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CONCEPTUAL JUSTIFICATION FOR THE SELECTION OF ELECTRO-HYDRAULIC CONTROL SYSTEMS FOR STEAM TURBINES USING ELECTROMECHANICAL CONVERTERS

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Abstract

The article describes the most common schematic diagrams of electro-hydraulic control systems for steam turbines. The main advantages and disadvantages of these schemes are given. It is noted that for the modernization of steam turbines in operation, the cheapest and most effective is the choice of electro-hydraulic systems built on the basis of electromechanical converters. Electromechanical converters are subject to repair in a power plant, provide the required resource with a high level of reliability, minimal modifications of the hydraulic part are required, steam distribution can be saved.

Keywords: Steam turbine, governor system, valve, safety governor, servomotor, electromechanical converter.

Currently, a large number of steam turbines with hydraulic governor systems (HGS) are in operation. They are usually made 30 or more years ago. However, the relevance of their operation for various reasons remains. At the same time, maintaining such turbines in working condition causes a number of objective difficulties:

- As a rule, the manufacturers of these turbines have significantly changed their range and many of them have stopped producing both the regulators themselves and spare parts for them.
- Manufacturers do not have qualified personnel to perform the adjustment of such regulators, and in general the entire governor system. Adjustment companies also have a big shortage of such specialists.
- The requirements for participants in the general generation of electricity have changed. Modern requirements have become significantly tougher in terms of technical characteristics for electrical generation equipment. In fact, a situation has arisen where the specified requirements cannot be met by governor systems with hydraulic governors. Failure to comply with these requirements entails the imposition of tangible financial sanctions on generating companies or a direct ban on connection to the electric grid.

These reasons require the modernization of governor systems. It is generally accepted to switch to electrohydraulic control systems (EHCS) with the parallel implementation of general automation of control and monitoring of the operating parameters of the main equipment, based on the widespread use of microprocessor technology.

Examples of the most common types of hydraulic governor systems are shown in Fig.1,2.

The main features of this scheme of the K-300-240 turbine, shown in Fig. 1, are:

- The use of a membrane-tape speed governor (SG) with speed governor slide valves (SGSV), in which a differential spool with a “nozzle-flap” amplifier is used as a sensitive element. At the same time, the air defense system has a built-in turbine operating mechanism (OM). The movement of this SGSV forms pressure in the control line of the intermediate valves;
- Use of intermediate slide valves (ISV) with a built-in power limiter (PL) to convert the pressure in the control line of the intermediate ISV into control valve control pressure;
- Use of individual servomotors with cut-off spools to control the position of each high pressure control valve and reheat.
- The use of mechanical feedback on the position of the slide valve and servomotor, which are made in the form of lever gears and springs;
- The use of a mechanical safety governor of the striker type paired with safety governor cut valves (SfGCV).

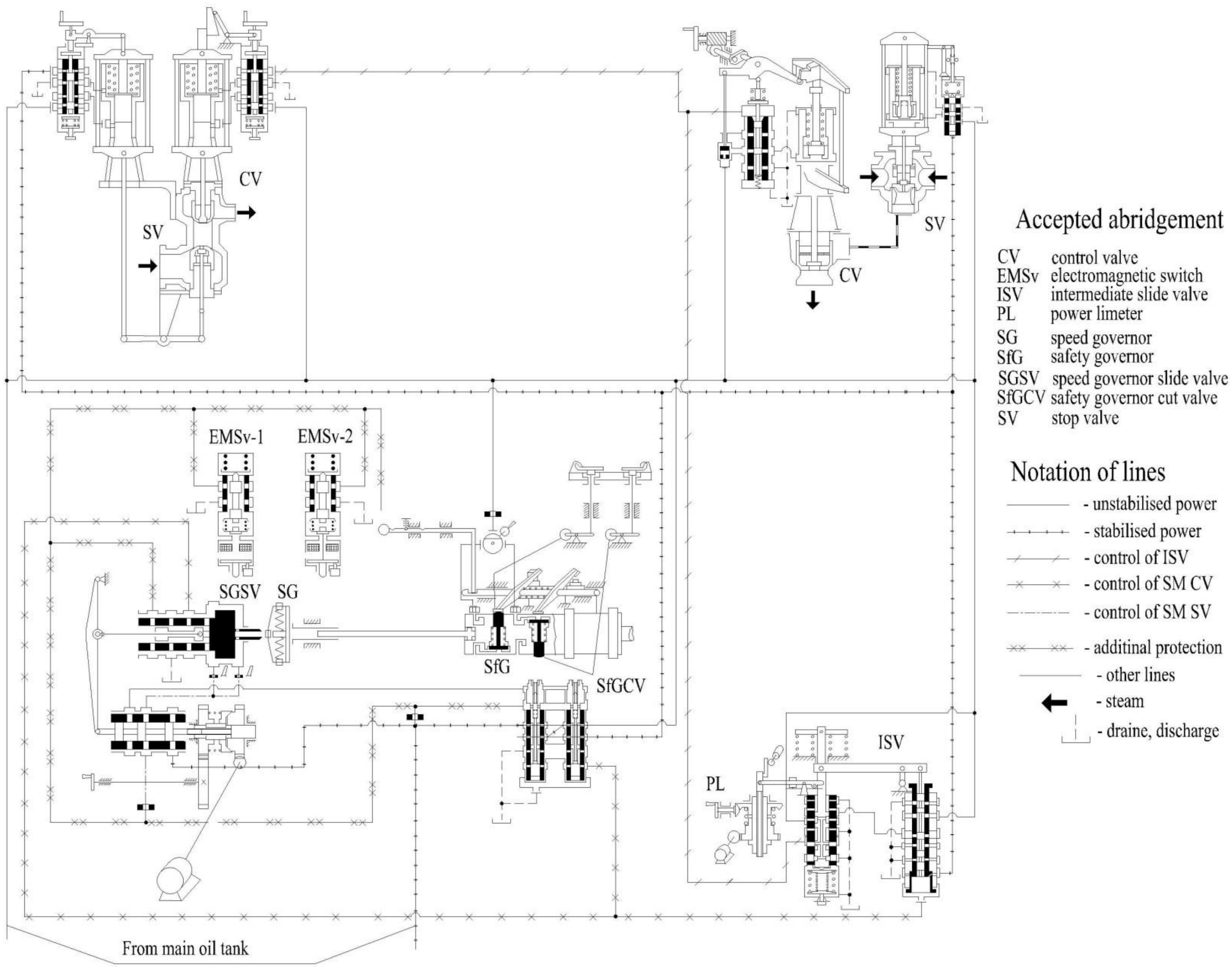

Fig.1 Schematic diagram of the hydraulic governor system with a membrane-belt speed governor

As a rule, a non-flammable working fluid of the firquel type is used as the working fluid for such governor systems. Significant disadvantages of the circuit in Fig. 1 are the following:

1. The circuit is uncompensated for the pressure of the working fluid. A change in the magnitude of the power pressure significantly affects the pressure in the control line of the servomotors of the control valves, and due to the fact that the force from this pressure created on the slide valves is compensated by springs, the position of the slide valves changes, and hence the position of the servomotors of the control valves. To compensate for this shortcoming, developers use various methods for stabilizing the force pressure, introducing separate lines of stabilized pressure to feed the impulse lines.

2. The working fluid is toxic and expensive. Because of this, the developers of the governor system seek to reduce the flow rate of the working fluid and its total volume. Because of this, the force pressure is increased, the gaps in the spool pairs and throttle devices are reduced. At the same time, the chemical activity of the working fluid limits the range of non-metallic materials for use. For this reason, pneumohydraulic accumulators are not used to stabilize the working pressure in dynamic modes. For this reason, the stability margins of the system during self-oscillations are low. The characteristics of the working fluid supply pumps do not allow maintaining the pressure in the power line unchanged. The system is sensitive to the purity and working properties of the working fluid. Careful cleaning of the working fluid and maintaining its temperature during operation is required.

3. The high structural complexity of the mechanisms does not allow for their disassembly and maintenance during operation. The system cannot be flushed completely after repair.

4. The working fluid is prone to insoluble precipitation, which leads to jamming of the actuating spools. For this reason, constant increased control of the properties of the working fluid is required, the installation of additional filters with all the ensuing disadvantages.

Such control systems are described in most detail in [1].

The hydraulic governor systems shown in Fig. 2 have a different principle of operation. Their features are:

1. The use of a special pump (PI) and a hydraulic speed governor (SG) as a turbine rotor speed sensor;

2. The use of hydraulic feedback on the position of slide valves and executive servomotors. One servomotor (SMCV) is used to drive a pair of control valves CV1 HP and CV2 HP. The HP stop valve (SV) has its own one-way servomotor (SMSV). To regulate the steam supply to the IP control valve, blocks of reheat valves are installed, in which a locking pusher rod and a control valve are located in one housing. To drive these valves, a servomotor block (BSMIP)

is used. Condensate is used as the working fluid in the governor system. The given system is called hydro-dynamic due to the use of a pump (PI). Compared to the circuit in Fig. 1, it is compensated for force pressure. In static modes, a change in force pressure leads to a corresponding change in pressure in impulse lines, control lines, and feedback lines. For this reason, the configuration of the system as a whole is preserved. However, the flow rate of the working fluid in such a system is much higher. However, this is not a fundamental disadvantage when using condensate as a working fluid. In addition, the choice of pumps of the governor system with excess power allows to reduce fluctuations in the pressure of the working fluid in dynamic and transient modes. As experience in operating governor systems using condensate as a working fluid has shown, increasing the power pressure above 3.0 MPa is not advisable, because leads to increased hydraulic wear (washout) of the main parts of the devices. This limits the magnitude of the force pressure.

The main components in this system are easily disassembled and subject to repair in a power plant. This makes it possible to flush the housings after installation and repair together with the control pipelines. However, the use of an impulse pump as a sensor of the angular velocity of rotation of the turbine rotor entailed the presence of constant self-oscillations in the governor system due to the fact that this pump is a source of constant impulses in the hydraulic lines at the input to the speed governor.

A description of such systems can be found in [2].

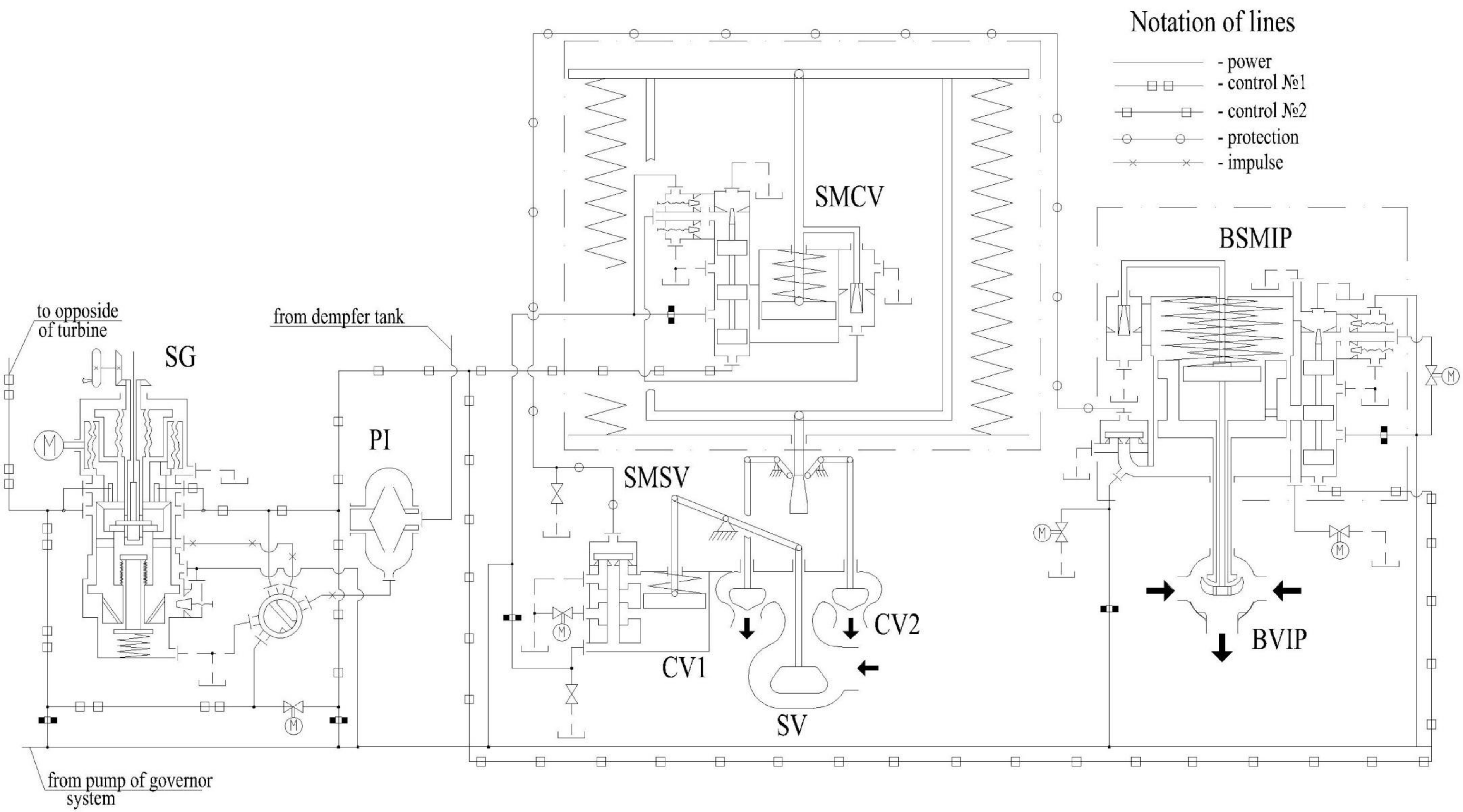

Fig.2 Schematic diagram of the hydraulic governor system of the hydrodynamic type

In the earliest versions, electro-hydraulic control systems were installed in parallel with the existing hydraulic speed controller [3], [4], [5] (see Fig. 3).

As a rule, these schemes were used for large-capacity turbines of nuclear power plants. This made it possible to achieve an increase in reliability due to the redundancy of the governor system as a whole and made it possible to keep the turbine at power in the event of a failure of the electronic part of the EHCS.

To convert the signals from the electronic part of the EHCS into hydraulic pressure in the control lines, electrohydraulic converters (EHC) developed by turbine manufacturers were used [3], [5]. In order to ensure shockless switching from EHCS to HGS, a current unloading mechanism (CUM) was installed. At the same time, all “fast” disturbances were worked out by the EHCS using the EHC, and the CUM moved parallel to the EHC with a lower travel speed, which led to the removal of the control current from the EHC control coils while maintaining pressure in the control line for any position of the servomotors. The work of a pair of EHC and CUM on a common for servomotors of control valves and control dampers entailed a significant reduction in the number of actuators, and therefore a significant reduction in the cost of the electronic part (EP) of the EHCS.

The described EHCS fully comply with all modern requirements for steam turbine governor systems. Their reliability is confirmed by many years of experience in successful operation. EHC and CUM are subject to repair in a power plant, they have a long resource. The use of sensors for the angular velocity of rotation of the turbine rotor significantly reduced self-oscillations during operation.

Further development of EHCS using EHCS and CUM continued in the replacement of the hydraulic speed controller with an electronic one [6], [7].

The electronic speed controller is actually an EHCS with limited functionality. In the future, it was considered expedient to replace the electronic speed controller with a full-fledged EHCS. As a rule, steam turbines are equipped with such EHCS during manufacture by the turbine manufacturers themselves and they are not used to modernize existing turbines.

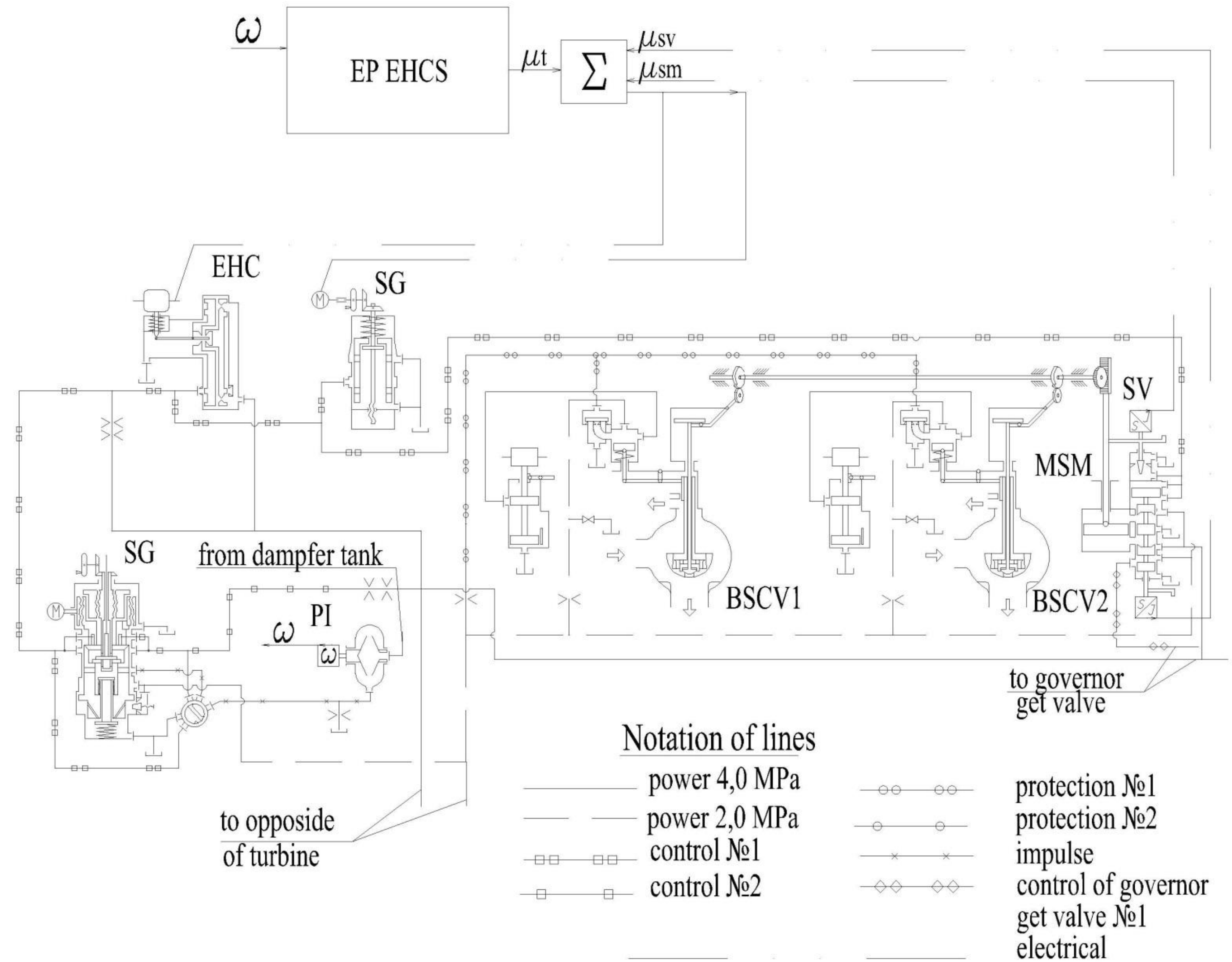

Fig.3 Schematic diagram of EHCS with backup HCS

During modernization, these nodes can be compactly placed on a separate column and included in the control line parallel to the speed controller (see photo in Fig. 4).

Fig.4 Regulation column with EHC and CUM installed on it.

In this case, the mechanical speed governor can be saved as a backup governor system. The advantage of this solution is the presence of a backup governor system, less rework in the hydraulic part, the convenience of the operating personnel, especially in the initial period of operation, when there is no experience. This solution makes it possible to avoid the inevitable shutdown of the turbine in the event of failure of the EP EHCS. In case of simultaneous failure of EHCS and HCS, manual control of the turbine is retained.

The disadvantage of the described solution is the increased amount of maintenance and repair, the difficulty of switching from EHCS to HGS, especially if the failure occurs in dynamic operating modes. To diagnose the HGS, it is necessary to carry out periodic tests by directly putting it into operation, which is an inconvenience when the turbine participates in the normalized maintenance of the frequency in the electrical network. HCS during operation can be a source of failure of the governor system as a whole.

The use of the described systems for turbines of small and medium power is not acceptable due to the significantly greater simplicity of these turbines. Since the servomotors of these turbines have a significantly smaller volume of working chambers, and the shutdown of the turbine is not critical for the electrical network, for these turbines EHCS is used in which the EHC combines the functions of a cut-off spool and directly controls its own servomotor [6], [8].

The advantage of the EHC of the mentioned type is the increased shifting forces on the executive spool (more than 3000 N). This is achieved by using a multi-stage amplification of the electrical signal, namely the use of a linkage and a "nozzle-shutter" amplifier. The main feedbacks and feedbacks on the position of the servomotor are tripled in order to increase reliability.

A positive result was achieved when using the electronic part of the control system in which the control signal is generated by pulse-width modulation of the second kind. This led to a significant increase in the sensitivity of the control loop as a whole without changing the design of the EHC. The EHC cutoff frequency increased by more than three times. In this case, there were no self-oscillations of the servomotors.

The electronic part of such turbines was carried out in the form of program-logical complex of EHCS (PLC EHCS). This complex performed all the functions of control, protection and regulation of the turbine. Frequency protection was carried out in the form of an electric safety machine. The use of pulse-width modulation made it possible to reduce the total cost of the PLC EHCS, by eliminating the output summing amplifiers. Amplifiers with pulse width modulation are easier to integrate with the processor digital part. The feedback from the sensors was digital, which simplified their diagnostics and processing of incoming signals.

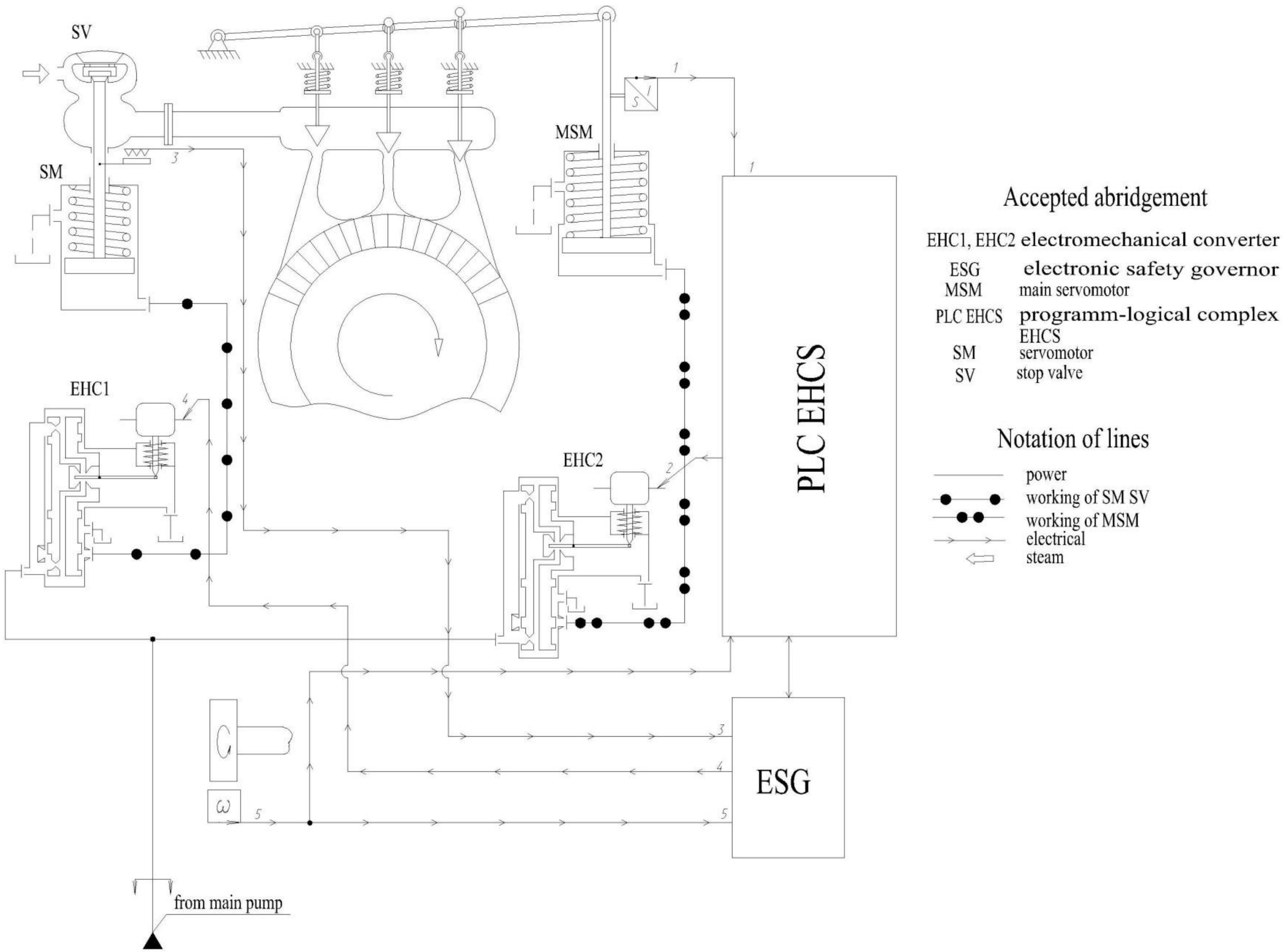

Fig.5 Schematic diagram of EHCS with EHC for direct control of a servomotor

The disadvantage of the described systems in the modernization of turbines with HCS can be considered the relative bulkiness of the units, the complexity of their integration with protection systems with mechanical safety regulators, the difficulty of EHC redundancy, the additional consumption of the working fluid, which must be correlated with the existing pumps for supplying the working fluid.
At the same time, the design of the EHC is simple, maintainable in a power plant, has a sufficient resource and does not require additional requirements for cleaning and stability of the properties of the working fluid.
As a rule, the described systems were used for newly delivered turbines.

Fig. 6 Steam turbine P-2.4-3.4 with EHCS, in which the EHC directly controls the servomotor

Modernization with the introduction of EHCS based on EHC of well-known manufacturers of hydraulic equipment MOOG, Rexrot and other companies. As a rule, when upgrading, it is proposed to replace not only the main devices of the hydraulic part, such as the speed governor, the CUM, but also the replacement of the main servomotors and the working fluid supply system. These proposals are justified by the higher quality of the equipment and its unification. However, the real reasons for these proposals are that in order to be able to use standard serial EHCs, it is necessary to increase the supply pressure of the working fluid, and this clearly leads to increased requirements for oil purification and requires the use of only fire-resistant oil due to an increase in the risk of fire. These upgrades are carried out without the participation of the turbine manufacturer, so the design of the EHC for the existing operating conditions of the standard HCS is impossible. As an advantage, the authors of the modernization offer EHC redundancy with the possibility of replacement on a running turbine. The disadvantages of the modernization method described above are:

1. A significantly larger amount of modernization, and hence its cost.

2. The complexity of integration with the existing protection system, which, as a rule, was performed before on the basis of a mechanical safety governor with safety governor cut valves. The replacement of a mechanical safety governor with an electronic one in this case is not accompanied by the determination of the rules for testing and testing the safety regulator. This is a critical circumstance with a high degree of risk, as companies carrying out the modernization cannot determine and make all the necessary changes to the list of protections and blocking of the turbine, change the order of implementation of protections.

3. The EHCs used have low shifting forces on the actuating valves. These efforts are 5 or more times lower than the efforts that are available at the EHC produced by turbo-building companies. This significantly reduces the reliability of the EHC, requires additional measures to clean the working fluid, such as installing filters. The presence of these filters requires their additional monitoring and maintenance during operation. And manual operations with these devices are an additional opportunity to stop the turbine due to an error of the maintenance personnel.

4. Used EHCs are not subject to repair, their maintenance is carried out only by the manufacturer of these EHCs. At the same time, after performing this maintenance, EHC manufacturers, as a rule, do not give guarantees for the entire period between full repears. In fact, during the overhaul, the replacement of all EHCs is required. And since the change in the range of products manufactured by manufacturers of hydraulic equipment is constantly carried out, there is always a risk of inconsistency between the newly purchased EHC and the existing electronic part. All this significantly increases the cost of turbine repair, requires the constant participation of the EHCS developer and the supplier of the electronic part.

5. The applied EHCs, as a rule, perform positioning in proportion to the magnitude of the control signal. For this reason, the procedure for a bumpless transition from the main EHC to the backup one always requires additional measures to ensure a bumpless transition. It is also required to periodically reswitch from the main EHC to the backup one during turbine operation to ensure that the backup EHC is working properly.

An alternative way to upgrade turbines in operation is the introduction of EHCS using electromechanical converters (EMC) [9], [10], [11].

Various versions are possible, both with installation on separate spools that control the control lines of cut-off spools, and direct installation of EMC on each slide valves that controls a specific servomotor. In the first case, the volume of alterations of the hydraulic part is minimized, the cost of the electronic part is reduced due to the reduction in the number of EMC, the system is easily integrated with the existing mechanical safety regulator. However, in this case, many disadvantages remain, such as low stability margins, a tendency to self-oscillations. In this option, it is more difficult to achieve the dynamic accuracy of the system.

An example of an EHCS with an EMC installation directly on the slide valves is shown in Fig. 7.

The undoubted advantage of the presented option is the minimum alteration of the hydraulic part and the cheapness of the project. The cost of the EMC itself, as a rule, is comparable to the cost of hydroblocks from the EHC of manufacturers of standard hydraulic equipment.

One of the most common is the use of EMC series GSX30 from Exlar (USA).

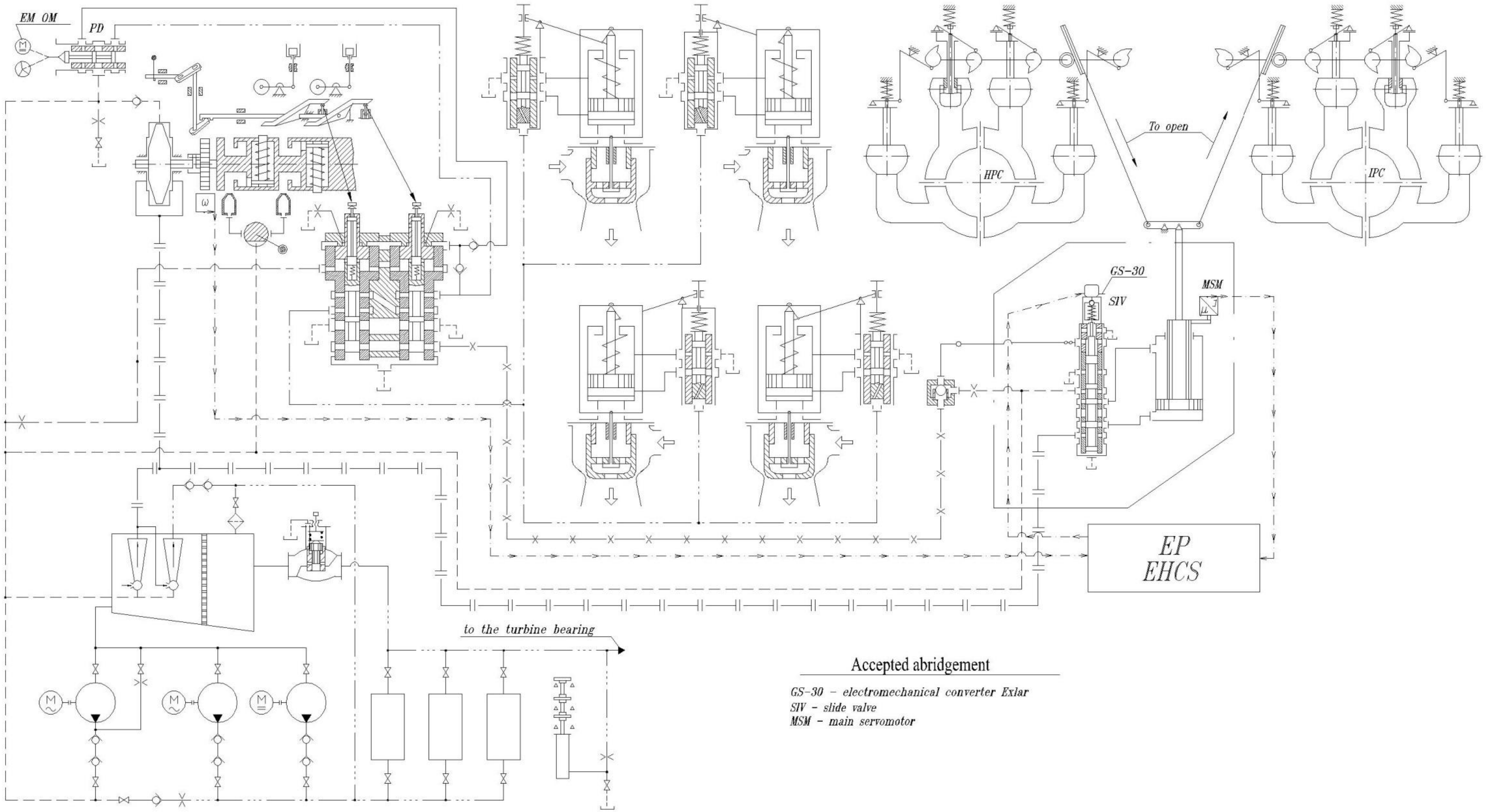

Fig.7 Schematic diagram of EHCS with EMC of turbine K-200-130

It provides the required positioning accuracy, travel speed and high adjustment forces. (more than 3500 N). A wide variety of designs allow at the request of the customer, equip the EMC with a manual drive flywheel, which facilitates adjustment on a tripped turbine. There are versions with a duplicated control coil, which makes it possible to install a backup EP EHCS. At the same time, the simultaneous action on one output rod ensures the simplicity of a shockless transition from the main control channel to the backup one, and the simultaneous action on the rod from two control coils makes it possible to increase the speed and reliability of operation by increasing the shifting forces on the rod in emergency operation. A feature of the EMC is the ability of a short-term increase in 5 or more times to increase the EMC shifting force in the event of jamming of the spool. This property significantly increases the reliability of operation in case of emergency shutdown of the turbine or discharge of the electrical load.

EMC is subject to repair and maintenance in a power plant.

Installing the EMC directly on the slide valves allows you to abandon the mechanical and hydraulic feedback, which eliminates the disadvantages of the HCS with the lack of compensation for power pressure, reduces the required flow rate of the working fluid for any schemes. In this case, it is possible to integrate a mechanical speed governor controller with the implemented EHCS. A well-known technical solution for such integration is the connection of the EMC rods and the slide valves through a spring release mechanism [10]. In this case, the slide valves is actuated and the control valves are closed, regardless of the commands of the EP EHCS.

A large number of completed projects and long-term operation of turbines, the modernization of which was carried out according to this method, confirmed the positive experience of using EMC. The confirmed resource of EMC is more than 15 years. The introduction of EHCS made it possible to significantly increase the turbine steam distribution resource due to a significant reduction in self-oscillations.

The introduction of EHCS does not require replacement of control valves and alteration of the steam distribution mechanism. An increase in the throughput of the turbine and an increase in its efficiency can be achieved by increasing the opening of the control valve No. 4 by replacing the shaped fist of the distribution mechanism.

EMC does not depend on the type of working fluid used in the control system. All the technical characteristics required by the UCTE rules have been achieved, including for turbines whose working fluid is condensate [11].

The above descriptions of various EHCS schemes confirm the position that the choice of the type of EHCS is determined rather by the experience and capabilities of the developers, as well as economic factors, rather than technical limitations. At the same time, EHCS based on the use of EMC are more attractive due to the fact that they make it possible to obtain the specified goals at a lower cost.

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