Список літератури

1.   Электрооборудование лифтов массового применения [Текст]/ П. И. Чутчиков, Н. И. Алексеев, А. К. Прокофьев. – М.: Машиностроение, 1983. – 168 с.
2.   Тулин В. С. Электропривод и автоматика многоканатных рудничных подъемных машин. – М.: Недра, 1964. – 181 с.
3.   Савастеев В.Г. Элементы оптимального режима работы автоматизированного рудничного подъема [Текст]// Сб. Автоматизация в угольной промышленности. – М.: Углетехиздат, 1956. – С. 109-126.
4.   Киричок Ю.Г., Чермалых В.М. Привод шахтных подъемных установок большой мощности. – М.: Недра, 1979. – 336 с.
5.   Чермалых В.М. Исследование сложных электромеханических систем: Текст лекций. – К.: КПИ, 1979. – 64 с.
6.   Чермалых В.М., Рудь Б.Н., Гужовский А.Т. Исследование динамики канатов многоканатных подъемных установок при следящей системе управления приводом // Сб. Стальные канаты. – К.: Техника. – 1968. – Вып. 5. – С. 29-33.
7.   Довгань С. М., Самойленко А. А. Способы формирования задающих воздействий в системах управления подъемными установками, обеспечивающие отсутствие колебаний в конце периода разгона// Вісник Кременчуцького державного політехнічного університету: Наукові праці КДПУ. Кременчук: КДПУ, 2003. Вип. 2(19), Т. 1. С. 68 – 72.

Рекомендовано до друку: к-том техн. наук, проф. Івановим О.Б.

УДК 621.313.8

V.I. Panchenko, S.I. Fedorov, V.V. Sukhova (language adviser).
(Ukraine, Dnepropetrovsk, State Higher Educational Institution "National Mining University")

EFFICIENCY OF PERMANENT MAGNET IN ELECTRIC GENERATORS WITH MAGNETOELECTRIC EXCITATION

As a result of creation of iron-based, neodymium-based and boron-based permanent magnet (PM) with high specific energy the range of capacity for permanent magnet machines enables them to compete with electromagnetic excitation electric cars by their parameters and excel them in weight-size parameters. Synchronous machines with PM have a relatively simple design, are featured as reliable and able to maintain long-run (from 5 to 10 years) initial technical performance . In addition, they are easy to maintain and characterized by high efficiency factor because of lack of power losses in the excitation and sliding contact. Only high price of PM limits its large-scale implementation. Therefore, at the initial stage of structural design of PM it is necessary to determine (at least approximately) the right size and weight of the magnets and estimate the associated costs.

The paper [1] proposes the formula for determining the amount of PM in electric machine in generator mode:

$$V_m = \frac{2K_d \cdot K_z \cdot S_H}{\pi^2 \cdot f \cdot K_u \cdot B_r \cdot H_c \left(E_0{}^* \cdot I_k{}^* \right)} \,, \tag{1}$$

where K_d – convergence ratio for longitudinal armature reaction to the form of magnetomotive force (MMF)of magnet; K_z - the depredation factor; S_H - generator capacity; f – current frequency; $K_u = u\left(\sqrt{1-u^2 cos^2\,\varphi} - u\,sin\varphi \right)$ - coefficient characterizing operating conditions; $u = \dfrac{U}{E_0}$: U - output voltage ; E_0 - electromotive force (EMF) at idle winding course; $cos\varphi$ - power factor; B_r, H_c - residual magnetic induction and coercive force of the magnet; $E_0{}^*$, $I_k{}^*$ - relative values of EMF E_0 and short-circuit current I_k.

Product $E_0{}^* \cdot I_k{}^*$ is for a magnet utilization factor. Ideally, when there is no dissipation of the magnetic flux of the magnets and armature winding and with zero air gap value $E_0{}^* \cdot I_k{}^* = 1$ according to [1] and use of PM would be ideal and amount of magnets can be minimal .

In the case of magnets with linear demagnetization curve we get [1]:

$$E_0{}^* = \frac{\Lambda_\delta{}^*}{1+\Lambda_\sigma{}^*+\Lambda_\delta{}^*} \,; \tag{2}$$

and
$$I_k^* = \left[\Lambda_{\delta a}^* + \left(1 + \Lambda_\sigma^*\right)\left(1 + \frac{\Lambda_{\sigma a}^*}{\Lambda_\delta^*}\right) \right]^{-1}, \tag{3}$$

where $\Lambda_\delta^*; \Lambda_\sigma^*; \Lambda_{\sigma a}^*$ are relative magnetic conductivities of air gap, ways for dissipation and dispersion of PM and armature winding respectively, wherein:

$$\Lambda_\delta^* = \frac{\mu_0 S_\delta}{\delta} \cdot \frac{H_c \cdot h_m}{B_r \cdot S_M}; \tag{4}$$

where $\mu_0 = 12{,}56 \cdot 10^{-7}$ H/m - magnetic constant; S_δ, S_M - areas of air gap and magnet inverted towards it respectively; δ, h_m - gap size and height of the PM.

As it follows from (4) to determine Λ_δ^* and subsequently E_0^* and I_k^* we have to know the size of the PM. Therefore, the formula (1) can be used only to evaluate the degree of approximation of the PM volume to the theoretical minimum after selecting S_M and h_m.

Let us define the components of the product $E_0^* \cdot I_k^*$ differently. The relative value $E_0^* = \frac{E_0}{m_E}$, where

$E_0 = \pi\sqrt{2} f w_1 K_{W1} B_{\delta 0} S_\delta$ - EMF of phase of generator; $m_E = \pi\sqrt{2} f w_1 K_{W1} B_r S_M$ - scale of EMF reduction; w_1 - the number of turns of phase armature winding; K_{W1} - winding factor for the first harmonic component of EMF; $B_{\delta 0}$- magnetic induction in the air gap (average value along its length). Typically $S_\delta = S_M$ and after substitutions we obtain:

$$E_0^* = \frac{B_{\delta 0}}{B_r}. \tag{5}$$

The relative value of short-circuit current:

$$I_K^* = \frac{E_0}{X_d \cdot m_I} = \frac{E_0}{K_{\sigma a} \cdot X_{ad} \cdot m_I}, \tag{6}$$

where X_d – inductive reactance of phase along the longitudinal axis of the generator; X_{ad} - inductive reactance of armature reaction in a specified direction; $K_{\sigma a} = 1 + \frac{X_{\sigma a}}{X_{ad}}$ – coefficient; $X_{\sigma a}$ – inductive reactance of coil scattering; $m_I = \pi \cdot p \cdot H_c h_m / \sqrt{2} \cdot m \cdot K_d \cdot K_{W1} \cdot w_1$ – scale of current reduction; m – number of phases; p – number of pole pairs.

Considering [2]:

$$X_{ad} = \frac{4mf}{\pi} \cdot \frac{\mu_0 \cdot \tau \cdot l}{K_\delta \cdot K_\mu \cdot \delta} \cdot \frac{w_1^2 \cdot K_W^2}{p} \cdot K_d, \tag{7}$$

where τ - pole division; l - the length of the magnetic anchor ; K_δ - the coefficient of the air gap ; K_μ - coefficient of magnetic saturation , we obtain:

$$I_K^* = \frac{\pi \cdot \alpha_i . K_\delta \cdot K_\mu B_{\delta 0}}{2\mu_0 \cdot K_{\sigma a} \cdot H_c} \cdot \left(\frac{\delta}{h_m} \right) \tag{8}$$

where α_i - the estimated coefficient of pole arc.

Let us define utilization factor of PM as K_m and rewrite equation considering (5) and (8):

$$K_m = E_0^* \cdot I_K^* = \frac{\pi}{2} \cdot \frac{\alpha_i . \cdot K_\delta \cdot K_\mu \cdot B_{\delta 0}^2}{\mu_0 \cdot K_{\sigma a} \cdot B_r \cdot H_c} \cdot \left(\frac{\delta}{h_m} \right) \tag{9}$$

Ratio $\left(\dfrac{\delta}{h_m}\right)$ is found through the following considerations. Voltage drop in the magnetic range of electric car (taking into account the reaction of the anchor) should be compensated by MMF of permanent magnets , that is:

$$2 \cdot K_\delta \cdot K_\mu \cdot K_Z \cdot K_p \cdot \frac{B_M}{\mu_0} \cdot \delta = 2 \cdot h_m \cdot H_M \ , \tag{10}$$

where $K_z < 1$ - coefficient considering the reduction of the magnetic induction on the length of the air gap, B_M - magnetic induction at the surface of the PM inverted to air gap, H_M - the magnetic field of the magnet; $K_p > 1$ - coefficient considering the influence of the armature reaction:

$$K_p = 1 + \frac{K_W \cdot D \cdot A \cdot K_d \cdot \mu_0 \cdot sin\psi}{\sqrt{2} \cdot p \cdot K_\mu \cdot K_Z \cdot K_\delta \cdot \delta \cdot B_M}, \tag{11}$$

where D - bore diameter, A - linear load of armature winding; ψ - the angle between the EMF vectors and current in phase vector diagram generator. The values of A and B_M are usually given, the value $\psi \approx 40^0 \div 45^0$.

The equations describing the linear demagnetization curve PM has the form:

$$\frac{B}{B_r} = 1 - \frac{H}{H_c} \ , \tag{12}$$

where B - magnetic induction in the middle section of the magnet, $B = K_{\sigma\mu} \cdot B_M$, $K_{\sigma\mu} > 1$- coefficient of magnet discharge. From equation (12) we have:

$$H = H_M = H_C\left(1 - \frac{B_M K_{o\delta 1}}{B_r}\right). \tag{13}$$

After substituting (13) into (10) and the corresponding transformations we obtain:

$$\frac{\delta}{h_m} = \frac{\left(\dfrac{B_r}{B_\delta} - \dfrac{K_{\sigma m}}{K_Z}\right)}{K_\mu \cdot K_\delta \cdot K_p \cdot \mu_m} \ , \tag{14}$$

where $\mu_M = \dfrac{B_r}{\mu_0 \cdot H_C}$ - relative permeability of the PM; $B_\delta = B_M \cdot K_Z$ - the average value of the magnetic induction in the air gap along its length during the load of generator.

After the substitutions in (1) formulas (14) and (9) we obtain the formula for calculating the required amount of PM in electric machine:

$$V_M = \frac{4}{\pi^3} \cdot \frac{K_d \cdot K_z \cdot K_{\sigma a} \cdot K_p \cdot S_H}{f \cdot K_u \cdot \alpha_i \cdot B_{\delta 0}^2 \cdot \left(\dfrac{B_r}{B_\delta} - \dfrac{K_{\sigma M}}{K_Z}\right)} \cdot \frac{B_r}{H_C} \ . \tag{15}$$

Magnetic induction and B_δ and $B_{\delta 0}$ in (15) have ratio:

$$B_\delta = K_H \cdot B_{\delta 0} ; \tag{16}$$

where $K_H = \dfrac{K_{\sigma M}\left(K_\mu K_Z \mu_M \dfrac{\delta}{h_M}\right)^{-1} + 1}{K_{\sigma M}\left(K_\mu K_Z \mu_M \dfrac{\delta}{h_M}\right)^{-1} + K_P}$ – coefficient considering the influence of the load of generator, and

$K_H \cong 0.95 - 0.99$.

Examining the formula (15) for at least considering (16) gave the optimum value for the induction of the surface of the magnet the following result:

$$(B_{\delta 0})_{opt} = \frac{0.5 \cdot B_r \cdot K_Z}{K_{\sigma M} \cdot K_H} \approx \frac{0.5 \cdot B_r}{K_{\sigma M}} . \tag{17}$$

Magnetic induction ($0,5 \cdot B_r$) in a neutral section of the magnet corresponding to its maximum external energy.

Let us consider the utilization factor of PM more detailed, applying (14):

$$K_{M} = \frac{\pi \alpha_i}{2 K_{\sigma a} K_p} \left(\frac{1}{K_H} - \frac{B_{\delta 0}}{B_r} \cdot \frac{K_{\sigma M}}{K_Z} \right) \cdot \frac{B_{\delta 0}}{B_r} . \tag{18}$$

Substituting in the last formula values of induction from (17) we obtain:

$$K_{M} = \frac{0.25 \cdot K_Z}{K_{\sigma a} \cdot K_p \cdot K_{\sigma M} \cdot K_H{}^2} . \tag{19}$$

Considering that $\frac{\pi}{2} \cdot \alpha_i \approx 1.0$, which usually occurs when all the coefficients in (19) equal units, that is, in the ideal case for magnets with linear demagnetization curve of the maximum value of $K_m = 0.25$, not 1.0 , which is theoretically possible in the general case [1] for magnets with some form of demagnetization curve.

It is possible to increase the coefficient K_m as it follows from (17) by two ways: first, by enabling parallel load generator capacitors that are partially or fully offset the effect of the armature reaction (with decrease of K_p); the second, by turning the series in each of the phases of the armature winding capacitors, and the inductive reactance phase:

$$X_{\phi} = X_d - X_c = X_d \cdot \left(1 - \frac{X_c}{X_d} \right) = K_{\sigma a} K_c \cdot X_{ad} , \text{ where } K_c = 1 - \frac{X_c}{X_d} < 1$$

X_c- capacity reactance. Then we introduce the coefficient K_c into the denominator of the formula (18) to testify the increasing of K_m.

Draw attention to the formula (14). Obviously, the part in brackets must be greater than zero. This means that $B_r / B_\delta > K_{\sigma \mu} / K_z$, where value of magnetic induction, which is possible in the air gap machines:

$$B_\delta < \frac{B_r K_Z}{K_{\sigma M}} \tag{20}$$

Theoretically, it is possible to reach induction $B_\delta = \frac{B_Z K_Z}{K_{\sigma M}}$ only if $h_M = \infty$.

Conclusion. The formula for calculating the volume of permanent magnets in electric machines with permanent magnet excitation was obtained. The analysis and evaluation for the utilization factor of permanent magnet are presented.

References

1. Бут Д.А. Анализ и расчет электрических машин с возбуждением от постоянных магнитов. – Электричество, 1996, № 6, с. 25-32.
2. Вольдек А.И. Электрические машины. И. «Энергия», 1966.

Рекомендовано до друку: к-том техн. наук, проф. Івановим О.Б.

В.І. Самуся, д-р техн. наук, Д.Л. Колосов, канд. техн. наук
(Україна, Дніпропетровськ, Державний вищий навчальний заклад «Національний гірничий університет»)

НАПРУЖЕНО-ДЕФОРМОВАНИЙ СТАН КАНАТА З БЕЗМЕЖНОЮ КІЛЬКІСТЮ ТРОСІВ ПРИ НАВАНТАЖЕННІ РОЗПОДІЛЕНИМ ДОТИЧНИМ ЗУСИЛЛЯМ

Вступ. Розширення області застосування гумотросових канатів на промислових підприємствах вимагає розв'язання цілого комплексу наукоємних завдань з розробки наукових основ та принципів створення нових, більш довговічних і надійних ліфтових установок з гумотросовими канатами. У зв'язку з цим розробка високотехнологічного ліфтового обладнання нового покоління з гумотросовими канатами є актуальною проблемою прикладного дослідження.