UDC 628.12

ANALYSIS OF PUMP STATION CONTROL SYSTEMS

D.V. Tolparov, Yu.N. Dementiev

Tomsk Polytechnic University
E-mail: tdv@elti.tpu.ru

Systematization and comparative analysis of circuit solutions of pump station control systems has been carried out. The main features at operation of various control systems of the automated stations are presented. The criteria for selection of the efficient configurations of control systems are formulated.

Introduction

In current conditions of Russian economics development the programs of energy and resource conservation starts playing a key role in rising domestic product competitiveness. Decreasing any product first cost and increasing its quality become serious tasks for enterprises working at constant deficiency of qualitative staff and restricted investment. In this case, a strong growth of demand for modern power efficient instruments of workflow intensification and automation are observed. Frequency converters for controlling induction motors may be selected among them.

Currently the mass introduction of frequency control systems is possible owing to high indices of energy conservation at mechanisms with a variable moment. First of all, it's a centrifugal pump. They are the principle mechanisms of the first and secondary communications of industrial and domestic objects. The psychological barrier of introducing new equipment is overcome long ago in these fields. Ubiquitous use of frequency converters at pump equipment showed the considerable influence of the majority of technological system features and their maintenance on the value of the obtained effect [1]. In addition, the functional capabilities of frequency converters allow constructing the automated control systems of pump stations with high service life on their basis. These systems represent a particular interest by reason of minimal process requirements to them [1, 2].

The aim of the article is to construct the efficient structures of the pump station control systems. For this purpose the influence of the main processing and operational factors on operation of shared group control of pumps is studied. In addition, the modern engineering solutions of pump station control systems and criteria of their selection are analyzed.

Principles of pump station operation

The process floowsheet with pumps is often a system with variable parameters, often circulating fluid consumption. According to this fact the pumping equipment should provide a certain consumption of pumped media overcoming hydraulic resistance of pipe manifold. Increasing a bandwidth of the required consumption the groups of pumps set in parallel may be used instead of a big one. In this case, connecting and disconnecting the required quantity of pumps, the desired level of consumption may be supported in concrete period of time. This solution is known for a long time and used almost at all enterprises. Pumps work in this case in areas of high hydraulic efficiency and the whole system possesses high reliability from the position of reservation. Such pump group control in station structure underwent considerable change in the power end at appearance of the up-to-date frequency converters.

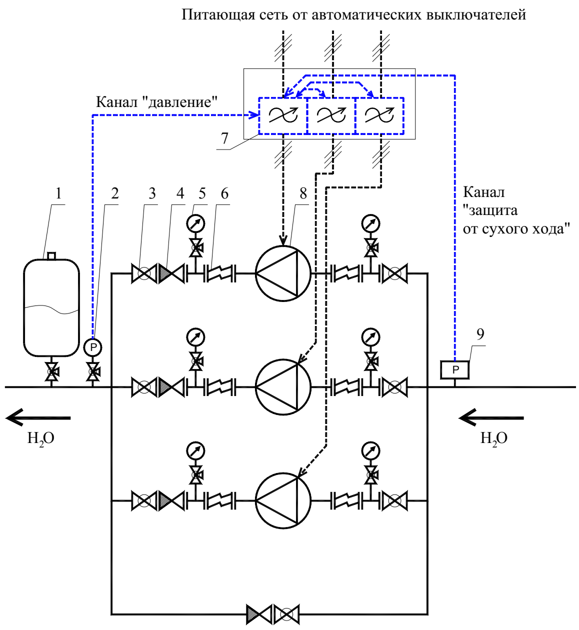

Fig. 1. *The example of functional diagram of pump station in water supply system: 1) hydro-pneumatic container, «pressure accumulator» with binding and safety valve; 2) pressure sensor with binding; 3) stop valve; 4) check valve; 5) manometer with binding; 6) vibro-compensator; 7) frequency converter; 8) pump, liquid end with electric motor; 9) pressure relay*

Питающая сеть от автоматических выключателей – Supply mains from automatic circuit breaker; Канал «давление» – Channel «pressure»; Канал «Защита от сухого хода» – Channel «Dry running protection»

The up-to-date pump station is a group of pumps and their control system operating according to a certain law in automatic mode, possessing a full set of electric and engineering protections. The example of functional diagram of water supply station is introduced in Fig. 1. The principle of operation of pump group control may be examined by the diagram. The parallel operation of pumps to a unified output collector as a process variable, pressure in this case, is in the base of automatic operation. All the pumps in the group increase the same head. At change of performance of the system to deviation of measured physical quantity the automatic insertion or breaking of supplementary pumps is performed. The amount of pumps in real systems varies from two to seven and determined by optimum between the efficiency area, discharge tolerance of pumped media, control system costs, the required reliability and reservation. Control loop of process variable is constructed on the basis of proportional-integral (PI)-controller. The feature of pump station circuit performance consists in the fact that at initiation and cutoff time of supplementary pumps the PI-controller operation is blocked for decreasing pressure jump values in a pipeline and absence of false commutations of supplementary pump electric motors.

An inlet screen is absent in Fig. 1 as it presents in the majority of systems at the input of metering station or the system of water discharge accounting. The elements of power and information electrics are denoted by a dashed line.

Typical configurations of the pump station control systems

Let us examine in details the solutions which are proposed by leading manufacturers of pump stations and control systems for them [1–6]. In horizontal columns of different implementation five main diagrams for constructing control systems may be singled out:

1. Pump electric motors in station are connected directly to the circuit through starters. At motor power higher than 4 kW the initiation is implemented by delta star connection. Control loop is made at the external controller. Pressure sensor of pressure and suction header as well as starter coils are connected to it.
2. One of pumps in the station has the built in decentralized frequency converter. Control loop is made on the basis of external controller PI-controller which changes the efficiency of the main pump by communication bus. Increasing the required system flow the controller commutates the starter coils of supplementary pumps with the help of the built in relays of the controller. At electric motor power more than 4 kW the initiation is carried out by delta star connection.
3. All station pumps have the built in frequency converters. The control loop is made on the basis of PI-controller of one of the frequency converter. The controller connects and disconnects the subordinate frequency converters by monobus as well as forms rotational velocity demand for them.
4. There is one external frequency converter in the control system which has an additional possibility of switching to any electric motor of station pump by commutation of starters of power output circuits. Control loop is also made at its program PI-controller. Starter coils of supplementary pumps are commutated from several relays of frequency converter. At electric motor power higher than 4 kW the connection and disconnection of supplementary pumps is carried out by delta star connection.
5. All electric motors of pumps are controlled from the external frequency converters. Control loop is made on the basis of PI-controller of one of frequency converters. The controller fulfills the connection and disconnection the subordinate frequency converters as well as forms by monobus the rotational velocity demand for them.

It is said in instruction for station selection that the choice of any control system is connected with a set of demands on the part of processing. From the position of station producer the installation of systems with pumps controlled only from frequency converters is recommended at pressure drops in suction manifold not less than 100 kPa [1, 2]. Configurations 3 and 5 correspond to this condition.

Diagrams 1 and 2 providing direct pump initiations cause considerable pressure drops, stresses in the system. Therefore, their application is possible only at hydro-pneumatic containers of increased required volume in station thrust face. It is possible, in its turn, in small systems where container volumes do not exceed 1 m^3/h. In the systems with the required large container volumes the level of costs exceeds the initial investment from selection of more functional configurations of stations 3 or 5.

Configuration 4 of the diagram for the control system is recommended at use of five or six pumps in the station. Such quantity increases the probability of lengthy downtime of some of them. These are rubber pumps more often. The corrosion processes are in progress in their liquid end at dissolved air in liquid. They touch contact areas of a runner, seals and volute. Crevice corrosion results in the fact that standby pumps with the fixed shafts are initiated at the main pumps failing. The emergency system stops completely and the standby pump life is not fully used. The similar result is observed at electric motor standstill. As the pipelines are often not isolated in station areas and the temperature changes seasonally then moisture is congregated in the electric motor. In the course of time it results in decrease of insulation strength and corrosion of the machine moving members. At pump initiation in such motor the rotor jamming or starter winding failing is possible. In order to load uniformly all the pumps in time, including the rubber ones, the configuration of the station control circuit 4 allows commutating the output circuits of frequency converter to various electric motors.

The problems of standstill are observed in the systems of fire-fighting stations where pumps are long time stand-by. At their initiation the automatic cutout was switched off by the above mentioned reasons. In order to avoid this, besides the short-length initiation by the timer, a special configuration for these systems exists today. It allows initiating the pump smoothly and decreasing starting currents reducing the probability of automatic cutout switching off. If the device of smooth start does not provide the required starting torque of the electric motor then the direct initiation occurs at the end of delay time through the bridging contactor.

The generalized structures of the pump station control systems

The indicated configurations of the diagrams for constructing control systems are efficient for the ready pump stations with unit capacity of the electric motor to 30...45 kW. Practically, this is the range for the majority of industrial systems at station operation in automatic mode with direct initiations to the open gate. A general functional diagram of such control systems is introduced in Fig. 2. Further increase of pump size and unit capacity of pump electric motors in stations determines considerable differences in control circuits from the above mentioned configurations.

The industrial pumps with the electric motor capacity over 45 kW were almost always initiated with the decreased torque to the closed gate and required constant servicing and monitoring of engineering service. Modern requirements to pump station automation do not allow spreading in full the world experience over the domestic industrial objects. There are many reasons here and they are connected more with the questions of relatively low payback of total reconstruction projects. Therefore, forth it makes sense to consider the pump station automation from the position of updating the power end and control equipment.

As it was already said, the variants of configurations of the control system circuits 1, 2, 4 can not be used owing to impossibility of initiation to the open gate. The most popular and budgetary configuration of the systems recalls circuit 4 with the addition of thyristor devices of the smooth start and stop block of electric motors of the subordinate pumps into it. It provides their smooth start and stop to the open pipeline system. The functional circuit of this configuration is introduced in Fig. 3.

One more variant of solution when the output circuits of frequency converter may be connected with the electric motor of each subordinate pump through the additional starters should be singled out. It allows commutating the frequency actuator at any of station electric motor that provides system undisturbed operation at failure of any pump as well as compensate in time their load at increase of the whole circuit resource. Among the disadvantages of this solution the increase of the amount of motor-starting device may be noted. Starting with electric motor capacity higher than 90 kW it is hardly justified and results in increase of costs in service and maintenance. Therefore, at unit capacity higher than 110 kW the configuration circuit 5 of station control system, when frequency converter is set at each electric motor, is appropriate.

The functional diagram of such pump station control system is introduced in Fig. 4. The efficiency form rotational velocity of all pumps may have additionally to 10...12 % from the total contribution into energy saving. The reason is in the absence of pressure loss in output

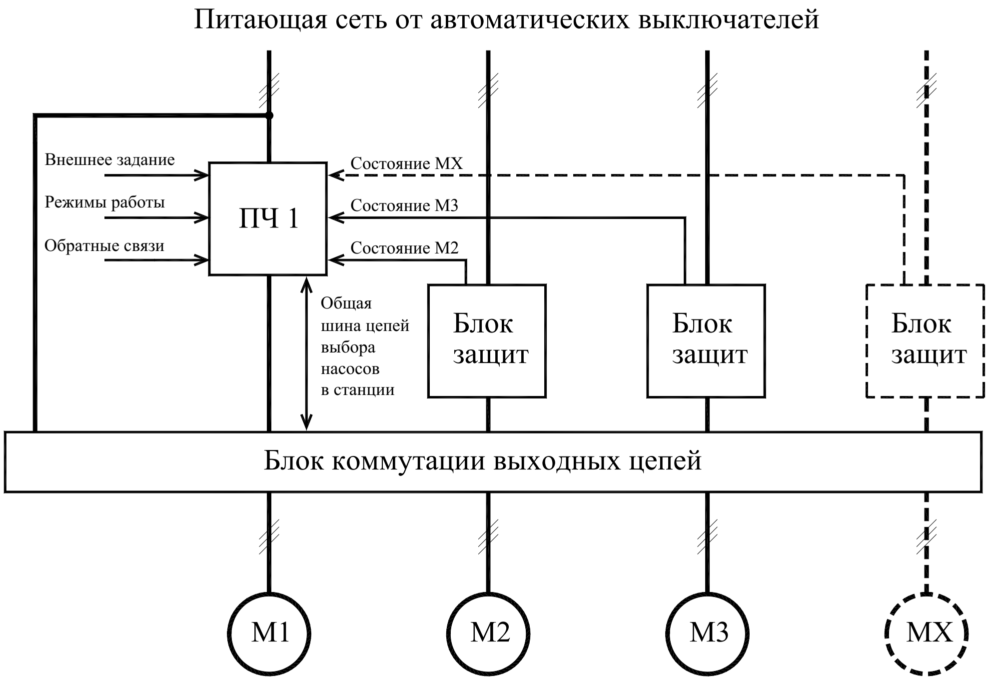

Fig. 2. *Functional diagram of the control system of pump station with one frequency converter: M1, M2, M3, MX are the induction motors of the pumps in the station; ПЧ 1 is the frequency converter*

Внешнее задание – External specification; Режим работы – Operation mode; Обратные связи – Feedback; Состояние – State; Общая шина цепей выброса насосов в станции – Common bus of the pump discharge circuits in station; Блок защит – Protection unit; Блок коммутации выходных цепей – Switching unit of the output circuits; Питающая сеть от автоматических выключателей – Supply main from the automatic cutout

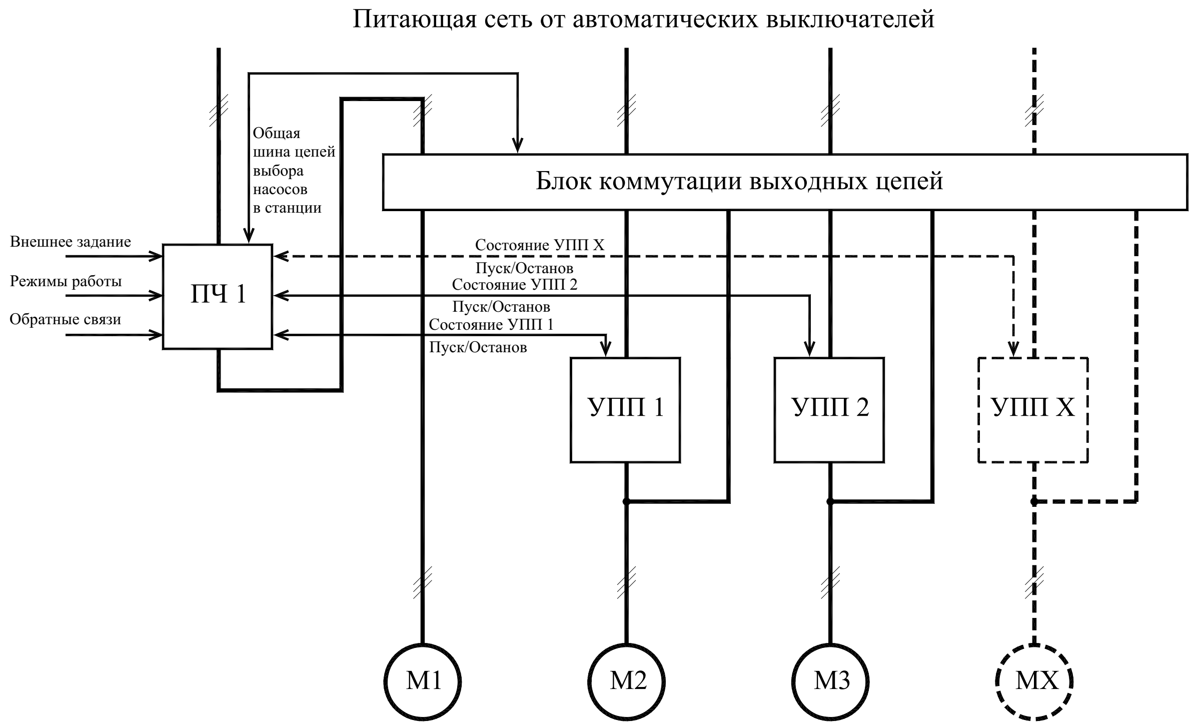

Fig. 3. *Functional diagram of the control system of pump station with one frequency converter and smooth start devices: UPP 1, UPP 2, UPP X – thyristror devices of smooth start*

Питающая сеть от автоматических выключателей – Supply main from the automatic cutout; Блок коммутации выходных цепей – Switching unit of the output circuits

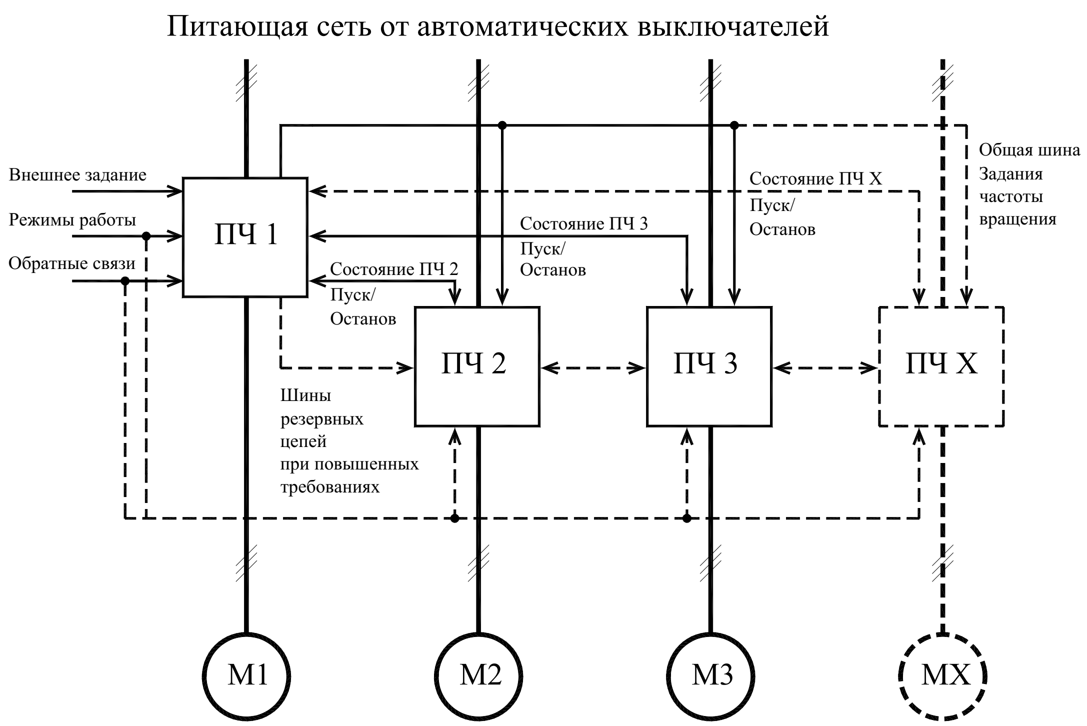

Fig. 4. *Functional diagram of the pump station control system with subordinate frequency converters: ПЧ 1, ПЧ 2, ПЧ 3 are the frequency converters*

Внешнее задание – External specification; Режим работы – Operation mode; Обратные связи – Feedback; Состояние ПЧ 2 – State of ПЧ 2; Шины резервных цепей при повышенных требованиях – Standby circuit buses at raise standards; Пуск/Останов – Start/Stop; Общая шина задания частоты вращения – Common bus of rotation frequency specification collector owing to the different velocities of pumped media flows from the pumps in the group. In this case costs for service and maintenance of the station control system decrease considerably. Choice of any pump as the main one without bulky plugging charts of the output circuits may be provided and control loop in operation at other pumps may be retained in emergency by the output circuits of frequency converters. Frequencies, at which the smooth start, stop and control of electric motor velocity of subordinate pumps occur, are selected by highest efficiency areas of the pumps accounting the acceptable number of starts per hour of the electric motors and the acceptable change of pressure in the pipeline system.

There is one more engineering solution of the pump station control system on the basis of converter device of some manufacturers. The frequency converter with a special function controls as well the efficiency of one of the pumps. Exceeding its efficiency over the assigned level the frequency converter provides the input and output voltage locking by phase and amplitude. After locking the bridging of the converter with a direct connection of electric motor to the supply main is provided. Locking provides the decrease of current rushes approximately to the level of inrushes with shorter period of time. Shunted frequency converter is switched to the next electric motor by the output circuit commutation. In this case the second pump becomes controlled.

Then this motor may be also brought to maximum efficiency and connected to the network and so on. Station motors are inversely disconnected. This circuit has a number of disadvantages, such as the increased initial and operating costs for motor-starting devices as well as a very low reliability of the circuit design itself. The idea of the circuit with a synchronizer is borrowed from the systems of starting the powerful synchronous motors. The quantity of investment and a payback period in such systems restrict the amount of conversion devices. Therefore, the circuit is used in the pump station systems with electric motors with voltage higher than 1 kV.

The systems of pumps with the built-in frequency converters may require the use of additional standby pumps from the position of undisturbed operation. In case of such frequency converter failing the pump can not operate [5].

The results of investigation

By the results of investigations the existing variety of circuit configurations of systems controlling the automated pump stations may be noted. The economic prerequisites at upgrading of pump station power end result in constant increase of the amount of conversion equipment. In this case, the requirement of decentralized protective performance of frequency converters increases. The control system designed on such converters allows abandoning the overall wiring boxes or prepared areas, approximating frequency converter direct to electric motor and decreasing the problems with electromagnetic compatibility, coil loss, increasing isolation resource. Additionally, the maximum effect from energy saving at minimal cost for reconstruction and arrangement is achieved.

Obtaining the unified integral efficiency index of introducing the examined circuits is a complex multicriterion problem. For each system the unique value engineering is carried out. Nevertheless, the relative cost and efficiency indices may be compared between the circuits. For this purpose the control systems for capacities of pump electric motors from several tens to 500 kW are considered. The number of pumps in the station amounts from three to four units. In these conditions the main relative indices of costs and efficiency between the circuits in the considered ranges are approximately constant [4]. The results of comparison are introduced in the Table. Maximal costs among the examined circuits for the conditional one and the same station are taken as 100 % of costs. Maximal value is taken as well as 100 % of relative efficiency.

Table. *The results of comparison of generalized structures of pump station control systems by the main indices*

The main indices	Circuit		
	Fig. 2	Fig. 3	Fig. 4
Relative value of the initial investment, %	45	68	100
Relative costs for maintenance of station engineering for 5 years, %	100	60	50
Relative costs for maintenance of station control system for 5 years, %	100	83	56
Relative power efficiency (direct effect), %	81	82	100
Relative efficiency, accuracy, special functions (indirect effect), %	80	85	100
The recommended power range of pump electric motors in station, kW	0,37...45(90*)	30...110	75...500
The recommended number of pumps, items	2–5	2–4	3–4

** Capacity for the variant of the synchronizing circuit with a network is given in brackets*

Using the data of the Table the conclusions may be drawn about the presence of optimal range of the efficient use of the examined structures. For the pump electric motors of low and average capacities to 110 kW, the structures in Fig. 2, 3 are more efficient. At further increase of electric motor unit capacity the use of structure, Fig. 4, is justified. In the recommended range of the number of pumps a proper structure allows providing the maximum effect and minimal costs. As a result, having the initial information on concrete pump station it is possible to adjust rapidly the level of the obtained effect and costs in feasibility study of control system upgrading. Each of three structures has its own field of application and subject to the given references allows selecting the optimal configuration of control system at pump station automation.

REFERENCES

1. Chebaevskiy V.F. Pump station design and pump unit test. – Moscow: Kolos, 2000. – 376 p.
2. General course of the processes and devices of chemical engineering / Ed. by V.G. Ainshtein. – Moscow: Khimiya, 1999. – 888 p.
3. Gritsenko K.G., Tolbatov V.A. Chervyakov V.D. The universal model of pump station flowsheet // Problems of control and information science. – 1998. – № 4. – P. 106–111.
4. Tysivskiy I.V., Gritsenko K.G., Chervyakov V.D. Resources-economy control of pump electric drives of public water supply system // Problems of the automatic electric drive. Theory and practice: KhGPU Bulletin. – 1998. – P. 237–238.
5. Tolparov D.V. The efficiency of using pumps with the built-in frequency converters in systems of ventilating, heating and water supply // Equipment – region. – 2006. – № 3. – P. 23.

Received on 03.10.2007

UDC 621.313.36

DIAGNOSING THE MECHANICAL STATE OF THE COLLECTOR-BRUSH UNIT OF THE HIGH-SPEED ELECTRIC MACHINE AT RESOURCE TESTS

O.S. Kachin

Tomsk Polytechnic University
E-mail: kos@tpu.ru

The questions on defining the mechanical state of collector-brush units in dynamic modes applying the techniques of result processing obtained with use of contactless profilometer developed in TPU have been considered. The results of experimental researches of the collector-brush unit mechanical state of the electric motor with alternating current during the process of resource operating time are introduced. The experimental data are analyzed. Recommendations on improvement of current collection conditions in sliding contact and increasing of brush resource are developed.

The increase of communication reliability and resource of modern high-speed commutator machines is determined to a large extent by mechanical stability of electric sliding contact (SC). However, SC behavior in dynamics is not studied enough theoretically and experimentally owing to the process complexity as well as the absence of special measuring systems and techniques of processing measured information [1–4].

The aim of the carried out researches was to test the techniques developed in Tomsk Polytechnic University (TPU). They allow extracting the information interesting for the designers of commutator electric machines about a change of collector profile at maintenance, about the value and character of armature chatter as well as about the other mechanical parameters from the whole array of the results of measuring carried out with application of contactless profilometer. On the basis of the carried out experimental investigations and further data processing with application of the developed techniques the separation of the initial array of source information into components characterizing the collector surface levels without armature chatter and changes of these levels owing to armature chatter was carried out. As a result, the quantitative information about the state of collector profile of high-speed electric machine, size and character of bearing armature chatter, as well as the degree of their influence on mechanical state of collector-brush unit (CBU) at resource operating was obtained. The data obtained during investigations should become a base for modeling dynamic processes in SC and working out references concerning the increase of CBU working resource.

The test subject: electric motor of vacuum-cleaner unit of LG Electronics company, VCE280E02 model, 35000 rev/min, 1800 W, electric brushes of HG25 type.

During the tests the electric motor operated with ventilator load. Endurance test duration amounted to 709 hours. Brush wear was measured by a micrometer with interval of 35...45 h. Collector profile of electric machine was measured as well in dynamics at rated revolutions with the use of contactless hardware-software measuring system developed in TPU [5]. All the graphic materials introduced in this article are constructed on the basis of experimental data and their mathematical processing by special techniques.

The experimental data obtained during resource tests show that at brush limiting wear of 28,8 mm (1900 mm^3) the collector sliding path wear amounted to 0,74 mm (532 mm^3). It indicates the triple collector resource stock in comparison with brush set resource (on the basis of the constructive included stock for lamel wear amounting about 2...3 mm [6]). Therefore, the increase of CBU resource in similar machines is possible by decreasing the intensity of electric brush wear which depends on the factors of friction, electrocorrosion (current) and electroerosion nature. The electroerosion component of SC element wear is the most significant and determined by the commutation character which is conditioned to a large extent by collector profile state and armature chatter.

Distances form measuring transducer (eddy current type) stationary relative to the studied electric motor body to collector working surface in rated duty were me-