Researcher Links UK-Russia Workshop

Scientific and Technical Grounds of Future Low-Carbon Propulsion

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Methods of analysis and synthesis of traction drivers of electric vehicles

Alexey Gorozhankin

Federal State Autonomous Educational Institution of Higher Education "South Ural State University (national research university)"

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The requirements for electric vehicle traction drive

- The starting torque of the motor should be up to four times the rated torque to enable electric launch;
- The corresponding torque density should be maximized to reduce the weight and size;
- The corresponding power density should be maximized to reduce the weight and size;
- The constant-power operation range of the motor should be up to four times the base speed to enable wide-speed operation;
- The motor should be able to offer efficiency higher than 85% over wide torque-speed regions;
- The system should have high reliability and good serviceability. Particularly, the motor and generator should be maintenance-free.

Electric machines for electric drive

Indicator	*IM*	*SynR*	*SRM*	*DSDC*	*FSDC*	*FRRM*
Power density	2	3	2	3	4	3
Torque density	2	3	4	3	4	3
Efficiency	2	3	2	4	4	4
Constant power range	2	3	2	3	4	3
Controllability	1	3	1	4	4	3
Robustness	4	2	4	3	3	4
Manufacture	2	2	4	2	2	4
Material cost	4	3	4	3	3	4
Summary	19	22	23	25	**28**	**28**

Symmary of mathematical models for synthesis and analysis of traction electric drive

Type of a model	Source Data Set	Accuracy	The required amount of computing resources	Application area
1. Based on the electrical equivalent circuit	- electric machine parameters; - specifying control actions;	Error 10-30%	Min	Selection of the main dimensions of the electromechanical transducer and optimal ratios
2. Based on the energy method	- the parameters of the magnetic system;	Error 10-25%	Mean	Analysis of integral indicators (for example, M).
3. Based on the method of winding functions	- electric machine parameters; - specifying control actions.	Error 10-30%	Min	In solving the problems of the synthesis of the electric drive control system
4. Based on the finite element method	- electric machine parameters; - specifying control actions.	Error 2-5%	Max	To solve the problems of analysis and optimization procedures

Proposed mathematical model

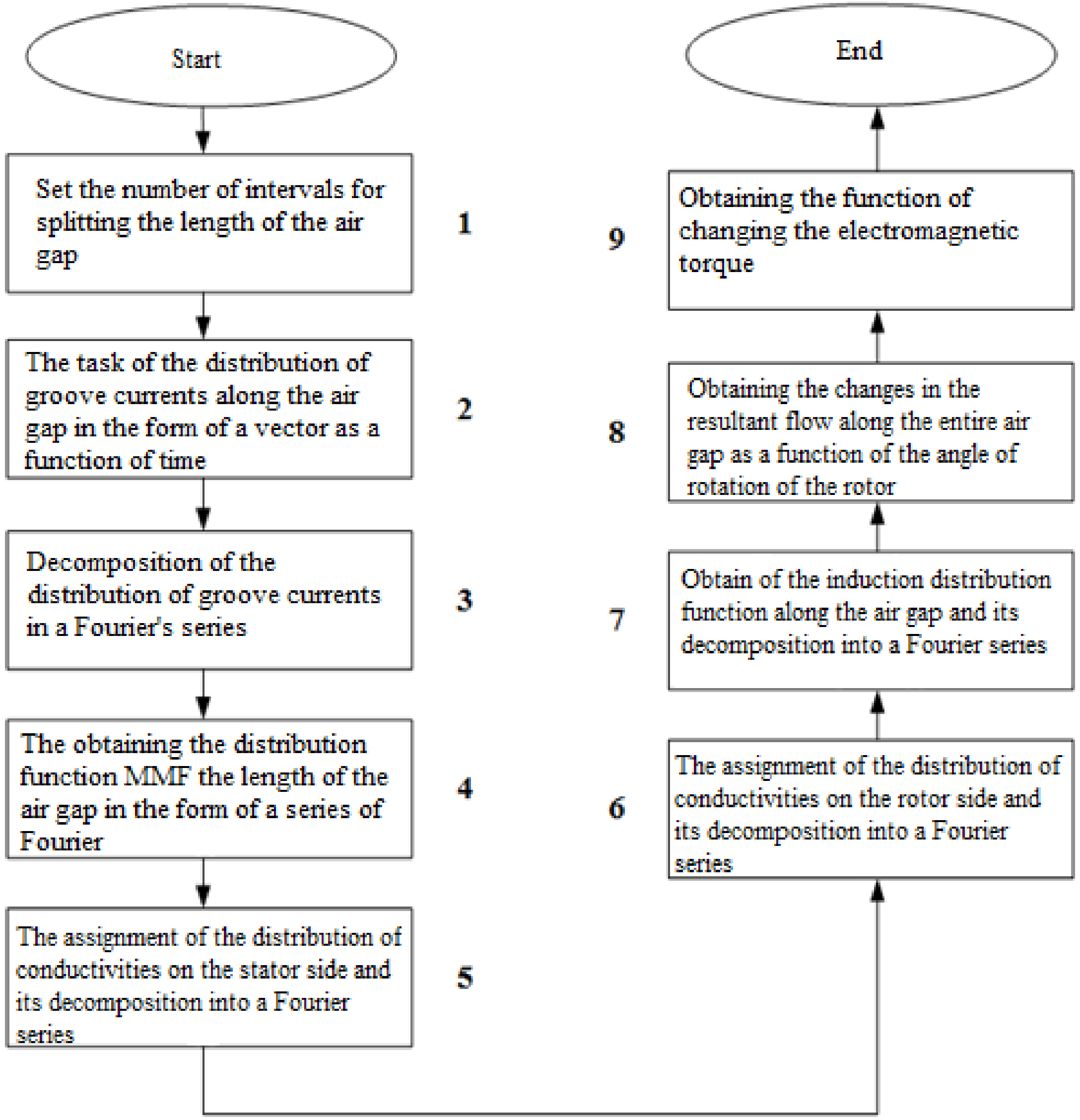
Mathematical Model Assumptions:

- The magnetic system is not saturated;
- There are no scatter streams;
- Magnetic conductivity of steel equals infinity.

Applications of the mathematical model:

- Pre-selection of the topology and design of the electric machine for the electric drive;
- As an observer in the drive control system;
- As a basis for the synthesis of the shape of the currents in the control circuit of the torque of the electric drive.

Algorithm for calculating the mathematical model



2 $$\overrightarrow{Ip(t)} = \begin{pmatrix} f_1(t) & \dots & f_m(t) \end{pmatrix}$$

4 $$f(x,t) = \int I(x,t)\,dx$$

5 $$\overrightarrow{Zst} = \begin{pmatrix} Cst_1 & \dots & Cst_m \end{pmatrix}$$

6 $$\overrightarrow{Zrot} = \begin{pmatrix} Crot_1 & \dots & Crot_m \end{pmatrix}$$

7 $$F(x,t,\alpha) = f(x,t) \cdot Zst(x) \cdot Zrot(x,\alpha)$$

8 $$Fsum(t,\alpha) = \int_0^{2\pi} \left| F(x,t,\alpha) \right| dx$$

9 $$M(t,\alpha) = \frac{\partial Fsum(t,\alpha)}{\partial \alpha}$$

The idea of spectral analysis of variables

Classical Fourier's expansion

$$I\left(x,t,\alpha\right)=\frac{a_0(t)}{2}+\sum_{k=1}^{\infty}\left(a_k(t)\cdot\cos\left(k\cdot\left[x+\alpha\right]\right)+b_k(t)\cdot\sin\left(k\cdot\left[x+\alpha\right]\right)\right)$$

$$S\left(x,t,\alpha\right)=\frac{a_0(t)}{2}+\sum_{k=1}^{n}\left(a_k(t)\cdot\cos\left(k\cdot\left[x+\alpha\right]\right)+b_k(t)\cdot\sin\left(k\cdot\left[x+\alpha\right]\right)\right)$$

$$\Delta=\frac{1}{\pi}\cdot\int_0^{2\cdot\pi}\left(I\left(x,t,\alpha\right)-S(x,t,\alpha)\right)^2dx$$

$$a_0(t)=\frac{1}{\pi}\cdot\int_0^{2\cdot\pi}I\left(x,t\right)dx$$

$$a_k(t)=\frac{1}{\pi}\cdot\int_0^{2\cdot\pi}I\left(x,t\right)\cdot\cos\left(k\cdot x\right)dx$$

$$b_k(t)=\frac{1}{\pi}\cdot\int_0^{2\cdot\pi}I\left(x,t\right)\cdot\sin\left(k\cdot x\right)dx$$

$$A_k=\sqrt{a_k(t)^2+b_k(t)^2}$$

$$\varphi_k=arctg\left(\frac{b_k(t)}{a_k(t)}\right)$$

Fourier's coefficients of the pulse-modulated function:

$$a_0(t)=\frac{2}{\pi}\cdot\sum_{j=0}^{m-1}I_j(t)\cdot\frac{\pi}{m}$$

$$a_k(t)=\frac{1}{\pi}\cdot\sum_{j=0}^{m-1}\frac{I_j(t)}{k}\cdot\left(\sin\left(k\cdot2\cdot\pi\cdot\frac{j+1}{m}\right)-\sin\left(k\cdot2\cdot\pi\cdot\frac{j}{m}\right)\right)$$

$$b_k(t)=\frac{1}{\pi}\cdot\sum_{j=0}^{m-1}\frac{I_j(t)}{k}\cdot\left(\cos\left(k\cdot2\cdot\pi\cdot\frac{j}{m}\right)-\cos\left(k\cdot2\cdot\pi\cdot\frac{j+1}{m}\right)\right)$$

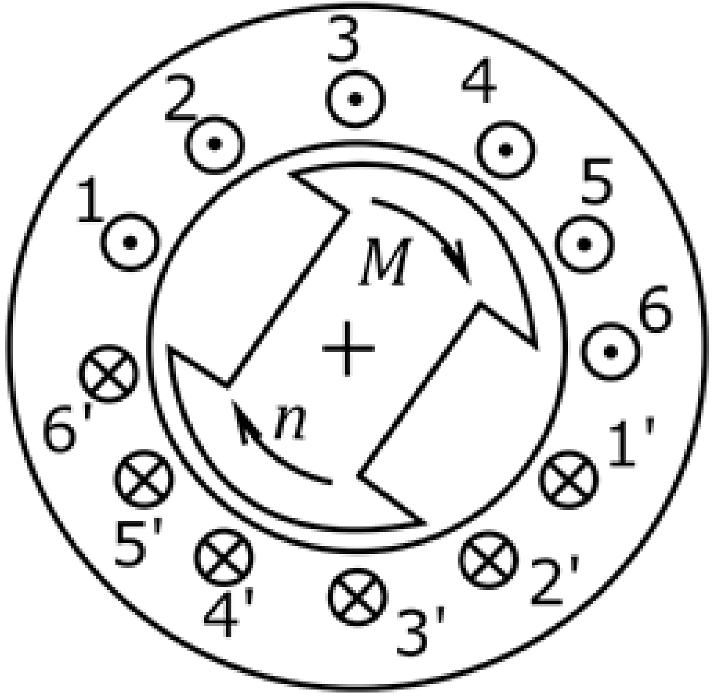
The final expression of the Fourier's coefficients:

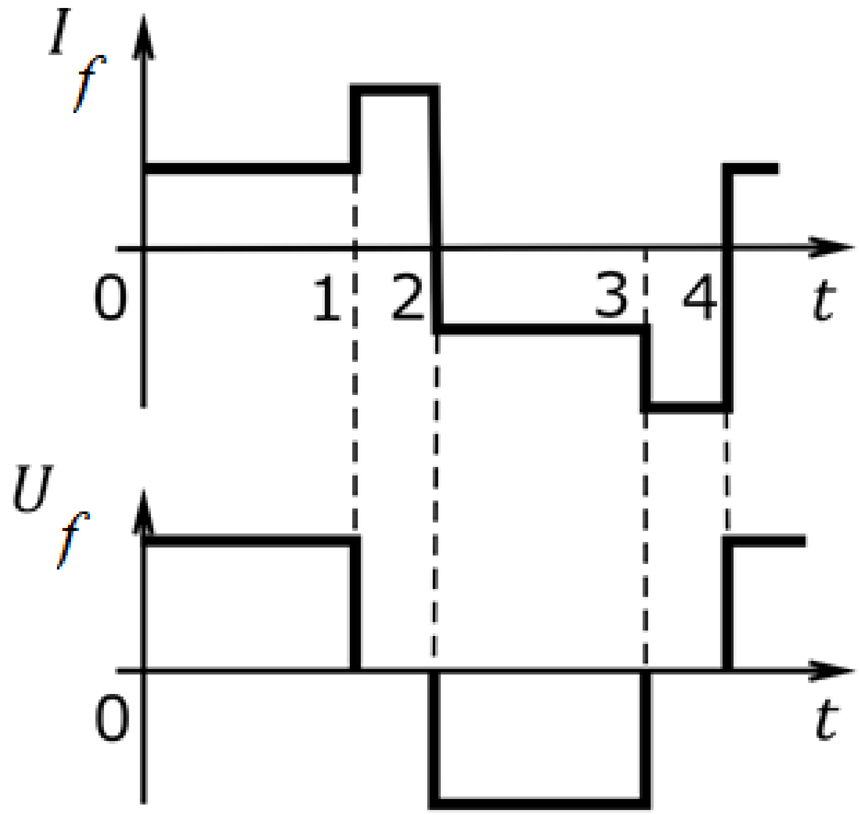
$$a_0(t)=\frac{2}{m}\cdot\sum_{j=0}^{m-1}I_j(t)$$

$$a_k(t)=\frac{2}{\pi\cdot k}\cdot\sin\left(\frac{k\cdot\pi}{m}\right)\cdot\sum_{j=0}^{m-1}I_j(t)\cdot\cos\left(k\cdot2\cdot\pi\cdot\left[\frac{2j+1}{2\cdot m}\right]\right)$$

$$b_k(t)=\frac{2}{\pi\cdot k}\cdot\sin\left(\frac{k\cdot\pi}{m}\right)\cdot\sum_{j=0}^{m-1}I_j(t)\cdot\sin\left(k\cdot2\cdot\pi\cdot\left[\frac{2j+1}{2\cdot m}\right]\right)$$

Explanation of working principle FRRM





An example of the calculation of the induction in airgap and the torque of FRRM according to the model

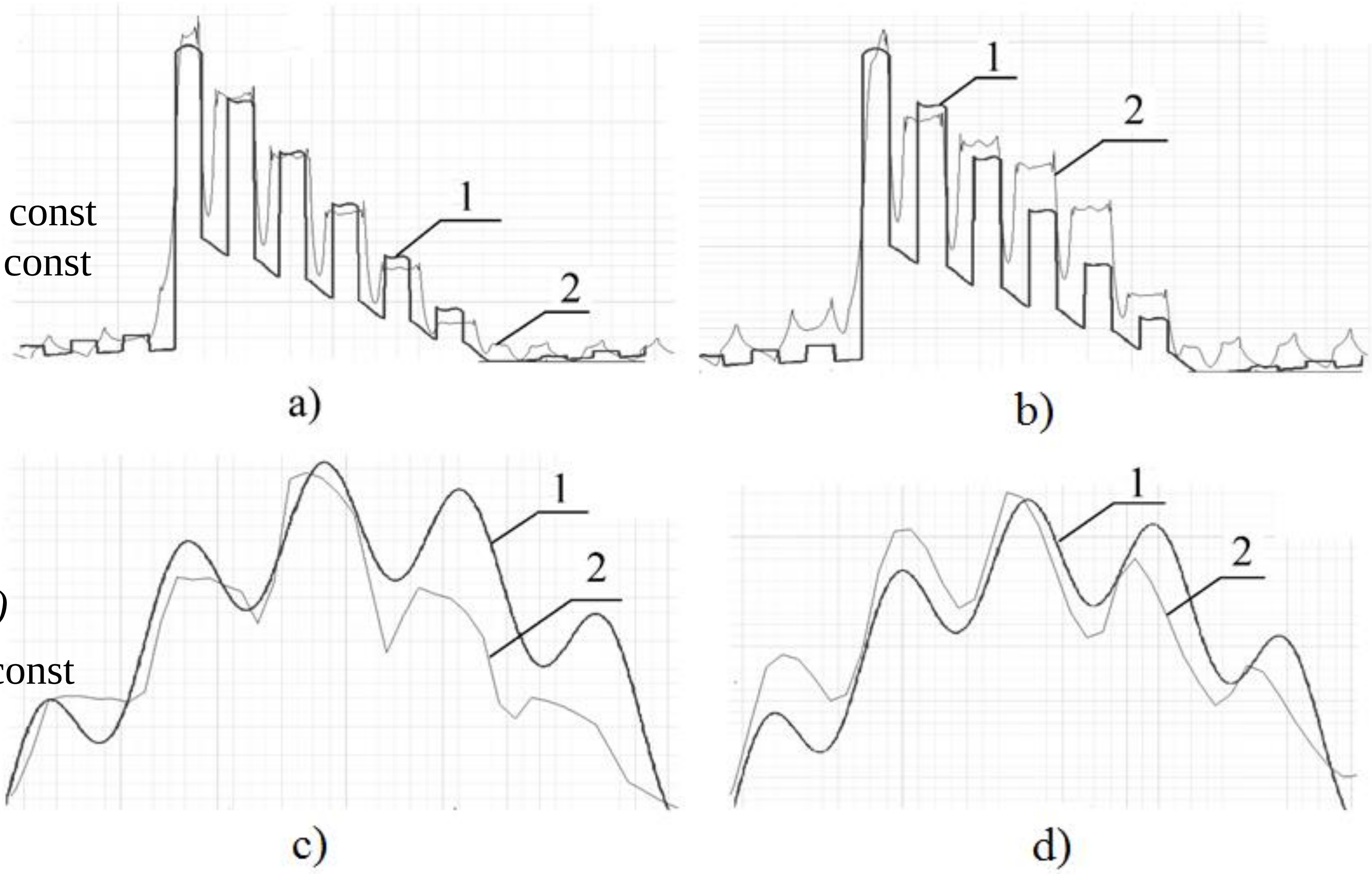
F(x)

α = const

t = const

M(α)

t = const

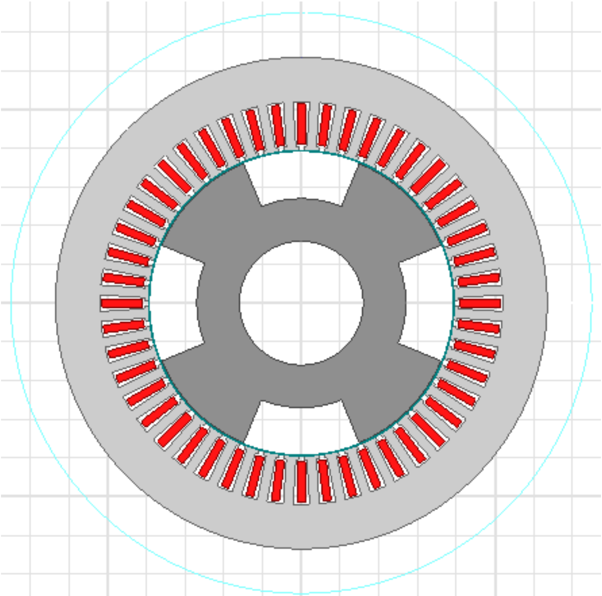


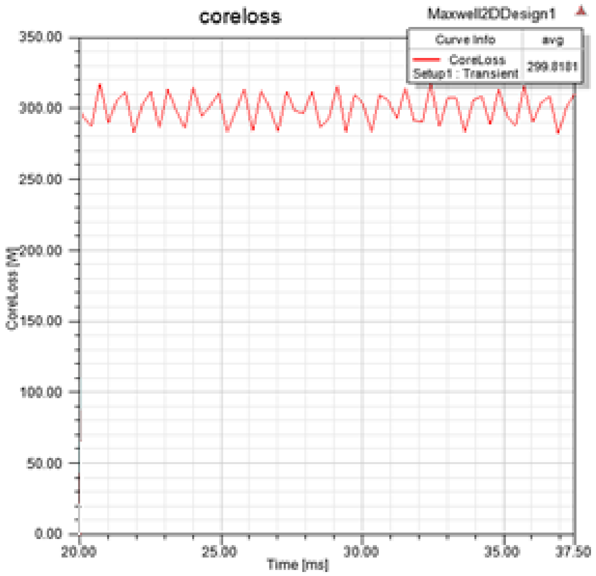
1 – Proposed mathematical model;

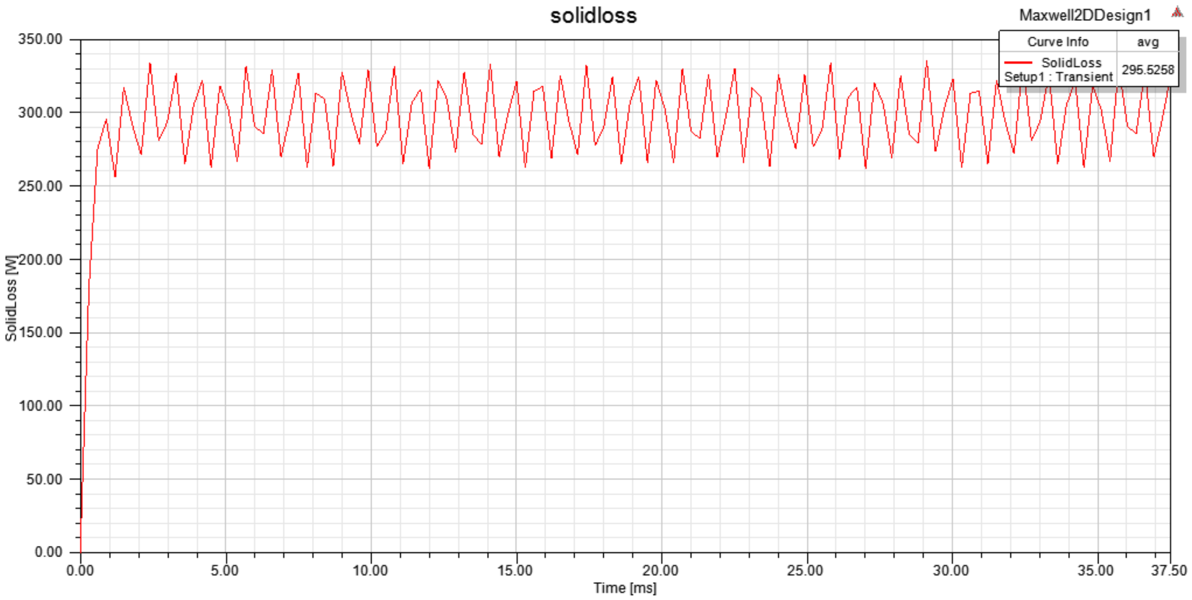
2 – finite-element analysis

Features of calculation of losses in steel

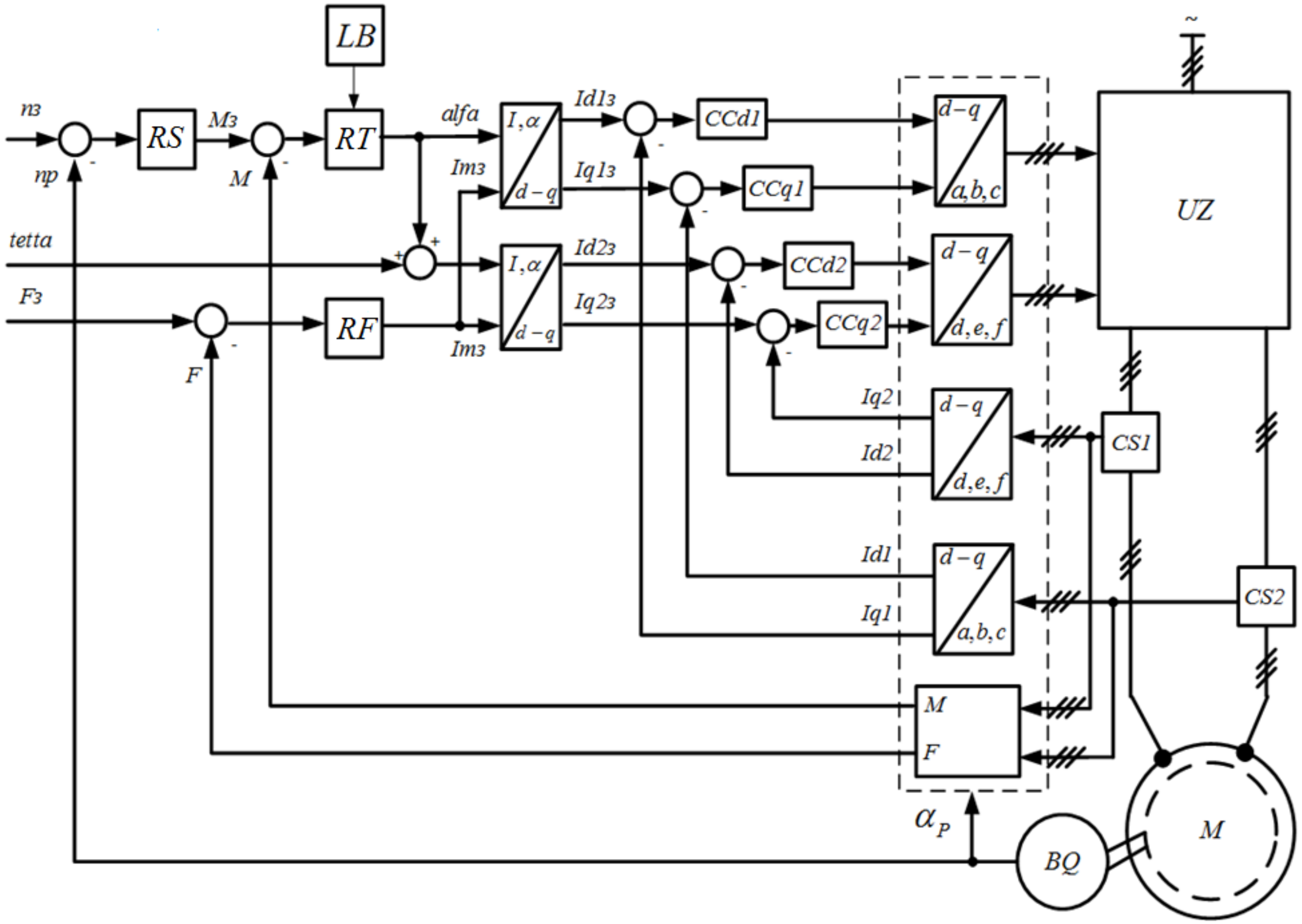
№	Parameter	Dimension	Value
1	Nominal rotating power	kW	16
2	Nominal speed	rmp	1500
3	Nominal torque	N·m	98
4	The outer diameter of the stator core	mm	254
5	The inner diameter of the stator core	mm	158
6	Stator pack length	mm	184
7	Air-gap distance	mm	1
8	Number of phase	-	6
9	Number of poles	-	2
10	Nominal neutral voltage	V	220
11	Nominal current	A	50
12	Nominal frequency	Hz	50

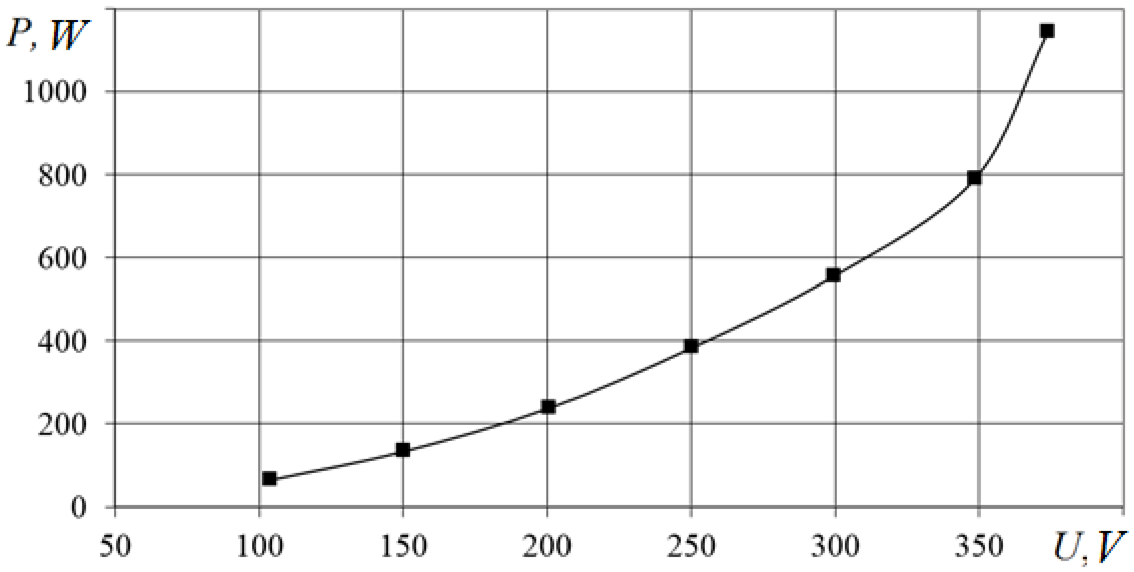






Experimental result





Result discussion

Вид потерь	Loss calculation methods			
	Steinmitz	CoreLoss	SolidLoss	Experiment
Hysteresis loss, W	58	18	15	–
Losses on eddy currents, W	101	282	280	–
Main loss, W	159	–	–	–
Surface loss, W	13	–	–	–
Total loss, W	172	300	295	289

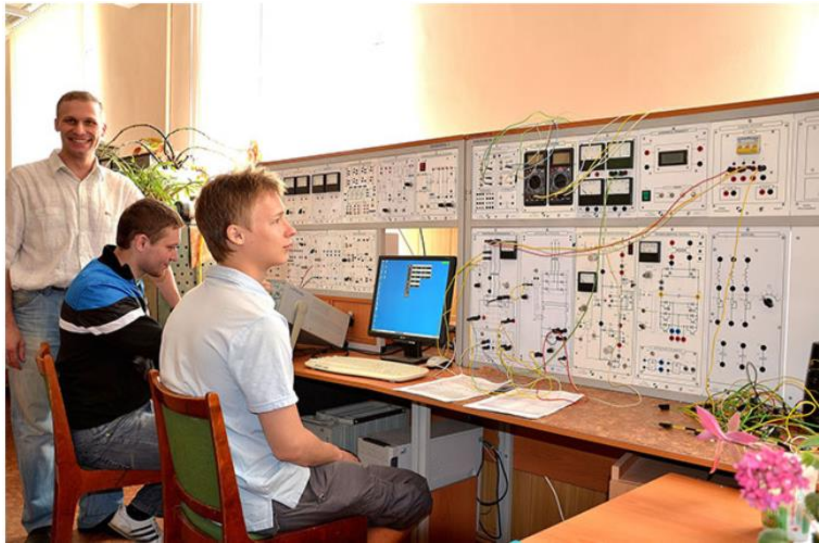
South Ual State University

Education

Ranking

Institute of Engineering and Technology
Department of Electric Drive and Industrial Automation

Laboratory



Electric drivers

Siemens, Emerson, ABB, Shnider electric

Computer Modeling

Matlab, Ansys

Power electronics

Diode, IGBT, IGCT, GTO

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Thank you for your attention
Ready to answer your questions

Alexey Gorozhankin
SUSU «South Ural State University»
gorozhankinan@susu.ru
Mobile: +7 919 337 13 94
76, Lenin prospekt, Chelyabinsk, Russia, 454080
http://www.susu.ru

Northumbria University NEWCASTLE
South Ural State University National Research University 1943
Newcastle University
University of Sunderland
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