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SWITCHED RELUCTANCE MOTOR FOR THE WHEEL DRIVE OF AN INVALID CHAIR

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Abstract: Constructions of an electromechanical transducer for a switched reluctance motor (SRM) and the circuit of a transistor switch with a serial energy storage are considered. The electromechanical transducer with pseudo U-shaped stator core elements has rational (efficient) magnetic system, and applied circuit design for the electronic commutator of the switched reluctance motor (SRM) allows improving power characteristics.

A computer-aided design (CAD) software for designing switched reluctance motors (SRM) is described and the results of devising the switched motor for a wheel drive of an invalid chair using this system are shown.

The investigations of mechanical and operational characteristics of the developed motor have been performed with the help of CAD intended for investigating the switched reluctance motor with the serial energy storage.

The results of the numeric investigation of electromechanical processes in the electric drive of the chair motor-wheel are verified by the experimental investigations and indicate the adequacy of proposed mathematical models and expedience of applying the developed motor for the drive of the invalid chair.

Key words: switched reluctance motor, series energy storage, pseudo U-shaped elements, motor-wheel.

1. Introduction

The deterioration of global environment situation and aftermath of wars cause the problem of the rehabilitation of victims of war which is more and more important nowadays. One of the priority directions in this sphere is the development of means of transport with the use of electric drives for disabled persons. The tendency towards developing the electric drive vehicles with normal weight and dimensions poses the task of creating new kinds of electric motors for the drives of motor-wheels, switch motors being considered the most prospective among them.

One of the simplest, most manufacturable and reliable switched motors is an electromechanical transducer (EMT) with a salient-pole stator and concentrated coils of its winding connected via the electronic switch to a direct-current mains and a passive toothed rotor. Such an EMT is simpler, cheaper and more producible than the simplest in the kind asynchronous electric machines, and the switched reluctance motors (SRM) based on them are not worse than direct current commutator motors according to their adjustment features.

2. Analysis of previous investigations

In [2] some new construction solutions of the electromechanical transducer for a switched reluctance motor (SRM) are proposed. The first one is called EMT with U-shaped stator core elements and the second one – with pseudo U-shaped stator core elements, which are the basis for the development of the drive for driving the wheel chair (Fig. 1) at the Department of Electromechatronics and Computerized Electromechanical Systems of Lviv Polytechnic National University.

Fig. 1. Electric drive of invalid chair wheels.

The advantages of such EMT are: simple construction of stator and rotor; high produceability of stator winding; low producing costs; low material costs; the possibility of creating comparatively large motive torques.

Wide spread of the switched reluctance motors is restrained by their rather low power characteristics which, in turn, are caused by the necessity of the

dissipation of energy stored in the electromagnetic field during current commutation in sections performed by transistor switches for protecting them from overvoltage. It is demonstrated the most strikingly in switched motors containing a half-wave switch with a stabilitron receiver of magnetic field energy.

3. Material basis and the results of research

In Figure 2, the circuit of the transistor switch with the serial capacitive energy storage (CES) is shown. With the use of such a circuit, three tasks are solved. Firstly, the energy stored in the electromagnetic field of an EMT armature is utilized; secondly, voltage build-up on a collector-emitter junction of the transistor switch of the commutator is limited to the acceptable level; thirdly, dynamic losses caused by switching a commutator transistor decrease considerably because of almost momentary interception of a turn-off current of the transistor by the circuit of capacitor charge. Computations and experimental investigations show that the application of circuits with CES in the switched reluctance motors improves their efficiency factor 1.7–1.8 times comparing to the circuit with stabilitron protection from over-voltages on the power switches of the commutator [3].

The requirements list for developing a certain switched motor can be so versatile that it is not reasonable to create universal CAD software. Therefore, we propose the CAD software for switched motors with passive rotor, in which only main parameters, as supply voltage, mechanical output, torque on the shaft and shaft speed are given. Other independent parameters are set in the dialog mode depending on other listed requirements.

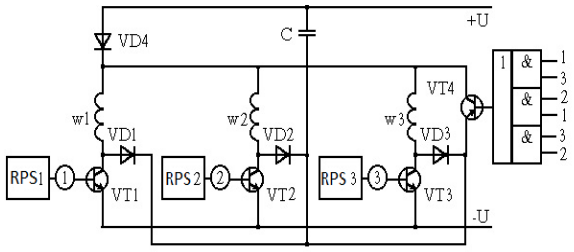

Fig. 2. Circuit of the transistor commutator with the serial capacitive energy storage (CES).

The system is the set of software modules, each of them performing some finite stage of calculations, as the calculation of machine geometry, calculation of winding quantities or magnetic circuit etc. Data provided consists of a database containing magnetization characteristics of different grades of electric steel, as well as supplemental information, which is given to the user by the system in the interactive dialog operational mode [4].

Having excellent mathematical apparatus [5], the system allows performing the synthesis and analysis of the switched motors with the passive rotor, that is, conducting checking and optimizing computations of described above motor constructions, calculating electromagnetic circuits, static characteristics and, on their basis, determining the parameters and characteristics of a certain kind of SRM, in which the researcher is interested. The system prepares input data for performing the thorough research on electric drives based on the SRM with CES in the CAD subsystem intended for investigating the switched reluctance motors.

During the operation the system visualizes the cross-sections of the EMT in a proper scale, as well as graphs of design and approximated magnetization characteristics of the SRM magnetic core, mechanical and operational characteristics. The results of calculations are completed in a calculation form.

The unit of calculating the dimensions and wiring quantities for the construction variants of EMT stators of the switched motor can synthesize two kinds of circuits, namely, classical and pseudo *U*-shaped constructions.

According to the requirements list, nominal voltage U [V], nominal shaft speed n [rpm] and nominal output power P_2 [W] (or torque on the shift M [N-m]) are input to the computer memory in the dialog mode.

For taking quick and correct decision about acceptability of the correlation of calculated dimensions, modules of graphical programming are included into the CAD system. They display the cross-sections of the active part of the electromechanical transducer in the proper scale.

A mathematical model of the switched motor with the passive rotor for instantaneous values is created on the basis of nonlinear theory of electromechanical energy conversion [6]. It is based on analytical expression for flux linkage in the function of section current and the angle between relative position of the rotor and the stator, whose coefficients are calculated by the module entitled “Computation of approximation coefficients” with the use of the calculated value of magnetic characteristic of the SRM section.

According to obtained values of these coefficients, the graphical module of graph visualization builds dependences $\psi = f(I_c)$ for the values of the angle between the axes of a rotor slot and stator tooth $\theta=\pi$ and $\theta=0$. Moreover, these data are fixed in the table and recorded on the CD in the form of a file.

The module of computing the capacity of a storage capacitor is created on the basis of the theory described in [7].

In the module, the calculation of transients of switching on and off the section with a calculated capacity value of the capacitor is performed. The results of calculations are displayed on the monitor in the form of the graphs of current and voltage on the capacitor.

The mathematical model for mean values, proposed in [8], was used as the basis for the creation of a subprogram calculating the static operational characteristics of the switched motor with the passive rotor and capacity energy storage.

The subsystem displays the results of development on the monitor and records them in the file on the CD. The partial extract from such a file obtained while developing the switched motor for the motor-wheel of the invalid chair is shown below.

For providing the necessary characteristics of the motor-wheel (fed with voltage 24 V from an accumulator battery, climbing the maximum slope of 15 %, providing maximum speed on the horizontal parts of local roads 6 km/h etc.) with the use of a reducer with reduction ratio 1:10, two switched motors should be used for separate wheel drives with the parameters shown in the development requirements list.

***Requirements list for the development**: supply voltage is 24 V; rotary speed is 650 rpm; efficiency rate is 65 %; load moment is 2 Nm.*

Partial record from the calculation form of computing the motor for the motor-wheel drive with the help of CAD for the SRM with energy storage [9].

***Main dimensions of the active part:** construction of the stator – pseudo U-shaped; steel brand 2013; stator diameter 100 mm; external diameter of the stator 145 mm; axial length of the stator 30 mm; stator tooth width 12 mm; stator tooth height 12 mm; number of stator teeth 12; stator steel weight 1.25 kg; length of air gap 0.2 mm; number of rotor teeth 10; relative rotor tooth width 0.4; rotor tooth height 8.3 mm; rotor steel weight 0.42 kg.*

***Parameters of stator winding:** number of winds on one tooth is 59; number of sections of stator winding is 3; number of coils in the section is 4; height of a stator coil is 8.9 mm; one-side width of the coil is 8.3 mm; wire grade is enameled wire with high-temperature high-strength insulation; diameter of conductor is 0.9 mm; diameter of the wire with insulation is 0.965 mm; phase resistance at $t = 20\,^{o}C$ is 0.78 Ohm; phase resistance at $t=75\,^{o}C$ is 0.946 Ohm.*

***Electromagnetic loads:** induction in the air gap T = 1.57; linear load is 14183 A/m; coefficient of inductivity amplitude of the section is 0.45; steel saturation coefficient is 1.53.*

***Approximation coefficients of saturation characteristics:** $y_{1t} = 0.108E\text{-}02$; $y_{u} = 0.1357$; $y_{10} = 0.2177E\text{-}02$; $a = 0.376$; $y_{n} = 0.1456$; In =10.62; resistive impedance of the Foucault current circuit is 190; minimum section inductivity is 0.2177E-02; maximum section inductivity is 0.2272E-0.*

***Design objectives:** mains current is 8.88 A; section current is 6.66 A; rotary speed is 594 rpm; power consumption is 213 W; useful power is 124 W; losses in copper are 58.1 W; losses in steel are 10.08 W; losses in the switch is 20.66 W; efficiency is 0.58; capacity of the storage capacitor 37.7 μF; period of section commutation 160 el. degrees.*

***Result of thermal design:** temperature of stator winding is 84.6 ^{o}C; temperature of stator core is 60.3 ^{o}C; temperature of rotor core is 66.8 ^{o}C; air temperature inside a machine is 69.5 ^{o}C; case temperature is 52.9 ^{o}C; outside air temperature is 40 ^{o}C.*

In Fig. 3 operational characteristics of SRM with series capacitive energy storage obtained by computing in the CAD subsystem are demonstrated. They indicate that the developed motor satisfies the requirements list.

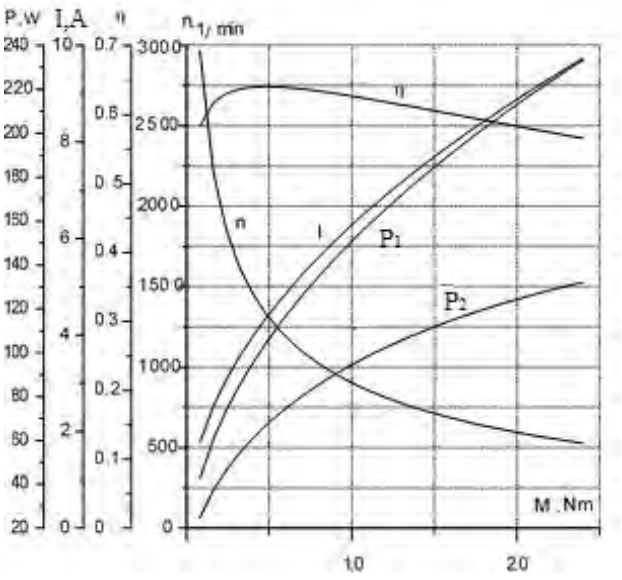

Fig. 3. SRM operational characteristics for the motor-wheel drive of the invalid chair.

More profound investigations of SRM operation can be performed with the use of the CAD subsystem for SRM [10]. In Fig. 4, the graphs of changing the section currents, electromagnetic torque and engine speed of this motor fed with the transistor commutator with certain capacitive storage connected in series and limited section current are shown.

In Fig. 5, the graphs of changing section currents, electromagnetic torque and voltage on one of capacitors in quasi-steady are shown.

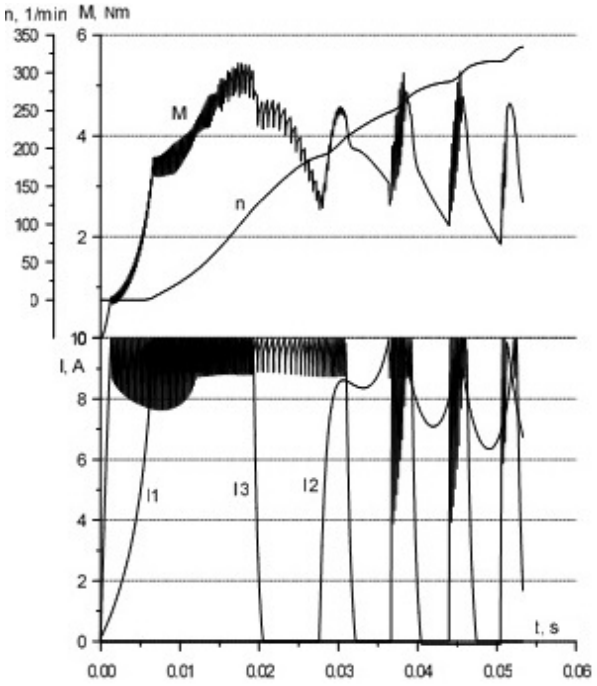

Fig. 4. Start transient of the SRM with series capacitive energy storage and limited current.

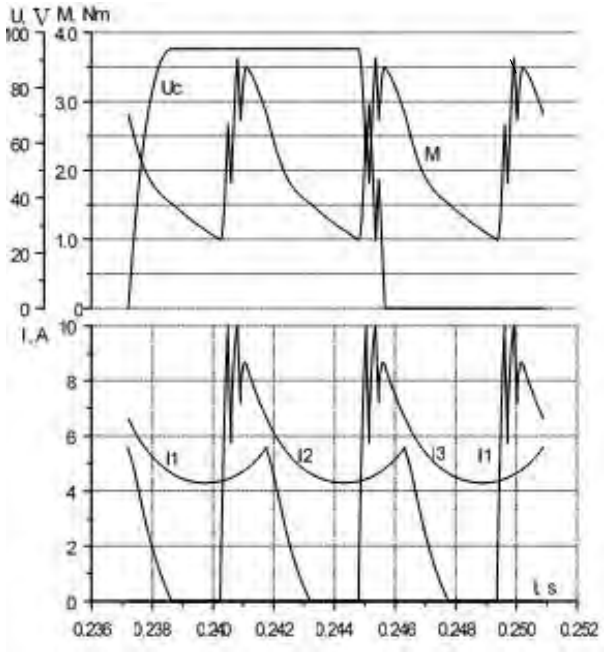

Fig. 5. Graphic presentation of currents, electromagnetic torque and voltage on the capacitor at a stable operational mode.

Operation mode of the such SRM at supply voltage 24 V, load moment 2 N-m and current limited at 10 A.

Applying separated electric drives for each driving wheel allows driving the invalid chair by a joystick manual manipulator. Speed regulation is done by a pulse-duration modulation of a control signal which comes to power switches of the electronic commutator.

Presented results of the numeric research on electromechanical processes in the electric drive of the motor-wheels of the invalid chair are proven by the results of experimental investigations and confirm the adequacy of proposed mathematical models at the level (2–5) %.

4. Conclusions

For the reduction drive of the motor-wheel of the invalid chair, the reactive motor on the basis of a reliable, constructively and technologically simple EMT with the salient-pole stator and lumped inductance has been developed.

The electromechanical transducer with the pseudo U-shaped stator core elements has the advantage of the rational magnetic system. The applied circuit solutions of transistor inverters of the SRM allow the repeated use of the energy stored during the commutation in the electromagnetic field for forced turning on the current in the sections, at the same time protecting power transistors from overvoltage and considerably improving the power characteristics of the SRM.

The motor has been developed and investigated in the environment of CAD subsystems for computing and investigating the SRM correspondingly according to mathematical models for mean and instantaneous values of state variables which are based on the non-linear theory of electromechanical energy transformation and take into account the peculiarities of the EMT motor.

The results of research show that the developed motor provides necessary characteristics given in the requirements list and it is reasonable to use it for the wheel drive of the invalid chair.

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ВЕНТИЛЬНИЙ РЕАКТИВНИЙ ДВИГУН ДЛЯ ПРИВОДУ КОЛЕСА ІНВАЛІДНОГО ВІЗКА

Василь Ткачук, Ігор Біляковський, Лідія Каша

Розглянуто конструкції електромеханічного перетворювача вентильного реактивного двигуна та схему транзисторного комутатора з послідовним буфером енергії. Електромеханічний перетворювач з псевдо-U-подібними елементами осердя статора вирізняється раціональною магнітною системою, а застосовані схемні рішення електронного комутатора вентильного реактивного двигуна дають змогу підвищити енергетичні показники.

Описано автоматизовану систему проектування вентильних реактивних двигунів та наведено результати проектування з її допомогою вентильного двигуна для приводу колеса інвалідного візка.

Дослідження механічних та робочих характеристик розробленого двигуна проведено за допомогою автоматизованої системи дослідження вентильних реактивних двигунів з послідовним буфером енергії.

Результати чисельного дослідження електромеханічних процесів в електроприводі мотор-коліс візка підтверджені експериментальними дослідженнями і свідчать про адекватність запропонованих математичних моделей та доцільність використання розробленого двигуна для приводу колеса інвалідного візка.

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