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Copper-squirrel-cage Solid Rotor Teeth Zone Parameter Rational Choice for Induction Motor Operating under Geophysical Conditions

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Introduction

Borehole investigation devices are used for different parameter rock solid, boring coordinate and other measurements, as well as for oil, gas, minerals exploration and the storage of knowledge about the composition of earth crust, eruptive phenomena and the history of organic life on earth. The small-power motors can be used in acoustic TV sets and cameras to register underground bag or borehole profile and for similar purposes.

Operation conditions of borehole investigation device electric motors are such as: wide temperature change interval reaching from –20°C up to +200°C; hydrostatic pressure – from atmospheric up to 150 MPa and more; operation medium– dielectric liquid; limited power supply source; long geophysical cable up to (5000 – 8000) m; non-constant motor load during the operating cycle and at different cycles, non-constant voltage of the motor power source – affect reliable operation of the motor, transmission of maximum electric power to the motor and changes of motor characteristics.

The effects of the number of rotor slots and rotor slit depth on the performance characteristics of cage solid rotor [1] and slitted solid rotor [2, 3] induction motors are analyzed. The improvement of the copper-squirrel-cage solid rotor parameters can be achieved choosing the number of teeth and optimizing rotor teeth geometry [4]. The optimizing criterions have been proposed: minimum value of the magnetizing current; minimum value of the magnetizing reactance.

So, it is necessary to investigate the optimization of copper-squirrel-cage solid rotor geometry taking into account the parameters of the supply circuit and the motor equivalent circuit.

On the other hand, in case of the motor diameter decrease, the solid rotor active resistance increases and if it is designed for the operation with smaller supply circuit resistance, it will be impossible to match the resistances of supply circuit and the motor.

In this study the most powerful motors operating in the boreholes, such as electric drills and submerged pumps, the power of which reaches ten and hundred kilowatts, are not analyzed. Since the problem discussed in this study is closely related to those motors, some conclusions could be useful designing and maintaining the latter.

Proposed Algorithm

The rotors teeth number choice of conventional induction motors taking into account the number of stator teeth, the number of pole pairs and the influence of higher harmonics on motor characteristics are presented in many of books on electrical machines. Of course, the slitted solid rotor induction motor must have the certain number of teeth and optimal width and height [2]. In case of copper-squirrel-cage solid rotor the rational teeth zone geometric dimensions and the number of teeth also plays an important role in order to match the borehole motor and supply circuit parameters.

The calculation resistances and leakage reactances of the rotor teeth and yoke are carried out using the iteration method: for the teeth according to the teeth magnetic permeability change, depending on the effective magnetic field intensity of teeth and for the yoke according to the yoke magnetic permeability change, depending on the rotor yoke linear load.

Since the rotor copper bars are inserted into slots the rectangular shape is rational from the technological point of view if the slots would be milled skew. In this case the tooth width will be used as average value:

$$b_{z.a} = \frac{b_z + b_{zy}}{2}; \qquad (1)$$

here $b_z = t_z - b_g$; $b_{zy} = t_{zy} - b_g$; b_z is the tooth width at rotor outer diameter surface; b_{zy} is the tooth width at rotor yoke diameter surface; b_g is the rotor slot width.

The resistance of copper-squirrel-cage solid rotor can be reduced if the teeth zone geometry will be rationally chosen. Solely the decreasing of the changing rotor bar cross-section is not rational. The copper-squirrel-cage solid rotor complex impedance referred to the stator is expressed as [5]:

$$\underline{Z}'_{2Z}(s)=\frac{1}{\dfrac{1}{\dfrac{R'_{2Cu}}{s}+jX'_{2Cu}}+\dfrac{1}{\dfrac{\underline{Z}'_{2Z}(s)}{s}}+\dfrac{1}{\dfrac{\underline{Z}'_{2Y}(s)}{s}}}; \quad (2)$$

here

$\underline{Z}'_{2Z}(s)=R'_{2Z}(s)+jX'_{2Z}(s); \underline{Z}'_{2Y}(s)=R'_{2Y}(s)+jX'_{2Y}(s).$

The resistance of copper-squirrel-cage solid rotor when s=1:

$$R'_{2\Sigma}(1)=\frac{Y'_{2r}}{\left(Y'_{2r}\right)^2+\left(Y'_{2x}\right)^2}; \quad (3)$$

here

$$Y'_{2r}=\frac{R'_{2Cu}}{\left(Z'_{2Cu}\right)^2}+\frac{R'_{2Z}}{\left(Z'_{2Z}\right)^2}+\frac{R'_{2Y}}{\left(Z'_{2Y}\right)^2};$$

$$Y'_{2x}=\frac{X'_{2Cu}}{\left(Z'_{2Cu}\right)^2}+\frac{X'_{2Z}}{\left(Z'_{2Z}\right)^2}+\frac{X'_{2Y}}{\left(Z'_{2Y}\right)^2};$$

$$\left(Z'_{2Cu}\right)^2=\left(R'_{2Cu}\right)^2+\left(X'_{2Cu}\right)^2; \left(Z'_{2Z}\right)^2=\left(R'_{2Z}\right)^2+\left(X'_{2Z}\right)^2;$$

$$\left(Z'_{2Y}\right)^2=\left(R'_{2Y}\right)^2+\left(X'_{2Y}\right)^2.$$

The copper-squirrel-cage solid rotor teeth zone optimization criterion is accepted as

$$J_Z=\left|\frac{\mathrm{Re}(\underline{Z}'_{2\Sigma}(1,b_g(T_{em.a.\max})))}{\mathrm{Re}(\underline{Z}_C)}-1\right|\rightarrow \min \quad (4)$$

with the limitations $X'_{2\Sigma}(1)=X'_{2\Sigma\min}(1)<R'_{2\Sigma}(1)$, $B_{Z\max}<[B_Z]$. Here $[B_Z]$ is the limited value of the rotor tooth magnetic flux density; $\underline{Z}_C$ is the complex impedance of the supply circuit.

The change of the rotor tooth geometric dimensions in any way must be limited by maximum value of the magnetic flux density

$$B_{Z\max}=B_\delta\frac{t_z\, l_S}{b_{z.\min}\, l_R}; \quad (5)$$

here l_S, l_R is the stator, rotor active lengths.

According to the magnetic circuit calculations of these motors, it can be accepted that: $[B_Z]=(1.7\div1.9)$ T; $B_\delta=(0.5\div0.55)$ T; $B_{j2\max}=(1.3\div1.5)$ T; (here $B_{j2\max}$ is the maximum value of the rotor yoke magnetic flux density). The parameters $\underline{Z}_1$, $\underline{Z}_m$, $\underline{Z}'_{2Cu}$ are calculated according to traditional methods. The individual stages of the motor optimization (geometric dimension of magnetic circuit, winding data, and synthesis of equivalent parameters) are done according to methods presented in [6]. The calculation algorithm of copper-cage solid rotor tooth zone parameters is presented in Fig. 1. The rotor tooth width is changed by adequate pitch when the height is constant and vice versa. The slot (tooth) height is chosen taking into account the limited value of rotor yoke computable magnetic flux density.

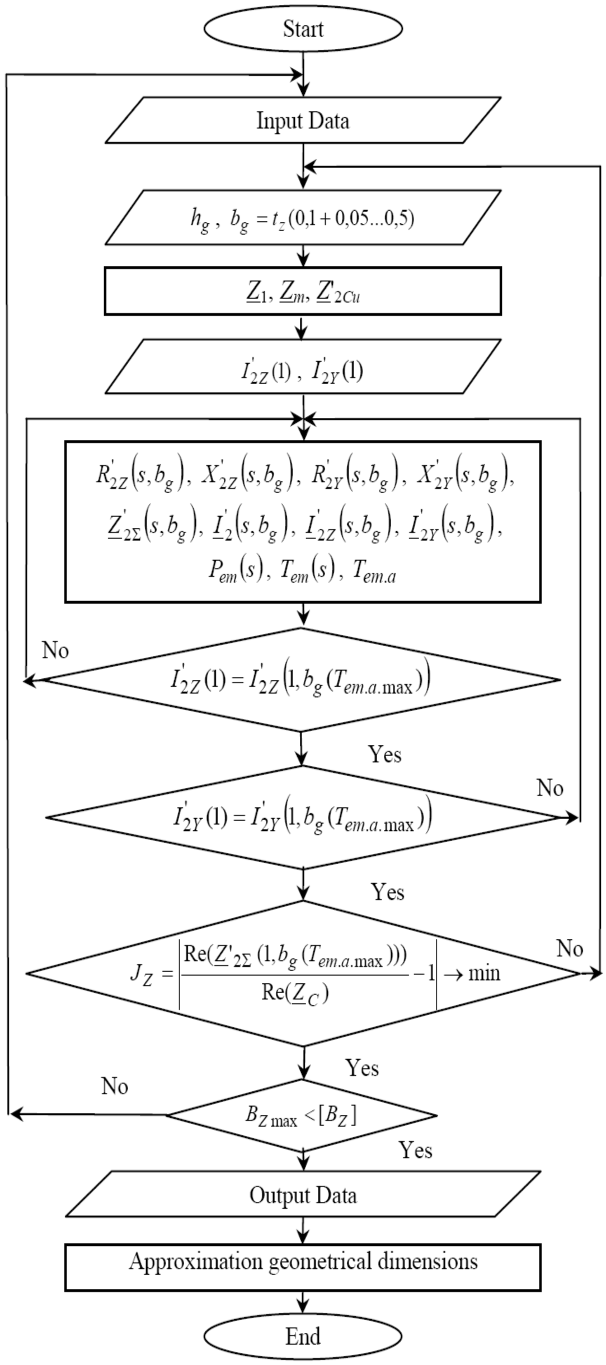

Fig. 1. Parameter calculation algorithm of copper-cage solid rotor teeth zone

Results and discussion

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 phase turns - $w_1=1100$, the number of the rotor slots was varied from 12 to 20. The same stator was used in all optimization calculations in order to achieve comparable results.

The investigations with a slitted solid rotors show the choice of teeth geometry influenced by solid rotor parameters [2, 3]. The copper-squirrel-cage rotor parameters analyzed in the study are the number, the depth and width of the slots and the geometry of end rings through which the maximum electromagnetic torque is achieved. In this case the rotor resistance rather decreases and leakage reactance also decreases.

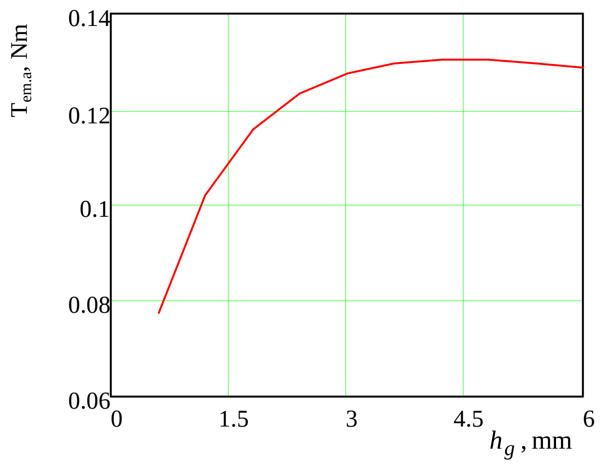

Fig. 2. Average electromagnetic torque as a function of the depth h_g of rotor slot; b_g = const

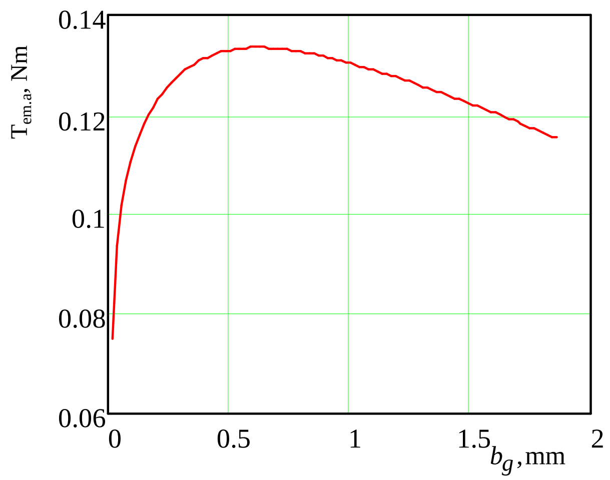

Fig. 3. Average electromagnetic torque as a function of the width b_g of rotor slot; h_g = const

The ratio of the resistance and leakage reactance of the rotor changes to the side of increasing reactance.

Usually the air gap in an induction motor is chosen to be smaller in order to keep magnetizing current at minimum. On the other hand, if the stator of small-power motor has only eight slots the higher spatial harmonics (seventh and ninth) are of the first order slot harmonics. For this reason, the air gap reduces the leakage reactance but also reduces the magnetizing reactance.

Theoretically the combination stator-rotor slots for the small-power two-pole squirrel-cage induction motors with eight stator slots (the number of slots per pole per phase is 2) is no suitable as it is recommended in books on electrical machines.

The odd rotor slot number in case of two-pole induction motor leads to a distortion of the magnetic flux distribution and is the reason for the unbalanced magnetic pull.

The optimization calculations are carried out at symmetrical supply-source voltage 260 V and media temperature (the resistance of the supply circuit is 200 Ω) +150 °C. The best value of average electromagnetic torque (or power) as a function of rotor slot (tooth) depth (Fig. 4.) and as a function of rotor slot width (Fig. 3.) can be considered the main factor for choosing the rational rotor teeth zone geometrical dimensions.

The calculations at medium temperature +20°C (the resistance of the supply circuit is 165 Ω) shows that the leakage reactance of cage winding practically changes negligibly, while the resistances of rotor teeth and yoke decrease to (42–44) % and appropriately the leakage reactances decrease to (13–16) %.

In order to the optimization criterion will approach to minimum the most influence has the copper-cage winding resistance R'_{2Cu} because it is 3–4 times smaller than the rotor teeth resistance R'_{2Z} and up to 10 times smaller than the rotor yoke resistance R'_{2Y} .

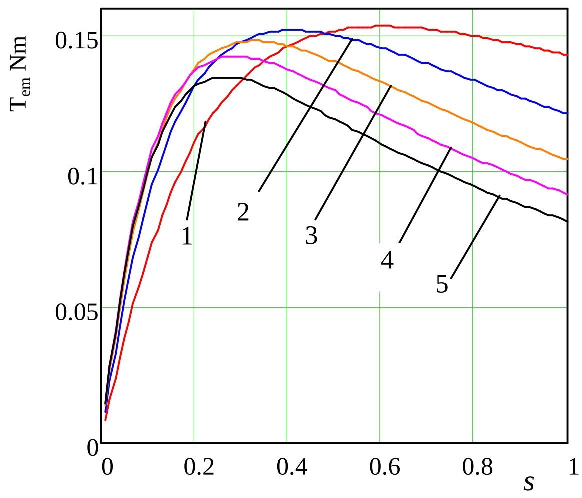

Fig. 4. Torque-slip characteristics of motor: h_g = 4.5 mm; 1- b_g = 0.4 mm; 2- b_g = 0.8 mm; 3- b_g = 1.2 mm; 4 - b_g = 1.6 mm; 5- b_g = 2 mm

It is important to remark that the rational rotor teeth zone geometrical dimensions can be chosen when the motor operates at the worst conditions (maximum medium temperature and concrete supply circuit) while it operates at less medium temperatures the optimization criterion (4) is not fully satisfied $(R'_{2\Sigma}(1, b_g(T_{em.a.\max})) \approx R_C)$ but the created electromagnetic torque of the motor is larger. At least the change of rotor teeth number influences the distortion of squirrel-cage solid rotor resistances and reactance while the average electromagnetic torque is practically the same.

Conclusions

The algorithm for the teeth zone geometrical dimensions optimization of the copper-squirrel-cage solid rotor induction motor, used in the borehole investigation devices, is created.

As the optimization criterion, the comparison of the rotor equivalent resistance with the supply circuit resistance is accepted. The maximum value of average electromagnetic torque is considered as the main factor.

The choice of an even number rotor teeth is recommended taking into account the limitations of the optimization criterion and the possible influence of higher spatial harmonics and technologically minimum tooth width at rotor yoke diameter surface. The difference on the average electromagnetic torque is considerably small as the number of rotor slots is 14 or 18.

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The optimization of copper-squirrel-cage solid rotor geometry of the small power induction motors, operating in borehole investigation devices while considering the parameters of the supply circuit and the motor equivalent circuit, is studied. The optimization criterion is the comparison of the copper-squirrel-cage solid rotor equivalent resistance to the supply circuit resistance taking into account the following limitations: the minimum copper-squirrel-cage solid rotor leakage reactance; the maximum value of rotor tooth magnetic flux density. The same stator was used in all optimization calculations in order to achieve comparable results. The maximum value of average electromagnetic torque as a function of rotor slot (tooth) depth and as a function of rotor slot width is accepted as the main factor for choosing the rational rotor teeth zone geometrical dimensions considering the maximum borehole medium temperature and the parameters of the concrete supply circuit. Ill. 1, bibl. 6 (in English; summaries in English, Russian and Lithuanian).

С. Гячис, П. Смольскас. Рациональный выбор параметров зубцовой зоны массивного короткозамкнутого ротора асинхронного двигателя, работающего в геофизических условиях // Электроника и электротехника. – Каунас: Технология, 2009. – № 1(89). – С. 91–94.

Представлена оптимизация зубцовой зоны массивного короткозамкнутого ротора асинхронного двигателя малой мощности для геофизических скважинных приборов, учитывая параметры цепи питания и схемы замещения двигателя. Критерием оптимизации является согласование активных сопротивлений цепи питания и массивного короткозамкнутого ротора двигателя, учитывая следующие ограничения: минимальное индуктивное сопротивление ротора; максимально допустимое значение магнитной индукции в ножке зубца. При оптимизационных расчетах параметры статора двигателя были постоянными. Максимальное среднее значение зависимости электромагнитного момента двигателя от высоты паза (зубца) ротора и ширины паза принято одним из основных факторов при выборе рациональных геометрических размеров зубцовой зоны ротора, учитывая максимальную температуру среды скважины и параметры конкретной цепи питания. Ил. 1, библ.6 (на английском языке; рефераты на английском, русском и литовском яз.).

S. Gečys, P. Smolskas. Geofizinėmis sąlygomis dirbančių asinchroninių variklių su vientisuoju narveliniu rotoriumi dantų zonos racionalių parametrų parinkimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 1(89). – P. 91–94.

Pateikiama mažos galios gręžinių tyrimo įtaisų asinchroninių variklių vientisojo narvelinio rotoriaus dantų zonos geometrinių matmenų optimizavimas, atsižvelgiant į maitinimo grandinės ir variklio atstojamosios schemos parametrus. Optimizavimo kriterijus yra maitinimo grandinės ir variklio vientisojo narvelinio rotoriaus aktyviųjų varžų suderinimas, atsižvelgiant į šiuos apribojimus: mažiausiąją vientisojo narvelinio rotoriaus induktyviosios varžos vertę; didžiausiąją leistinąją rotoriaus danties magnetinio srauto tankio vertę. Optimizaciniuose skaičiavimuose variklio statoriaus parametrai nebuvo keičiami. Didžiausioji vidutinė variklio elektromagnetinio momento priklausomybės nuo rotoriaus griovelio (danties) gylio ir griovelio pločio vertė laikoma pagrindiniu veiksniu parenkant racionalius rotoriaus dantų zonos geometrinius matmenis, atsižvelgiant į maksimalią gręžinio terpės temperatūrą ir konkrečios maitinimo grandinės parametrus. Il. 1, bibl.6 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).