets, especially their behaviour at different temperatures. In the introduction one possible application is described briefly. It is the usage in the synchronous machine with a rotor whose permanent magnets are located inside the rotor. There is almost always an increase in temperature inside the machine and thus it is important to know the characteristic curve of the momentum decrease with temperature. Using permanent magnets on the basis of rare earth acceptable results can be calculated. The article deals with several kinds of these magnets. Calculations were done using FEM. The results of the solution are discussed in the conclusion.

Introduction. Recently, using permanent magnets in electric machines has been spreading considerably. First it was direct machines where the exciting winding were replaced with permanent magnets, later synchronous machines with magnets in rotor, with both cylinder or disc rotor, different kinds of pacing machines and some types of reluctant machines, both classical and switching ones (for the latter the name hybrid reluctance machines is used).

Transformation of energy into mechanical work in electrical machines is related with the existence of the magnetic field, which is excited with the system of suitably arranged conductors, permanent magnets or their combinations. In a suitably designed electrical machine the magnets might be the source of magnetic flux, which is the quantity that causes the existence of rotating momentum. But this contribution of permanent magnets to the increase of output or efficiency is connected with many problems stemming from the qualities of permanent magnets as well as from the complexity of the equipment used for feeding these machines. One of the possible kinds of drives that are used at present are synchronous machines with permanent magnets. The machine on which the calculations were carried out is the machine whose stator is identical with the stator of the drive of the poles of the reactor VVER440. Within the reconstruction of this drive the variant of the machine with magnets is being considered. Here the question arouses what qualities these magnets will have at higher temperatures and what the drop of the momentum will be like.

Today the most frequently used types of permanent magnets are on the basis of NdFeB and SmCo. These magnets have different qualities and that is why it is necessary to define their behaviour using some of today used methods – FEM.

Advantages of using permanent magnets. A permanent magnet (PM) can produce magnetic field in an air gap with no excision winding and no dissipation of electric power. External energy is involved only in changing the energy of magnetic field, not in maintaining it.

The use of permanent magnets (PMs) in construction of electrical machines brings the following benefits:

- no electrical energy is absorbed by the field excitation system and thus there are no excitation losses which means substantial increase in the efficiency.
- higher torque and/ or output power per volume than when using electromagnetic excitation,
- better dynamic performance than motors with electromagnetic excitation,
- better dynamic performance than motors with electromagnetic excitation
- simplification of construction and maintenance
- reduction of prices for some types of machines

There are three classes of PMs currently used for electric motors:

- Alnicos (Al, Ni, Co, Fe);
- Ceramics (ferrites), e.g., barium ferrite BaOx6Fe2O3
- Rare-earth materials, i.e., samarium –cobalt SmCo and neodymium-iron-boron NdFeB.

This article deals evaluation of the static torque in dependence on the temperature. The synchronous reluctance machine with permanent magnets was used as example calculation. Same machines work by higher temperature that it needed to know machine response – decrease of HC and torque.

Properties of permanent magnets. Demagnetisation curves of the above PM materials are given in Fig. 1.

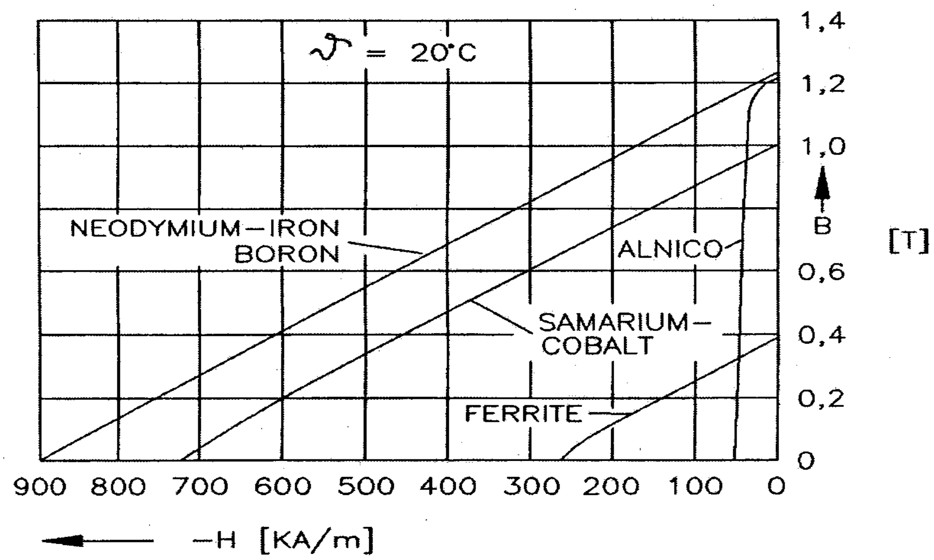


Fig. 1 Demagnetisation curves for different permanent magnets

Demagnetisation curves are sensitive to the temperature. Both Br and Hc decrease as the magnet temperature increases, i.e.,

$$B_r = B_{r20}\left[1 + \frac{\alpha_B}{100}\left(\vartheta_{PM} - 20\right)\right] \quad (1)$$

$$H_c = H_{c20}\left[1 + \frac{\alpha_H}{100}\left(\vartheta_{PM} - 20\right)\right] \quad (2)$$

where θ_{PM} is the temperature of PM, B_{r20} and H_{c20} are the remanent magnetic flux density and coercitive force at 20 °C and $\alpha_B < 0$ and $\alpha_H < 0$ are temperature coefficients for B_r and H_c in %/°C, respectively.

Table 1

	ND-31HR	ND-31SHR	ND-35R	Vacomax
B_r [T]	1.14 to 1.24	1.08 to 1.18	1.22 to 1.32	1.05 to 1.12
H_c[kA/m]	828 to 907	820 to 899	875 to 955	600 to 730
μ_r [-]	1.05			1.22 to 1.39
α_B	-0.10			-0.03
α_H	-0.50			-0.15

Formulation of the problem. The cross-section of the RSM (Fig. 2) is divided into several parts:

- Ω_1 – the subdomain of the iron, B-H curve
- Ω_{2-8} – subdomains of the stator winding (tab. 2), J_C = 2,7A/mm^2

Table 2

Slots		1	2	3	4	5	6	7	8	9	10	11	12
Coils	up	0	0	J_C	J_C	J_C	J_C	0	0	- J_C	-J_C	- J_C	- J_C

	down	0	J_C	J_C	J_C	J_C	0	0	- J_C	- J_C	- J_C	- J_C	0

Slots		13	14	15	16	17	18	19	20	21	22	23	24
Coils	up	0	0	J_C	J_C	J_C	J_C	0	0	$-J_C$	$-J_C$	$-J_C$	$-J_C$
	down	0	J_C	J_C	J_C	J_C	0	0	$-J_C$	$-J_C$	$-J_C$	$-J_C$	0

- Ω_9 – the subdomain of the air, $\mu_r = 1$.
- Ω_{10} – the subdomain of the rotor iron, $B = f(H)$,
- Ω_{11} – the subdomain of the permanent magnets , parameters in tab. 1
- Ω_{12} – the subdomain of the shaft, $\mu_r = 800$
- boundary Γ: $A = 0$.

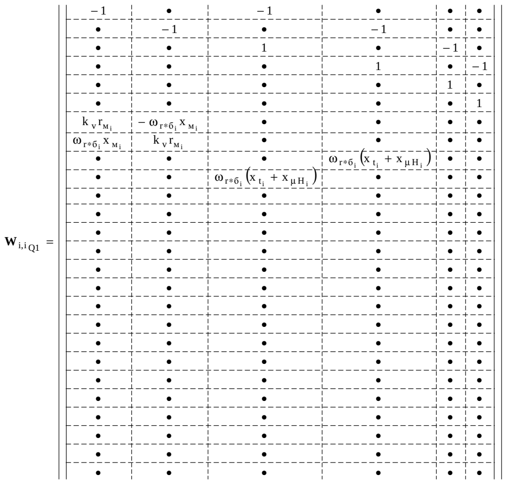


Fig. 2. Cross section of the stator

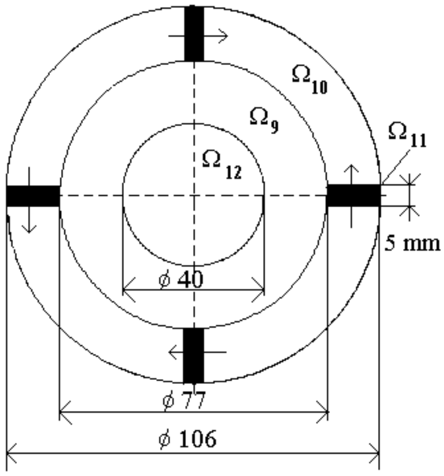


Fig. 3. Cross section of the rotor

Example of calculation. For solving of the task – operation characteristics T = f (t) – torque T, temperature t - was used the FEM-based program - FEMM. Graph 1. shows dependence H_c on the temperature. The static torque in dependence on the temperature was determined for one position of the rotor (angle 25°) – graph 2.

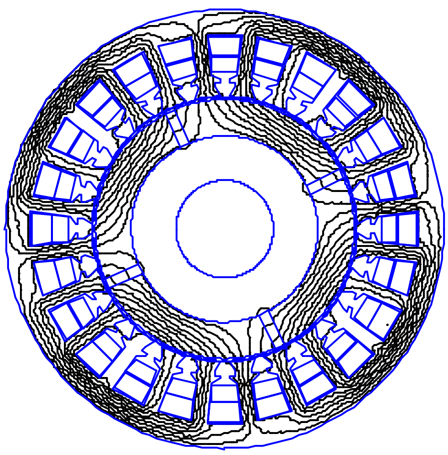
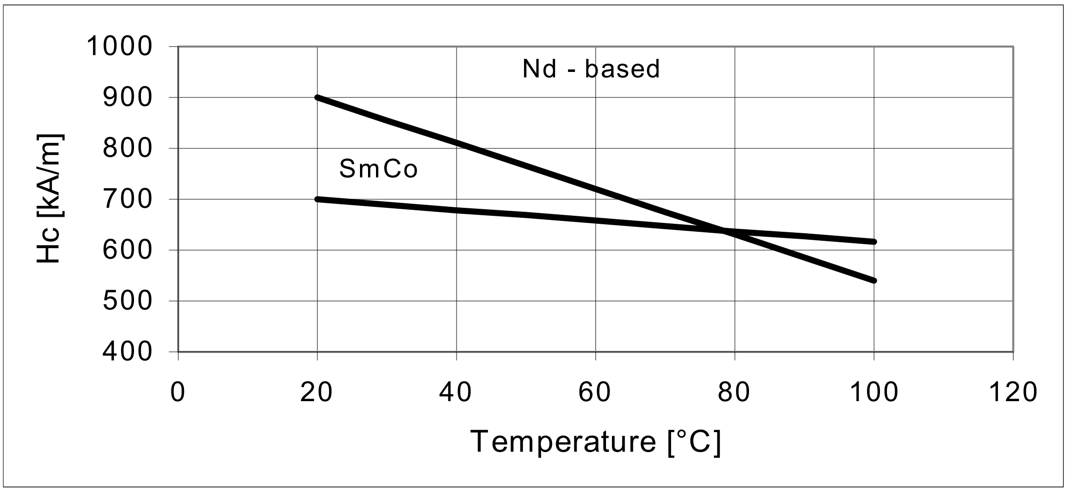
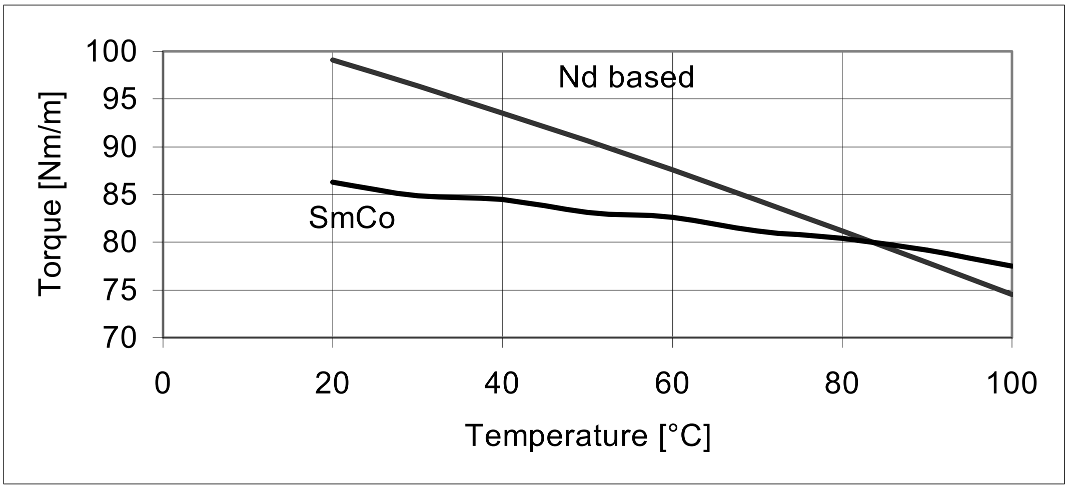


Fig. 4. Map of the magnetic field, angle 25°



Graph 1. Dependence H_C on the temperature



Graph 2. Operation characteristic T = f (t)

Conclusion. Decreasing of the static torque in dependence of the temperature is very distinct. This decrease is as many as 25 % in range 20 °C – 100 °C, for Nd – based magnets. The higher dependence display Nd – based magnets, however, Nd – based magnets have higher H_C by normal temperature than SmCo magnets.

1. Gieras J.F., Wing M. Permanent magnet motor technology, Marcel Dekker, Inc. 2. Krasl M., Rybár J. Renovation of drive roads of nuclear reactor VVER440. Elektroenergetika 2003. Visalaje. ISBN 80-248-0225-2. 3. manual FEMM.