Forming of Six-Phase Double Layer Induction Motor Windings
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Abstract—The article deals with forming of two type six-phase induction windings: concentrated double layer short pitch coil winding and concentrated double layer full pitch coil winding. Two types of six-phase motor windings are discussed, magnetomotive forces are considered.

I. INTRODUCTION

Multiphase (more than three phase) machine drives are the focus of research recently due to their inherent advantages compared to three-phase machine drives. Multiphase machines drive has increased torque per ampere for the same volume machine, reduced stator copper losses, and reduced rotor harmonic currents, high power handling capability by dividing the required power between multiple phases, reduced torque pulsations and higher reliability. In particular, unlike in a three phase drive, the loss of stator phase does not prevent the machine from starting and running [1], [2].

The applicability of multiphase motors is explored in ship propulsion, locomotive traction, electric vehicles, where the main advantage of multiphase drives consists of splitting the controlled current on more inverter legs, reducing the single switch current stress compared to the three-phase converters. Improved reliability is advantageous in nuclear power plants for its circulation pumps and for other similar applications in process industries [4] – [8].

This paper presents forming of two types windings for six-phase induction motor, shows elaborated connection of winding sections and comparison of two types concentrated double layer windings: short pitch coil six-phase winding and full pitch coil six-phase winding.

II. SIX-PHASE WINDDINGS

Double layer windings have many advantages over single layer windings: easier to manufacture and lower cost of coils, fractional-slot can be used, chorded-winding is possible, lower leakage reactance and therefore, better performance of the machine.

Six-phase motor was elaborated by rewinding of three phase motor with number of slots $S = 48$.

Parameters of concentrated double layer short pitch coil six-phase stator winding: total number of slots $S = 48$, number of poles $2P = 8$, number of phase $m = 6$, pole pitch $\tau = 6$, slot angular pitch $\gamma = 30^\circ$, number of slots per pole per phase $q = 1$, coil pitch $y = 6$, phase spread $\sigma = 30^\circ$, angle between stator current phasors is $60^\circ$. Connection of concentrated double layer short pitch coil six-phase winding section is presented in “Fig. 1”. Parameters of concentrated double layer full pitch coil six-phase stator winding: total number of slots $S = 48$, number of poles $2P = 8$, number of phase $m = 6$, pole pitch $\tau = 6$, slot angular pitch $\gamma = 30^\circ$, number of slots per pole per phase $q = 1$, coil pitch $y = 6$, phase spread $\sigma = 30^\circ$, angle between stator current phasors is $60^\circ$. Connection of concentrated double layer full pitch coil six-phase winding section is presented in “Fig. 2”.

Fig. 1. Connection of concentrated double layer short pitch coil six-phase winding section.

Fig. 2. Connection of concentrated double layer full pitch coil six-phase winding section.

“Fig. 3” shows instantaneous current values in the slots of concentrated double layer short pitch coil six-phase winding at time instant $t = 0$. Connection of concentrated double layer short pitch coil six-phase winding section and distribution of magnetomotive force is presented in “Fig. 4”.

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Fig. 3. Instantaneous current values: a) at the time instant $t = 0$; b) in upper and lower levels of slots.

Fig. 4. Connection of concentrated double layer short pitch coil six-phase winding section and distribution of magnetomotive force.

"Fig. 5" shows instantaneous current values in the slots of concentrated double layer full pitch coil six-phase winding at time instant $t = 0$. Connection of concentrated double layer full pitch coil six-phase winding section and distribution of magnetomotive force is presented in "Fig. 6".

It is evident that in case of concentrated double layer short pitch coil six-phase winding, instantaneous current values, during pole pitch margins, are the same in upper and lower levels of five slots and only once the values of instantaneous current in upper and lower levels are different.
Fig. 5. Instantaneous current values: a) at the time instant $t = 0$; b) in upper and lower levels of slots.

In case of concentrated double layer full pitch coil six-phase winding, instantaneous current values, during pole pitch margins, are the same in all upper and lower levels of slots. Research shows, that magnetomotive force amplitude of six-phase motor with concentrated double layer short pitch
coil winding is smaller than six-phase motor with concentrated double layer full pitch coil winding.

Analysis of the considered first type of winding indicates, that during one pole pitch the relative magnetomotive force $F1(\phi)$ has the shape, shown in “Fig. 7”. Analysis of the second type winding shows, that relative magnetomotive force $F2(\phi)$ in the one pole pitch displacement varies in the way, shown in “Fig. 8”.

![Relative magnetomotive force $F1(\phi)$ and its approximation by Fourier series $F1 \Sigma \alpha(\phi)$.](image1)

![Relative magnetomotive force $F2(\phi)$ and its approximation by Fourier series $F2 \Sigma \beta(\phi)$.](image2)

Space harmonic spectrum of each winding magnetomotive force was obtained on the base of Fourier series. Analysis of magnetomotive forces gives information about higher harmonics that appear in the air gap. More detailed calculation shows that concentrated double layer short pitch coil six-phase winding has the first harmonic significantly greater (22 %) than concentrated double layer full pitch coil six-phase winding. Analysis shows, that relative amplitude of the first harmonic of the first winding approximately is equal to 0.8 and that of the second winding is equal to 0.6. So from the view of first harmonic the motor with concentrated double layer short pitch coil winding will have higher efficiency than motor with concentrated double layer full pitch coil winding. Analysis shows, that even harmonics have the same amplitude and they are equal to zero. Research indicates that the odd higher harmonics of concentrated double layer full pitch coil winding having greater amplitude than concentrated double layer short pitch coil winding. While the higher harmonics increase torque oscillations and heat loss, it is possible to state, that the first winding has greater efficiency.

So research indicated that according to the harmonic spectrum, the concentrated double layer short pitch coil winding has greater efficiency than concentrated double layer full pitch coil winding.

### III. Conclusions

The advantages of multiphase motors against three phase motors are discussed. The areas of application of the multiphase motors are considered.

Two types of six-phase motor windings connections are analysed: concentrated double layer short pitch coil winding and concentrated double layer full pitch coil winding.

Concentrated double layer short pitch coil six phase winding has the first harmonic greater by 22 % than concentrated double layer full pitch coil six phase winding.

Research indicated that according to the harmonic spectrum, the short pitch coil winding has greater efficiency than full pitch coil.

### REFERENCES


