THE STATE AND PROSPECTS OF DEVELOPMENT OF THE INTERCONNECTED MULTI-MOTOR SEMICONDUCTOR ELECTRIC DRIVES

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Abstract: *In this chapter the retrospective analysis of the theory condition and practice of the interconnected multi-motor controlled electric drives is performed. Research and development in this field developed in the last third of the 20th century. In these years, virtually was created the interconnected multi-motor drives theory but the research majority in the field of interconnected electric drives with elastic-plastic and distributed connections is not realized. Now the construction principles of means and control systems for the interconnected electric drive with the help programmatically – hardware functional modules are realized. These modules were created on the basis of new semiconductor converters and the logical controllers. In the future will develop the theoretical research and the practical applications on the basis of the fuzzy neural networks, including the control in the online modes, the sliding modes with use high-speed controllers. Development of new exact synchronization methods of the electric multi-motor drives will ensure the creation of a multi - motor direct-drive. New group of mechatronic objects will be created by the interconnected multi-motor electric drives which not only have the traditional feedbacks on speed, currents, tension etc., and also the feedbacks based on the technological variables of machines and mechanisms: torques, efforts, pressure, vibrations, expenses etc. Development and creation of adaptive systems which interconnected through a processed material or working body of electric drives with is elastoplastic links (which properties change in the course of work) is an actual problem. Considerable interest represents application of the fuzzy-regulation methods for the creation of the control systems by the nonlinear nonstationary interconnected electromechanical systems. Practical realization of the robust control methods for the multi-motor electric drives in the emergency situation or emergency modes is also the perspective direction*

Key words: *multi-motor semiconductor electric drives, the theory, technical solutions, retrospective, condition, prospects*

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1. The Basic Principles of Creation of the Interconnected Multi-Motor Electric Drives

The special place among all appendices of the electric drive is taken by the interconnected multi-motor systems of operated electric drives on the basis of which many technological processes are realized. There are among them hot and cold rolling of metals, production of wires, paper, polymeric materials, conveyer belts and other processes of continuous processing of materials (Basharin et al.,1982).

Creation of such machines as mining excavators, robots and manipulators, various load-lifting machines, conveyors, etc. became possible only at emergence of the interconnected multi-motor operated electric drives (Klyuchev & Terekhov, 1980). The interrelation of multi-motor electric drives of machines of this class is carried out through working bodies or reducers. Working bodies can be infinitely closed, have the distributed character (a tape, a chain, a rope), to possess elastic or elastic plastic properties.

Development of the interconnected multi-motor electric drives began at the same time with emergence of electric drives as electromechanical converters of energy for industrial appendices at the beginning of the 20th century. The first interconnected electric drives received power supply from group converting devices and were imperfect (Chilikin & Sandler, 1981).

But most intensively development and researches of the interconnected operated electric drives developed in the last third of the 20th century.

For multi-motor drives of a direct current of the most widespread there was a three-phase two-half-period completely operated scheme of rectifying which is still the main. Converters for powerful electric drives of alternating current on system of direct transformation of frequency were carried out on the basis of 18 - or 36-phase operated rectifiers working in the invertor modes.

Scopes of operated electric drives were extended mainly at the expense of thyristor electric drives of a direct current.

Controlled semiconductor electric drives of alternating current for asynchronous electric motors with a squirrel rotor on the basis of converters with artificial schemes of switching possessed small capacity, had the high cost and insufficient reliability in comparison with thyristor drives of a direct current.

In the course of application of semiconductor electric drives there were the serious problems connected with bad electromagnetic compatibility of controlled rectifiers with an electric network. Especially sharply these problems were shown in the interconnected electric drives for the rolling production, the excavators and other appendices. Operated filter compensating devices (Solodukho, 1981), (Solodukho & Tsallagov, 1986) and also power specialized three-winding transformers with an increased resistance of short circuit of secondary windings for separate power supply of thyristor converters (Fischler et al., 1986) were created.

Absolutely unexpectedly the electric DC drive on system the generator – the motor received a new life. It occurred after mass modernization of electric drives of the excavators which essence was consisted in replacement of electro machine exciters of generators of the main mechanisms of excavators by the semiconductor.

It should be noted that these systems are highly reliable, possess good adjusting characteristics and therefore still are in operation. In this regard the existing park of open-cast mine excavators of the CIS, behind a small exception, is equipped with electric DC drives, mainly on GENERATOR-MOTOR system.

In these years began the development of the theory of the controlled interconnected DC and AC electric drives, which now is generally realized in the modern semiconductor drives (Baryshnikov & Kulikov, 1982), (Ivanov et al.,1978).

According to classification (Ivanov et al.,1978) all controlled electric drives of the technological lines interconnected through a processed material, are divided into 4 main groups:

1) The electric drives providing smooth regulation and stabilization of speed of the line in the certain range at variable loading;
2) The electric drives supporting the set ratio of speeds of mechanisms of the line in relation to the leading mechanism of the line;
3) The electric drives of mechanisms which are carrying out uncoiling, broach, uncoiling and coiling of material, creation and maintenance of the set tension or material extract;
4) The electric drives providing compensation of the static and dynamic torques of loading.

Electric drives of mechanisms of zones of technological processing of materials belong to the first group. Local electric drives of such mechanisms are performed mainly on the basis of systems of the subordinated regulation of speed and current with the corresponding feedback connections.

Electric drives of the mechanisms being masters in the line or regarding the line are switched on in the second group. The set relation of speeds of mechanisms in the 2nd group is provided by distribution of a task of speeds in the set relation to the set speed of the slave mechanism (Basharin et al.,1982).

In the third group there are the electric drives providing the demanded tension or the extract of a material at the expense of interaction of electric drives of adjacent sections. Systems of regulation of the tension are performed either one-loop or three-loop.

In the fourth group compensation of influence of the dynamic and the static torques on an extract and the tension of a material and on the speed of its movement is provided (Ivanov et al.,1978).

It is known that distinctive features of an analyzed class of electric drives are different interrelations between local mechanisms and electric drives through a processed material.

Mechanically electric drives are connected through a processed material. These connections can be distributed (Basharin et al., 1982.), (Kiseley et al., 1978), (Rassudov & Myadzel, 1987), have elastic (Borodin et al., 1987), (Breido et al., 1987), both elastic and plastic character (Baryshnikov & Kulikov, 1982), (Ivanov et

al., 1978) or to be absolutely rigid. Working bodies also can be rigid, elastic, distributed.

Priority value for dynamics of such systems has the mechanism of gap forming or at the distributed working body - the mechanism of loop forming (Basharin et al., 1982).

The special group is represented by infinitely closed working bodies (Chugreev, 1976), (Novikov & Smirnov, 1978), (Shtockamn, 1959).

Processed material or working body defines static and dynamic properties of electromechanical system as a whole.

The conducted researches allowed studying influence of elastic connections on dynamics of the interconnected electric drives, to reveal optimum laws of movement of the elastic connected masses and to develop effective ways of decrease in loadings (Barry & Putkov, 1990), (Baryshnikov et al., 1986), (Breido, 1985), (Breido & Slobodskaya, 1991), (Egorov & Shestakov, 1983), (Kraus et al.,1987), (Pereslegin, 1990), (Rubashkin, 1975).

The close attention was traditionally paid to multi-motor electric drives mechanical connection between which is exercised out through executive body of the working machine.

For the electric drives interconnected through a processed material, methods of decomposition of systems which turn the interconnected separate systems into quasiautonomous are offered. It should be noted that these methods provide good results in technological lines where between mechanisms of a technological zone there are different stores providing a mechanical outcome. If stores are absent, at elastic and both elastic and plastic material, the distribution of a wave of elastic deformation along a strip both in the direction of movement of a material and against its movement is observed. Thus, in the analysis of the processes happening in the interconnected electric drives, it is necessary to consider essential influence of additional dynamic efforts from adjacent mechanisms.

Multi-motor electric drives possess such advantages, as reduction of weight and dimensions of gears, the total torque of inertia, increase in speed and reliability in comparison with single-motor analogs of the corresponding power. When designing these drives depending on appendices the following problems can be solved:

1) Synchronization of operating modes of machines and mechanisms;
2) Alignment of loadings between drives;
3) Distribution of loadings between drives in the set ratio.

The following main options of multi-motor electric drives are known:

1) Electrically interconnected electric drives;
2) Mechanically interconnected electric drives;
3) Electrically and mechanically interconnected electric drives.

The electric drives providing synchronous movement of two and more executive bodies of the working machine belong to the 1st group, not having mechanical

connection. In such interconnected electric drive there is only electric connection between motors, and it is called as electric shaft. In process of creation and gradual reduction in cost of semiconductor converters in the industry the remote electric shaft is rather widely used.

This system is applied for coordination of operation of drives of different power and intention. The system is universal and is widely used in the modern drives both direct and alternating current and the "master-slave" technology (Angular, 1999) here are usually applied. However the electric shaft synchronizes operation of mechanisms, but doesn't level currents and the torques.

In the second group mechanical connection between several electric motors is executed through executive body of the working machine. These are mechanisms of lifting and movement of load-lifting mechanisms, screw-press devices (in rolling mills), live rolls, load-lifting mechanisms, conveyors, etc. Essential lack of these systems is not identity of mechanical characteristics of electric motors even of the same type. It is known that according to the DIN VDE 0530 standard a sliding tolerance is allowed up to 20% (Novikov & Trizna, 2009). At mechanically interconnected systems it leads to uneven distribution of loadings between drives in static and dynamic operating modes.

For multi-motor electric drives of the mechanisms having rigid kinematic interrelations, the main objective is a control of loading of each electric drive at an identical speed of their movements. In the drives which have been mechanically connected by several driving axes, loading has to be distributed between motors evenly or according to the set ratios. When all motors are connected to one converter of frequency the deviation in distribution of loading arises at different characteristics of sliding at motors. Problems with distribution of loading can arise also because of transmission gears. Discrepancy of speeds of elements of transmission gears leads to that the motor with a smaller speed assumes bigger loading.

For alignment of loading and control of ratios of the torques of loading of mechanically interconnected electric drives using of individual converters on each motor is most effective (Novikov & Trizna, 2009).

Uneven distribution of loadings is especially critical for the frequency and adjustable drives having systems of stabilization of speed which increase rigidity of mechanical characteristics. Thus the negative effect due to continuous transition processes in system that is a serious problem at use of the multi-motor electric drive amplifies (Klyuchev, 2001).

The increase in number of elastic connected masses in the multi-motor drive leads to emergence of elastic mechanical fluctuations and breaks balance of distribution of loadings between mechanisms, both in transitional, and in the established modes.

In all cases, when influence of gaps and unevenness of rotation of gears on dynamic loadings of the drive is insignificantly, the use of consecutive connection of motors is the most rationally way. But at considerable mechanical indignations and shocks when closing gaps the development of antiphased oscillations undamped by the electric drive (which breaks uniformity of distribution of loading, both in

transitional, and in the established modes) is possible. Therefore consecutive connection can't be recommended at essential influence of gaps in gears and the indignations caused by errors of gears (Chilikin et al., 1979).

Effective damping of fluctuations and restriction of the maximum loadings in all modes are provided by the schemes of an independent supply of each motor from individual controlled converters (Klyuchev, 1971). The organization of an additional loop of regulation of loadings is thus expedient. Use of individual independent converters in the multi-motor drive allows improving significantly dynamic and static properties of the drive (Krivitskiy & Epstein, 1970).

In the machines with infinitely closed working body (conveyors) of load of working and single branches significantly differ therefore loadings between drives need to be distributed (Breido, 1985). In electric drives of pulling rollers of camps of the cold rolling mill, providing a tension of a strip, loading between top and bottom rollers also are distributed in the set relation, loadings between the master and slave drums of tape conveyors are similarly distributed.

Quite widespread system providing alignment of loadings is the electric and mechanical shaft. In such scheme two electric motors connected in series are switched to the common power source and the common mechanical connection. However the system provides alignment of the torques only in case of absolute identity of electric motors and absolutely rigid mechanical connection.

It should be noted that during of these years the theory of the interconnected multi-motor electric drives was almost created. But the most part of researches, especially in the field of the interconnected electric drives with the elastic, both elastic and plastic and distributed connections, for various reasons didn't receive during that period of time a due practical embodiment.

Generally researches were based on analytical methods of synthesis that limited an order of studied systems.

Applied methods of linearization of nonlinear systems possess adequacy at deviations in small that is unacceptable for the interconnected electric drives possessing essential discontinuities, at emergence loops or gaps, and also in acceleration and braking modes.

In the executed researches it was proved that damping and active restriction of dynamic loadings in elastic connections is the most effective when provided the feedback on the elastic torques and speeds of mechanisms which in practice wasn't achieved as a reliable system.

For realization of the complicated algorithms that necessary for creation of effective systems of regulation, analog and analog/digital systems are adapted in insufficient degree, they don't have enough accuracy and speed. The principles of creation of the interconnected electric drives possessing nonlinear properties with drift of parameters and dispersion of technical characteristics weren't fully developed.

2. Current State of Theoretical Researches and Practical Appendices of The Interconnected Multi-Engine Semiconductor Electric Drives

A new stage in the development of controlled drives started in the 90's of the past century and continuing into the present.

First of all it is connected with development of industrial production of power intelligent modules (IPM) with a set of IGBT transistors and also with release of specialized DSP microcontrollers for management of the electric motors. Such systems provide high speed and accuracy, a wide pass-band, and as the developed interface opportunities, including built-in standard communications protocols (Glazunov et al., 2005). On the basis systems of the vector control has developed a range of electric drives with a direct digital control torque. For them is typical of extremely high speed of contours of current. The contours are usually realized on the basis of digital relay regulators or the regulators working at the principles of indistinct logic. Perspective control systems of electric drives are developed with orientation to complex automation of technological processes and the coordinated work of several drives as a part of an industrial network (Markov&Markov).

The block and modular architecture of the universal drive controller and control system in whole is developed. Modular mathematical, algorithmic and the software were created: (Siemens, 1999), (Simoreg), (Simovert).

Functional modules for electric drives interconnected through the processed material implement the following typical functions of control (Baryshnikov, 1986):

1) control of a ratio of the load moments of the electric drives having mechanical link; the control carried out relatively the master electric drive having feedback on speeds or position;
2) speed control and ratio of speeds;
3) control of position and ratio of positions of the electric drives having mechanical interconnections;
4) simultaneous control of a ratio of speeds and the positions applied in aggregates of rolling production;
5) control of a ratio of speeds and tension (efforts);
6) control of speeds and tension with realization of brake modes of electric drives on the uncoil devices, control of a tension in a zone of processing of a strip and linear speed in the coil device;
7) control of technological variables through position of executive mechanisms taking into account the transport delay;
8) control of technological variables through speeds of executive mechanisms;
9) control of technological variables through variables of electric drives (speed, situation, etc.) and variables of executive devices of other view (pressure, temperature).

Various producers created on the basis of program models of standard mechanisms and technological aggregates, and also program blocks providing control algorithms for mechanisms and aggregates.

The principles and algorithms of the vector control for AC drives were developed, and also in practice the modern and perspective algorithmic software for frequency and adjustable electric drives was realized (Kozyaruk & Rudakov, 2002).

For electric drives of the rolling mills received the further development of synthesis methods of multidimensional objects control systems. The basis of the synthesis is based on the principle of autonomy of the separate systems. By the

compensation relationships provide invariance, i.e. autonomy subsystems (separate systems), then carry out the synthesis of each subsystem, as a one-dimensional (Bondarenko).

Methods of synthesis of the nonlinear regulators of a condition of variable structure were developed for the multi-motor AC drive which sets the general working machine (kinematic relations of the object characterized by viscoelasticity) in motion (Vinogradov et al., 2005). Signal of a task for a contour of the electromagnetic moment, for the purpose of gap closing in mechanical transmission are counted of regulators. They also are used for regulation of speed of the working machine with use of the observer of a condition (Vinogradov et al., 2005).

Existence in a control system of observers of a condition allows creating systems of dynamic closing of gaps in the mechanical transmissions. The known solution of the task which has received the name of the electromechanical torsion consists in the following, the thrust moment at the expense of operation of one engine in the motor mode, and another in a generating operating mode in system is created. If the thrust mode maintained constant, the total installed power of the motors overstated by 2.2-2.4 times (Vinogradov et al., 2005). At the same time, this solution cannot be considered optimal.

In a control system of the multi-motor electric drive the data exchange between local electric drives with control systems of higher level is standardized is carried out on the basis of the standard communications protocols Modbus, Profibus, CANOpen, DeviceNet, Interbus and others (Markov & Markov).

Researches of control systems by the interconnected electric crane drives are executed (Orlovsky & Boot, 2009), (Gerasimyak et al.,2008). Developed the basic approaches to the creation of automatic control systems for AC drives using FUZZY logic (Kozachenko et al., 2002). In (Pankratov & Zalyatov, 2008) it is offered to use the fuzzy-regulator for optimum control of the electric drive of the mechanism of movement of the crane on speed without rocking cargo. New technical solutions are applied and in the multi-motor electric drives connected mechanically through the transmissions or the executive bodies of working machines. For example, multi-motor electric drives of hoisting mechanisms (Jeftenic et al., 2001), (Jeftenic et al., 2006), (Nebojsa et al., 2009).

In the modern drives depending on technological capabilities and requirements it is possible to create various systems of the loading distribution on the basis of the controller expansion modules without change of the system hardware. Thanks to such principle, schemes of alignment of loadings were developed for the closed and opened control systems of the frequency drive, allowing to form the proportional balance of loadings between the interconnected multi-motors drives (Siemens).

The next step in the development of systems of load balancing for mechanical interconnected multi-motor drive, with independent power supply of each engine from individual converters is the system of droop control. This scheme is the simplest way of distribution of total loading when using frequency converters (Micromaster).

The work principle of the system consists, in decrease in a task of speed of one or several drives proportionally to increase of the load moment at the expense of a correction coefficient. Adjusting the slip occurs in proportion to the specified torque.

In the case of high requirements to the dynamics of the drive, with frequent change of acceleration-deceleration modes and speeds of this solution is not used.

The most effective is the system of load alignment "master - slave". Use of this technology gives the chance of the organization of various variants the proportional distribution of loading (Simovert). For example, in the AC drive systems, and with use of the DC converters (Simoreg). Depending on the chosen source of a task, from the basic drive to the slave drive the controlled variables is transferred: torque (current) or speed. For the slave drive these values are additional values (droop) to own task of speed. Depending on the values tasks of rotation frequency of the master drive and all slave drives are corrected.

In this case, the slave drive is operating in the mode of direct torque control, which is a continuation and development of vector approach to building the control systems of the induction motor (Kozyaruk & Rudakov ,2002). The signal of a speed task is given only on the master drive. In compliance with which, and also load moment, the control system of the converter forms the electromagnetic moment necessary for full compensation of sliding of the induction motor. Further this value is transferred to the slave drive, and is a signal of a task of the electromagnetic moment from the master drive for the slave drive. Considering fast reaction of the electromagnetic moment of the slave drive to control action, such system effectively works in modes with fast and frequent change of transients.

In development of this system the project of the multi-motor electric drive of the turn mechanism of the converter containing not less than 4 motors was offered. According to the technology requirements at the exit from the operation of one of the drives must be provided for the normal operation for the converter with 30 -40 smelts. And when failure of any 2 motors - bringing to the end of the current cycle of smelting (Limonov, 2009).

In connection with such requirements the ring system was realized. At failure of one of motors it's the regulator of load alignment is deactivated. At the same time, a nearby drive becomes the master and the other two - the slaves. Thus, realization of the robust control principles in the emergencies is provided. Similar offers are submitted in (Liu et al., 2011).

But with all the advantages, the structure of the system has a serious shortcoming - inadmissibility of breaking a mechanical connection between the drives. For a number of important industrial applications such emergency operation of work as break of a shaft of the engine or failure of the converter are not admissible. For example, for load-lifting mechanisms where the guaranteed operation safety is required. In addition, in modes of start-up and in the presence of gaps in the mechanism, one of motors can pass to a generating mode, and another motor will assume the most part of loading. Therefore, for such applications is the most appropriate system of "master-master" (Breido & Gurushkin, 2009a). In the upgraded system the unbalance of moments between the drives in static and dynamic operation modes decreased from 20-45% to 1-2.5%, and the crane performance was doubled by increasing the operating speed. Also developed a system for emergency crane control which ensures the completion of the cycle if one of the drives fails. The principles of robust management are here too realized (Breido & Gurushkin, 2009b), (Simovert).

The new control principles by the interconnected multi-motor electric drives of belt conveyors for coal mines are developed. The master drive sets the conveyor speed and the intermediate drive provide load distribution via high-speed controllers based on fuzzy logic. The system showed good results (Li & Li, 2012). For control of the interconnected electric drives of lines on production of fiber the effective ways of control based on application of fuzzy PID – the regulator were offered (Feng & Zhang, 2010).

Control strategy has been developed based on neural networks for the three motor electric drives. As a result of the decomposition of a nonlinear system by converting it to the linear subsystem has been implemented (Liu et al., 2012).

It should be noted that the most part of projects with use of the interconnected electric drives is directed on modernization of operating technological lines and aggregates (Tetyaev, 2013).

There are three main approaches to modernization:

- Modernization of control systems by the interconnected electric drives by their replacement by industrial controllers. Thus local systems of the electric drive remain invariable.
- Modernization of control systems by the interconnected electric drives and partial modernization of local systems of the electric drive when replacing control systems and converters.
- Full modernization of the interconnected electric drives.

The cost of full modernization of technological lines is high. And the most part of expenses is connected with replacement of electric motors and the switching equipment. Therefore, the most common partial or phased modernization.

A characteristic example of the third level is a complex reconstruction of the mill «1200» PTS (the production of transformer steel), Novolipetsk metallurgical plant. The hardware part of the industrial control system of the mill is based on the PLC. Communication with stations of the distributed periphery is carried out via the Profibus-DP network. Data exchange between controllers and system of visualization is carried out via the Industrial Ethernet network. SCADA – system is developed. Control system of the rolling mill provides the transitional processes of operating modes with minimal deviation strip tension; produces tracking the passage ends of the strip, seams and faults (Brown et al., 2012), (Brown et al., 2009).

The second level of modernization was realized in the mill «Quarto 2800» for the hot rolling of aluminium sheets company «Alcoa Metallurg Rus» in the city New Kalitva. In the course of modernization it was provided: control of the rolling mill in a semi-automatic mode, replacement of mechanical connection between the press screws of electric synchronization, automatic synchronization of speeds of roller beds with the speed of the main mill drive, indirect calculation of thickness of a rolled sheet on the basis of mathematical model, etc. (Brown et al. 2013).

There are examples of consecutive realization of all three levels of modernization. In particular, on such technology phased reconstruction of electric

equipment and automatic equipment systems of the small-section mill was carried out (Kapustin, 2010).

Now on technology of the first level reconstruction of powerful thyristor electric DC drives of release of 70-80 years for mine hoist engines is actively carried out. In this case, involves the exchange of the electronic control units of the inverter and the electric drives. Expensive power part of the converter (transformer, reactor, thyristors, high-speed circuit-breakers and etc) remain without changes. This technology has reduced the cost of modernization at least three times, and reduce the time of commissioning.

Concern ABB in the framework of the concept MultiDrive developed a unified system drive control with the total supply bus DC (Kozyaruk, 2002). In multi-motor version of the electric drive with the group power supply one entrance power module - the rectifier and some output modules - inverters is applied. All power modules from controllers of drives are controlled. A supply from the general DC bus allows carrying out braking from the motor to the motor without use of the brake inverter or the recuperative module. The MultiDrive system is realized for control of inclined conveyors.

In 2011 the "Elektromashina" company successfully realized the project in mine "Kotinsky" on installation of a general industrial frequency and converting station for control of the conveyor belt on a coal mine (Implementation). Remoteness of a complex from motors makes more than 2 km; motors are at distance to 5 km underground. The general power of a complex made 5 MW, voltage of 3,3 kV. The ABB converter contains the entrance diode 12/24-pulsny rectifier and the output 3-level inverter of voltage with a zero point.

One of characteristic tendencies of modernization of the interconnected electric drives of high power is retention of local drives with the analog systems of regulation and replacement of system of the interconnected control system by modern hardware-software means. By this principle the multi-motor electric drive on the asynchronous valve cascade system for the unique steeply inclined conveyor of a pit of "Muruntau", Uzbekistan (Ganin) is created. System of automatic control of the asynchronous valve cascade parameters – traditional, analog, constructed by the principle of the subordinated regulation, double-circuit: with an external regulation contour of voltage rotor and an internal contour of current regulation.

A microcontroller controls the thyristors of inverter. The control system of the interconnected electric drives of the conveyor provides:

1) the alignment of speeds of the cargo bearing and the pressure belts;
2) the alignment of loadings between drives of the cargo belt;
3) the maintenance of the set distribution of loadings between drives of the lower and upper drums of pulling station;
4) the smooth start-up of the conveyor with the set acceleration and a restriction of motor current.

Development and serial release of high-voltage frequency converters of high power for cage induction motor, seemed, shook positions of the electric drive using wound-rotor induction motor. However creation of new rotor converters of frequency designated new prospects of development of such systems of the electric drive,

including on the basis of machines of a double-way feed. Examples of this are the rotary converters of type "ERATON-FR". Converters are represented by consecutive connection of two transistor voltage inverters (rotor and network) with the accumulative condenser in an DC link (Ivancov), (Otchenash & Ivancov).
The rotor and network inverters of voltage are controlled under the law of sinusoidal pulse-width modulation and provide smooth start-up and regulation of speed of electric motors at the expense of an exchange of energy between a rotor of each electric motor and a high-voltage power line without loss of the power in the starting rotor resistance.

The network inverter of the converter returns the slip power of motor in a power line via the matching transformer without power loss in the starting resistors that provides the energy saving at start-up and allows to regulate the conveyor speed over a wide range of without loss power in the motor-starting devices of the electric drive.
Rotor converters of frequency found also the application in two-motor electric drives on the basis of high-voltage wound-rotor induction motor with power more than 1000 kW for the mine hoist machines (Ivancov).

In the semiconductor electric drives containing the object - oriented controllers, appeared prospects of effective control of the complex technological aggregates.
As the traditional methods based on simplified models of working bodies and the processed material, practically exhausted themselves, new approaches and the principles of design of the interconnected electromechanical systems are offered.
At modernization of complex aggregates the known principles of design, parametrical setting and adjustment of electromechanical systems on the basis of analytical methods and imitating modeling, with the subsequent debugging on object, were insufficiently effective. It is connected with lack of reliable information about quantitative values of elasticity, and (or) plasticity of a processed material, dissipation, gaps, sags, damping coefficients, etc., without knowledge of these values it is impossible to provide adequacy of mathematical models and, as a result, high-quality structural parametrical synthesis of the complex electromechanical systems.

In the articles (Breido & Gurushkin, 2009), (Breido & Gurushkin, 2008), (Breido & Sivyakova, 2008), (Breido & Sivyakova, 2005) the combined technologies of modernization of the complex electromechanical systems, combining physical and imitating experiments for receiving adequate mathematical models and completion of new systems in regular and emergency operation on imitating models are offered. In this case, used a powerful new tool as integrated information subsystems that make up the modern complete electric AC and DC drives.

According described technologies for steel plant (Kazakhstan, the city of Temirtau) was carried out modernization of a unique continuous annealing aggregate (CAA) with interconnected via the processed metal strip the thyristor DC electric drive. Use of the principle of decomposition of system on subsystems, subsystems on elements taking into account their interrelations allowed creating model of complex system (Breido et al., 1989). The structure of the interconnected electric drive CAA, containing the distributed regulators of a tension on the basis of group electric drives of the tower furnaces closed by positive feedback on derivative speed and negative - on loading current is as a result synthesized. This increased the speed of heat treatment of metal with 2.5 to 8 m/s at the minimum dynamic loadings in a strip (Breido & Sivyakova, 2007).

Modernization of the main hoist mechanism of the foundry crane with a loading capacity of 420 tons was made for the same steel plant and the same methods. The crane has the two motor interconnected mechanism of the main hoist with frequency - controlled AC electric drives and the vector control system. In the course of modernization, the physical model (stand) was created. The combination of experimental and imitating research on physical and mathematical models allowed creating system of alignment of loadings between drives (Breido & Gurushkin, 2009).

3. Prospects of Development of the Theory and Practice of Interconnected Multi-Motor Electric Drives

Significant successes in realization modular ideology construction of means and control systems by interconnected electric drives based on the constantly developing software and hardware automation system may result to the conclusion that all scientific and applied problems in the field of electric drives are resolved. Standard tasks of engineering selecting of complete systems of the electric drivers and additional options for different applications, with their subsequent parameterization are remained.

In fact, namely new opportunities will provide further development of research and development in the most difficult multi-motor interconnected electric drives of technological lines and unique aggregates.

Prospective control systems interconnected electric drives will be focused on the complex automation of technological processes and coordinated operation of several drives within industrial network. There will be developed theoretical research and practical applications by construction systems of synchronize multi-motor drives based on fuzzy neural networks, including management in online regimes and the application of sliding modes by using high-speed controllers (Gao et al., 2012), (Xu et al.,2012), (Zhang et al., 2007), (Zhang, 2012).

Management in online regimes will be required an assessment of ways to transfer and processing of information, especially in the feedback circuits of electric drives, in order to determine the effect on the quality of regulation. In sliding modes regulation accuracy will increased due to the invariance of disturbing influences, but dynamic loads can significantly increase and thermal modes of work of electric drivers deteriorate because of constant action dynamic currents through the channel of control actions. It motivates development of new algorithms of optimal control of multi-motor electric drives.

The development of new accurate methods of electric synchronization of multi-motor of electric drives will give a push to create a gearless (direct-drive) multi-motor electric drive that will lead to reduction in the size of equipment and improving its reliability (Lemmens & Driesen, 2012).

Multi-motor electric drive (Lopez et al., 2013) of lifting mechanism has perspectives in which to control the distribution of loads will be applied predictive models of converter and electric machines.

Great perspectives for use in the interconnected electric drives of technological lines have a non-contact brushless motor which is powered from a DC network through the standalone inverter, controlled by signals from the sensors of rotor

position. It is necessary to satisfy of research in field of new systems of multi-motor electric drives.

Interconnected multi-engine electric drives, closed feedback loops, not only on traditional speed currents and voltages engines, but also by the process variables of machines and mechanisms (for speed, torque and efforts, pressure, flow) can be attributed to a new class of mechatronic objects.

Researches, directed on the creation of theoretical frameworks and new technical solutions for related mechatronic objects of this class, have a good perspective. For example, the introduction of feedbacks by speed and torque of engines and mechanisms can control of clearances formation and sagged distributed operating element or processed material, damping of mechanical loads in the working bodies. Increasing of machine life for heavy duty work by increasing resource of working organs whose value reaches, for example, for conveyors up to 70-80% of the cost of conveyor is relevant scientific and technical challenge. It can be solved by increasing the damping capacity of the electric drive.

Can also be recommend the following direction of research and development. It is known that in industrial environment such as casting steel cranes mechanisms of continuous casting machines, mining equipment and etc. during the operation develop increased vibration activity units and mechanisms caused by continuous heavy-duty using. Development of systems of optimization of working modes multi-engine interconnected electric drive with the use of feedbacks from the spectrum and vibration level will provide increasing of resource, reliability and safe operation of equipment. These feedback loops can be applied to present diagnostic of equipment.

The next promising area of research is the development of systems of modal control interconnected electric drives with the organization feedbacks to the variables and their derivatives for the control of dynamic systems. Given the powerful computing capabilities of industrial controllers can be obtained not only the first but also the second derivatives of the signals, which would ensure making of new results in the control the dynamics of processed material or the distribution of operating element.

There are relevant researches and developments to create adaptive systems of interconnected through the processed material or member of electric drives with elastic-plastic ties properties of which is modified during operation. It's about production lines and aggregates in which there is a continuous heat treatment of the material with change of its properties (aggregates of aluminizing, zinc aluminizing, continuous annealing, etc.).

The new and promising directions can be attributed development of diagnostic systems difficult technological units and production lines based on fuzzy - logic.

It is promising the development and practical implementation methods of robust control in multi-motor of electric drivers for abnormal or emergency conditions. In these conditions the technological process is to be continued or completed by automatically restructuring, but at the cost of some loss of quality. For these purposes can be applied methods for building adaptive systems with model (Electric, 1987), (Barry & Putkov, 1990). In connection with this, a significant interest are the development of universal means of protection multi-motor electric drives for violations of technological processes, damaged or broken mechanical linkages or

processed material, in case of failures directly in the local electric drives of the process lines.

Sufficiently powerful computing capabilities of controllers allow developing new methods and systems for identification of unobservable parameters of interconnected electric drives, which in turn will ensure the development of adaptive systems. These settings include the elasticity and (or) the plasticity of the working parts and processed materials.

An extensive field of research connected with creation reliable sensors force (torque), linear velocity of the working bodies and the technological processes parameters. New sensors must provide preliminary signal processing, high noise immunity, and have a standard interface protocols.

The growth of computing capabilities of embedded systems drive control is accompanied by expansion of their functions. Prospective control system interconnected electric drives will focus on the complex automation of technological processes and coordinated operation of multi-motor systems in the industrial network. Industrial networks will be widely used for the transmission of control information and data from sensors in a single format.

It is desirable to perform a complex of researches to determine the principles of the transmission of information through channels of feedback, given volumes of information necessary speed and permissible delays with minimization their impact on the dynamic characteristics of the electric drive.

Interconnected multi-engine electric drives powerful conveyors, rolling mills hot rolling are large consumers of electricity, and therefore, the development of new control algorithms which do not affect to performance but minimizing electricity consumption, is a promising direction.

Application of high-frequency converters for regulation of speed synchronous electric drives used in the roughing stands hot rolling mills, practically unexplored. It may give good results in the plan improving the quality of rolling of metal and expanding the range of products. The characteristic tendency of development of managed electric drives is the expansion of application areas controlled AC electric drivers and a decrease in the proportion of regulated DC electric drives. The view that the DC drive has no future is a widespread. However, it appears that the positions managed DC electric drivers for a number of applications continue for long time. In the first place, it refers to the units and vehicles with heavy-duty, working with constant dynamic overloads or shock loads, for which work at loading is not on emergency but operating mode. In the constant overloads mills of hot metal rolling, excavators, conveyors and mining etc. are working.

In connection with this development of interconnected electric DC at the system "unmanaged rectifier" - latitude pulse converter with high modulation frequency (10-20 kHz) based on IGBT - transistors represent a specific interest. Application of such a system practically eliminates regimes of discontinuous currents, improves the energy characteristics of electric drives, improves electromagnetic compatibility with networks enhances the range of speed control.

Generating regimes of multi-motor interconnected electric drives with a wide range of speed regulation virtually unexplored.

Obvious that the development of theoretical research in the field of managed multi-motor interconnected electric drives will be directed for implementation of

projects that provide new qualitative and quantitative level of technological processes. In turn, implementation of such projects will motivate further theoretical research and development.

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