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ALMATY UNIVERSITY OF POWER ENGINEERING & TELECOMMUNICATION

Department of Electric
Drive and Automation of
Industrial Installations

ELECTRICAL MACHINES ASYNCHRONOUS MOTOR WITH WOUNOL ROTOR

(calculation of geometric dimensions and windings)
Methodical instructions to course work
of specialty 5B071800 - Electrical engineering

Almaty 2016

COMPILER: R. Shiderova, A. Sapakov. Electrical machines asynchronous motor with wounol rotor (calculation of geometric dimensions and windings) methodical instructions to course work of specialty 5B071800 - Electrical engineering.- Almaty: AUPET, 2016, 36 p.

Methodical instructions contain options of task for the course work, the definition of the main sizes of the asynchronous motor, the calculation of the stator and rotor windings and include the necessary background materials and tables [1].

Methodical instructions are intended for students of specialty 5V071800 - Electrical engineering.

Illustration. 10, table. 15, bibliographies. - 7 titles.

Reviewer: Doctor of Technical Sciences, Professor I.T. Aldibekov.

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Introduction

Course work is to teach students to apply their theoretical knowledge in solving a specific engineering problem - designing an asynchronous motor with squirrel-cage rotor for general industrial use.

Coursework should include:

a) the task for course work;

b) the calculation note containing electromagnetic calculation, sketches, explaining the main decisions of the table, in to which basic and calculated data are entered. The text should contain the calculation formulas in general form. The dimensions each value resulting from the calculation, must be specified. All calculations are done on a computer. When performing the course work it is necessary to use the recommended literature. Course work done not per assignment, which is the corresponding to figures of the cipher and the first letter of the last name, must be done again. On the cover of the explanatory note cipher must be specified.

Option of a task is selected by according to the table 1 - choose the rated power, the table 2 - choose the line voltage the table 3 - choose synchronous speed.

Table 1

Initial letter of student last name	А	Б	В	Г	Д	Е	Ж	П	Р	С	Т	У	Ф	Х
Rated power (kW) P_{2H}	1,3	1,7	2,3	2,8	3,0	3,5	4,1	13,5	14,5	15,5	17,2	19,5	24,0	29,0
Initial letter of student last name	З	И	К	Л	М	Н	О	Ц	Ч	Ш	Щ	Э	Ю	Я
Rated power (kW) P_{2H}	5,0	5,5	6,5	8,0	8,7	10,0	11,8	32,0	34,0	39,0	42,7	52,0	55,0	60,0

Table 2

The penultimate digit of cipher	1	2	3	4	5	6	7	8	9	0
Linear power supply voltage (V)	380	380	380	380	380	380	380	380	380	380
A connectio of the stator winding	Y	Δ	Δ	Y	Δ	Y	Y	Δ	Y	Δ

Table 3

The last digit of the cipher number	1	2	3	4	5	6	7	8	9	0
Rotational speed, n1 (rev / min)	3000	1500	1000	750	3000	1000	1500	750	3000	1500
Note: Line voltage is given in the task U_{1L}; phase voltage - U_{1F} depends on the method of connection of the stator winding.										

1 Determination of the main sizes and the choice of electromagnetic loads

The number of pole pairs

$$p = \frac{f60}{\text{n}}.$$

Rotation axis h height is the pre-determined according to the table 1 for given values $P_{2н}$ and 2p depending on engine performance (performance of the engine is selected by yourself).

The outer diameter of the stator core is according to the table 2.

The inner diameter of the core *D* is

$$p = k_D D,$$

where coefficient k_d is determined according to the table 3.

Table 1- Linking power and height of the rotation axis of motors of series 4A

Rotation axis height, h, (mm)	Conventional core length	Rated power P_{2n} kW including 2p poles					
		2	4	6	8	10	12
71	A B	0,75 1,1	0,55 0,75	0,37 0,55	0,25	- -	- -
80	A B	1,5 2,2	1,1 1,5	0,75 1,1	0,37 0,55	- -	- -
90	L A(B)	3	2,2	1,5	0,75 (1,1)	- -	- -
100	S L	4 5,5	3 4	- 2,2	1,5	- -	- -
112	MA(B)	7,5	5,5	3 (4)	2 (3)	- -	- -
132	S M	- 11	7,5 11	5,5 7,5	4 5,5	- -	- -
160	S M	15 18,5	15 18,5	11 15	7,5 11	- -	- -
180	S M	22 30	22 30	- 18,5	- 15	- -	- -
200	M L	37 45	37 45	22 30	18,5 22	-	-

Continuation of the table 1

Rotation axis height, h, (mm)	Conventional core length	Rated power P_{2n} kW including 2p poles					
		2	4	6	8	10	12
225	M	55	55	37	30	-	-
250	S	75	75	45	37	30	-
	M	90	90	55	45	37	-
280	S	110	110	75	55	37	-
	M	132	132	90	75	45	-
315	S	160	160	110	90	55	45
	M	200	200	132	110	75	55
355	S	250	250	160	132	90	75
	M	315	315	200	160	110	90

Table 2 - External diameters of stators of asynchronous motors fordifferent heights of the axis of rotation

h, mm	56	63	71	80	90	
D_a,*м*	0,08-0,096	0,1-1,08	0,116-0,122	0,131-0,139	0,149-0,157	
h,мм	100	112	132	160	180	
D_a,*м*	0,168-0,175	0,191-0,197	0,225-0,233	0,272-0,285	0,313-0,322	
h,мм	200	225	250	280	315	255
D_a,*м*	0,349-0,359	0,392-0,406	0,437-0,452	0,52-0,53	0,59	0,66

Table 3 - Values K_D coefficient

2p	2	4	6	8	10-12
K_D	0,52-0,6	0,62-0,68	0,7-0,72	0,72-0,75	0,75-0,77

Pole pitch τ, m is:

$$\tau = \frac{\pi D}{2p}.$$

Rated power of the induction motor P (kVA) is:

$$P = mIE = P_2 \frac{K_E}{\eta \cos\varphi}.$$

Preliminary values of η and $cos\varphi_1$ can be taken from in drawing 2, and $K_E = E_1/U_{1f}$- in from drawing 1.

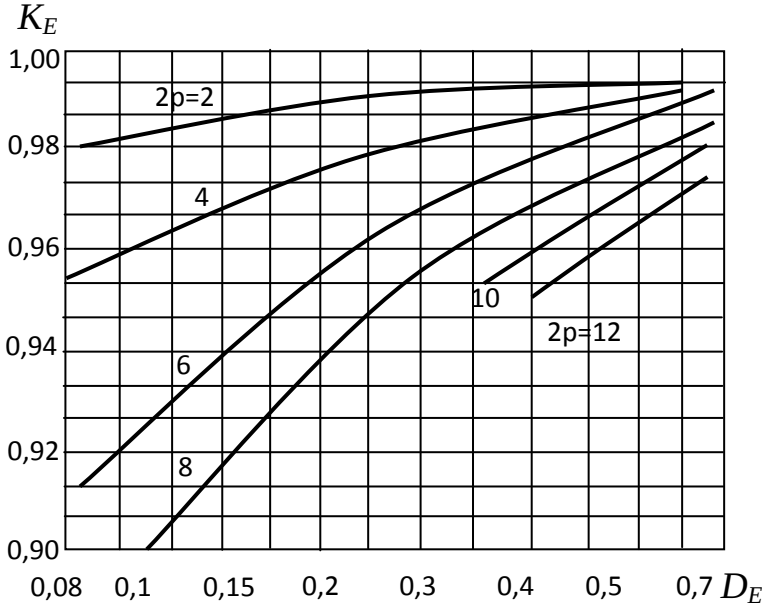


Figure 1 - The value of the coefficient K_E

Recommendations for choosing B_δ and A are shown in figure 3 and 4.

The values of the coefficient of pole overlapping α_δ and form factor of the field k_B are preliminarily equal to:

$$\alpha_\delta = \frac{2}{\pi} = 0.64;\ k_B = \frac{\pi}{2\sqrt{2}} = 1.11.$$

Winding type is selected according to the table 2. The preliminary value of winding coefficient $K_{об1}$ is selected depending on the type of the stator winding. For single-layer windings - $K_{об1}$=0.95 ... 0.96; for dual layer ones at 2p=2 windings coefficient $K_{об1}$=0.82 ... 0.86, and with greater poles - $K_{об1}$=0.91 ... 0.92.

Synchronous motor angular frequency ω, rad / sec is:

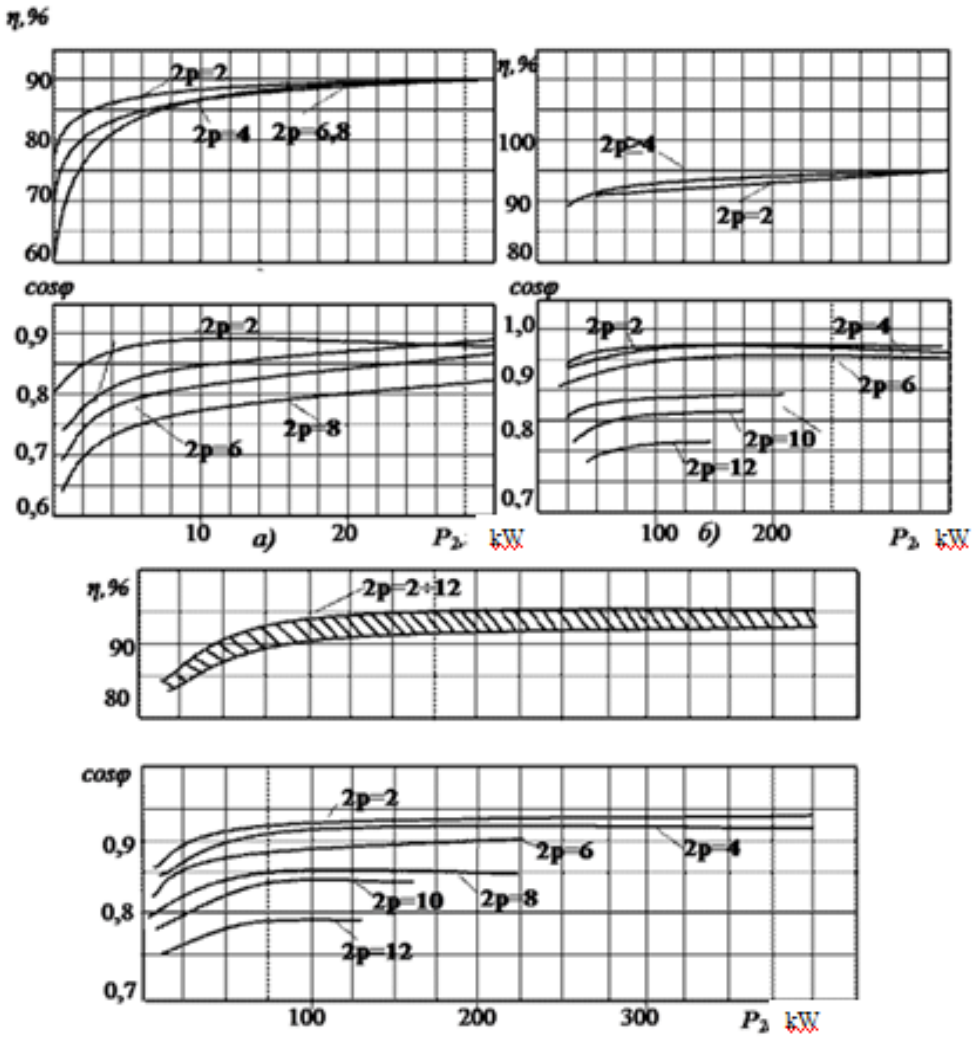
$$\omega = 2\pi \frac{n_1}{60},$$

where n_1 - synchronous speed, turnover/min;
f_1 - supply frequency, Hz.

Calculation length of the magnetic core, m is:

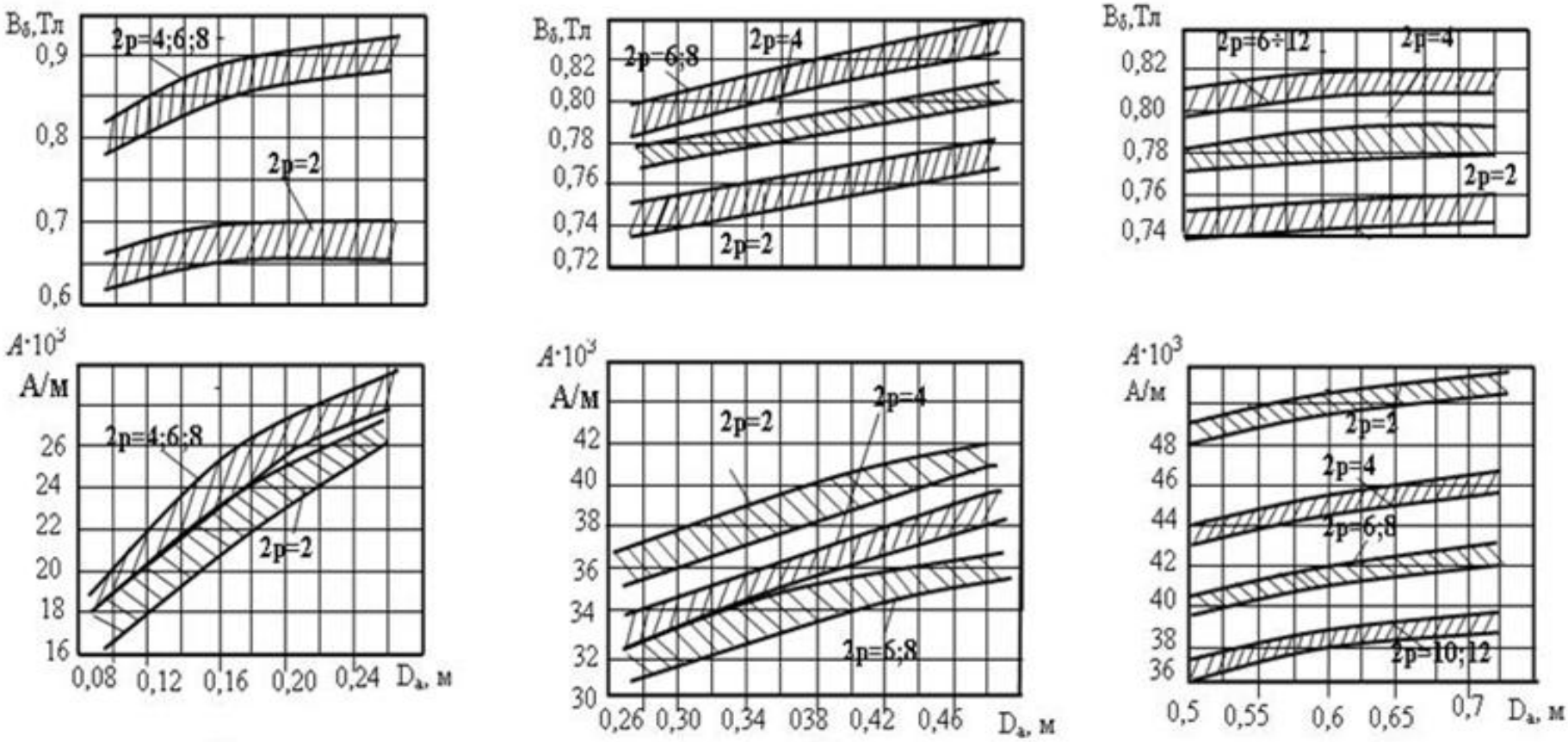
$$l_\delta = \frac{P'}{D^2 \omega k_в K_{об1} A B_\delta}.$$

The criterion for the correctness of the choice of the main dimensions of D and l_δ is a attitude relation $\lambda = l_\delta / \tau$ that is usually in the range indicated in figure 5 for the accepted machine performance. If λ is too large, the calculation should be repeated for the next series of standard one of larger rotation axis height h, and if λ is too small, then the calculation is repeated for the next row at the standard one of lowter height h.



a) the degree of protection IP44 with router up to 30 kW;
b) the degree of protection IP44 with power up to 400 kW;
c) the degree of protection IP23.

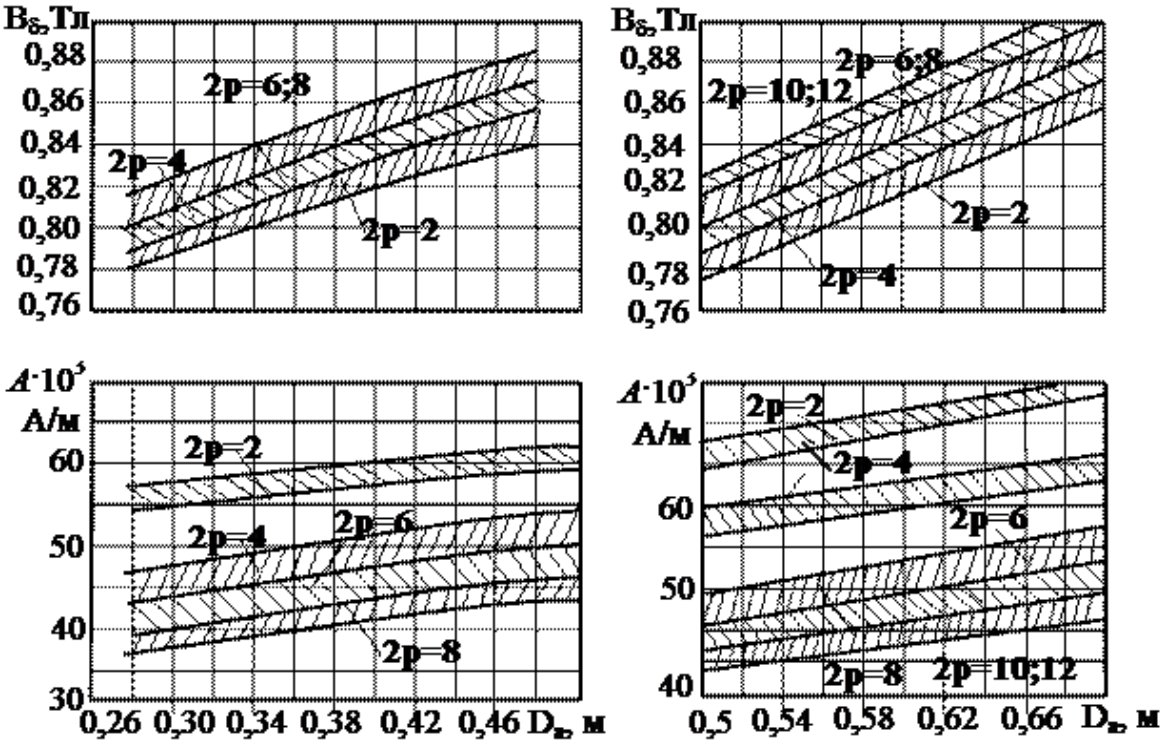
Figure 2 - Approximate values efficiency and cosφ of asynchronous motors



a) b) c)

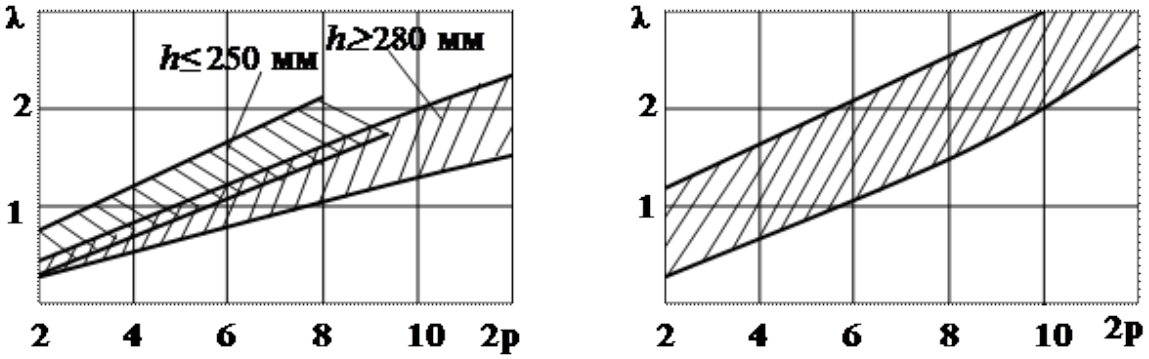
a) - $h^3 = 132\ mm; b) - h = 150 \ldots 250\ mm;\ c) - h^3 = 280\ mm$ (with forced ventilated rotor)

Figure 3 - Electromagnetic loads of induction motors with degree of protection IP44



а) $h = 160 \ldots 250\ mm$; b) $h \geq 280 mm$.

Figure 1.4 - Electromagnetic loads of induction motors with degree of protection IP23



а) *б)*

a) IP44 and b) IP23.
Figure 5 - The ratio λ

For the calculation of the magnetic circuit in addition to l_δ it is necessary to determine the total length of the structural steel and the length of the stator core (l_1 and l_{cm1}) and the rotor (l_2 and l_{cm2}). In asynchronous motors, the stator cores lendth of which does not exceed 250 ... 300 mm, radial ducts are not made. For this design

$$l_1 = l_{cm1} = l_\delta.$$

In longer machines cores are divided into individual packages, separated by a radial air ducts.

Standard width of the radial air channel between packets is $b_к$=10 мм. The number of packages $n_{пак.}$ And their length $l_{нак.}$ are associated with the gauge length by the following relation:

$$l_{нак} = (40 \dots 60)mm;$$

$$n_{nak} = \frac{l_\delta}{l_{нак}} integer.$$

Upon that the number of radial channels is $n_k = n_{нак} - 1$.

The length of the steel of core of the motor stator is:

$$n_{cm1} = l_{нак} n_{нак}.$$

The structural length of the stator core is:

$$l_1 = l_{cm1} + b_k n_k.$$

The final value for engines l_δ with an air gap $\delta > 1{,}5\ mm$ is:

$$l_\delta \approx l_{cm1}.$$

In the machines with $\delta \geq 1{,}5\ mm$ there is:

$$l_\delta \approx l_1 - b_k n_k,$$

where $b_{1k}^{'}$ - the estimated width of the radial channels defined by the table 4.

Table 4 - Estimated radial width of the channel $b_{1k}^{'}$ at $b_k = 10mm$

δ, mm	1,5	1,6	1,7	1,8	1,9	2,0	2,5	3,0
$b_{1k}^{'}$, mm	7,3	7,1	7,0	6,9	6,8	6,7	6,2	5,7

2 Determination of the number of stator slots z_i and the calculation of the stator winding

The number of turns of the phase of winding should be such one that the linear load A and the induction B_j in the air gap as close as possible coincide with their values taken previously in determining the main dimensions, and the number of stator slots provided sufficiently uniform distribution of coil of windings.

Winding type and shape of the stator slots are chosen according to the table 5. Stator slots of AC machines are shown in Figures 6 and 7.

The number of stator slots is:

$$Z_1 = 2pm_1q_1,$$

where m_1 - the number of stator winding phases (m_1=3);
q_1 - the number of the pole and phase slots (selected from table 2.1).

Tooth division of stator t_{z1} , mm is:

$$t_{z1} = \frac{\pi D}{Z_1}.$$

Rated phase stator I_{1H} winding current, A:

$$I_{1H} = \frac{P_{2H}}{m_1 U_{1\phi} \eta \cos\varphi},$$

where m_1 - the number of stator phases; $U_{1\phi}$ - phase voltage.

The number of effective conductors per slot is:

$$u_l = \frac{At_1a}{I_{1H}},$$

where a - the number of parallel branches of the be selected for table.

The obtained U_n number rounded to the nearest integer, and it must be an even for a two-layer winding.

The number of turns in the stator windings phase:

$$W_1 = \frac{u_п Z_1}{2am_1}.$$

The two-layer winding loop is usually performed with a shortened step along the grooves:

$$y_1 = \beta_1 \frac{Z_1}{2p},$$

where $\beta = y_1/\tau$ - shortening step.

At 2p=2 β=0,58-0,63, at $2p \geq 4$, $\beta_1 \approx 0.83$.

A single-layer winding is performed with a diametrical pitch:

$$y_1 = \frac{z_1}{2p}, \beta = 1.$$

Table 5 - Recommended shape of the groove type of stator winding, the values of q_1, a_1, J_1.

h, mm	*2p*	Form of stator slots	Type of stator winding	q_1	a_1 the number of parallel branches	Current density J_1	
						enclosed execution	secure execution
71÷112	2 4	Trapezium	Single layer random-wound	4 2;3	1;2	6,3;6,5	6,5;8,5
132÷160	2	Trapezium	The two-layer	6	1;2	6,3÷6,5	7,5÷8,5
	4		random-wound	3;4	1;2	5,5÷6	6,5÷7,5
	6		Single-layer random-wound	2;3	1;2;3	5÷6	6,5÷7
	8		Single-layer random-wound	2	1;2;4	5÷6	6÷6,5
180÷315	2	Trapezium	The two-layer random wound	5;6	2	6,2÷5,2	7÷6
	4			3;4	2	6÷5	6,5÷5,5
	6			3	2;3	6÷5	6,5÷5,5
	8			2	2;4	6÷5	6,5÷5,5
355	2	Rectangular semi-open	A double layer of rigid half coils	8	2	5÷4	5,5÷4,5
	4			4;5	2;4	4÷3,5	5,5÷4,5
	6		The two-layer random-wound	4	2;3;6	3,8÷4	5÷4,5
	8	Trapezium semi-closed		3;4	2;4		

Winding ratio is:

$$k_{об1} = k_{y1} k_{p1},$$

where the velocity factor of the winding $k_{об1}$ and winding distribution coefficient k_{p1} are:

$$k_{y1} = \sin(\frac{\pi}{2}) \text{ and } k_{p1} = \frac{0{,}5}{q_1 sin\frac{30}{q_1}}.$$

The magnetic flux F, WB is:

$$F = \frac{k_z U_{1\phi}}{4k_в W_1 k_{об1} f_1}.$$

Adjusted value of the magnetic induction in the air gap B_δ, T is:

$$B_\delta = \frac{F}{\alpha_\delta l_\delta \tau} = \frac{pF}{D l_\delta}.$$

Adjusted value of the linear load A, A / m is:

$$A = \frac{2I_{1н} m_1 W_1}{\pi D}.$$

Adjusted values must not deviate from the pre-selected ones by more than 10%.

Current density in the stator winding is (pre) selected in accordance with the table 5.

Cross section of the effective conductor phase is (previously) $q_{эф1}$, mm:

$$q_{эф1} = \frac{I_{1H}}{a_1 J_1}.$$

For random-wound coils for technological conditions of their placement in the slots diameter of the winding wire must not exceed 1.4-1.8 mm (corresponding to them maximum wire cross-section are $q_{max} = (1{,}54 \dots 2{,}54)$, mm^2). If $q_{эф1} > q_{эmax}$, then an efficient conductor is made of several elementary $n_{эл1}$. The number of elementary conductors in the effective one is:

$$n_{эл1} \geq \frac{q_{эф1}}{q_{эmax}} = whole\ number.$$

Conductor cross-section of the elementary (previously) is:

$$q_{эл1} = \frac{q_{эф1}}{n_{эл.1}}.$$

According to Annex 1 the closest standard conductor on section is selected. This finally determine elementary conductor section and its diameter.

When calculating the stator winding with rigid coils cross-sectional area of the rectangular wire must not exceed 18 mm^2. If $q_{эф1}$ is more than 16 mm^2, the effective conductor must be performed from several elementary ones:

$$n_{эл1} = \frac{q_{эф1}}{18} = whole\ number.$$

Conductor cross-section of the elementary wire is pre-determined.

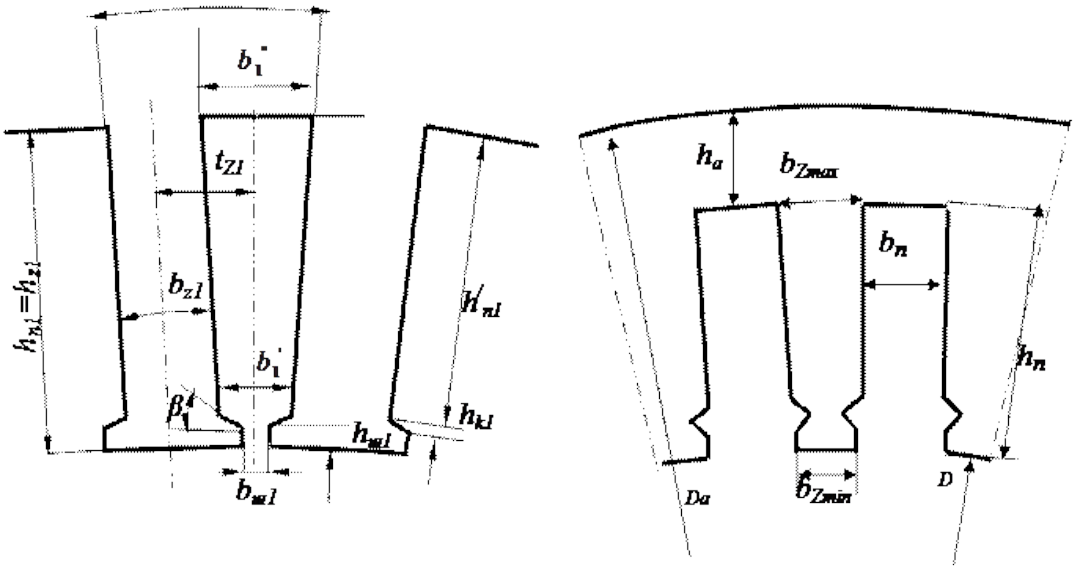
The current density in the stator winding (refined value) is:

$$J_1 = \frac{I_{1н}}{a_1 q_{эф1}} = \frac{I_{1н}}{a_1 q_{эл1} n_{эл1}}.$$

3 Calculation of the size of the stator slots

The choice of form of the groove is made in accordance with the table 5. When is trapezoidal slot shape, then the calculation should be based on point A if the groove shape is rectangular, then the one is - on the point B.

a) Calculating the size of the trapezoidal semi-closed slot of random-wound stator winding (see figure 8).



.

a) trapezoidal semi-opened; b) rectangular open.

Figure 8 – Slots of random-wound stator winding

At first the width of the tooth b_{z1} mm according the recommended value of induction in the teeth B_{z1}, mm:

$$b_{z1} = \frac{B_\delta}{B_{z1}} \frac{t_1 l_\delta}{K_c l_{cm1}},$$

where K_c =*0,95-0,97*- factor of filling by magnetic steel (0.97 to h = 132 - 250 mm, h = 0.95 for 280-355 mm);

B_{Z1}- according to the Table 6.

Table 6 - Recommended values of induction in the yoke and stator teeth

$B_a\ (T)$	$B_z\ (T)$		$B_{zmax}\ (T)$	
	Closed	Protected	Closed	Protected
1,4-1,65	1,6-1,9	1,8-2,05	1,75-1,95	1,9-2,1

The height of the stator yoke h_{a1}, m:

$$h_{a1} = \frac{\alpha_\delta}{2l_{cm\,1}K_c B_{a1}} = \frac{F}{(2B_a l_{cm\,1} k_c)}.$$

B_{a1} is selected according to the table 6.

The height of the tooth h_{z1}, m:

$$h_{z1} = 0{,}5(D_a - D) - h_{a1}$$

The height of the groove $h_{n1} = h_{z1}$.

Slot width b_{u1} should be such that you can lay out over a single wire in the coil slots. Hence, the width of the slot:

$$\mathrm{b}_{u1} = d_{u\text{з}1} + (1{,}5 \ldots 2)mm,$$

where d_{ec1} - the diameter of the wire with insulation (mm).

The height of the wedge is $h_k = 3 \div 3{,}5\ mm$ in the middle power machines and reaches 5 mm in large machines.

The minimum width of the groove in the die $b_1^{'}$,, m is

$$b_1^{'} = t_1^{'} - b_{z1};\ t_1^{'} = \frac{\pi(D + 2h_{u1} + 2h_{k1})}{Z_1};$$

$$h_{n1}^{'} = h_{z1} - h_u - h_k.$$

Usually $b_1^{'} \approx (0{,}4 - 0{,}5)t_z$.

Maximum width of the groove in the die $b_{n1}^{''}, m$ is:

$$b_1^{''} = t_1^{''} - b_{z1};\ t_1^{''} = \frac{\pi(D+2h_{z1})}{Z_1}.$$

The height of the slot (m) is $h_{ш1} \approx 0{,}8 \div 1{,}2\ м$. Angle $\beta = 45^0$ at the height of the axis of rotation is $h \leq 250\ мм$ and $\beta = 30^0$ at $h \geq 280\ мм$.

Slot dimensions in the light taking into account gaps in the assembly:

$$b_{1c}^{'} = b_1^{'} - \Delta b_1\ ;\ h_{1N}^{'} = h_{1N}^{'} - \Delta h_1;\ b_1^{''} = b_2^{'} - \Delta b_1.$$

Cross-sectional area of the slot in the light are determined by the allowances for laminating and assembling cores $S_n^{'}$, mm^2:

$$S_n^{'} = \frac{b_1^{'} + b_1^{''}}{2} h_1^{'} - S_{пр.ш};$$
$$S_{пр.ш} = \left(b_1^{'} + b_1^{''}\right)\Delta b_n\ + 2h^{'}\ \Delta h_n;$$
$$S_{1c}^{'} = \frac{b_{1c}^{'} + b_{1c}^{''}}{2} h_{1c}^{'},$$

where $S_{пр.ш}$ is area of allowances on the blending.

Table 7 - Allowances on blending

The height of the axis of rotation h, (mm)	Allowances (mm)	
	According to the width of the groove - Δb_n	At the height of the groove - Δh_n
50-132	0,1	0,1
160-250	0,2	0,2
280-355	0,3	0,3
400-500	0,4	0,4

Select the class of the stator winding insulation: in motors with heights of rotation axis h=50 ÷ 132 mm it is recommended to use a system of insulation of thermal class B, and in engines with h=160 ÷ 355 mm the one of thermal class F. Insulation structure of random-wound stator winding is shown in the table 8 and 9, respectively.

Groove cross-sectional area occupied by the winding is $S_{п1}$ mm

$$S_{n1} = S_{n1} - S_{из1},$$

where $S_{из1} = b_{из}\left(2h_n^{'} + b_1^{'} + b_1^{''}\right)$ is the cross-sectional area of the slot insulation (mm);

$b_{из}$ is insulation thickness, mm.

Choose from the table 7.

The filling factor of the groove:

$$K_{з1} = \frac{(d_{из1}^2 u_n n_{эл})}{S_{n1}}.$$

The resulting value of the filling factor should be within the recommended range $K_{з1}$=0,69...0,71. If $K_{з1}$ coefficient value exceeds the recommended limits, it must be adjusted by several ways:

- by varying the current density (i.e., by changing the cross-sectional area of the elementary conductor, and thus by changing its diameter $d_{из1}$);
- due to changes in B_{a1} within and B_{z1} the suggested values (i.e., by changing the sizes and cross-sectional area of the groove S'_{n1});
- at the expense of both;
- by changing the electromagnetic loads B_d and A.

After the final determination of the slot sizes should be recalculated the induction of tooth:

$$B_z = B_\delta \frac{t_1 l_\delta}{b_{z1min} K_c l_{cm1}}.$$

This calculation of trapezoidal groove is completed.

Preliminary stator tooth width at the narrowest point b_{z1min}, m is:

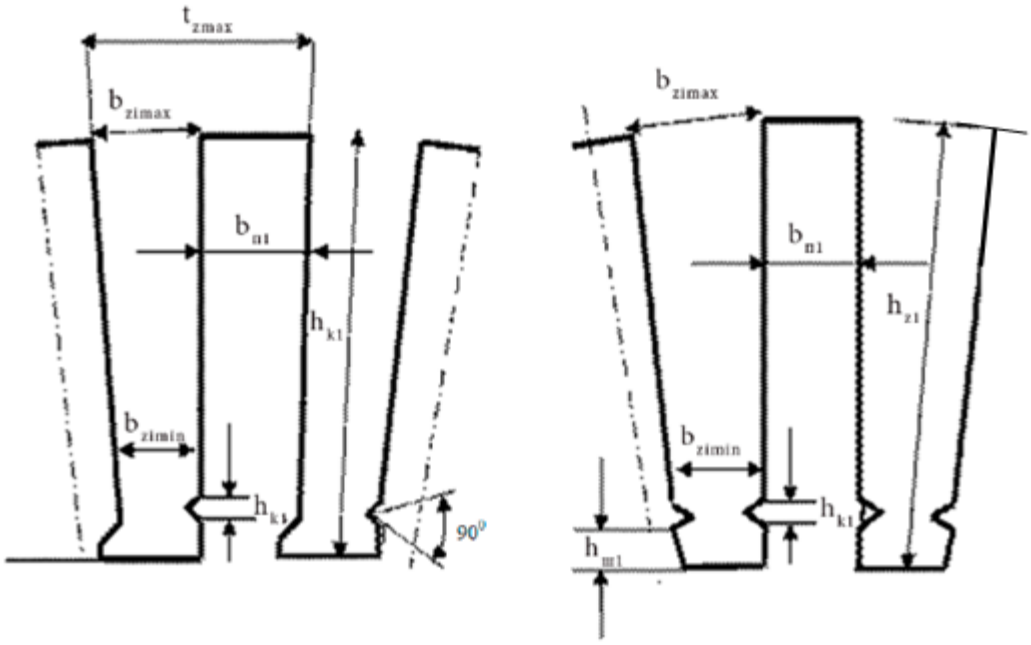
$$b_{z1max} = \frac{b_\delta}{B_{z1max}} \frac{t_{z1} l_\delta}{K_{c1} l_{cm1}},$$

where B_{z1max} - is recommended maximum induction in the narrowest section of the tooth, it is selected from table 6.

Tooth division at the narrowest point $t_{zmin}, mm\ is$

$$t_{zmin} = \frac{\pi(D + 2h_{ш1} + 2h_{k1})}{Z_1}, h_{ш1} = (1 - 1{,}2).$$

Calculation of rectangular semi-open and open slots of the stator winding with rigid sections sizes.



а) б)

a) the half-open; b) open.
Figure 9 - The rectangular slots of the stator

Preliminary slot width in the die b_{n1}, mm is*:*

$$b_{n1} = t_{1min} - b_{z1min},$$

The preliminary height of the yoke and the tooth (slot) is determined by the points 9, 10.

Often that the development of a slot structure is performed according to the table 9. The number and cross-section of the effective conductors (if necessary, they are divided into elementary ones) are known from the calculation. Dimensions of rectangular conductors, the number of them by the height and the width of the groove should be close the preliminary ones (difference should be no more than 5-10%). Dimensions of standard conductors are given in the appendix 2. Thus, we obtain the final (refined) value of b_{n1}, h_{n1}.

The final value of the stator tooth width at the most narrow and wide places, m is:

$$b_{z1min} = t_{1min} - b_{n1};$$

$$b_{z1max} = t_{1max} - b_{n1}.$$

Where

$$t_{1max} = \frac{\pi(D + 2h_{n1})}{Z_1}.$$

Induction in the most narrow and broad places of the tooth, m is:

$$B_{z1max} = B_\delta \frac{t_1 l_\delta}{b_{z1min} K_c l_{cm1}};$$

$$B_{zlmin} = B_\delta \delta \frac{t_1 l_\delta}{b_{z1max} K_c l_{cm1}}.$$

This calculation of the rectangular slot ends and then calculation the total for both coil types is performed.

Induction in the stator yoke, T is:

$$B_{a1} = B_\delta \frac{\alpha_\delta \tau l_\delta}{2h_{a1} l_{cm1} K_c},$$

where $h_{a1} = 0{,}5(D_a - D) - h_{n1}$.

The final value of the current density.

The final value of current density J_1 must satisfy the recommended values of the table 10, and the values of inductions B_{z1max}, B_{a1} are must satisfy the values in table 11.

4 Calculation of the core sizes, number of slots and rotor winding shorted

Selection of the air gap.

For engine with the capacity of less than 20 kW air gap, m, at 2p – 2 is.

$$\delta \approx (0{,}3 + 1{,}5D)10^{-3}.$$

The one at 2p> 4 is:

$$\delta \approx (0{,}25 + 1{,}5D)10^{-3}.$$

Table 10 - Insulation of stator windings of induction motors with rotation axis height up to of 250 mm for voltage up to 660 V

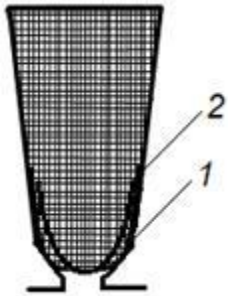
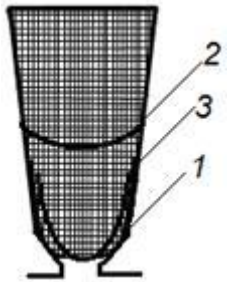
Drawing	The position of the figure	Type of winding	The height of the axis of rotation	Name of the insulation material (glass reinforced plastic film)			Number of layers	One-sided thickness, mm
				Temperature class		Material Thickness (mm)		
				B	F, H			
	1 2 1 2 1 2	Single Layer	50…80 90…132 160	Izofleks Also Also	Imidofleks Also Also	0,2 0,3 0,25 0,35 0,4 0,5	1 1 1	0,2 0,3 0,25 0,35 0,4 0,5
	1 2 3	The two-layer	180…250	Izofleks	Imidofleks	0,4 0,4 0,5	1	0,4 0,4 0,5

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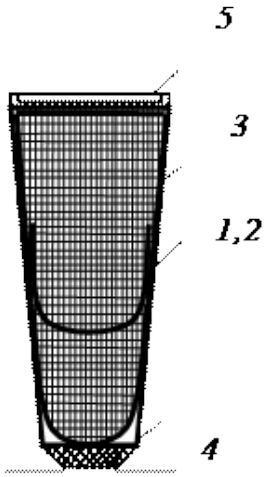
Table 11 - The insulation of the windings of the round wire stators of asynchronous motors with the height of the axis of rotation to h> 280 mm for voltage up to 660 V

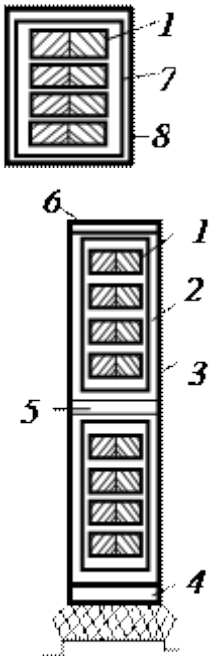
Drawing	Position	Material						number of layers	One-sided thickness, mm		
		Name and mark			Thickness				Temperature class		
		Temperature class									
		B	F	H	B	F	H		B	F	H
		Plenkosintokarton									
	1*	PCK-L	PCK-P	PCK-H	0,25	0,28	0,28	1	0,25	0,28	0,28
	2**	electronic			0,3	0,3	0,28	1	0,3	0,3	0,28
	-	the total thickness of the slot insulation			0,55	0,58	0,56	-	0,55	0,58	0,56
	3	Varnished micaceous									
		GYT	GYP	GYK							
		LCB	ЛСР	LCK							
		LCL	LCL	LCL	0,55	0,55	0,55	1	0,55	0,55	0,55
		Plenkosintokarton									
	4	PCK-L	PCK-P	PCK-H	0,25	0,28	0,28	1	0,25	0,28	0,28
	5	PCK-L	PCK-P	PCK-H	0,25	0,28	0,28	1	0,25	0,28	0,28

* By winding

*By the groove wall

Note - interphase spacers in the end parts are made of varnished cloth Micaceous

Table 12 - Continuous thermo reactive insulation of temperature classes B and F of stator windings of AC machines

Part of winding	Position	Insulation purpose	Material			Number of layers	Insulation thickness, mm						
			name	model	Thickness, mm		width		height				
							1	2	1	2	3	4	5
	*1*	Coiling	Glass tape (soaked in lacquer PE-933	LEC	0,1	1 layer	0,45	0,45	0.9	1,35	1,8	2,25	2,7
							0,05	0,1	0,1	0,15	0,20	0,25	0,3
	2	Freestanding	Swelling isolation from greasing varnish	LCP-7	0,13		2.08	2.08	2.08	2.08	2.08	2.08	2.08
	3	Coating	Glass mica tape			4 layer	0,45	0,45	0,45	0,45	0,45	0,45	0,45
	4	Gasket	Glass tape (soaked in lacquer PE-933)	LEC	0,2								
	5	Also					3,03	3,08	3,53	4,03	4,53	5,03	5,53
	6	Also	Total insulation in the slot			1 layer							
				CTEP-1	0,5		-	-	0,5	0,5	0,5	0,5	0,5
			Glass fiber	CTEP-1	1		-	-	1		1	1	1
			Also	CTEP-1	0,5		-	-	0,5	1	0,5	0,5	0,5
			Also	-		1	0,2	0,2		0,5	-	-	-
	1	Coiling	Demission to the laying	-		1				-			
			Total insulation in the groove deviations			1	3,23	3,23	9,06	10,06	11,06	12,06	13,06
	7	Freestanding	glass tape (impregnated in Lackey PE 933)	JIEC	0,1		0,45	0,45	0,9	1,35	1,8	2,25	2,7
	8	Coating	An swelling insulation	JIC-PE-934-TP	0,13	1 layer	0,05	0,1	0,1	0,15	0,2	0,15	0,3
				LEC			1,56	1,56	1,56	1,56	1,56	1,56	1,56
			Glass mica tape		0,2	3 layer	0,9	0,9	0,9	0,9	0,9	0,9	0,9
			Glass tape (soaked in lacquer PE-933)				2,96	3,01	3,46	4,96	4,46	4,96	5,46
			Total isolation in the frontal parts			2 layer							

For engines of medium and high power:

$$\delta \approx \frac{D}{1,2}\left(1+\frac{9}{2p}\right)10^{-3}.$$

The number of rotor slots

Table 13 - Recommended numbers of rotor slots of induction motors with squirrel-cage rotor

2p	The number of stator slots	The number of rotor slots	
		without slant of slots	With slant of slots
1	2	3	4
2	12 18 24 30 36 42 48	9*, 15* 11*, 12*. 15*, 21*, 22 15* (16)*, 17*, 19, 32 22,38 26, 28, 44, 46 32, 33, 34, 50, 52 38, 40, 56, 58	— 14*, (18), 19*, 22*, 26, 28*, (30), 31,33, 34, 35 18,20,26,31,33,34,35 (18), 20, 21,23, 24, 37, 39, 40 25,27,29,43,45, 47 — 37.39.41.55.57.59
4	12 18 24 36 42 48 60 72	9* 10*. 14* 15*, 16*, 17, (32) 26, 44, 46 (34), (50), 52, 54 34, 38, 56, 58, 62, 64 50, 52, 68, 70, 74 62, 64. 80. 82. 86	15* 18*, 22* 16, 18, (20), 30, 33, 34, 35, 36 (24), 27, 28, 30, (32), 34, 45, 48 (33), 34, (38), (51), 53 (36), (38), (39), 40, (44), 57, 59 48,49,51,56,64,69,71 61.63.68.76.81.83
6	36 54 72 90	26, 46, (48) 44, 50, 64, 66, 68 56, 58, 62, 82, 84, 86, 88, 74, 76, 78, 80, 100,102,104	28*, 33, 47, 49, 50 42,43,51,65,67 57,59,60,61,83,85,87,90 75,77,79,101,103,105
8	48 72 84 96	(34), 36, 44, 62, 64 56, 58, 86, 88, 90 66, (68), 70, 98, 100, 102, 104 78,82,110,112, 114	35,44,61,63,65 56, 57, 59, 85, 87, 89 (68), (69), (71), (97), (99), (101) 79.80.81.83.109.111.113

Continuation of the table 13

1	2	3	4
10	60 90 120	44, 46, 74, 76 68, 72, 74, 76,104, 106, 108, 110, 112,114 86, 88, 92, 94, 96, 98, 102, 104, 106,134, 136, 138, 140, 142,146	57, 69, 77, 78, 79 70,71,73,87,93,107,109 99,101,103,117,123,137,139
12	72 90 108 144	56, 64, 80, 88 68,70.74,88,98,106,108,110 ,112,114 86, 88, 92, 100, 116, 124, 128, 130, 132 124, 128, 136, 152, 160, 164, 166, 168, 170. 172	69,75,80,89,91,92 (71), (73), 86, 87, 93, 94, (107), (109) 84,89,91,104,105,111,112,125, 127 125, 127, 141, 147, 161, 163

Notes - Figures in parentheses are the number of slots in which it is possible to increase the vibration motors.

An asterisk denotes the number of slots used, mainly in low-power machines.

The external diameter of the rotor, m

$$D_2 = D - 2\delta.$$

The length of the rotor yoke, m

$$l_2 = l_1.$$

Tooth division of the rotor, mm

$$t_{z2} = \frac{\pi D_2}{Z_2}.$$

The inner diameter of the rotor is equal to the diameter of the shaft as the rotor core itself is mounted on the shaft:

$$D_j = D_в = \kappa_в D_a,$$

where $\kappa_в$ is according to the table 14.

Table 14

h, mm	50 - 63	71 - 250	280 - 355		400 - 500		
2p	2 - 6	2 - 8	2	4 - 12	4	6	8 - 12
$k_в$	0,19	0,23	0,22	0,23	0,2	0,23	0,25

The current in the rotor winding, A:

$$I_2 = k_i I_1 v_i;$$

where k is a factor taking into account the magnetizing current impact on the ratio I_1/I_2. Its approximate value can be calculated depending on the rated power factor cosφ:

$$k_i = 0{,}2 + 0{,}8\cos\varphi.$$

Coefficient of reduction current for squirrel-cage motors:

$$v_i = \frac{2m_i w k_{об}}{Z_{c1} k_{ck}},$$

k_{ck} is bevel coefficient taking into account the decrease EMF of winding with the rotor tapered grooves:

$$k_{ck} = \frac{2\sin(\frac{\gamma_{ck}}{2})}{\gamma_{ck}};$$

$$\gamma_{ck} = \beta_{ck}\frac{2p}{Z};\ \beta_{ck} = \frac{b_{ck}}{t_{z2}}.$$

b_{ck} - through the grooves, mm.

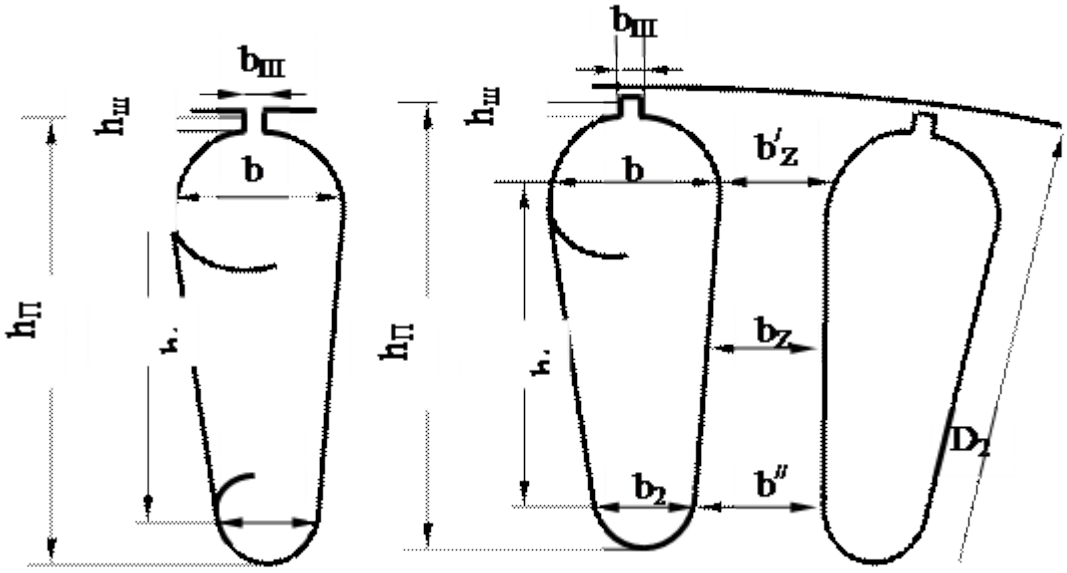
The rod cross-sectional area mm^2 is:

$$S_n = \frac{I_2}{J_2}.$$

The current density in the rotor bars of closed blown type machines when filling the slots by aluminum is chosen within J_2 =(2,5...3,5) of 106 A/m^2, while protected construction, it is by 10 ... 15% higher.

5 Calculation of the rotor slots sizes

Rotor slots determined by the drawing 10. We accept $b_ш$, $h_ш$, $h_ш'$, mm.



a) half-open; b) closed.
Figure 10 - Trapezoidal grooves of cage rotor

Most in the of asynchronous motors having with squirrel-cage rotor with a height of axis of rotation h≤250 mm trapezoidal grooves and molded coil on the rotor are performed (figure 5.1). The dimensional ratios of grooves b_1, b_2 and h_1 provide parallel of side faces of the teeth. In engines with h<160 mm slots have narrow slot with the following dimensions: $b_ш$ =1.0 mm and $h_ш$ =0.5 mm at height of the axis of rotation h <100 mm; $b_ш$=1.5 mm and $h_ш$ =0.75 mm at height of rotation h=112 ... 132 mm. In engines with h=160 ... 250 mm closed trapezoidal slots (see figure 5.1 b), with the dimensions of the slot $b_ш$=1.5 mm and $h_ш$=0.7 mm are performed. Headroom above the slot in engines with 2p> 4 runs equal $h'_ш$ =0.3 mm, in bipolar motors $h'_ш$ =1.0...1.5 mm.

Permissible tooth width in mm is:

$$b_{z2} = \frac{B_\delta}{B_{z2}} \frac{t_2 l_\delta}{K_c l_{cm\,2}};\ t_2 = \frac{\pi D_2}{Z_2},$$

where B_{z2} - according to the table 6.

Maximum width of the tooth, mm is:

$$b_1 = \frac{\pi\left(D_2 - 2h_ш - 2h'_ш\right) - Z_2 b_{Z2}}{\pi + Z_2}.$$

The minimum width of the tooth, mm is:

$$b_2 = \sqrt{\frac{b_1^2\left(\frac{Z_2}{\pi}+\frac{\pi}{2}\right)-4q_c}{\frac{Z_2}{\pi}+\frac{\pi}{2}}}.$$

The height of the tooth, mm is:

$$h_1 = (b_1 - b_2)\frac{Z_2}{2\pi}.$$

We specify the width of the rotor teeth, mm:

$$b'_{z2} = \pi\frac{D_2 - 2(h_ш + h'_ш)b_1}{Z_2} - b_1;$$

$$b''_{z2} = \pi\frac{D_2 - 2h_п + b_2}{Z_2} - b_2;$$

$$b'_{z2} = b''_{z2}.$$

The total height of the slot, mm is:

$$h_{п2} = h'_ш + h_ш + \frac{b_1}{2} + h_1 + \frac{b_2}{2}.$$

The rod cross-sectional area mm^2 is:

$$q_c = \frac{\pi}{8}(b_1^2 + b_2^2) + \frac{1}{2}(b_1 + b_2)h_1.$$

The current density in the rod A / m is:

$$J_2 = \frac{I_2}{q_c}.$$

Shorting rings

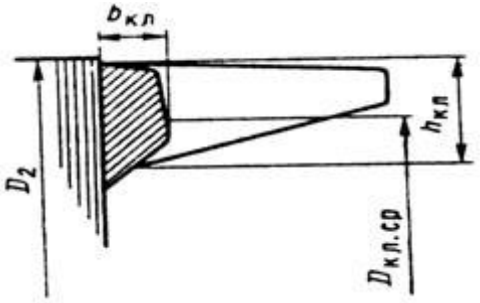


Figure 6.1 - Dimensions of end rings of cage rotor with cast winding

Dimensions $h_{кл}$ and $b_{кл}$ are taken approximately, based on the cross-sectional configuration of the ring. The height of the rings is chosen $h_{кл} \geq 1{,}2h_{п2}$.

The cross sectional area of the ring, mm^2;

$$q_{кл} = \frac{I_{кл}}{J_{кл}}.$$

Currents in the ring, A is

$$I_{кл} = \frac{I_2}{\Delta},$$

Where $\Delta = 2\sin\frac{\alpha_z}{2} = 2\sin\frac{\pi\rho}{z_2}$.

Current density of ring A / m^2 is.

$$J_{кл} = 0{,}85J_2.$$

The width of the locking ring, mm is:

$$b_{кл} = \frac{q_{кл}}{h_{кл}}.$$

Height of ring cross section is:

$$h_{кл} = (1{,}1 - 1{,}25)h_{п2}.$$

The cross section of the locking ring, mm^2 is:

$$q_{кл} = h_{кл}b_{кл}.$$

The cross section of the locking ring, mm^2 is:

$$S_{кл} = \frac{h_{кл}}{b_{кл}}.$$

The average diameter of the locking ring, m is:

$$D_{к.ср.} = D_2 - h_{кл}.$$

Appendix 1

Table 1 - The diameter and cross-sectional areas of round enameled copper wires of PET - 155

Nominal diameter of bare wire, mm	The average value of the of the insulated diameter wire, $d_{из1}$ mm	The cross sectional area of uninsulated wire, $q_{эл1}$ mm^2
0.53	0.585	0.221
0.56	0.615	0.246
0.6	0.655	0.283
0.63	0.69	0.312
0.67	0.73	0.353
0.71	0.77	0.396
0.75	0.815	0.422
0.80	0.865	0.503
0.85	0.915	0.567
0.90	0.965	0.636
1,00	1.08	0.785
1.06	1.14	0.883
1.12	1.20	0.985
1.18	1.26	1.094
1.25	1.33	1.227
1.32	1.405	1.368
1.40	1.485	1.539
1.50	1.585	1.767
1.60	1.685	2.011
1.70	1.785	2.27
1.80	1.895	2.54
1.90	1.995	2.83

Appendix 2

Table 2 - The dimensions and cross-sectional areas of the rectangular wire

On the larger side b, мм	At the smaller side of the bare wire - *a,mm*												
	1,5	1,6	1,7	1,8	1,9	2	2,12	3	3,15	3,35	3,55	4	Note
2	-	-	-	-	-	-	-	-	-	-	-	-	Double-sided insulation thickness rectangular winding wires PETB (class Temperature B) - 0.15 mm, winding wires PETP (Temperature Class) - 0.2 mm.
2,12	-	-	-	-	-	-	-	-	-	-	-	-	
2,24	3,145	3,369	-	-	-	-	-	-	-	-	-	-	
2,36	-	3,561	-	-	-	-	-	-	-	-	-	-	
2,5	3,285	3,785	3,887	4,137	-	-	-		-	-	-	-	
2,65	-	4,025	-	4,407	-	-	-	-	-	-	-	-	
2,8	3,985	4,265	4,397	4,677	4,957	5,237	-	-	-	-	-	-	
3	-	4,585	-	5,038	-	5,638	-	-	-	-	-	-	
3,15	4,51	4,825	4,992	5,307	5,622	5,937	6,315	-	-	-	-	-	
3,35	-	5,145	-	5,667	-	6,337	8,117	-	-	-	-	-	
3,75	-	5,785	-	6,837	-	7,137	-	-	-	-	-	-	
4	5,185	6,185	6,437	6,837	7,237	7,637	8,117	-	-	-	-	-	
4,25	-	6,585	-	7,287	-	8,137	-	-	-	-	-	-	
4,5	6,535	6,985	7,287	7,737	8,187	8,637	9,177	12,95	13,63				
5	7,285	7,785	8,137	8,637	9,137	9,637	10,24	14,45	15,2	16,2			
5,3	-	8,265	-	9,177	-	10,24	-	-	16,15	-	18,27	-	

Continued appendix of table 2

On the larger side b, мм	at the smaller side of the bare wire - *a,mm*											
	1,5	1,6	1,7	1,8	1,9	2	2,12	3	3,15	3,35	3,55	4
5,6	6,393	8,101	7,625	8,185	9,717	10,28	10,84	11,51	14,29	15,13	17,09	-
6	-	-	8,185	-	10,44	-	11,64	-	-	16,25	18,35	-
6,3	7,219	9,101	8,605	9,235	10,98	11,61	12,24	12,99	16,15	17,09	19,3	22,77
6,7	-	7,22	-	-	11,7	-	13,04	-	-	18,21	-	-
7,1	8,163	7,76	8,35	8,99	10,5	11,3	11,9	13,9	15,0	16,2	17,5	20,3
7,5	7,21	9,157	9,725	10,44	12,42	13,13	13,84	14,69	-	20,45	23,08	-
8	9,225	10,35	10,99	11,79	14,04	14,84	15,64	16,6	20,65	21,85	24,65	-
8,5	-	-	11,69	-	14,94	-	15,64	16,6	-	23,25	26,23	29,14
9	10,41	11,67	12,39	13,29	15,84	16,74	17,64	18,72	23,3	24,65	27,8	-
9,5	-	-	13,09	-	16,74	-	18,64	-	-	26,05	29,38	32,89
10	-	-	13,79	14,79	17,64	18,64	19,64	-	25,95	27,45	30,95	36,64
10,6	-	-	14,63	-	18,72	-	20,84	20,84	27,9	30,1	32,4	37,6
11,2	-	-	15,47	16,59	19,8	20,92	22,04	23,38	29,13	30,81	34,73	41,14
11,8	-	-	-	-	20,88	-	23,24	-	-	32,49	36,62	-
12,5	-	-	-	20,8	24,2	26,1	27,9	32,4	35,0	37,7	40,7	47,2
14,5	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-

Continued appendix of table 2

On the larger side b, мм	at the smaller side of the bare wire - *a, mm*											
	3,28	3,35	3,53	3,55	3,75	3,8	4	4,1	4,25	4,4	4,5	4,75
16	-	53,05	-	56,25	59,14	-	63,14	-	67,14	-	-	-
16,8	54,62	-	58,82	-	-	63,36	-	68,02	-	73,06	-	-
18,0	58,56	-	63,06	-	-	67,92	-	72,94	-	78,34	-	-
19,5	63,48	-	68,35	-	-	73,68	-	79,09	-	84,94	-	-
20	-	-	-	-	-	-	79,52	-	-	-		
22	71,68	-	77,18	-	-	83,12	-	89,34	-	95,94	-	-
25	81,52	-	-	-	-	94,52	99,52	101,64	-	109,14	-	-
26,3	-	-	92,36	-	-	94,46	-	106,97	-	114,86	-	-
30,0	-	-	-	-	-	113,52	119,52	122,14	-	131,14	-	-
32,0	-	-	-	-	-	-	-	130,34	-	139,94	-	-
35	-	-	-	-		-	-	-	-	153,14	-	163,64

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