Control System of Operating Parameters of Vehicle Electric Drive Taking into Account the Driver State

Control System of Operating Parameters of Vehicle Electric Drive

Alexander N. Varnavsky, Ivan E. Sinitsyn, Elisey S. Korochkin
Department of information and automation of technological processes
Ryazan State Radio Engineering University
Ryazan, Russia
varnavsky_alex@rambler.ru

Abstract— **This article studies the design features of certain types of electrical motors applied in electrical drives adapted to operation with due regard to operator state. Expediency of the design modifications of electrical motors and possibility of application of amplifier motors are shown in this article. Control system of operating parameters of vehicle electric drive taking into account the driver state is designed.**

Keywords- control system, DC motor, driver state, electric drive, EMF, induction motor, magnetic flux, power, security system, safety, torque

I. Introduction

The increased number of vehicles involved in road traffic worsens the environmental conditions due to the use of the toxic fuels and lubricants, increases neuropsychic tension members of the road traffic, which often disrupt the nervous system with varying degrees of interaction effects vehicles. In this regard, special attention is paid to the introduction of environmentally friendly electric drive for vehicles and ensures their safe operation. From this point of view the interest is the search of methods and tools for the realization of systems for the safe operation of vehicles and electric drive power elements taking into account the state of the driver, including and building security systems.

The aim of this work is to build the security system for safe operation of vehicles with electric drive in accordance with the driver's physical state.

Under the driver's physical state, we mean the set of characteristics and parameters of the psycho-physiological and psycho-emotional state that allow to effectively perform activities with a minimum of errors [1, 2].

Vehicle safety is mainly determined by safety and efficiency of the drive mechanisms employed in vehicles, their service and control elements. Control elements of the vehicle electrical drive are mainly complex expensive systems where such equipment is used as electronic devices, various energy converters, microcontrollers and others, including small-size energy storage systems and accumulators.

Special attention is given to power electric motors used in the drive system of vehicles and to the respective control methods.

Total control of the electrical drive is carried out by an operator. Safety and failure-free operation of the vehicle depend upon his physical state. As one of the ways of influencing the functional state of the drive motor it is suggested to use auxiliary winding on the stator. Nowadays, judging from the practical application of the drive electric motor there is not enough information about usage of drive electrical motors with the auxiliary winding which is designed to compensate the main magnetic flow of the stator winding partially or fully without disconnecting it from the power source. There are motors in which the auxiliary winding of the stator is used for changing the number of poles of the stator winding without changing the main magnetic flow. The stator winding and the other stator windings form a single multi-phase (3-phase) winding system with the number of poles oddly even for each phase.

Therefore, the research of interaction between magnetic field of the stator winding – the main magnetic flow – and the magnetic field, generated by the auxiliary winding when closing is of some scientific interest. As such research is not covered in the press, the set task is of current interest and has all the features of scientific novelty. To evaluate the interaction efficiency of magnetic fields it is recommended to use the attenuation coefficient of the main magnetic flow of electric motor – $k_{atten.}$, which is determined during operation.

II. Statement of Reasons for Design Modifications of Traction Electric Motor

Forecasting of vehicle trouble-free operation is carried out prior to its operation start with the help of some check programs and operator medical examination. However it is impossible to predict all the prospective situations.

In this regard a requirement for detection of operator current physical state and for procedure of decision making in critical situations appears. The result of the decision making is decelerating and complete stop of the vehicle. Partial braking

978-1-5090-6742-8/17/$31.00 ©2017 IEEE

and braking operation performed by electric drive is complied with the general law of motion [3]

$$M_M - M_R = J\frac{d\omega}{dt}$$

where M_M *is* motor torque; M_R is resistive torque; J is moment of inertia of all the moving (revolving) parts; ω is rotation velocity of motor rotor.

The product $J\frac{d\omega}{dt}$ is called a dynamic torque, that can be positive while acceleration and negative while deceleration of the vehicle. Electric motor torque is calculated for three-phase asynchronous motor in the following way [4]:

$$M = C_M \Phi_m I_2 \cos\psi_2 ,$$

where $C_M = \frac{1}{\sqrt{2}} p \cdot m_2 \cdot k_{w2}$ is constant; p is number of rotor winding pole pairs; m_2 is number of rotor winding phases; Φ_m is peak value of stator winding magnetic flux; I_2 is rotor winding current; ψ_2 is angle between E_2 and I_2 of the rotor winding.

It has been established [5], that

$$I_2 = \frac{E_{2S}}{Z_2} = \frac{E_{2S}}{\sqrt{R_2^2 + X_{2S}^2}} ,$$

where $E_{2S} = E_2\ S$ is EMF of rotor winding; $E_2 = 4,44 \cdot f_1 \cdot w_2 \cdot k_{w2} \cdot \Phi_m$ is EMF of rotor winding at blocked rotor; S is slippage (0<S<1); f_1 is mains frequency; w_2 is rotor winding turn number; k_{w2} is winding factor of rotor winding; R_2, X_2 is active and reactive resistance of rotor winding.

Taking into account that

$$\Phi = \frac{\Phi_m}{\sqrt{2}} \sin\left(\omega_1 t - \frac{\pi}{2}\right)$$

is active value of the air-gap flux and

$$I_2 = -\frac{w_{w2}\left(\frac{d\Phi}{dt}\right)S}{\sqrt{R_2^2 + X_{2S}^2}} ,$$

it can be shown that $I_2 = -\frac{w_{w2}\left(\frac{d\Phi}{dt}\right)S}{\sqrt{R_2^2 + X_{2S}^2}}$, than moving from the derivative to increments we obtain $I_2 \cong -\frac{w_{w2}(\Phi_1 - \Phi_0)S}{\Delta t\sqrt{R_2^2 + X_{2S}^2}}$, where Φ_0 is magnetic flux value at some instant t_0, Φ_1 is magnetic flux of stator winding. Changing Φ_0, we can change current of armature winding, and consequently, the torque, developed by the motor. It is known [6], that when magnetic lines of force cut the closed loop, a self-magnetic field appears in this closed loop, and the sense of this magnetic field is opposite to the sense of the magnetic field that produced it (Lenz's law). Strength of the self-magnetic field depends upon the change rate of the producing magnetic field, induced EMF and internal resistance of loop, and consequently, it is possible to influence the strength of the magnetic field by changing the resistance of the loop. Internal resistance (self-impedance) of the loop determines the current in the loop and, as a consequence, magnetic flux related to the current. In symbolic terms this correlation is expressed in the following way [5]

$$\Phi = \frac{IW}{R_m} ,$$

where Φ is magnetic flux of the loop; IW is loop ampere-turns; R_m is magnetic resistance of loop circuit.

Quantitative value of degree of influence on main magnetic flux on behalf of the magnetic flux of the auxiliary winding is evaluated via the attenuation coefficient k_{att}, that is defined on the basis of magnetic flux ratio. If the main winding has number of turns that is equal W_1, and the auxiliary one - $W_1^/$, define the ratio $W_1/W_1^/ = k$ – winding transformation ratio, express $W_1^/ = k^{-1}\ W_1$. If the magnetic flux is known $\Phi = \frac{\Phi_m}{\sqrt{2}} \sin\omega t$ EMF of the auxiliary winding $W_1^/$ is defined in the following way

$$E_1^/ = -W_1^/ \frac{d\Phi}{dt} = k^{-1} W_1 \omega \frac{\Phi_m}{\sqrt{2}} \sin\left(\omega t - \frac{\pi}{2}\right).$$

Making contact via contactor between the auxiliary winding and active resistance R_c, and defining the current in the auxiliary winding circuit without taking into consideration the active resistance of the winding itself, we get

$$I_1^/ = \frac{E_1^/}{R_c} = \frac{k^{-1} W_1 \omega \Phi_m \sin\left(\omega t - \frac{\pi}{2} - \psi_c\right)}{\sqrt{2} Z_c} ,$$

where Z_c is impedance of the auxiliary winding circuit, and

$$\psi_c = \operatorname{arc} tg \frac{X_c}{R_c} ,$$

X_c – reactive resistance of auxiliary winding. Auxiliary winding magnetic flux, produced be current $I_1^/$, is defined with the help of the expression:

$$\Phi_1^/ = \frac{I_1^/ W_1^/}{R_\mu} = \frac{(k^{-1})^2 W_1^2 \omega \Phi_m \sin\left(\omega t - \frac{\pi}{2} - \psi_c\right)}{\sqrt{2} Z_c R_\mu} ,$$

where R_μ is magnetic resistance of auxiliary winding circuit, that is identical to the main winding one. Summarizing the magnetic fluxes of the auxiliary and main windings we get:

$$\Phi_\Sigma = \frac{\Phi_m}{\sqrt{2}} \sin \omega t \left(1 + \frac{(k^{-1})^2 W_1^2 \omega \sin\left(\omega t - \frac{\pi}{2} - \psi_c \right)}{Z_c R_\mu \sin \omega t} \right).$$

At small R_c, $\psi_c = \operatorname{arc}tg \frac{X_c}{R_c} \approx \frac{\pi}{2}$ we have:

$$\Phi_\Sigma = \frac{\Phi_m}{\sqrt{2}} \sin \omega t \left(1 - \frac{(k^{-1})^2 W_1^2 \omega}{Z_c R_\mu} \right).$$

Total magnetic flux is different from the main magnetic flux by the value proportional to the coefficient

$$k_1 = 1 - \frac{(k^{-1})^2 W_1^2 \omega}{Z_c R_\mu},$$

that can be called attenuation coefficient k_{att}. The value of the **attenuation coefficient** is in the range from 0 to 1 and is a function of transformation ratio

$$k_{att} = k_1 = f(k).$$

As can be seen from the above, to achieve the stated objective it is necessary to set an additional winding on the stator of asynchronous motor, arranging it in the same slots, in which main winding is arranged.

III. WAYS OF MODIFICATION IMPLEMENTATION.

It is recommended to close auxiliary winding to active resistance by means of contactors. Active resistance shall have several ratings to get different levels of loop shorting incl. short circuit. Contactor – which is used for auxiliary winding closing – is controlled by a safety control system guided by the operator state independent of the other vehicle drive control tools. Level of effects is determined by the operator state and can be varied within certain limits. Braking modes of electric motor operation shall be available in vehicle safety control system for most critical situations which require the emergency braking application. The most effective of these modes is the reverse-current braking mode though it is the most energy-consuming.

The other version of asynchronous motor that can be used in electric vehicle drive adopted with regard to the operator state is an electric motor which stator winding includes controllable saturated-core reactors in particular magnetic amplifiers. In comparison with conventional asynchronous motor this motor type has many advantages. But at the same time due to its complicated design it is also characterized by some disadvantages. Asynchronous motors where magnetic amplifiers are applied together with the stator (on the stator back) are called amplifier motor [7]. Winding of magnetic amplifiers is dropped in the same slots which are used for primary motor winding. This motor type is given schematically in the following Fig. 1.

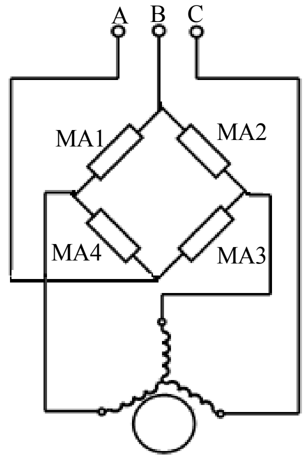

Figure 1. Reversible asynchronous motor equipped with magnetic amplifiers

The torque developed by an asynchronous motor is performed with the help of magnetic amplifiers. The degree of their saturation influences the voltage applied onto the asynchronous motor stator winding.

It is known [8] that

$$M_M = \frac{m_1 U_1^2 r_2^/ p}{2\pi f_1 s \left[(r_1 + r_2^/ / s)^2 + (x_1 + x_2^/)^2 \right]},$$

where U_1 is voltage applied to the stator winding. The rest parameters can be set to be invariables. In this case we have

$$M_M = kU_1^2,$$

k = const is proportionality factor.

Modifying the working reactance of a magnetic amplifier – which working winding is connected with stator winding in series – U_1 (voltage applied to the stator winding) also varies. There at the motor torque and vehicle speed also vary. Since the magnetic amplifier control power is low, magnetic amplifiers can be controlled directly from vehicle safety control devices with regard to the operator state. Thus the problem of vehicle safe use can be successfully solved by adopting the electric drive of the vehicle with regard to the operator state. Global settlement of the abovementioned problem is not restricted only to the considered solutions, it shall be studied further more thoroughly.

The considered processes make it possible structure of the control system of electric drive of vehicle in emergency situations and to build the adaptation system of electric drive work taking into account the driver state.

The undoubted advantage of this approach, for example, compared with the use modern solid state device drives for electric vehicles that offer fast and effective controllability of the propulsion motor, is the possibility of using very high power in engines.

IV. Building the Adaptation System and the Security System of the Electric Vehicle

Vehicle security system is connected directly to the control system of drive electric motor. The physical state of the driver may be determined by removal and analysis of bioelectric signals from the body of the driver. These signals must be input to the vehicle security system.

For asynchronous motors used in transport, it is proposed to lay an additional winding with a smaller number of revolutions in the grooves together with the primary winding of the stator. Additional wrapping, if required, vehicle security system through intermediate commuting device connects to the DC source. The need for such inclusion is determined by the physical state of the vehicle driver. Connecting an additional winding to the source DC can be carried out while disabling the main stator winding from the line and without disabling the additional winding.

Constant current flowing at an additional winding on the stator creates a constant magnetic field, which is retarding the magnetic field. As a result of the drive motor torque is reduced and a vehicle slows down.

Such situations correspond to the state change of the driver of low and medium severity without loss of memory and self-control. In the case of acute, critical changes to the driver state until its complete failure in the security system provides emergency braking mode, when the device is running electric braking. This device uses the most efficient method of braking - braking opposition, in which the stator winding of three-phase asynchronous motors are switched to another sequence of phase sequence and for DC motors is changing the polarity of the voltage supplied to the excitation winding or anchor winding but in only one case. To limit the current in the motor windings in emergency braking, the control system of brake modes include current-limiting elements in series with windings which are switched on or which changes the polarity of applied voltage. This measure of protection of electric motors in the brake modes allows to maintain traction engine from failure and improve the reliability of electric drive as a whole.

Fig. 2 presents a block diagram of the adaptation system. The basis of this scheme is the security system (SS) consisting the protection system (SP), the block of emergency braking (BEB) and the block of braking control (BBC). The input signals of the security system are the signals from the block of analysis of the functional state of driver (BAFSD), the power supply (PS), the voltage converter (VC). The output signals of the protection system are fed to the electric motor (EM). The arrows show the logical connections between separate functional blocks in the adaptation system and connections between the elements of the security system.

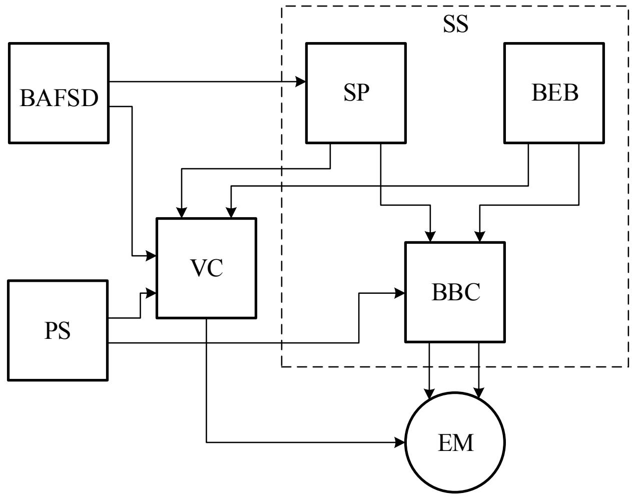

Figure 2. Block diagram of the adaptation system

Conclusion

As follows from the analysis carried out this article includes reasoned solutions for modification of some asynchronous motors and descriptions of special-typed asynchronous motors applied in electric drives which are adopted with regard to the operator state.

It has been proved that the article has all the features of scientific novelty. This article determines the criterion for influence of auxiliary winding expressed in attenuation coefficient. Change in attenuation coefficient is also shown in the present article. This coefficient ensures up to 95% influence on the attenuation of the main magnetic flux – that is extremely crucial when employing in vehicles.

It is rather complicated to calculate all the economic benefits from usage of the abovementioned solutions. However its social significance is obvious.

References

[1] Varnavsky A.N., Sinitsina N.V. “Determination of driver's psycho-emotional state parameters,” 2016 5th Mediterranean Conference on Embedded Computing (MECO). 2016. pp. 405-409.

[2] Varnavsky A.N. “Simulation of quality level dependence of human-machine system on the parameters of the operator labor organization,” 2016 5th Mediterranean Conference on Embedded Computing (MECO). 2016. pp. 410-414.

[3] Ilyinsky N.Ph. Design principles of electric drive: textbook for higher educational institutions. M.: Moscow Power Engineering Institute, 2003. 224 p.

[4] Bruskin D.E. Electrical machines and micromachines. M.: Higher school, 1981. 482 p.

[5] General Electrical Engineering: textbook for higher educational institutions; under the editorship of A.T. Blazhkin, L.: Energy, 1979. 472 p.

[6] Savelyev I.V. Course on general physics. Vol. 2. M.: Higher school, 1978. 480 p.

[7] Kopylov I.P. Electrical machines. M.: Higher school, 2006. 607 p.

Geyler L.B. Design principles of electric drive: M.: Higher school, 1972. 608 p.