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Research of Electromagnetic Parameters of Sinusoidal Three-Phase Windings

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Introduction

The sinusoidal three-phase windings may be of maximum or of average short-pitch according to the forming structure of the connection diagrams [1–3]. The pitch of each group of sections of the maximum average pitch sinusoidal three-phase windings corresponds to the pole pitch τ (Fig. 1,a), while the pitch of the short-pitch average windings is one slot pitch smaller than the pole pitch (Fig. 2,a).

Sinusoidal three-phase windings may be formed by optimizing the pulsating magnetomotive forces that are formed by each phase winding or the rotational magnetomotive forces that are generally formed by all three phase windings. This depends on which reference axis is used while selecting the number of turns in sections that form groups of sections according to the sinusoid law. If the symmetry axis of any phase winding group of sections is chosen as the reference axis, thus, with reference to it while selecting the numbers of turns of sections according to the sinusoid law the pulsating magnetomotive force is optimized [1–3]. If the symmetry axis of the two adjacent groups of sections belonging to the same phase winding is chosen as the reference axis, then with reference to it while dispensing the numbers of turns of sections according to the sinusoid law the rotational magnetomotive force is optimized [1;3]. Therefore, at the present time four different types of sinusoidal three-phase windings are known, which are different both in their formation, and probably electromagnetic parameters.

The aim of this article is to determine the number of turns of all types sinusoidal three-phase windings with various numbers of pole and phase slot numbers in the groups of their sections by using the derived expressions, and to analyze and compare the electromagnetic parameters of these windings according to the obtained momentary functions of the rotating magnetomotive force, and to determine the optimal according to this.

Optimization of the Pulsating and the Rotational Magnetomotive Forces of Sinusoidal Three-phase Windings

In order to get the dimensional function that is made by any phase winding in the fixed time moment of the pulsating magnetomotive force and that is the closest to the sinusoid, the number of the turns of sections in the groups of sections must be allocated from the symmetry axes of these groups according to the sinusoid law because in the sections of any of these groups of sections the current of the same phase and magnitude is flowing. Thus, the repartition form of the pulsating magnetomotive force is directly influenced by the number of sections in their groups and by the number of turns that are in them. Considering this, the values of the sinusoidal function of any section group of the position from the solid angles of the group's symmetry axis, expressed in electrical degrees, are found out. These values will correspond to the tentative relative quantities of the number of the turns of sections. Optimizing the pulsating magnetomotive force the tentative relative quantities of the turns of sections of the maximum average pitch sinusoidal three-phase windings are evaluated according to this expression [4]:

$$\lambda^{1}_{\mathrm{p}i} = \sin\left[\pi/2 - \beta\left(i-1\right)\right]; \tag{1}$$

here: $\beta = 2\pi\, p\,/\,Z = \pi\,/\,\tau$ is the slot pitch in electrical degrees; p is the number of the pole pairs; Z is the number of the slots; τ is the pole pitch; $i = 1 \div q$ is the number of the section in the group (first number is attributed to the sections of the largest pitch); q is the number of sections that form the group of sections or the number of the pole and phase slots.

Continuing the theoretical research, the maximum average pitch sinusoidal three-phase winding is linked with the concentrated three-phase winding by recalculating the tentative relative quantities of the number of turns of sections that are derived from the expression (1) to the real ones:

$$N^{*1}_{\mathrm{p}i} = \lambda^{1}_{\mathrm{p}i}\,/\,C^{1}_{\mathrm{p}}\,; \tag{2}$$

here C^{l}_{p} is the sum of the tentative relative quantities of the number of turns of sections that are derived from the (1) expression:

$$C^{1}_{\mathrm{p}} = \sum_{i=1}^{q} \lambda^{1}_{\mathrm{p}i}\ . \tag{3}$$

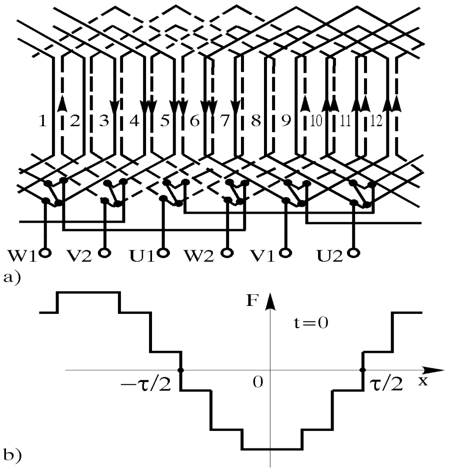

Fig. 1. The evolvent of the electrical diagram of the maximum average pitch sinusoidal three-phase winding with q = 2 (a) and the distribution of the optimized rotating magnetomotive force of this winding in time moment t=0 (b)

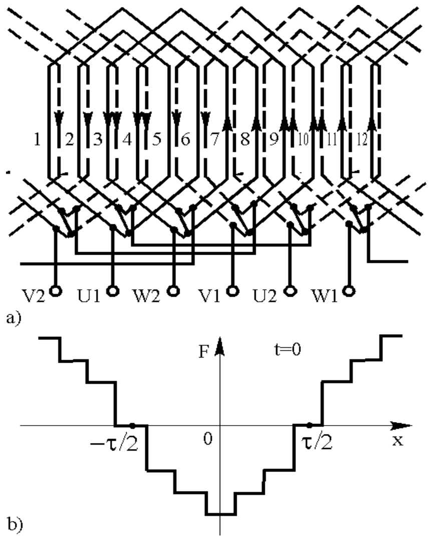

Fig. 2. The evolvent of the electrical diagram of the average short-pitch sinusoidal three-phase winding with q = 2 (a) and the distribution of the optimized rotating magnetomotive force of this winding in time moment t=0 (b)

The tentative relative quantities of the number of turns of the average short-pitch sinusoidal three-phase winding sections, when optimizing the pulsating magnetomotive force, are calculated according to the following expression [4]:

$$\lambda_{\mathrm{p}i}^{2} = \sin\left[(\pi-\beta)/2-\beta(i-1)\right]. \qquad (4)$$

Continuing the theoretical analyses, the average short-pitch sinusoidal three-phase winding is also linked with the concentrated three-phase winding by recalculating the tentative relative quantities of the number of section turns that are derived from the expression (4) to the real ones:

$$N_{\mathrm{p}i}^{*2} = \lambda_{\mathrm{p}i}^{2} / C_{\mathrm{p}}^{2}; \qquad (5)$$

here C^{2}_{p} is the sum of the tentative relative quantities of the number of section turns that are derived from the expression (4):

$$C_{\mathrm{p}}^{2} = \sum_{i=1}^{q} \lambda_{\mathrm{p}i}^{2}. \qquad (6)$$

Summing up the optimized dimensional functions of the pulsating magnetomotive forces of all three phases in fixed time moments the dimensional functions of the rotating magnetomotive forces in certain moments of time are obtained. However, these functions are not closest to the sinusoidal repartition. This may be explained by that the dimensional repartition of the pulsating magnetomotive force is formed by q, while $Z/4p = \tau/2$ of the rotating magnetomotive force is formed by the active sides of sections. Since the quantity of the three-phase windings $\tau/2$ is half as great again as the number of sections q in the group of sections ($\tau/2/q = 3q/2q = 1{,}5$), thus, while directly optimizing the dimensional repartition of the rotating magnetomotive force it is possible to set it closer to sinusoid.

On purpose to optimize the dimensional function of the rotating magnetomotive force, for example, in a moment of time t = 0, the number of turns of sections in the groups of sections must be set according to the sinusoidal function of the dimensional coordinates the beginning of which should be the reference axis that should be coincident with the symmetry axis of the two adjacent groups of sections of the U phase. Considering this, the sinusoidal function values of the sections in their group of the position from the solid angles (that are expressed in electrical degrees) of the given reference axis are found, and these values will conform the tentative relative quantities of the number of the turns of sections. When optimizing the rotating magnetomotive force these relative quantities of the maximum average pitch sinusoidal three-phase windings are evaluated as follows [4]:

$$\lambda_{\mathrm{s}i}^{1} = \sin\left[\beta(q+1-i)\right]. \qquad (7)$$

The maximum average pitch sinusoidal three-phase winding is also linked to the concentrated three-phase winding by recalculating the tentative relative quantities of the number of turns of sections that are derived from the expression (7) to the real ones:

$$N_{\mathrm{s}1}^{*1} = \lambda_{\mathrm{s}1}^{1} / 2C_{\mathrm{s}}^{1}; \qquad (8)$$

$$N_{\mathrm{s}i}^{*1} = \lambda_{\mathrm{s}i}^{1} / C_{\mathrm{s}}^{1}; \qquad (9)$$

here C^{1}_{s} is the sum of the tentative relative quantities of the number of turns of sections derived from the expression (7):

$$C_{\mathrm{s}}^{1} = \lambda_{\mathrm{s}1}^{1}/2 + \sum_{i=2}^{q} \lambda_{\mathrm{s}i}^{1}. \qquad (10)$$

When optimizing the rotating magnetomotive force the tentative relative quantities of the number of turns of sections of the average short-pitch sinusoidal three-phase windings are evaluated as follows [4]:

$$\lambda_{\mathrm{s}i}^{2} = \sin\left[(q-i)\beta + \beta/2\right]. \qquad (11)$$

In further research the average short-pitch sinusoidal three-phase winding is also linked to the concentrated three-phase winding by recalculating the tentative relative quantities of the number of turns of sections that are derived from the expression (11) to the real ones:

$$N_{si}^{*2} = \lambda_{si}^{2} / C_{s}^{2}\,; \tag{12}$$

here C^2_s is the sum of the tentative relative quantities of the number of turns of sections that are derived from the expression (11):

$$C_{s}^{2} = \sum_{i=1}^{q} \lambda_{si}^{2}\,. \tag{13}$$

The real relative quantities N_i^* of the number of turns of sections of the sinusoidal three-phase windings of all types that are linked to the concentrated three-phase windings are evaluated according to the derived expressions (1) – (13) and are given in Table 1.

Table 1. The real relative quantities of the number of turns of sections of the sinusoidal three-phase windings

q	β	Relative quantities of the number of turns of sections, N_i^*				
		i	P^1	P^2	S^1	S^2
2	30°	1	0,5359	0,5774	0,4641	0,7321
		2	0,4641	0,4226	0,5359	0,2679
3	20°	1	0,3696	0,3949	0,3054	0,5321
		2	0,3473	0,3473	0,4534	0,3473
		3	0,2831	0,2578	0,2412	0,1206
4	15°	1	0,2826	0,2989	0,2280	0,4142
		2	0,2729	0,2785	0,3724	0,3178
		3	0,2447	0,2391	0,2633	0,1998
		4	0,1998	0,1835	0,1363	0,0682

P^1, S^1 – the maximum average pitch sinusoidal three-phase winding (1) with the optimized pulsating (P) and rotating (S) magnetomotive force. P^2, S^2 – average short-pitch sinusoidal three-phase winding (2) with the optimized pulsating (P) and rotating (S) magnetomotive force.

The Research of Electromagnetic Parameters of Sinusoidal Three-phase Windings

The theoretical research of electromagnetic parameters is conducted by using graphical views of the rotational magnetomotive force functions (which change over time) of the considered three-phase windings (Fig. 1,b, Fig. 2,b), based on the evolvents of the electrical diagrams from Fig. 1,a and Fig. 2,a, Table 1 and vector diagram of the currents stopped in the moment of time $t = 0$. It was assumed, that the relative amplitude values of currents in the phases of the windings are $I_{mU} = I_{mV} = I_{mW} = 1$. Then the relative quantities of the momentary current values in the phase windings in the moment of time $t = 0$ are:

$$\begin{cases} i_U^* = \sin \omega t = \sin 0^{o} = 0\,; \\ i_V^* = \sin\left(\omega t - 120^{o}\right) = \sin\left(-120^{o}\right) = -0{,}866\,; \\ i_W^* = \sin\left(\omega t - 240^{o}\right) = \sin\left(-240^{o}\right) = 0{,}866\,. \end{cases} \tag{14}$$

With reference to the determined relative quantities N_i^* (Table 1) and i^* (14), the conditional quantities of magnetomotive force change in the magnetic circuit slot ΔF in the moment of time $t = 0$ (Table 2) are found.

Table 2. Conditional quantities of magnetomotive force change of considered sinusoidal three-phase winding slots in the moment of time $t = 0$

q	No. of the slot	Conditional values of magnetomotive force change			
		P^1	P^2	S^1	S^2
2	4	-0,464	-0,433	-0,402	-0433
	5	-0,402	-0,250	-0,464	-0,317
	6	-0,464	-0,183	-0,402	-0,116
	7	-0,201	0,183	-0,232	0,116
	8	0	0,250	0	0,317
	9	0,201	0,433	0.232	0,433
	10	0,464	0,433	0,402	0,433
3	6	-0,273	-0,2826	-0,3005	-0,2828
	7	-0,320	-0,1710	-0,265	-0,2304
	8	-0,1504	-0,1504	-0,1962	-0,1503
	9	-0,1226	-0,1116	-0,1044	-0,0524
	10	0	0,1116	0	0,0524
	11	0,1226	0,1504	0,1044	0,1503
	12	0,1504	0,1710	0,1962	0,2304
	13	0,320	0,2826	0,265	0,2828
	14	0,273	0,3008	0,3005	0,3005
4	7	-0,2119	-0,2241	-0,2280	-0,224
	8	-0,2047	-0,2089	-0,2203	-0,209
	9	-0,2447	-0,1294	-0,1975	-0,1793
	10	-0,1182	-0,1206	-0,1613	-0,1377
	11	-0,1060	-0,1035	-0,1140	-0,0866
	12	-0,0865	-0,0795	-0,0590	-0,0294
	13	0	0,0795	0	0,0294
	14	0,0865	0,1035	0,0590	0,0866
	15	0,1060	0,1206	0,1140	0,1377
	16	0,1182	0,1294	0,1613	0,1793
	17	0,2447	0,2089	0,1975	0,209
	18	0,2047	0,2241	0,2203	0,224
	19	0,2119	0,2241	0,2280	0,224

Since the analyzed sinusoidal three-phase windings are symmetrical, the changes of the magnetomotive force in the slots over entire perimeter of the air gap repeat periodically. With reference to the data from Table 2 the momentary periodical non-sinusoidal magnetomotive force functions of the considered sinusoidal three-phase windings in the moment of time $t = 0$ are obtained (Fig. 1, b; Fig. 2, b). The following expression [5] is used to calculate analytically the conditional quantities of amplitude values of ν-th harmonics of magnetomotive force of the considered sinusoidal three-phase windings:

$$F_{m\nu} = \frac{4}{\pi\,\nu} \sum_{i=1}^{k} F_i \sin \nu \frac{\alpha_i}{2}\;; \tag{15}$$

here: k – the number of rectangles forming the half-periods of stair-shape magnetomotive force; ν – index of odd dimensional harmonic; F_i – the conditional height of i-th rectangle of the half-period of stair-shape magnetomotive force; α_i – the width of i-th rectangle of the stair-shape magnetomotive force curve expressed in electrical degrees of fundamental harmonic.

Negative half-periods located between dimensional coordinate points $-\tau/2$ and $\tau/2$ are used to perform the harmonic analysis of dimensional momentary functions or rotational magnetomotive force (Fig. 1, b; Fig. 2, b). Real and conditional parameters of half-periods of rotational magnetomotive force created by the analyzed sinusoidal three-phase windings are presented in Table 3.

Table 3. Real and conditional parameters of half-periods of rotational magnetomotive force created by the analyzed sinusoidal three-phase windings

q	Parameters of the half-period of magnetomotive force	P^1	P^2	S^1	S^2
2	k	3	3	3	3
	F_1	-0,201	-0,433	-0,232	-0,433
	F_2	-0,464	-0,250	-0,402	-0,317
	F_3	-0,201	-0,183	-0,232	-0,116
	α_1	180°	150°	180°	150°
	α_2	120°	90°	120°	90°
	α_3	60	30°	60°	30°
3	k	4	5	4	5
	F_1	-0,273	-0,1504	-0,3005	-0,1503
	F_2	-0,320	-0,2826	-0,265	-0,2828
	F_3	-0,1504	-0,1710	-0,1962	-0,2304
	F_4	-0,1226	-0,1504	-0,1044	-0,1503
	F_5		-0,1116		-0,0524
	α_1	160°	180°	160°	180°
	α_2	120°	140°	120°	140°
	α_3	80°	100°	80°	100°
	α_4	40°	60°	40°	60°
	α_5		20°		20°
4	k	6	6	6	6
	F_1	-0,1060	-0,2241	-0,1140	-0,224
	F_2	-0,2047	-0,2089	-0,2203	-0,209
	F_3	-0,2447	-0,1294	-0,1975	-0,1793
	F_4	-0,1182	-0,1206	-0,1613	-0,1377
	F_5	-0,1060	-0,1035	-0,1140	-0,0866
	F_6	-0,0865	-0,0795	-0,0590	-0,0294
	α_1	180°	165°	180°	165°
	α_2	150°	135°	150°	135°
	α_3	120°	105°	120°	105°
	α_4	90°	75°	90°	75°
	α_5	60°	45°	60°	45°
	α_6	30	15°	30°	15°

Conditional quantities of amplitude values of the dimensional harmonics of rotational magnetomotive force $F_{m\nu}$,derived by expression (15), are given in Table 4.

With reference to the data from Table 4, the absolute relative quantities of dimensional harmonics of rotational magnetomotive force with reference to fundamental harmonic are presented in Table 5:

$$f_\nu = F_{m\nu} / F_{m1} \ . \tag{16}$$

Table 4. Conditional quantities of amplitude values of the dimensional harmonics of rotational magnetomotive force created by considered sinusoidal three-phase windings

q	ν	$F_{m\nu}$			
		P^1	P^2	S^1	S^2
2	1	-0,896	-0,818	-0,886	-0,856
	5	0,026	-0,029	0	0
	7	-0,018	-0,020	0	0
	11	0,081	-0,074	0,081	-0,078
	13	-0,069	0,063	-0,068	0,066
	17	0,008	0,008	0	0
	19	-0,007	0,008	0	0
3	1	-0,872	-0,817	-0,875	-0,862
	5	0,008	-0,026	0	0
	7	-0,021	-0,012	0	0
	11	0,013	-0,008	0	0
	13	-0,003	-0,010	0	0
	17	0,051	-0,048	0,051	-0,051
	19	-0,046	0,043	-0,046	0,045
4	1	-0,859	-0,816	-0,871	-0,864
	5	0	-0,025	0	0
	7	-0,019	-0,010	0	0
	11	0,008	-0,006	0	0
	13	-0,007	-0,005	0	0
	17	0,008	-0,004	0	0
	19	0	-0,007	0	0

Table 5. The absolute relative quantities of dimensional harmonics of rotational magnetomotive force, created by considered sinusoidal three-phase windings, with reference to fundamental harmonic

q	ν	f_ν			
		P^1	P^2	S^1	S^2
2	1	1	1	1	1
	5	0,029	0,035	0	0
	7	0,020	0,024	0	0
	11	0,090	0,090	0,091	0,091
	13	0,077	0,077	0,077	0,077
	17	0,009	0,010	0	0
	19	0,008	0,010	0	0
3	1	1	1	1	1
	5	0,009	0,032	0	0
	7	0,024	0,015	0	0
	11	0,015	0,010	0	0
	13	0,003	0,012	0	0
	17	0,058	0,059	0,058	0,059
	19	0,053	0,053	0,053	0,052
4	1	1	1	1	1
	5	0	0,031	0	0
	7	0,022	0,012	0	0
	11	0,009	0,007	0	0
	13	0,008	0,006	0	0
	17	0,009	0,005	0	0
	19	0	0,009	0	0

Momentary dimensional non-sinusoidal functions of rotational magnetomotive force of three-phase windings can be characterized by distortion factor or factor of electromagnetic efficiency, which are determined by using the results of harmonic analysis of these functions. Distortion factor k_i of rotational magnetomotive force is evaluated according to the following expression [6]:

$$k_\text{i} = F_{m1} \Big/ \sqrt{\sum_{\nu=1}^{\infty} F_{m\nu}^2} = 1 \Big/ \sqrt{\sum_{\nu=1}^{\infty} \left(f_\nu^*\right)^2} \ . \tag{17}$$

Factor of electromagnetic efficiency k_{ef} of rotational magnetomotive force is evaluated according to the following expression [6]:

$$k_{\mathrm{ef}} = 1 - \sqrt{\sum_{\nu=1}^{\infty} \left(f_{\nu}^{*}\right)^{2} - 1}\ . \qquad (18)$$

For the considered sinusoidal three-phase windings, the distortion and electromagnetic efficiency factor values, were obtained from expressions (17) and (18) and are given in Table 6.

Table 6. The distortion and electromagnetic efficiency factors of rotational magnetomotive force of the considered sinusoidal three-phase windings

q	Factors	P^1	P^2	S^1	S^2
2	k_{i}	0,9893	0,9889	0,9899	0,9900
	k_{ef}	0,8525	0,8499	0,8570	0,8574
3	k_{i}	0,9953	0,9950	0,9958	0,9958
	k_{ef}	0,9027	0,8998	0,9081	0,9080
4	k_{i}	0,9975	0,9972	0,9978	0,9978
	k_{ef}	0,9287	0,9246	0,9335	0,9333

Winding factors of fundamental and higher harmonics are also attributed to the electromagnetic parameters of three-phase windings. For sinusoidal three-phase windings these factors are evaluated according to the following expression:

$$k_{\mathrm{w}\nu} = \sum_{i=1}^{q} N_i^{*} \sin\left(\nu\, y_i\, \beta / 2\right)\ ; \qquad (19)$$

here y_i – the pitch of the i-th section.

Winding factors of the analyzed sinusoidal three-phase windings were calculated by expression (19) and are presented in Table 7.

Table 7. Winding factors of the analyzed sinusoidal three-phase windings

q	ν	$k_{\mathrm{w}\nu}$			
		P^1	P^2	S^1	S^2
2	1	0,938	0,856	0,928	0,896
	5	0,1361	0,1518	0	0
	7	0,1324	0,1471	0	0
	11	0,931	0,851	0,931	0,897
	13	0,945	0,863	0,932	0,904
	17	0,1429	0,1429	0	0
	19	0,140	0,160	0	0
3	1	0,913	0,855	0,916	0,903
	5	0,042	0,1361	0	0
	7	0,1544	0,088	0	0
	11	0,1494	0,092	0	0
	13	0,041	0,1370	0	0
	17	0,911	0,857	0,911	0,911
	19	0,920	0,860	0,920	0,90
4	1	0,899	0,854	0,912	0,905
	5	0	0,1309	0	0
	7	0,1397	0,074	0	0
	11	0,092	0,069	0	0
	13	0,096	0,068	0	0
	17	0,1429	0,071	0	0
	19	0	0,140	0	0

Conclusions

1. Sinusoidal three-phase windings can be classified according to the structure of connection diagrams into maximum or average short-pitch windings, which in turn, depending on the repartition of the number of turns in the sections, can be with optimized pulsating or rotational magnetomotive forces. Electromagnetic parameters of these windings, when the number of pole and phase slots is constant, are different.
2. The highest amplitude value of the first harmonic of magnetomotive force, when the number of pole and phase slots $q = 2$, is created by maximum average pitch sinusoidal three-phase winding with optimized pulsating magnetomotive force, and when $q > 2$ – by the same winding with optimized rotational magnetomotive force.
3. When the number of pole and phase slots q increases, the amplitude value of fundamental harmonic of magnetomotive force decreases for both types of sinusoidal three-phase windings of maximum average pitch (by 1,5 % on the average), and this quantity remains practically constant for average short-pitch windings with optimized pulsating magnetomotive force, and amplitude value even slowly increases for these windings with optimized rotational magnetomotive force.
4. Differences of amplitude values of fundamental harmonic magnetomotive force, when the number of pole and phase slots q is equal, between maximum and average short-pitch sinusoidal three-phase windings with optimized pulsating magnetomotive force are considerably larger than between these windings with optimized rotational magnetomotive force.
5. Amplitude values of higher odd harmonics (except multiples of three) of magnetomotive force in maximum and average short-pitch sinusoidal three-phase windings with optimized pulsating magnetomotive force do not become equal zero, but (except for tooth harmonics) they considerably decrease compare to corresponding harmonics of magnetomotive force of simple two-layer concentric three-phase windings.
6. Amplitude values of all higher odd harmonics (except tooth harmonics) of magnetomotive force in maximum and average short-pitch sinusoidal three-phase windings with optimized rotational magnetomotive force become equal zero.
7. In sinusoidal three-phase windings of all types, the amplitude values of corresponding tooth harmonics of magnetomotive force remain the same as in simple two-layer concentric three-phase windings.
8. The numerical values of distortion factor and factor of electromagnetic efficiency in maximum and average short-pitch sinusoidal three-phase windings with optimized rotational magnetomotive forces are higher compared with tthe values of corresponding factors of these windings with optimized pulsating magnetomotive force.
9. Numerical values of distortion factor and factor of electromagnetic efficiency of sinusoidal three-phase windings of all types increase (approach one) with the increase of number of pole and phase slots.

10. Electromagnetic properties of sinusoidal three-phase windings are more reflected by factors of electromagnetic efficiency than by distortion factors.

11. Tooth harmonic winding factors in sinusoidal three-phase windings are of the same magnitude as the same factors of the fundamental harmonic. Winding factors of the other higher harmonics are close to zero or equal zero.

12. On the basis of the results of conducted research, maximum and average short pitch sinusoidal three-phase windings with optimized rotational magnetomotive force are the most optimal from the electromagnetical point of view.

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J. Bukšnaitis. Research of Electromagnetic Parameters of Sinusoidal Three-Phase Windings // Electronics and Electrical Engineering. – Kaunas: Technologija, 2007. – No. 8(80). – P. 77–82.

The distribution of the turns within section groups of the sinusoidal three-phase windings with maximum and average short-pitch are analyzed, for which pulsating or rotational magnetomotive forces can be optimized. Analytical expressions for evaluation of number of turns in the sections of windings of all four types were derived. On the basis of these expressions, there were calculated numbers of turns in relative quantities for sections, which form groups from two to four sections. These relative quantities are related to concentrated three-phase winding. Data table of magnetomotive force changes in the slots of considered sinusoidal three-phase windings in the moments of time $t = 0$ was formed and momentary dimensional stair-shape functions of rotational magnetomotive force were obtained according to this data. Real and conditional parameters of stair-shape half-periods were determined from the graphical representations of rotational magnetomotive force. On their basis the conditional amplitude values of dimensional harmonics of rotational magnetomotive force were found, which were used to evaluate analytically the conditional amplitude values of dimensional harmonics of rotating magnetomotive force. According to the data of conditional amplitude values the relative quantities of rotational magnetomotive force dimensional harmonics were found, which were later used to calculate magnetomotive force distortion and electromagnetic efficiency factors of considered three-phase windings. Winding factors of fundamental and higher harmonics were also determined according to the derived expression. Conclusions are offered on the basis of research of electromagnetic parameters of sinusoidal three-phase windings. Ill. 2, bibl. 6 (in Lithuanian; summaries in English, Russian and Lithuanian).

Ю. Букшнайтис. Исследование электромагнитных параметров синусных трехфазных обмоток // Электроника и электротехника. – Каунас: Технология, 2007. – № 8(80). – С. 77–82.

Рассматривается распределение витков в группах секций синусных трёхфазных обмоток с максимальным и укороченным средним шагом, в которых может быть оптимизированы пульсирующие или вращающиеся магнитодвижущие силы. Приводятся аналитические выражения для определения относительных чисел витков секций всех четырёх типов этих обмоток. На основе этих выражений рассчитаны относительные числа витков секций в их группах, которые составляют от двух до четырех секций. Эти относительные числа витков секций связаны с сосредоточенной трёхфазной обмоткой. Далее составлена таблица относительными величинами изменений магнитодвижущей силы в пазах статора рассматриваемых синусных трехфазных обмоток. По этим данным получены графики мгновенных ступенчатых функцией вращающейся магнитодвижущей силы. Из этих графических видов определены параметры ступенчатых полупериодов магнитодвижущей силы, на основе которых по аналитическому выражению вычислены условные амплитудные значения пространственных гармоник вращающихся магнитодвижущих сил. По этим же данным определены относительные величины пространственных гармоник вращающихся магнитодвижущих сил, на основе которых вычислены коэффициенты искажений и электромагнитной эффективности. Также определены обмоточные коэффициенты этих обмоток. Из полученных результатов исследования сделаны выводы. Ил. 2, библ. 6 (на литовском языке; рефераты на английском, русском и литовском яз.).

J. Bukšnaitis. Sinusinių trifazių apvijų elektromagnetinių parametrų tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. – Nr. 8(80). – P. 77–82.

Nagrinėjamas didžiausio ir sutrumpinto vidutinio žingsnio sinusinių trifazių apvijų, kurių gali būti optimizuojamos pulsuojamosios arba sukamosios magnetovaros, vijų paskirstymas sekcijoms jų grupėse. Gautos analizinės išraiškos visų keturių šių apvijų tipų vijų skaičiui sekcijose nustatyti. Pagal šias išraiškas Šių išraiškų pagrindu apskaičiuoti sekcijų, sudarančių sekcijų grupę nuo dviejų iki keturių sekcijų, vijų skaičiai santykiniais dydžiais, susieti su sutelktąja trifaze apvija. Sudaryta nagrinėjamųjų sinusinių trifazių apvijų magnetovaros pokyčių grioveliuose santykiniais dydžiais laiko momentu t=0 lentelė ir pagal jos duomenis gautos akimirkinės sukamosios magnetovaros erdvinės laiptinės funkcijos. Iš šių sukamosios magnetovaros grafinių vaizdų nustatyti realūs ir sąlyginiai pakopų formos pusperiodžių parametrai, kurių pagrindu analiziškai apskaičiuotos erdvinių harmonikų sukamosios magnetovaros sąlyginės amplitudinės vertės. Pagal šių sąlyginių amplitudinių verčių duomenis surasti sukamųjų magnetovarų erdvinių harmonikų santykiniai dydžiai ir jais remiantis apskaičiuoti nagrinėjamųjų sinusinių trifazių apvijų magnetovaros iškreipių ir elektromagnetinio efektyvumo koeficientai. Pagal gautą išraišką taip pat nustatyti šioms apvijoms pagrindinės ir aukštesniųjų harmonikų apvijos koeficientai. Remiantis gautais sinusinių trifazių apvijų elektromagnetinių parametrų tyrimo rezultatais, padarytos išvados. Il. 2, bibl. 6 (lietuvių kalba; santraukos anglų, rusų ir lietuvių k.).