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RESEARCH OF ELECTROMAGNETIC PROCESSES IN TRACTION ELECTROMECHANICAL COMPLEXES WITH IGBT-CONVERTERS AT RESISTOR BRAKING OF ELECTRIC MOTORS

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Researches of electromagnetic processes in traction electromechanical complexes of a direct current are conducted at a pulse way of regulation of pressure of a food in a mode resister braking at casing of excitation of engines. The analytical expressions are received and are recommended for use, allowing to define parameters of composed elements of a subsystem of electric braking of a traction electrotechnical complex.

Key words: traction electric drive, electric braking, traction electric motors, impulse IGBT converter.

Introduction. Park of domestic industrial electric locomotives which are used as an intraindustrial type of transport, is more than 3500 units. Industrial electric locomotives, in particular their subsystems - miner electric locomotives, consume to 15 % of the general electric energy of the enterprise.

In recent years were created new power efficient structures of traction electromechanical complexes (TEMC) for such kinds of the electrified transport.

However their introduction in practice domestic electric locomotive building has not got expected levels yet.

Main ideas and solution methods. Creation and practicalintroduction of domestic electric locomotive building a modern structures of traction electromechanical complexes of industrial electric locomotives.

Experimental part and result obtained. Industrial electric locomotives besides single : functioning quite often work in system of many units i.e. when in rake a minimum two electric locomotives placed at a distance from each other along the length of rake are applied [1].

This reguites additional researches of braking modes taking into account all functioning electro technical traction complex.

For determination type of braking (regenerative, dynamic (resistor)) is subject to realization the analytical researches of the first above-mentioned type have been carried out. The analysis has shown that efficiency of a regenerative braking as most power efficient type including for the electrified types of transport, is defined first of all by speed of movement of locomotive rake. For industrial conditions, especially for mines and ore mines, speed of locomotive rake is limited by requirements of safety precautions to 10-15 km/h. Proceeding from such realias, as results of calculations testify, the energy which can be received from recuperation, taking into account real speeds of electric locomotives and their efficiency factor, is equal to 0,44 kW·h. That is during 1 lour it can be given to a network only 0,44 kW·h due to recuperation of braking energy. Considering that during 1 hour electric locomotive consisting of two traction engines with capacity on 45 kW everyone consumes from a network 18 kW·h, the economy of the electric power is equal to 2,4 %, i.e. expected efficiency recuperation will be insignificant. Besides, significant complication of an electric locomotive control system (its power pail) and also providing of accumulation possibility of recuperated energy will be required for recuperation of energy.

So, in the presence of regeneration braking unit the quantity of elements of a power pan of scheme TEMC doubles in 2 times, that is very problematic in the context of industrial electric locomotives with adhesive weight 7-14 kN.

Summarizing the above-stated, the conclusion about inexpediency of working out of TEMC-structure with a subsystem of regenerative of locomotive rake braking energy in feeding trolley system is made. Thus, for practical realization there is a type of electric braking- dynamic. In the given mode (however, as well as in any other electric type of braking) the traction electric motor (TEM) works as the generator with self-excitation to the brake resistor. In the scheme of single electric drive the parallel excitation of electric machine (the system equivalent circuit at parallel self-excitation is shown in fig 1) takes place.

In the scheme of the dual electric drive the series self-excitation of the electric machine takes place. The system equivalent circuit at series self-excitation is presented in fig 2.

The scheme with parallel self-excitation of the electric machine (fig 1) operates as follows. The exciting current i_E in system is regulated by the IGB-transistor TE by PWM-voltage pressure with change of pulse duty factor of the modulation period q_E practically from zero at high speed of movement to one for the speed close to the stopping.

At energized IGB-transistor TE on the interval t_E the difference of currents of an armature and excitation $i_R = i_Q - i_E$ flows in brake resistor R_Q.

As active field coil resistance more than 10 times less resistance of the brake resistor, the change of currents of an armature and excitation on the interval t_E can be considered regardless of a resistor current

$$i_{RE} \approx \frac{E_Q}{R_Q + R_M} . \qquad (1)$$

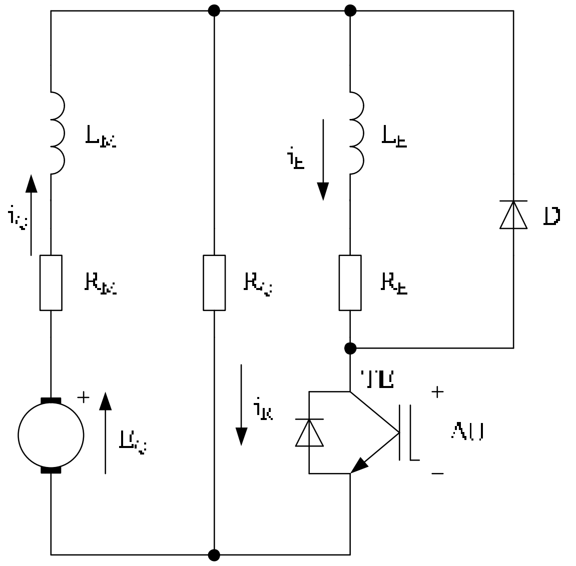

Figure 1 – The equivalent circuit of system with parallel self-excitation of electrical machine

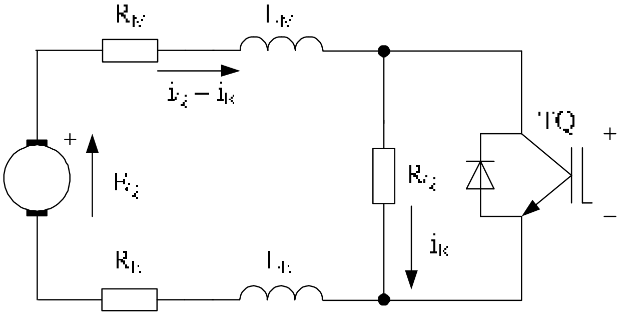

Figure 2 – The equivalent circuit of system with series self-excitation of electrical machine

$$i_{EE} \approx \frac{E_Q}{R_\Sigma}\left[1-exp(-\frac{t}{t_\Sigma})\right]+ \qquad (2)$$
$$+i_{EE}(0)\cdot exp(-\frac{t}{t_\Sigma}),$$

$$i_{EE}(\kappa)=\frac{E_Q}{R_\Sigma}\cdot(1-exp E_\Sigma)+i_{EE}(0)\cdot exp E_\Sigma, \qquad (3)$$

where E$_Q$ is taken with consideration for (-*ΔU*) of IGB-transistor TE;

$$R_\Sigma = R_M + R_E, \qquad (4)$$

$$t_\Sigma = \frac{L_M + L_E}{R_M + R_E}, \qquad (5)$$

$$E_\Sigma = -\frac{t_E}{t_\Sigma}. \qquad (6)$$

On the interval t$_D$, when IGB-transistor TE is deenergized:

$$i_{QD} = i_{RD}(0) \approx \frac{E_Q}{R_Q + R_M}, \qquad (7)$$

$$i_{ED} = i_{ED}(0)\cdot exp(-\frac{t}{t_E}), \qquad (8)$$

$$i_{ED}(\kappa)=i_{ED}(0)\cdot exp D. \qquad (9)$$

Boundary condition:

$$i_{EE}(\kappa)=i_{ED}(0);\quad i_{ED}(\kappa)=i_{EE}(0). \qquad (10)$$

Solving together (3), (9) and (10) we find:

$$i_{EE}(0)=\frac{E_Q}{R_\Sigma}\cdot\frac{(1-exp E_\Sigma)\cdot exp D}{1-exp E_\Sigma\cdot exp D}, \qquad (11)$$

$$i_{EE}(\kappa)=\frac{E_Q}{R_\Sigma}\cdot\frac{1-\exp E_\Sigma}{1-\exp E_\Sigma\cdot\exp D}. \qquad (12)$$

Absolute swing amplitude of armature current:

$$Di_Q \approx Di_E = i_{EE}(\kappa)-i_{EE}(0)=$$
$$=\frac{E_Q}{R_\Sigma}\cdot\frac{(1-exp E_\Sigma)\cdot(1-exp D)}{1-exp E_\Sigma\cdot exp D}. \qquad (13)$$

The maximum swing amplitude of armature current takes place practically at $t_E = t_D = \frac{T_M}{2}$, ($q_E = 0{,}5$). Further

$$Di_{Q0,5} = \frac{E_Q}{R_\Sigma}\cdot\frac{1-exp M_\Sigma}{1+exp M_\Sigma}, \qquad (14)$$

where $M_\Sigma = -\frac{T_M}{2t_\Sigma}$.

The equation (14) with regard to $U_d = E_Q$; $R_\Sigma > R_M$; $exp M_\Sigma$ shade more $exp M$ gives

$$Di_{Q0,5} < Di_{M0,5}. \qquad (15)$$

Thus, in a brake mode at parallel self-excitation of the electric machine the factor of armature current pulsation is not essential. More important factor in a braking mode is the bottom level of speed that is equivalent to bottom level of electric machine at which it is possible to provide the given current of braking I$_Q$, in particular I$_{Qmax}$. This system state corresponds to $q_E = 1{,}0$ when IGB-transistor TE is completely energized and PWM is absent. Further

$$E_{Q\,min} = I_{Q\,max}\cdot(R_M + \frac{R_Q\cdot R_E}{R_Q + R_E}) + \Delta U. \qquad (16)$$

Thus it should be remembered that $R_Q >> R_E$.

The scheme with series self-excitation of the electric machine (fig 2) operates as follows.

The brake current of an armature and the current of excitation, and also $i_Q = i_E$, is regulated by IGB-transistor TQ by PWM with change of pulse duty factor of the modulation period $q_Q = \frac{t_Q}{T_M}$ from zero on high speed of movement to one for the speed close to the stopping.

At energized TQ on the interval t$_Q$:

$$i_{QQ} = \frac{E_Q}{R_\Sigma}\left[1-exp(-\frac{t}{t_\Sigma})\right]+i_{QQ}(0)\cdot exp(-\frac{t}{t_\Sigma}), \qquad (17)$$

$$i_{QQ}(\kappa)=\frac{E_Q}{R_\Sigma}\cdot(1-exp Q)+i_{QQ}(0)\cdot exp Q, \qquad (18)$$

where $Q=-\frac{t_Q}{t_\Sigma}$; E_Q is taken with consideration for $(-DU)$of IGB-transistor TQ.

On the interval t_R, with deenergized TQ:

$$i_{QR}=\frac{E_Q}{R_R}\left[1-exp(-\frac{t}{t_R})\right]+i_{QR}(0)\cdot exp(-\frac{t}{t_R}),\qquad(19)$$

$$i_{QR}(\kappa)=\frac{E_Q}{R_R}\cdot(1-expR)+i_{QR}(0)\cdot expR,\qquad(20)$$

where $R_R=R_Q+R_M+R_E$;

$$t_R=\frac{L_M+L_E}{R_R};\qquad(21)$$

E_Q – без $(-DU)$;

$$R=(-\frac{t_R}{t_R}).\qquad(22)$$

Boundary conditions:

$$i_{QQ}(\kappa)=i_{QR}(0);\ i_{QR}(\kappa)=i_{QQ}(0).\qquad(23)$$

Solving togethe (18), (20) and (23) we find:

$$i_{QQ}(0)=\frac{E_Q}{R_\Sigma}\cdot\frac{(1-expQ)\cdot expR}{1-expQ\cdot expR}+\frac{E_Q}{R_R}\cdot\frac{1-expR}{1-expQ\cdot expR},\qquad(24)$$

$$i_{QQ}(\kappa)=\frac{E_Q}{R_\Sigma}\cdot\frac{(1-expQ)\cdot(1+expQ\cdot expR)}{1-expQ\cdot expR}+\frac{E_Q}{R_R}\cdot\frac{(1-expR)\cdot expQ}{1-expQ\cdot expR},\qquad(25)$$

$$Di_Q=i_{QQ}(\kappa)-i_{QQ}(0)=\frac{E_Q}{R_\Sigma}\cdot\frac{(1-expQ)\cdot(1-expR+expQ\cdot expR)}{1-expQ\cdot expR}-\frac{E_Q}{R_R}\cdot\frac{(1-expQ)\cdot(1-expR)}{1-expQ\cdot expR}.\qquad(26)$$

From comparison of (26) and (13) taking into account $R_R>>R_\Sigma$, $exp R<<expQ$, $expQ\approx expE_\Sigma$ it can be seen that swing amplitude of armature current at series self-excitation is less, than at parallel self-excitation.

The bottom limit of speed at resistor braking under the scheme with series excitation of the electric machine is found at $q_E=1{,}0$, i.e. at long energized IGB-transistor TQ.

$$E_{Q\,min}=I_{Q\,max}\cdot(R_M+R_E)+\Delta U.\qquad(27)$$

Practically (27) differs from (16) a little. Thus, both schemes of self-excitation of the electric machine are equivalent concerning providing of bottom level of braking speed.

The relation of the maximum speed of braking to the minimum one is broadly defined by formula:

$$\frac{\omega_{max}}{\omega_{min}}=\frac{R_R}{R_\Sigma}=8...10.\qquad(28)$$

Conclusions. 1. As a result of research of electromagnetic processes in systems of resistor braking with parallel and series self-excitation of the traction engine operating in generator mode, the formulas describing changes of an armature brake current and an excitation current for the period of modulation of the pulse converter wete obtained.

2. Pulsations of an armature current in a brake mode at parallel and at series self-excitation of traction engines are practically equal and less than in a traction mode.

3. The formulas allowing to define the bottom level of a traction motor emf at braking in schemes with parallel and series self-excitation are obtained. For both schemes the bottom levels of emf practically coincide. Both schemes provide a range of speed change of an electric locomotive at braking with a given brake current of armature broadly (8 ... I0):1.

4. From the description of operation of system of gradual field decay it is visible that the offered schemes allow to decay motor field to zero though for practice it is excessive.

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ИССЛЕДОВАНИЕ ЭЛЕКТРОМАГНИТНЫХ ПРОЦЕССОВ В ТЯГОВЫХ ЭЛЕКТРОМЕХАНИЧЕСКИХ КОМПЛЕКСАХ С IGBT-ПРЕОБРАЗОВАТЕЛЯМИ ПРИ РЕЗИСТОРНОМ ТОРМОЖЕНИИ ЭЛЕКТРИЧЕСКИХ ДВИГАТЕЛЕЙ

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Исследовались электромагнитные процессы в тяговых электромеханических комплексах постоянного тока методом импульсного регулирования питания обмотки возбуждения двигателя при резисторном торможении. Полученные аналитические выражения рекомендуются для использования и позволяют определить параметры элементов подсистемы электрического торможения тягового электротехнического комплекса.

Ключевые слова: тяговый электромеханический комплекс, электрическое торможение, тяговый электродвигатель, импульсный IGBT-преобразователь.

ДОСЛІДЖЕННЯ ЕЛЕКТРОМАГНІТНИХ ПРОЦЕСІВ В ТЯГОВИХ ЕЛЕКТРОМЕХАНІЧНИХ КОМПЛЕКСАХ З IGBT-ПЕРЕТВОРЮВАЧАМИ ПРИ РЕЗИСТОРНОМУ ГАЛЬМУВАННІ ЕЛЕКТРИЧНИХ ДВИГУНІВ

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Досліджувалися електромагнітні процеси в тягових електромеханічних комплексах постійного струму методом імпульсного регулювання живлення обмотки збудження двигуна при резисторному гальмуванні. Отримані аналітичні вирази рекомендуються для використання і дозволяють визначити параметри елементів підсистеми електричного гальмування тягового електротехнічного комплексу.

Ключові слова: тяговий електромеханічний комплекс, електричне гальмування, тяговий електродвигун, імпульсний IGBT-перетворювач.