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STEAM TURBINES OF GREAT OUTPUT

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III НАУЧНАЯ КОНФЕРЕНЦИЯ

на тему

ПАРОВЫЕ ТУРБИНЫ БОЛЬШОЙ МОЩНОСТИ

Гданьск, 24 - 27 сентября 1974 г.

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Automatic Control of a Turbo-Set Starting System

Introduction

The development of a control system of the courses of thermal processes and the selection of the magnitudes commanding in these processes and dependent on the selected magnitudes of the signals controlling the operation of the block is the basic problem connected with the automation of power blocks. The direct technological connection of the turbo-set with the steam generator brings about the necessity of measurements and checking the mechanical, thermal and electrical magnitudes in the whole block.

The following quantities are measured and processed: the pressure of the thermodynamic media, the temperatures, the temperature differences, the rotational speed, the power rating, the vibrations, the eccentricity, the thermal elongation, the layout of mechanisms and the intensity of flow of the various media.

The number of points of measurement on large blocks exceeds 1000.

Gradual automation of the separate units included in the composition of a power block, their operation being characterized by a smaller number of parameters than the number mentioned above and therefore easier to control by application of group systems of automatics, is a logical solution.

Automation should be applied first to periods of transient operation of the block units, as in these periods, as a rule, conventional systems of automatics are inoperative. Due to these considerations, the so called plant starting automats acquire a particular significance and the problem of automatic control of turbo-set loading on cold start parameters, i.e. with the pressure and temperature of supply steam rising during the starting period, will be discussed in this article against the background of the existing state of automation of block turbo-sets.

The object of automation and its range

The object of automation is a turbo-set of 215 MW rating running in a block with a bituminous coal fired steam generator. The nominal parameters of the steam generator and the turbine are given in Table 1. The turbine is composed of the high pressure (HP), the intermediate pressure (IP) and the low pressure (LP) cylinders.

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Table 1

The nominal parameters of the steam generator and of the turbine

Boiler	Pressure of the steam	152 kG/cm^2	14.9 MN/m^2
	Pressure after superheater	129 kG/cm^2	12.7 MN/m^2
	Pressure after interstage reheater	23 kG/cm^2	2.3 MN/m^2
	Temperature of the steam	540°C	813 K
	Temperature of the water	240°C	613 K
	Rate of flow of the steam	620 t/h	172 kg/s
Turbine	Power	215 MW	215 MW
	Speed	3000 obr/min	311 rad/s
	Pressure of the steam	129 kG/cm^2	12.75 MN/m^2
	Temperature of the steam	535°C	808 K
	Pressure after interstage rh.	23.6 kG/cm^2	2.31 MN/m^2
	Temperature after interstage rh.	535°C	808 K
	Pressure in the condenser	0.049 kG/cm^2	0.004 MN/m^2

The HP and LP cylinders are of the double-casing type, which fact, according to the assumptions of the designers, should ensure the distribution of temperatures in the turbine metal more equal than it takes place in single-casing cylinders, and possibly a faster and easier starting of the turbine.

The nominal distribution of temperatures in the inner casings of the turbine under the load of 215 MW is determined by the course of the temperature changes of the steam flowing through the turbine, which is illustrated in Table 2.

Table 2

The nominal distribution of the temperatures and pressures in the turbine under the load 215 MW

	Pressure		Temperature	
	kG/cm^2	KN/m^2	°C	K
Before HP cylinder	129	12650	535	808
After 9 stage	37.9	3716	368	641
After 12 stage	25.3	2480	317	590
Before IP cylinder	23.6	2314	35	808
After 15 stage	11.5	1127	447	720
After 19 stage	4.79	470	334	607
After 21 stage	2.7	264	268	541
After 23 stage	1.19	117	188	461
After 25 stage	0.25	24.5	64.6	337.6
In the exhaust	0.05	4.9	30	303

The turbo-set is equipped with an automatic system of hydraulic control, with the governor valves before the HP and IP cylinders actuated by separate servomotors; the so called starting slide valve makes possible a change in the relation of openings of the HP and IP valves. At present the rise of the rotational speed and of the turbo-set loading is controlled by the operator by manual action on the synchronizer and on the starting slide valve.

The starting system of the turbo-set is presented in Fig. 1.

The HP reduction and desuperheating station *RS1* makes possible directing of the steam from the steam generator to the interstage reheater, bypassing the HP cylinder of the turbine. It constitutes, therefore, a safeguard of the reheater against burning out at the beginning of the starting period of the block, when the turbine rotor does not rotate.

During this period the steam from the interstage reheater flows to the turbine condenser through the reduction stations *AR* (*AR2* and *AR4*).

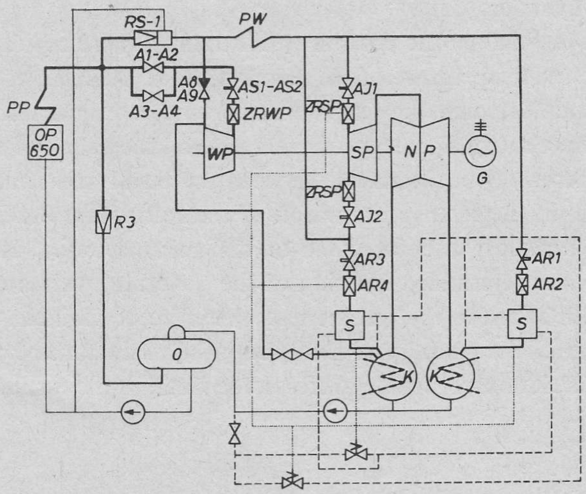

Fig. 1. The starting system of the turbo-set

During starting of the turbo-set the reduction stations *AR*, controlled in a system of hydraulic governing of the turbine, direct the excess steam produced by the steam generator to the condenser according to the actual requirement of the turbine. The *RS1* station is equipped with a separate system of automatics.

As a result of the analysis of the anticipated working conditions of the block it was assumed that during the first stage of automation of the block turbo-sets startings, startings after 2 - 36 hour standstills i.e. startings from hot condition, when the temperatures of HP and IP in the plane of the governing stages are approximately 350°C or more, will be taken over by sequence control.

To ensure that the ASURT system of starting automatics can begin to function all the auxiliary equipment of the turbo-set and the turbo-set itself should be efficient and the following initial conditions should be fulfilled:

a) the oil circulation should be started and the oil should have the proper, defined in the factory instructions, temperature and pressure,

b) the barring (turning) gear is operating,

c) the pressure in the condenser is nominal,

d) the vacuum load limiter is switched off.

The systems of the starting automatics which constitute ASURT are treated as supplementary ones and all the systems of automatics, safeguards and signalling, constituting standard factory equipment of the turbo-set, are retained.

The conception of starting and of shutting down the turbo-set

Control of the flow rate of the steam supplied to the turbine will take place by means of the speeder gear (synchronizer) and the governing valves before the HP and IP cylinders of the turbine.

It is possible, by acting on the starting slide valve, which changes the relation of openings of the HP and IP valves, to start the turbo-set by supplying the steam to the intermediate and low pressure cylinders only.

Such starting is justified by the possibility of attaining more rapidly the required steam temperature due to the temperature of the metal of the IP cylinder, as the steam generated in the boiler is superheated in the cascade arrangement: primary superheater-interstage reheater (Fig. 2). The control signals are current signals, the values of which depend on the differences of temperatures in the metal, between the metal and steam at selected points of the turbine, and on the relative expansion of the rotors and the cylinders.

Starting of the turbine will be executed on slip parameters i.e. at rising pressure and temperature. At a set, determined opening of the governing valves the quantity of heat energy supplied with steam to the turbine may therefore be variable.

In order to maintain the quantity of energy supplied to the turbine constant, as required e.g. by the actual distribution of temperatures in the metal of the turbine and by the relative

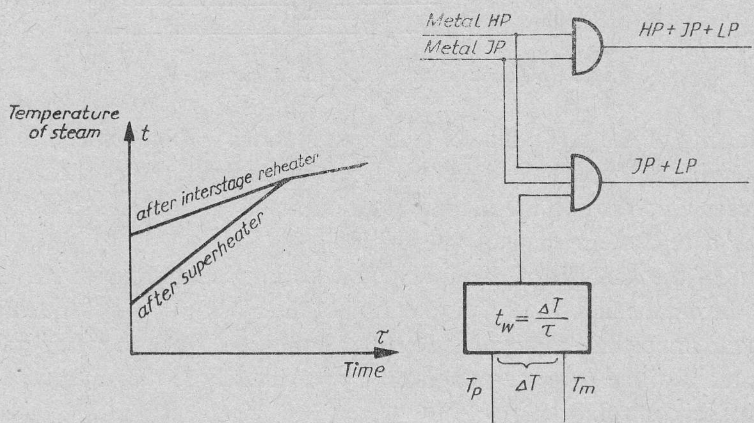

Fig. 2. Selection of starts: HP+IP+LP or IP+LP, bypass HP

elongations, it may be necessary to partially close the valves during the starting period. Hence the motors actuating the speeder gear and the starting slide valve ensure two-directional movements of the governing valves, depending on the control signals.

The control signals directed to the boiler operator's control desk also influence the magnitude of the temperature of the steam supplied to the turbine. The increase of turbine speed is realized according to numerous time programs determined on the basis of the starting curves given by the turbine producer and selected according to the thermal condition of the turbine.

Loading of the turbine during starting results from the intensity of the flow of steam determined on the basis of steam conditions, the distribution of temperatures in the metal of the turbine and on the arrangement of the relative elongations.

Unloading of the turbo-set is carried out according to the programmed load decrease at various speeds of unloading in MW/min, depending on the technical condition of the turbine before setting the speed and during unloading, which is also associated with the variations of steam conditions.

Besides the selected control signals from the detectors and from the measuring instruments for checking the temperatures, the bearing vibrations, the eccentricities of the shafts and the expansions, signals limiting the starting speeds, cutting off the steam supply to the turbine or acting on the emergency tripping of the turbine are also transmitted.

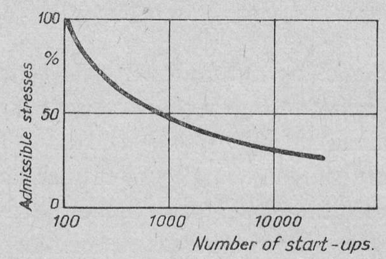

Fig. 3. The relation between the admissible stresses as a function of the number of start-ups

The loading of the turbo-set will take place in such a manner so as not to allow neither exceeding of the admissible stresses in the turbine casings nor the admissible relative elongations.

Due to the lack of possibilities of direct measurements of stresses in the metal of the turbine it is assumed that they depend on the temperature differences between points defined on the turbine casings. Admissible stresses, hence also the temperature differences, depend on the frequency of the start-ups and on the absolute values of the temperatures at the above mentioned points of the casings.

The relation between the admissible stresses in the turbine casings is illustrated in Fig. 3 as a function of the number of start-ups. The conclusion from this drawing is that after 1000 start-ups the admissible stresses are equal to the half of their initial value. Momentary-unstable stresses are considerably more difficult to cope with from the point of view of recording their appearance. Fig. 4 illustrates the relations of the unstable stresses in the turbine casings as a function of the rate of temperature rise in the turbine casing.

It is evident from Fig. 4 that unstable stresses may be eight times greater than admissible equal units at the rate of temperature growth of the casing equal to 10°C/min. They are particularly dangerous as they lead to uncontrolled creep in the turbine casings.

Fig. 5 illustrates the admissible temperature difference in the casing as a function of the casing temperature. This difference decreases at the metal temperature of 600°C to 5% of the at the casing temperature of 100°C.

Maintaining of the steam conditions should be carried out automatically or manually in such a manner that the pressure and the temperature of the steam will rise at a predetermined rate. This refers to the initial (live) steam as well as to the reheat steam.

The temperature of the live and reheat steam should exceed the temperature of the internal casing of the turbine by 10 to 70°C. If the pressure of the initial steam rises faster then

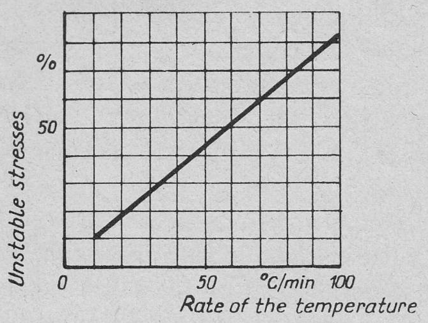

Fig. 4. The relation of the unstable stresses as a function of temperature rise in the turbine casing

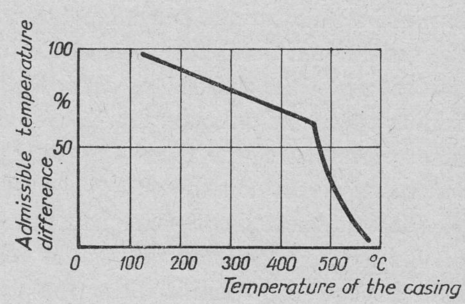

Fig. 5. Admissible temperature difference in the casing as a function of the casing temperature

the steam dumping station should open at the moment the set value is obtained. The HP and IP governing valves should be completely open to ensure a uniform heating of the governing stage chambers.

Every sudden change of pressure, and therefore of the load, results in a step change of temperature differences in the metal followed by a step change of stresses. Hence, in order to maintain constant temperature differences in the casings, it is necessary, besides applying a steam temperature control, to ensure the appropriate rate of steam pressure changes.

Operation on slip steam parameters does not, however, ensure full utilization of the accumulated boiler capacity and the rate of load increase is limited by the boiler output.

These limitations are eliminated by a combination of the slip parameter operation with an operation on constant pressure.

Such a manner of running a start-up is based on the fact that when the boiler assures the required change of the pressure, the turbine is loaded at variable pressure, while in the case when the pressure deviates from that which is required, the turbo-set operates at a continuous pressure before the governing valves up to the time of an appropriate rise of the pressure. It is necessary, however, to take into consideration that the temperature variation in the governing stage will be greater than in the case of an operation at a slip variable pressure.

According to the diagram in Fig. 6 the rate of steam flow to the turbine is controlled in relation to the actual steam conditions and to the temperatures of the casings. Such procedure is automatic and does not depend neither on decisions of the operator nor on unprecise running of the boiler which is corrected by the flow feedback. The system operates in such a manner that if the steam flow is cut off e.g. the IP part, the decreasing steam-metal temperature difference will bring about a decrease in the quantity of steam being transferred to the turbine casing. If simultaneously the set steam flow, e.g. M_{DZADSP}, is cut off and the rise of the temperature of steam from the interstage reheat is stopped, the quantity of heat transferred to the casing is further decreased.

The selection of systems with feedbacks for controlling the heating of the casing is justified by the necessity to avoid the influence of variable loading of the turbine and of running the boiler in a manner deviating from that called for by the program for operation for the turbo-set. The process of heating the turbine is therefore controlled in a dual manner i.e. by maintaining a determined reaction between the steam flow rate and the steam-metal temperature difference and by an appropriate steam temperature control which is carried out by the boiler operator.

The ultimate number of temperature difference measuring points may be determined, for lack of operational experience, only after an investigation.

It is expected that the number of measuring points will be decreased and that they will be selected from among those proposed up to now.

The loading and heating of the turbine takes place at slip parameters of the initial and reheat steam when the boiler ensures such a manner of operation. If the boiler does not fulfil the requirements set by slip loading these operations will have a combined character.

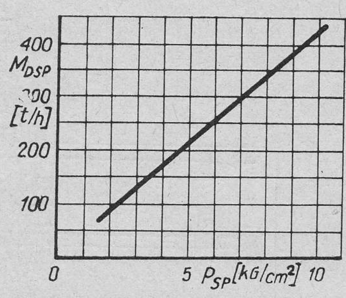

Fig. 6. The relation between the rate of steam flow and a pressure of steam before the IP part

Fixing the position of the governing valves of the HP and IP parts of the turbine does not lead to the stabilization of the steam flow as the loading depends on the pressure variation in the boiler and in the interstage reheater. This is the basic difference in the start-up between the block supply and the collector supply of the turbo-sets which result from the slip-variable parameters of steam.

Due to the design considerations and to the manner of piping layout of the IP part, and above all to the lack of straight sections, measuring of the steam flow rate to the IP part by the Venturi tube method is possible. In connection with this the steam flow rate and the pressure drop on the first group of stages of the IP part (from the governing stage to the third extraction point) will be utilized for controlling the steam flow rate to the IP part, as is shown in Fig. 6.

Fig. 7 presents the diagram of the system measurements and automatics for controlling the loading of the turbo-set.

The control of the rate of steam flow to the turbo-set is carried out by means of the governing valves *ZR* in the system of hydraulic governing of the turbine by acting through the speeder gear and loading gear (the so called synchronizer) and the starting slide valve (see p. 4). The speeder gear and the slide valve are controlled by magnetic amplifiers *W1* and *W2* depending on the actuation error between the set value and the actual (measured) value of the rate of steam flow to the HP or IP casing of the turbine.

The set value of the flow rate is formed in the computing arrangement, respectively HP or IP, depending on the temperature differences of the steam and the turbine metal and the set value experimentally determined during controlled start-ups, of the heat penetration *Q* (in accordance with the described in p. 4 conception of the control of turbine loading). In case of equipping the turbo-set with a system of electrohydraulic governing the above mentioned signal from the difference of the steam flow rates is directed to the electrohydraulic

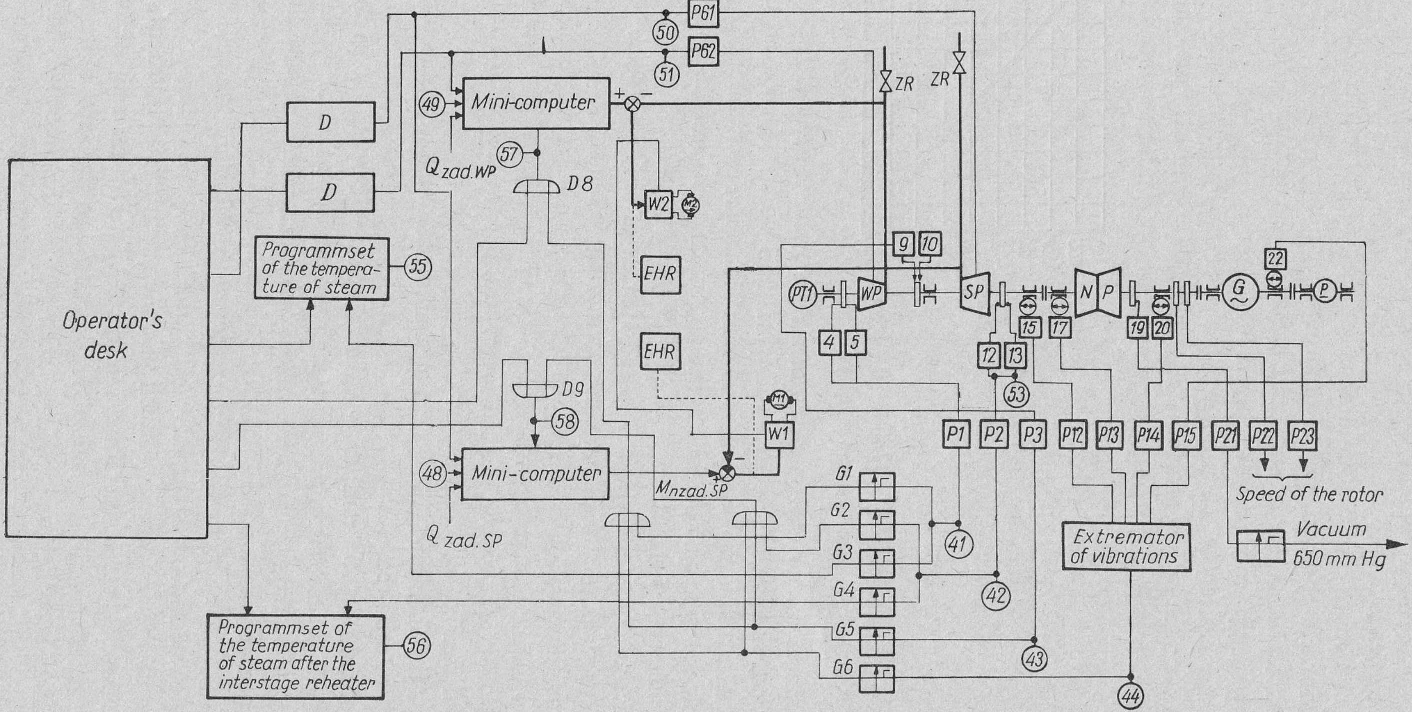

Fig. 7. The system of measurements and automatics for controlling the loading of the turbo-set

transducer (*EHR*), acting through it upon the governing system of the turbine. The differentiating elements differentiate the measured temperatures at the representative points of the metal signalling as a result the rates of change of these temperatures. The measured mechanical values (vibrations, displacements) and thermal values (temperatures and their differences) are converted into electrical signals in the transducers *P*. Fig. 7 shows a fragment of the design of the ASURT system and the numeration of the elements of the automatics in the figure is such as in that design.

Threshold limiters *G* safeguard against exceeding the admissible values of the measured magnitudes. The signals from the limiters cause stopping or recession of the turbo-set loading process.

The course of the starting operations (which are marked, e.g. 58 in Fig. 7) their run being signalled in the logical paths influences, among others, the value of the set flow rate and the programming of the temperature changes of the live and reheat steam.

End notes

The ASURT system ensures universal a control of the condition of the turbo-set during the starting and the stopping periods and corrects that condition in the direction of improving and accelerating a start-up and increasing its safety.

From among 80 signals from measurements of values controlled during operation of the turbo-set 4 groups of control signals were selected: the speed during the starting period, the steam and metal temperature differences, the flow rate during loading and the power during the loading period. The remaining values measured from safeguarding signals, various for different levels of the controlled values, and interlooking signals.

The information acquired from technical literature and direct contacts with designers of automatics systems (LMZ, Bergmann Borsing, CNIIKA) justify stating that application of the so called active starting automats, i.e. such that control and not only check the operation of the equipment, is a modern solution.

The ASURT devices are the equipment of the active type. Adaptation of the ASURT system to a co-operation with a turbo-set equipped with a system of electrohydraulic governing is possible and it is anticipated in the design of the system to project.

Realization of the project, preceded by working out the necessary shop and assembly documentation, requires a co-operation with research and designing institutions of the power industry.

The experience to date in this range allows anticipation of successful development of work on automation of the power equipment.

Automatyczne sterowanie układem rozruchowym turbozespołu

Streszczenie

W artykule opisano zasady działania i budowy systemu automatycznego sterowania układem rozruchowym turbozespołu (ASURT). ASURT obejmuje trzy etapy rozruchu i odstawienia turbozespołu:

1) sterowanie wzrostem prędkości obrotowej według wybieranych programów czasowych,

2) sterowanie obciążeniem turbozespołu przy zmiennych, tzw. poślizgowych parametrach pary; ASURT działa na tym etapie jak układ adaptacyjny,

3) odciążanie turbozespołu według wybieranej przez operatora prędkości zmian obciążenia w MW/min.

Omówiono zależności między naprężeniami w korpusie i różnicami temperatur metalu korpusów turbiny oraz związek tych wielkości z ilością rozruchów.

Przedstawiono schemat układów pomiarowych i automatyki składającej się na układ ASURT oraz bieżące i perspektywiczne prace dotyczące automatyzacji turbozespołów w blokach energetycznych.

Автоматическое управление пусковой системой турбоагрегата

Резюме

В статье описываются принципы действия и конструкции системы автоматического управления пусковой системой турбоагрегата (АУПСТ), польск. ASURT. АУПСТ охватывает три этапа пуска и остановки турбоагрегата:

1) управление нарастанием скорости вращения по избранным программам ее распределения по времени,

2) управление нагрузкой турбоагрегата при переменных, т. наз. скользящих параметрах пара; АУПСТ на этом этапе действует как адаптационная система,

3) сброс нагрузки турбоагрегата с выбираемой оператором скоростью изменений нагрузки в Мвт/мин.

Обсуждаются зависимости между напряжениями в корпусе и разницами температур металла турбинных корпусов, а также зависимости этих величин от количества пусков.

Представлена схема измерительных систем и автоматики, образующей систему АУПСТ. Обсуждаются текущие и перспективные работы, касающиеся автоматизации турбоагрегатов в энергетических блоках.