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Parametrical Optimization of Equivalent Circuit Parameters of Copper-squirrel-cage Solid Rotor Induction Motor supplied through Long Geophysical Cable

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Introduction

The parametrical method of synthesis first of all in detail was elaborated for the design of an induction control motors [1]. Later it was applied for the other types of conventional motors, such as stepping motors, gyroscopic motors, and special purpose motors. The equivalent circuit parameters are most essential for the performances of the induction motors. The parametrical optimization of executive and measuring electrical machines noncrossing windings is presented in [2].

The single-phase solid rotor capacitor induction motor for the borehole investigation devices is analyzed in [3, 4] and successfully employed in borehole logging.

The main demands for these motors are to guarantee the maximum reliability of the borehole investigation device under geophysical operating conditions, such as wide operating medium temperature change interval from –20ºC up to +150ºC or more; operating medium – dielectric liquid; length till 6000 m or more geophysical cable; changing of hydrostatic pressure from atmospheric up to 120 MPa; non-regular short-time and reverse duty-type; non-constant load due to operating cycle.

Taking into account the above-mentioned demands for the electric motor it is necessary to have relatively large starting torque with the small ratio of starting current while the reliable operation will be guaranteed in all slip range.

Sometimes the design and calculations of induction motors for borehole investigating devices are carried out when the stator parameters are already known. In this case it is necessary to select the rational parameters of rotor taking into account the parameters of the stator and the geophysical cable.

It is necessary to seek forming the torque-slip characteristic of the borehole motor, which could be reliably started up and could reach maximum rotational speed, while the load distribution is large i.e. the integral opening time of the spring system is minimal.

Primarily at the initial design stage it is important to determine the equivalent circuit parameters of copper-squirrel-cage solid rotor small-power induction motor for borehole investigation devices and then to use the parametrical design synthesis. Commonly, the parameters of the geophysical cable and maximum borehole medium temperature are known in advance.

Related equivalent circuit parameters of borehole motor

In case of conventional induction motors, the rotor resistance R_2', or in less rare cases, magnetizing reactance X_m is selected as the basic parameter [1]. The disadvantages of the rotor resistance are: the dependence upon temperature change and the sufficient sensitivity for technological deviations. The disadvantages of the magnetizing reactance are: the air gap fluctuations due to technological deviations affecting the resistance change and the dependence on the magnetic circuit saturation degree.

The parameter which uniquely would characterize the studied motor can be the electromagnetic power of the motor. It characterizes the form of torque-slip characteristic and also shows in what scale the supply circuit possibilities are exploited. Then this circumstance is very important for matching the parameters of the motor and geophysical cable. Considering the fact, that motor parameters must be matched to the supply circuit, the geophysical cable resistance R_C is accepted as the basic parameter for borehole investigation device induction motors. In this case the copper-squirrel-cage winding in a solid rotor increases in a noticeable degree compared to the other solid rotor constructions and it is more suitable.

The geophysical cable reactance X_C makes up to 5 % of resistance value. In case of the borehole motors investigated, it is more reasonable to choose the rational parameters but not the optimal parameters of the equivalent circuit (Fig. 1), because the concrete rated operating point, the motor load, the motor voltage, the motor and supply circuit parameter dependence from the operation medium temperature change are not fixed.

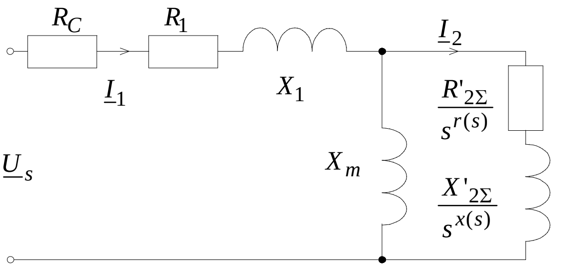


Fig.1. Per-phase equivalent circuit of the symmetrical motor (the insulation currents of the geophysical cable are denied)

The slips $s^{r(s)}$, $s^{x(s)}$ (Fig. 1) are expressed as:

$$\begin{aligned} s^{r(s)} &= \frac{\ln\left(\dfrac{\underline{Z}'_{2\Sigma}(1)+\underline{Z}'^{*}_{2\Sigma}(1)}{\underline{Z}'_{2\Sigma}(s)+\underline{Z}'^{*}_{2\Sigma}(s)}\right)}{\ln(s)}; \\ s^{x(s)} &= \frac{\ln\left(\dfrac{\underline{Z}'_{2\Sigma}(1)-\underline{Z}'^{*}_{2\Sigma}(1)}{\underline{Z}'_{2\Sigma}(s)-\underline{Z}'^{*}_{2\Sigma}(s)}\right)}{\ln(s)}; \end{aligned} \tag{1}$$

here $\underline{Z}'_{2\Sigma}(s)$, $\underline{Z}'^{*}_{2\Sigma}(s)$ are the referred to the stator complex (conjugate complex) impedances of the rotor. The rotor complex impedance consists from the parallel connected copper-cage winding, teeth and yoke complex impedances [5].

So the relative parameters, used for the calculations of motor characteristics, would be as follows:

$$\begin{cases} \rho_1 = \dfrac{R_1}{R_C}; \quad \xi_1 = \dfrac{X_1}{R_C}; \quad \xi_m = \dfrac{X_m}{R_C}; \\ \rho'_2 = \dfrac{R'_{2\Sigma}}{R_C}; \quad \xi'_2 = \dfrac{X'_{2\Sigma}}{R_C}, \end{cases} \tag{2}$$

here ρ_1, ξ_1 are the related stator resistance and reactance values; ξ_m is the related magnetizing reactance value; ρ'_2, ξ'_2 are the related rotor resistance and reactance values referred to stator parameters.

Optimization criterion

The process of finding the maximum or minimum value of an objective with various limitations is known as optimization. The software for the equivalent circuit parameter optimization of the motor is made on the basis of characteristics modeling algorithms. The maximization procedure of criterion J_P comprises the basis of algorithm optimization

$$J_p = \left(\frac{1}{1-s_0}\int_{s_0}^{1} k(s)P_{em}(s)ds\right) \to \max ; \tag{3}$$

here $k(s)$ is the weight function; s_0 is the no-load slip; s is the slip.

Therefore, the criterion (3) will not be sensitive to the local dips of the torque-slip characteristic due to the influence on higher harmonics. It is expedient to supplement it with limitations which will reject that characteristic where the dips would exceed the fixed limit *r* :

$$\frac{P_{em}(s_i)}{P_{em}(1)} \geq r; \quad 1 \geq s_i \geq 0{,}5 . \tag{4}$$

The objective of the procedure is the matching of motor equivalent circuit parameters, the development of which, in the stage of designing, allowed reaching the most rational torque-slip characteristics of the motor (form and maximum $T_{em.a}$ value), regarding the character of the load and maximally using the transmitting ability of the supply circuit. The ratio (5) shows how effectively the geophysical cable is exploited [6]:

$$\frac{P_M}{P_{M\max}} = \frac{4\dfrac{R_M}{R_C}}{\left(\dfrac{R_M}{R_C}+1\right)^2+\left(\dfrac{X_M}{R_C}\right)^2}; \tag{5}$$

here P_M is the input active motor power; $P_{M\max}$ is the limited maximum transmitted active power to motor; R_M is the resistance of the motor complex impedance $\underline{Z}_M$.

While the borehole medium temperature changes (due to borehole depth change) the motor torque-slip characteristic (or $P_{em} = f(s)$) form also changes, therefore, the average electromagnetic power (torque) becomes an important index.

The recalculating coefficient of the electromagnetic power from the related values into absolute in watts is expressed as follows:

$$k_p = \frac{U_s^2}{R_C}; \tag{6}$$

here U_s is the voltage of power-supply source.

Results and considerations

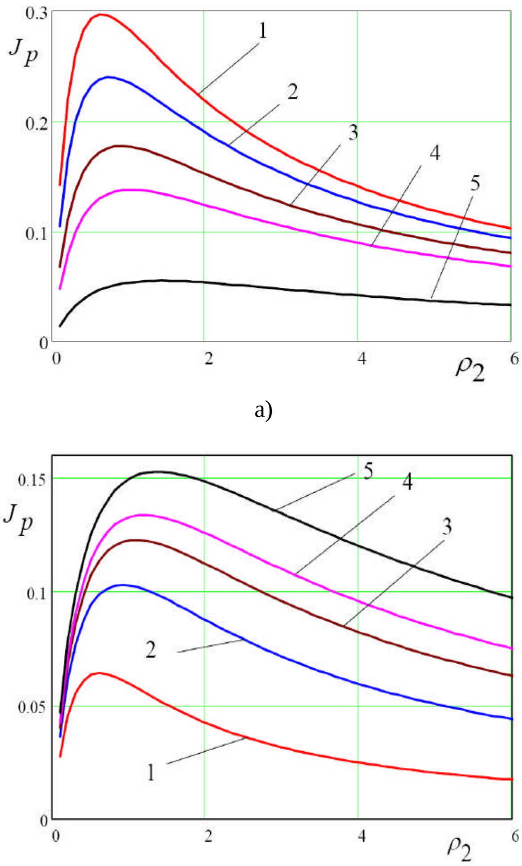
The basic geometrical dimensions of the studied two-phase and two-pole motor: outer diameter - 36 mm (outer diameter of the stator core is also the outer diameter of the motor), active length of the stator and also of the rotor - 50 mm, inner diameter of the stator core - 17 mm, air gap - 0.2 mm. The number of stator slots - 8, the stator winding is double-layer former short-pitch; the number of the rotor slots - 14.

It is important to remark that the outer diameters of these motors are strictly limited. The distributed parameters of the long geophysical cable are evaluated as the four-pole complex coefficients. The optimization calculations are carried out at symmetrical supply-source voltage 260 V and medium temperature (the resistance of the geophysical cable is 200 Ω) +150 °C.

The maximum change limits for related equivalent circuit parameters were set as follows: $\rho_1 = 0.1\div 5$; $\xi_1 = 0.1\div 5$; $\xi_m = 0.1\div 10$; $\rho'_2 = 0.1\div 10$; $\xi'_2 = 0.1\div 6$.

The slip change step is $\Delta s = 0{,}01$ and the step of relative parameters change is $\Delta = 0{,}1$.

The computed criterion J_p (2) dependences as the function of the related parameters ρ'_2 (Fig. 2), ρ_1 ξ_1 (Fig. 3, Fig. 4), ξ_m (Fig. 5) are presented when the other relative parameters (1) appropriately have been constant.



a)

b)

Fig. 2. Criterion J_p as the function of the relative equivalent resistance of the rotor: a) 1 – $\rho_1 = 0.2$; 2 – $\rho_1 = 0.5$; 3 – $\rho_1 = 1$; 4 – $\rho_1 = 1.5$; 5 – $\rho_1 = 4$; b) 1 – $\xi_m = 1$; 2 – $\xi_m = 2$; 3 – $\xi_m = 3$; 4 – $\xi_m = 4$; 5 – $\xi_m = 10$

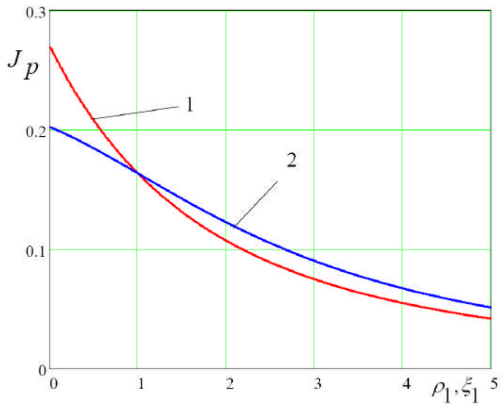


Fig. 3. Criterion J_p as the function of the stator relative equivalent resistance and leakage reactance:
1 – $k_p = f(\rho_1)$; 2 – $k_p = f(\xi_1)$

The determined rational real related parameters of equivalent circuit of copper-squirrel-cage solid rotor induction motor for borehole investigating devices are such: $\rho_1 = 1.4 \div 1.5$; $\xi_1 = 0.4 \div 0.6$; $\xi_m = 4 \div 6$; $\rho'_2 = 1 \div 1.2$; $\xi'_2 = 0.25 \div 0.36$.

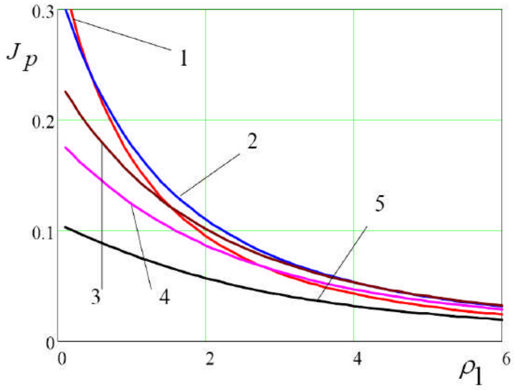
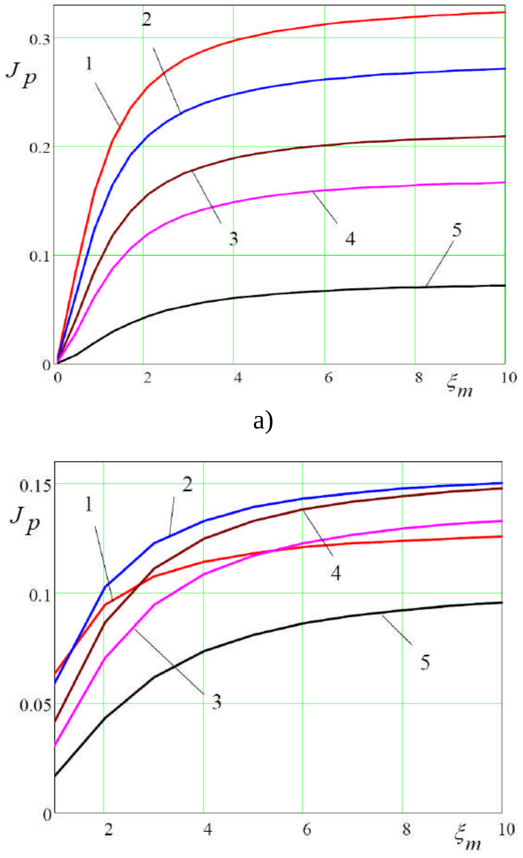


Fig. 4. Criterion J_p as the function of the stator relative equivalent resistance: 1 – $\rho'_2 = 0.2$; 2 – $\rho'_2 = 0.5$; 3 – $\rho'_2 = 1$; 4 – $\rho'_2 = 1.5$; 5 – $\rho'_2 = 4$



a)

b)

Fig. 5. Criterion J_p as the function of the relative magnetizing reactance: a) 1 – $\rho_1 = 0.2$; 2 – $\rho_1 = 0.5$; 3 – $\rho_1 = 1$; 4 – $\rho_1 = 1.5$; 5 – $\rho_1 = 4$; b) 1 – $\rho'_2 = 0.5$; 2 – $\rho'_2 = 1$; 3 – $\rho'_2 = 2$; 4 – $\rho'_2 = 3$; 5 – $\rho'_2 = 6$

Conclusions

The parametrical optimization of equivalent circuit parameters is applied for the formation of proper borehole motor torque-slip characteristic taking into account the known in advance parameters of the geophysical cable and maximum borehole medium temperature. For this reason the optimization integral criterion is proposed. The optimal parameters will be those which will ensure the maximum criterion value.

The computed criterion dependences as the function of the related motor equivalent circuit parameters can be used in order to preliminarily determine the designed borehole motor possibilities.

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In the investigation case of the small-power borehole motors, it is more expedient to discuss the rational parameters of the equivalent circuit but not the optimal ones, because the concrete rated operating point is not fixed due to specific operation peculiarities. Considering the fact, that motor parameters must be matched to the supply circuit, the geophysical cable resistance is accepted as the basic parameter. The basis of optimization algorithm comprises the integral criterion proportional to the motor average electromagnetic power maximization procedure by changing related values of the motor equivalent circuit. So, before starting the initial stage of designing the borehole motor, taking into account the parameters of the supply circuit and maximum borehole medium temperature, agreeably to the computed integral criterion dependences on the related equivalent circuit parameters of the copper-squirrel-cage solid rotor induction motor for borehole investigation devices, it is suggested to choose the rational motor parameters. Bibl. 6 (in English; summaries in English, Russian and Lithuanian).

С. Гячис, П. Смольскас. Параметрический метод оптимизации параметров схемы замещения асинхронного двигателя с массивным коротко замкнутым ротором питаемого через длинный геофизический кабель // Электроника и электротехника. – Каунас: Технология, 2009. – № 2(90). – С. 73–76.

Исследуя маломощные двигатели геофизического назначения, выбор рациональных параметров схемы замещения, а не оптимальных, является более целесообразный, так как такие двигатели из-за специфических особенностей работы не имеют конкретной фиксированной рабочей точки. Учитывая, что параметры двигателя и цепи должны быть согласованны, то в системе относительных параметров в качестве базисного параметра принято активное сопротивление цепи питания. Основу оптимизационного алгоритма составляет процедура максимизации интегрального критерия, пропорционального средней электромагнитной мощности двигателя, изменяя значения относительных параметров схемы замещения двигателя. Уже в начальной стадии проектирования двигателя, учитывая параметры цепи питания и максимальную температуру окружающей среды скважины, по расчётным зависимостям интегрального критерия от относительных параметров схемы замещения предполагается выбрать рациональные параметры. Библ. 6 (на английском языке; рефераты на английском, русском и литовском яз.).

S. Gečys, P. Smolskas. Asinchroninio variklio su vientisuoju narveliniu rotoriumi, maitinamo per ilgą geofizinį kabelį, atstojamosios schemos parametrų parametrinis optimizavimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 2(90). – P. 73–76.

Tiriant mažos galios gręžinių tyrimo prietaisų variklius, tikslinga diskutuoti apie racionalių atstojamosios schemos parametrų parinkimą, o ne optimalių, nes dėl darbo ypatumų nėra fiksuotas konkretus tokių variklių vardinis darbo taškas. Atsižvelgiant į tai, kad variklio ir maitinimo grandinės parametrai turi būti suderinti, santykinėje parametrų sistemoje maitinimo grandinės aktyvioji varža laikoma bazine. Optimizavimo algoritmo pagrindą sudaro integralinio kriterijaus, proporcingo variklio vidutinei elektromagnetinei galiai, maksimizavimo procedūra, keičiant variklio atstojamosios schemos santykinių parametrų reikšmes. Jau pradiniame variklių projektavimo etape, atsižvelgiant į maitinimo grandinės parametrus ir didžiausiąją gręžinio terpės temperatūrą, pagal apskaičiuotas integralinio kriterijaus priklausomybes nuo santykinių atstojamosios schemos parametrų siūloma parinkti racionalius variklio parametrus. Bibl. 6 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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