Method for Construction and Verification of the Stator Winding on a Permanent Magnet Synchronous Motor

Tsvetomir Stoyanov *
* Technical University of Sofia, Faculty of Electrical Engineering, Department of General Electrical Engineering, 1000 Sofia, Bulgaria, e-mail: cmetodiev@tu-sofia.bg

Abstract — **This paper aims to present the creation of the stator winding. Which is characterized by sixty stator's slots, the number of the stator's phases is three and two slot for pole and phase. When constructing the stator winding, the geometry of the machine, the possibility for technological and simple construction are taken into account. Another no less important fact that is paid attention to the sinusoidal shape of the magnetomotive force (mmf). The creation of the stator winding is an iterative method, which is presented in detail in this paper. Sequentially go through the following steps-determination of the current densities for each stator's slots, determination of the flux linkage created by permanent magnets and on load mode.**

Keywords—stator winding, synchronous motor, construction and verification, sinusoidal shape, magnetomotive force.

I. Introduction

Stator's windings can be classified according to various characteristics. According to the number of layers - single-layer and multilayer windings [3]. Depending on whether the winding is integral-slot or fractional-slot [1], [5], [7], [8]. Depending on the way of connecting the stator phase windings - star, delta or delta-star [4]. The ratio Z/p is important and is often studied [6]. The design of a stator winding is a very complex process in which a number of factors must be taken into account. They are the possibility for technological and simple construction. All these factors are subordinated to the fact that electromotive forces must have a sinusoidal shape or a shape as close as possible to the sinusoidal. To what extent this condition is met depends on magnetomotive force which the motor creates. Compliance with these requirements must be verified before the manufacturer has manufactured the permanent magnet synchronous motor. For this purpose, there are many methodologies that can give the desired result with great accuracy.

The method for construction and verification of the stator winding on a permanent magnet synchronous motor is presented in the separate parts of this paper. The following individual steps are presented as in the design process. Instantaneous values of current densities and their change over time- their distribution by slots and for the whole machine. For permanent magnets and on load mode the temporal and spatial functions of flux linkage are determined. In this way a check is made for the correct choice of the arrangement of the stator winding. This is done by analyzing the electromagnetic field using software based on Finite Element Method. When performing each of the steps of the method, the obtained results can be checked and the stator winding can be corrected if the results do not meet the expectations. All results in this paper are presented in per-unit system (pu).

II. Current Density

The electric motor is powered by a symmetrical voltage system. Their change of the current's density over time is shown in Fig.1.

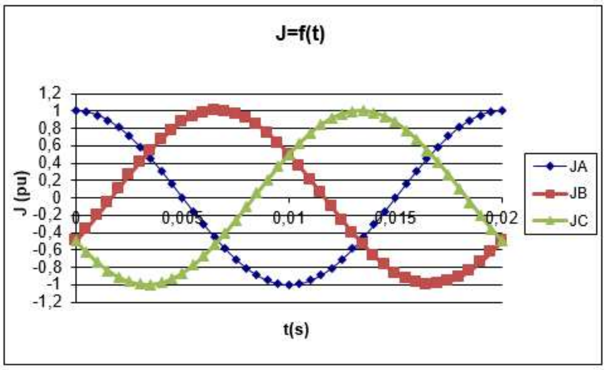

Fig. 1. Current density

The instantaneous values of the current densities for the initial time (blue-phase A, red-phase B and green-phase C), for the stator's slots covering one pair of poles is presented on Fig.2. The current densities for the other stator's slots are similar for each pole because the stator winding is symmetrical.

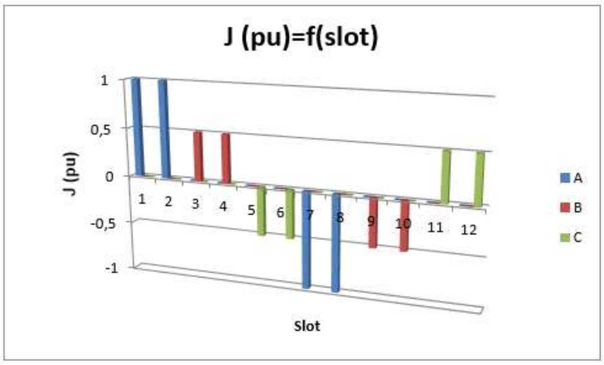

Fig. 2. Current density for each slot

The change in current density over time (for the first three steps) for the whole machine is depicted by Fig.3. Taking into account the methods of obtaining magnetomotive force presented in [2], [5] the total current density of the slots is determined as follows - the total value of the current density

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for the current slot is equal to that of the previous plus the current, if the slot are of the same phase.

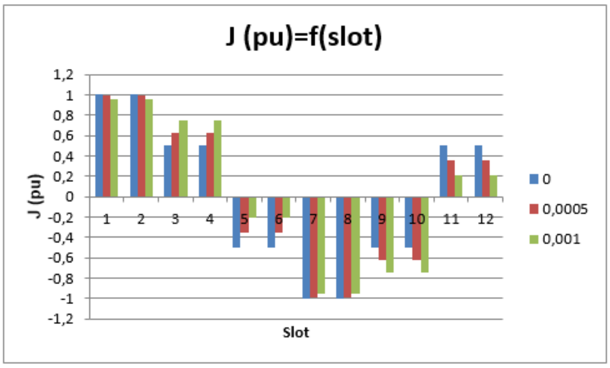

Fig. 3. Change in current density over time.

Provided that they are from different phases, the last value from the same phase is added to the current value. The results are presented on Fig.4.

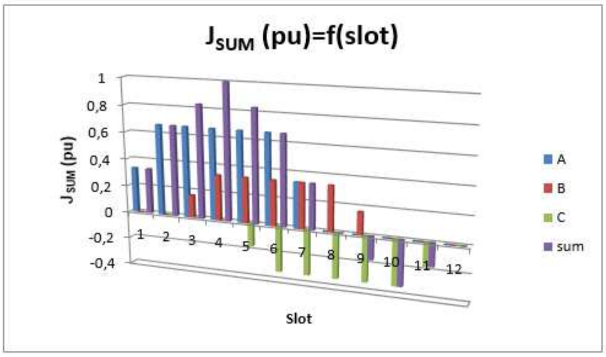

Fig. 4.Sum of current density for one pole pair

III. Determination of Magnetomotive Force

Determination of the magnetomotive force can be done in several ways – theoretically [4], by summing different magnetomotive forces [2], [5]. It is possible to find its spatial distribution [9]. This paper presents a combination of all these methods. The magnetomotive force is determined as follows- for the current slot it is equal to the sum of the previous slots plus the current density of the current slot. This dependence is represented by expression (1):

$$MMF_z = MMF_{SUM_{z-1}} + J_Z, \qquad (1)$$

where

MMF_z magnetomotive force for the current slot

$MMF_{SUM_{z-1}}$ sum of the magnetomotive forces for the the previous slots

J_z the current density of the current slot

Fig.5 and Fig.6 show the time change of magnetomotive force for the stator slots, which cover the first twelve slots (Fig.5 from the first to the sixth and Fig.6 from the seventh to the twelfth) of the motor.

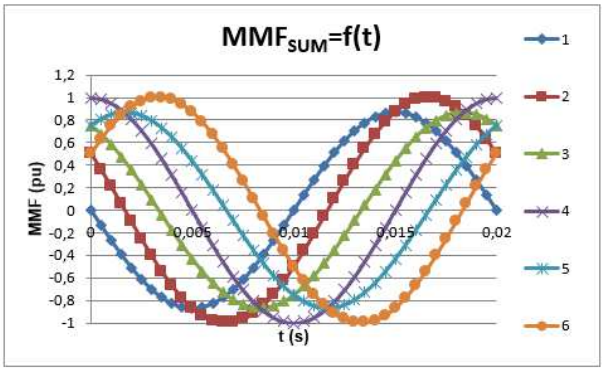

Fig. 5. The time change of magnetomotive force from the first to the sixth the stator slots.

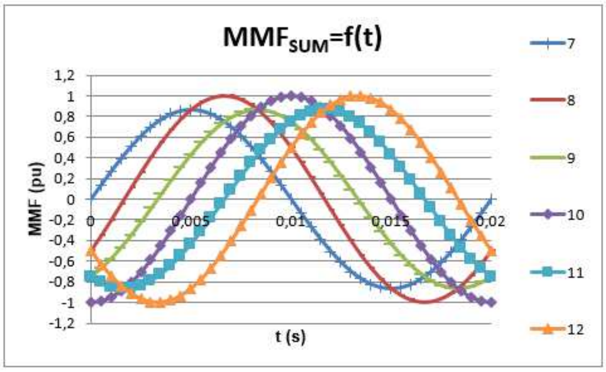

Fig. 6. The time change of magnetomotive force from seventh to the twelfth.

From these figures we can see the correct arrangement of the stator winding, because magnetomotive force change according to a sinusoidal law and their sequence of change after the numbering of the stator slots.

III. Flux Linkage from Permanent Magnets

The flux linkage from permanent magnets is determined by analyzing the electromagnetic field using software based on Finite Element Method. To this aim, a number of decisions of electromagnetic field are made at different points in time, covering the complete amendment of flux linkage. For each stator's slot, the time change of flux linkage is recorded for two poles of the machine. This dependence for the first two slots is shown on Fig.7 and Fig.8.

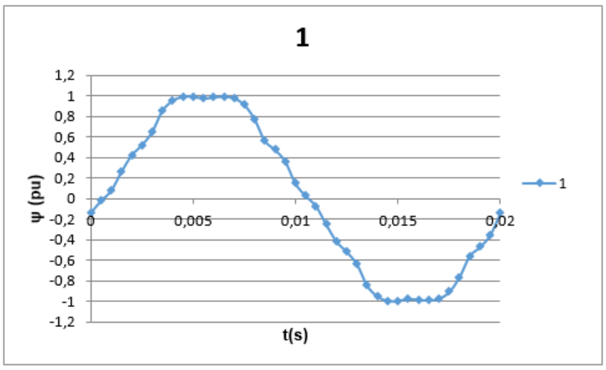

Fig. 7. The time change of flux linkage from permanent magnets for slot №1.

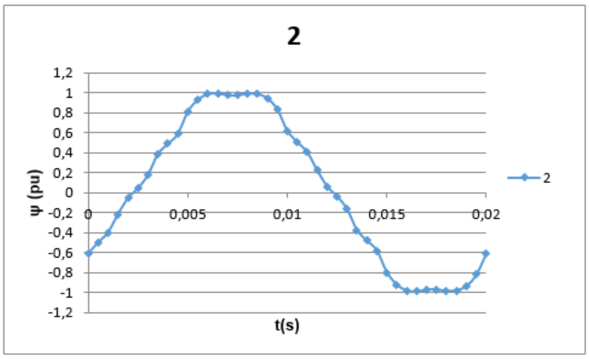

Fig. 8. The time change of flux linkage from permanent magnets for slot №2.

Fig.9 and Fig.10 show the time change of the flux linkage from permanent magnets for the stator slots, which cover the first twelve slots (Fig.9 from the first to the sixth and Fig.10 from the seventh to the twelfth) of the motor.

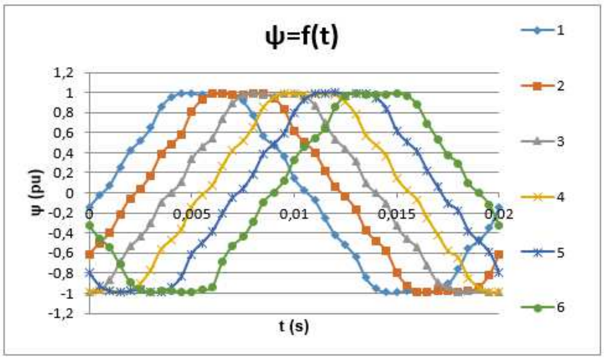

Fig. 9. The time change of flux linkage from permanent magnets from the first to the sixth the stator slots.

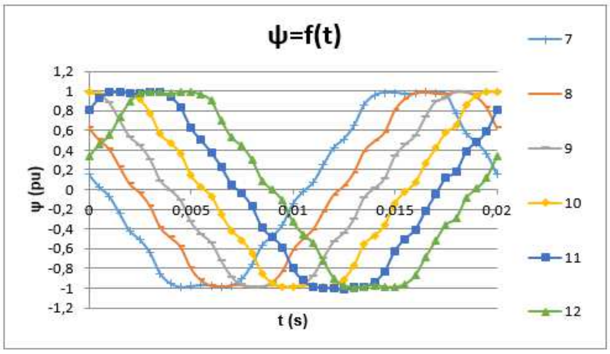

Fig. 10. The time change of of flux linkage from permanent magnets from seventh to the twelfth.

The next step is to determine the phase flux linkage from permanent magnets. For this purpose, collect flux linkage at from permanent magnets of the following slots: for phase A: 1-7 and 2-8; for phase B: 5-11 and 6-12; for phase C: 3-56 and 4-57. This dependence is shown on Fig.11. The result is shown on Fig.12. In this way, it can be determined whether a suitable arrangement has been selected for the stator winding. This goes through several checks - sinusoidal current density, correct sequence of stator phases, correct distribution of the flux linkage. All these checks are made not only spatially but also as a function of time. After the correct selection of the stator winding, proceed to the examination of the machine at on load mode for subsequent inspections.

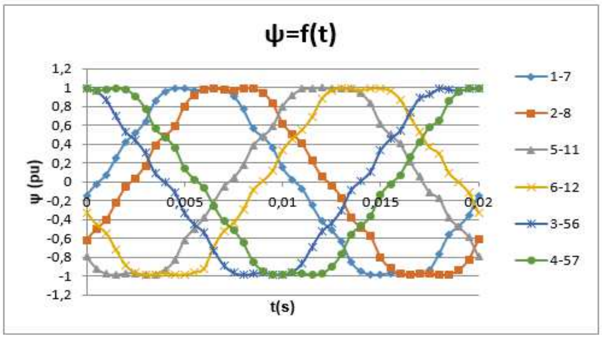

Fig. 11. Summation of flux linkage from permanent magnets.

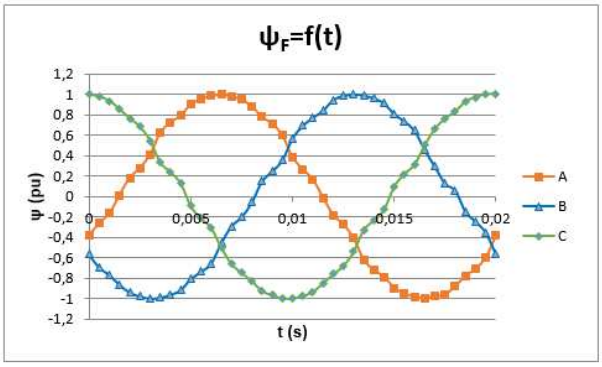

Fig. 12. The phase's flux linkage from permanent magnets.

IV. Flux Linkage at on Load Mode

The flux linkage at on load mode is determined again by analyzing the electromagnetic field. The resulting flux linkage is the sum of the flux linkage created by the permanent magnets and the flux linkage created by the stator winding. The research is performed in exactly the same way as in on load mode. The time change of flux linkage for slot №1 slot №2 show on Fig.13 and Fig.14. Fig.15 and Fig.16 shows the time change of the flux linkage at on load mode for the stator slots, which cover the first twelve slots (Fig.15 from the first to the sixth and Fig.16 from the seventh to the twelfth) of the motor. The next step is to determine of flux linkage and the phase flux linkage at on load mode- Fig.17. On Fig.18 are presented the flux linkage from permanent magnets and on load mode. From the data obtained in the two modes of operation of the motor it can be seen that the choice of the stator winding is correct. This is confirmed by the improvement of the sinusoidal shape of flux linkage.

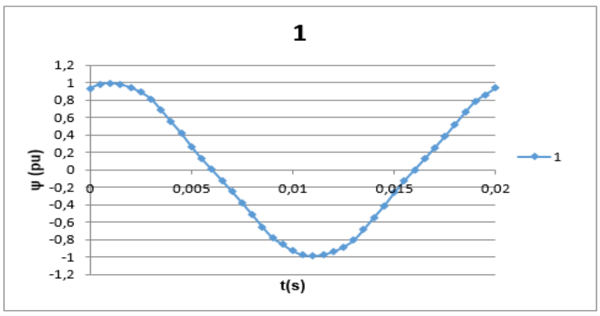

Fig. 13. The time change of flux linkage at on load mode for slot №1.

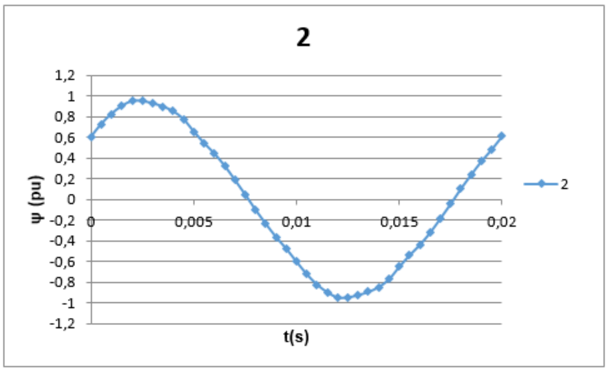

Fig. 14. The time change of flux linkage at on load mode for slot №2.

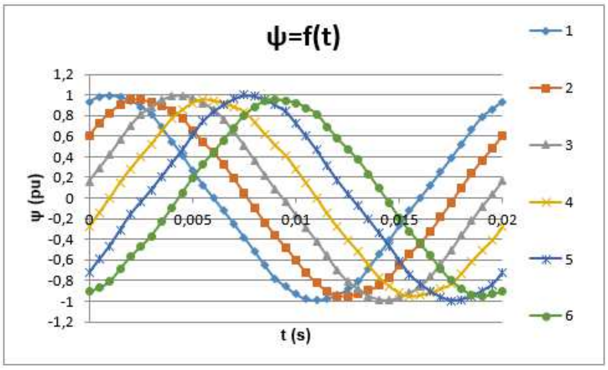

Fig. 15.The time change of flux linkage at on load mode from the first to the sixth the stator slots.

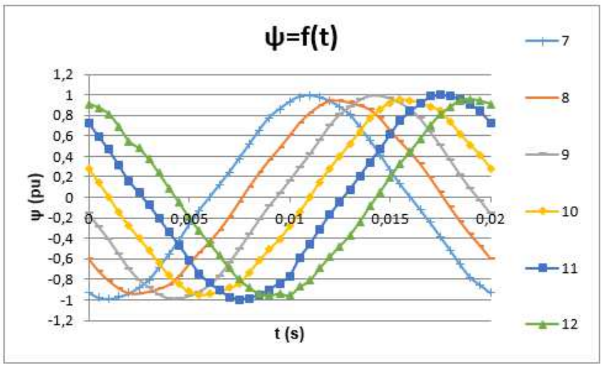

Fig. 16. The time change of of flux linkage at on load mode from seventh to the twelfth.

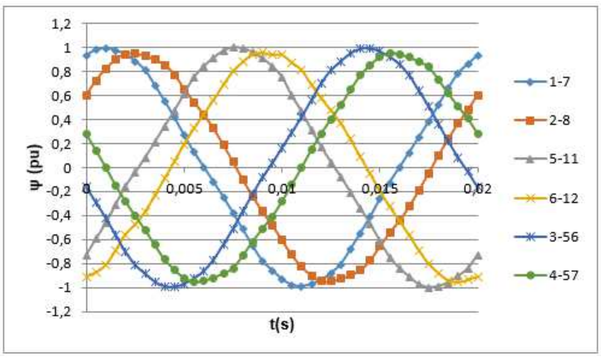

Fig. 17. Summation of flux linkage at on load mode.

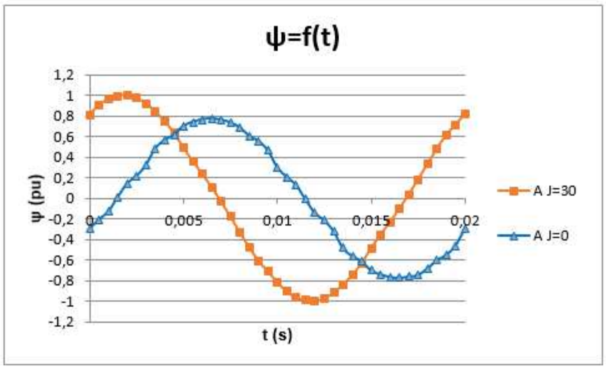

Fig. 18. Flux linkage from permanent magnets and on load mode.

V. CONCLUSIONS

The creation of the stator winding is an iterative method, which is presented in detail in this paper. Current density, magnetomotive force, the flux linkage from permanent magnets and the flux linkage at on load are successively defined. This determination is in time and space for each stator slot and for each phase. The resulting figures show improvement of the sinusoidal shape of flux linkage.

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