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exist for the publication of theoretical and experimental investigations of all aspects of the mechanics and thermodynamics of fluid-flow with special reference to fluid-flow machinery

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STEAM TURBINES OF GREAT OUTPUT

Gdańsk, September 24 - 27, 1974

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III НАУЧНАЯ КОНФЕРЕНЦИЯ

на тему

ПАРОВЫЕ ТУРБИНЫ БОЛЬШОЙ МОЩНОСТИ

Гданьск, 24 - 27 сентября 1974 г.

PRACE INSTYTUTU MASZYN PRZEPŁYWOWYCH
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Poland*

ZAMECH Power Station Steam Turbines

1. Introduction

Some manufacturing and operation problems are presented herein basing on the experience acquired by the ZAMECH-works during last years and concerning condensing steam turbines of 125 MW and 200 MW output produced there.

These turbines represent the substantial part of dynamically developing steam turbine production at ZAMECH-works. The turbine production started in 1950, and reached ca 1500 MW of annual production last year.

The development of steam turbines production is presented in Table 1, and Fig. 1 shows the increase of size of produced steam turbine units.

Table 1

Year	1950	1955	1960	1965	1970	1973	1974
Production in MW	0,5	16,5	186,0	471,0	1135,0	1407,0	ca 1950

Characteristic of that production is that for a particular size of condensing steam turbine it started from using either licence documentation (in case of 125 MW – licence

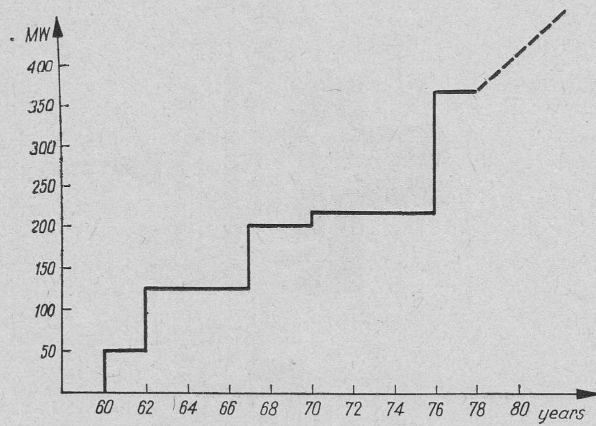

Fig. 1. Size of manufactured units

* ZAMECH – Mechanical Works, Elbląg.

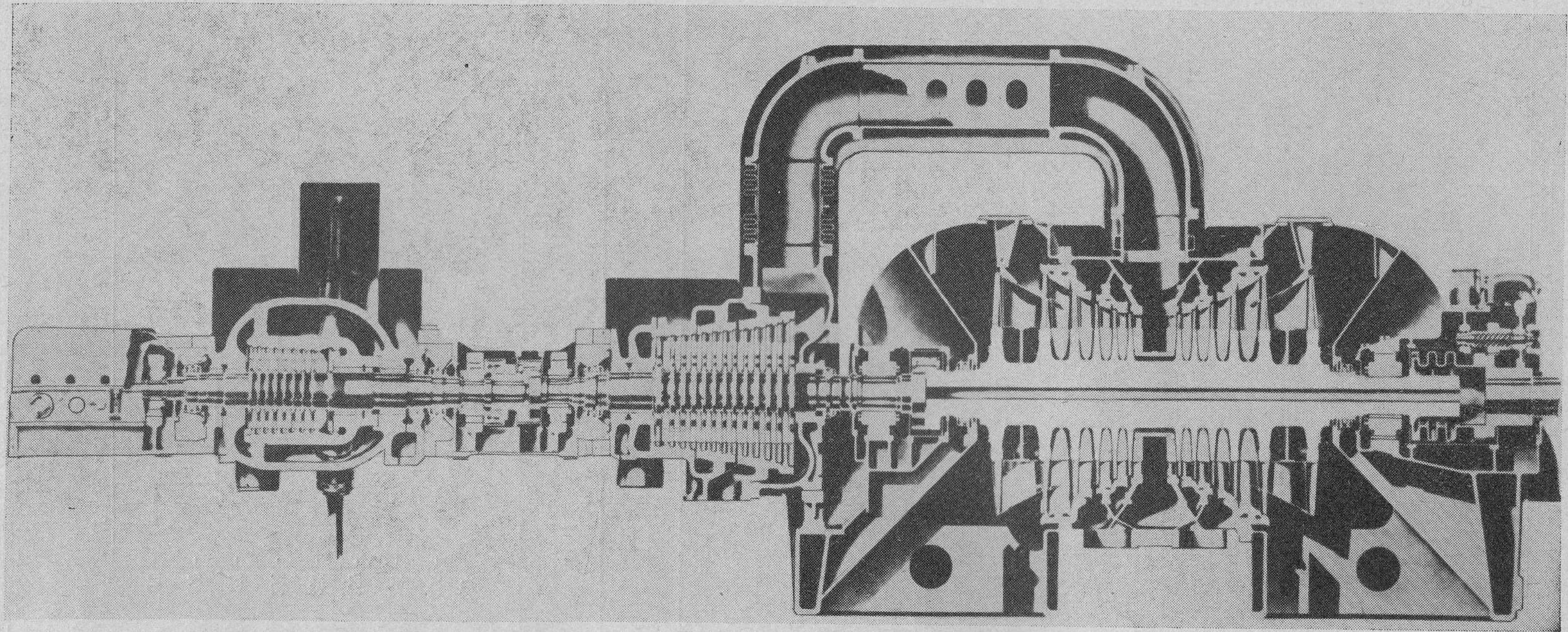

Fig. 2. AEI-ZAMECH TK120 turbine

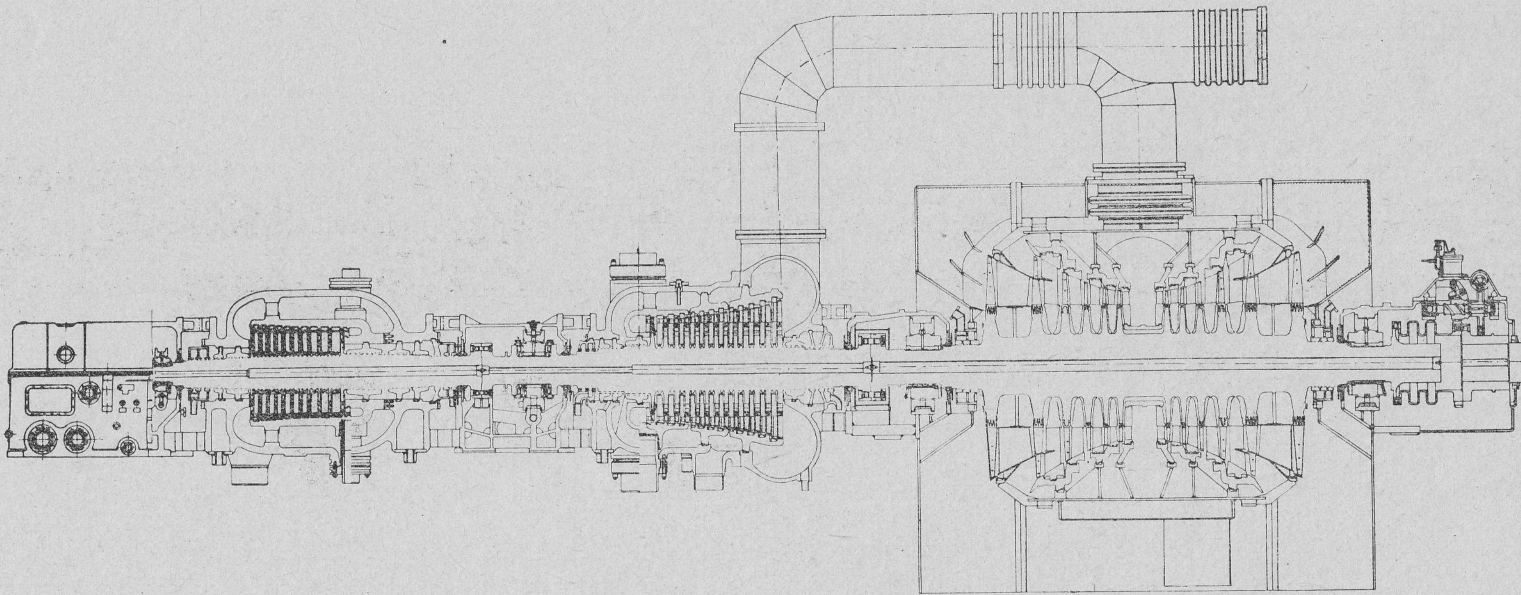

Fig. 3. ZAMECH 13K125 turbine

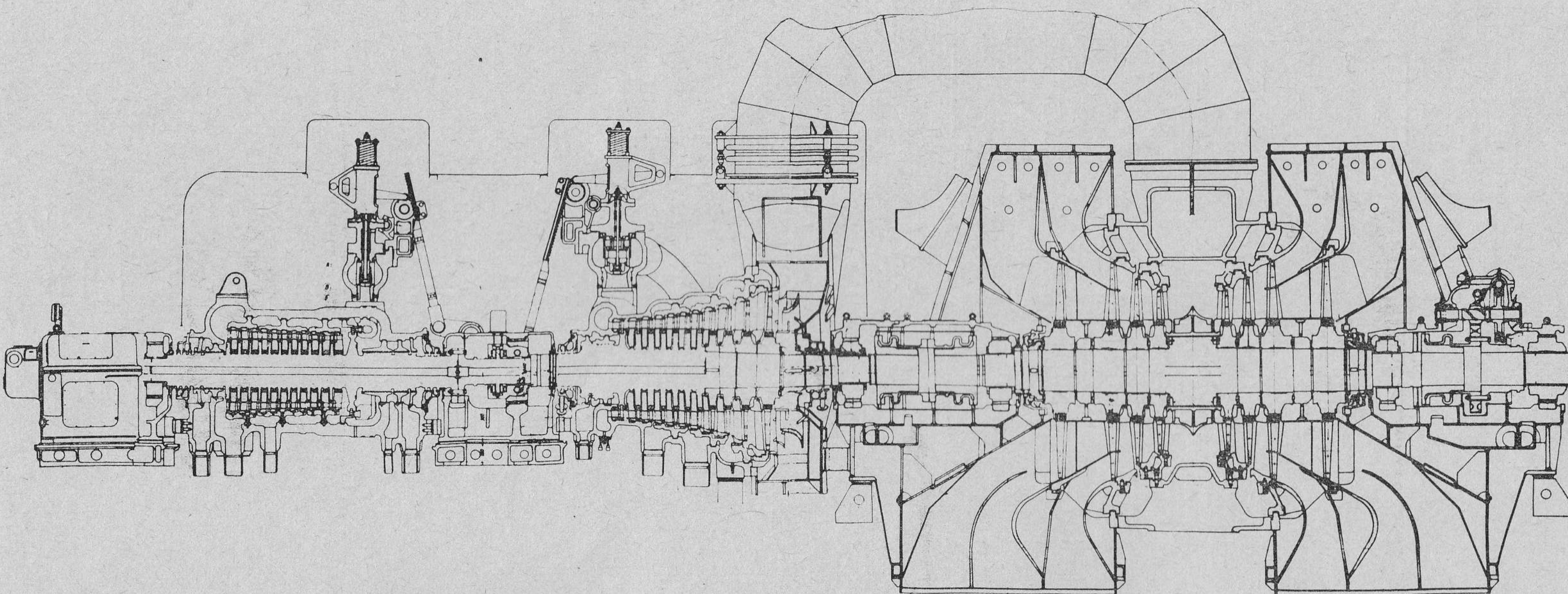

Fig. 4. LMZ-ZAMECH TK200 turbine

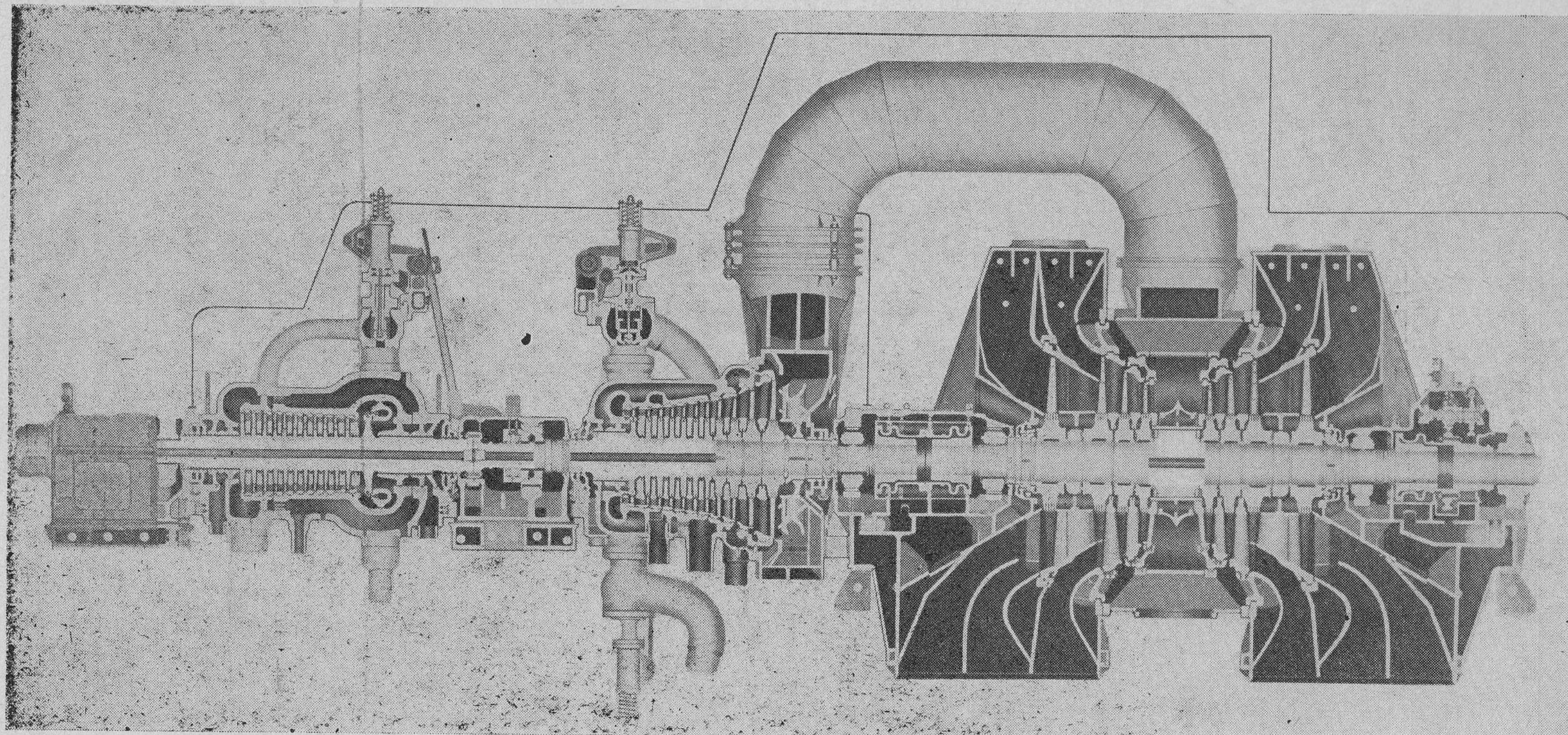

Fig. 5. ZAMECH 13K215 turbine

of AEI) or technical aid (as in case of 200 MW – LMZ documentation). Both above mentioned types as received from the other manufactures were standard units and not fully corresponding to the requirements of the Polish Electricity Board. From the early beginning of production they have been intensively developed and modified, so that in the present form their design elaborated by ZAMECH-works is completely different from the originals. The different design features are visible already in Figs 2, 3, 4 and 5, which show langitudinal-sections of these turbines:

Fig. 2 – 125 MW original turbine of AEI,
Fig. 3 – 125 MW turbine of Zamech design,
Fig. 4 – PWK-200 turbine of LMZ,
Fig. 5 – 13K215 turbine of Zamech design.

Basic reason of modification of AEI design were unsatisfactory operation results caused by the sensitivity of the turbine to even small steam condition changes (which resulted in excentricity variation and increase, dynamic state deterioration etc.).

On the other hand the turbine PWK-200 was designed as a turbine for basic operation and did not have sufficient thermal flexibility necessary for Polish electricity system. The turbine governing system was not accomodated for frequent starts and shutdowns and operation at very low load.

Some problems and design solutions introduced, which eliminated these difficulties, are treated in detail in further part of the report.

Here we should like to specify some more important solutions applied in the above mentioned turbines.

For 125 MW unit one can mention:

– change of rotor design and supporting system (four, instead of five, bearings arrangement),
– introduction of double-shell design in IP part of the turbine,
– introduction of central push-pull keys instead of transversal keys on palms,
– introduction of rigid LP cylinder,
– introduction of LP reducing and desuperheating by-pass to the condenser,
– application of steam outer glands, instead of water glands,
– changes in governing system concerning simultaneous beginning of HP and IP governing value opening, enabling the operation of turboset with various types of boilers.

For 215 MW unit the following can be mentioned:

– double-shell design of HP and IP cylinders,
– HP and IP control valves operated by two independent relay gears,
– application of LP reducing and desuperheating by-pass to the condenser,
– introduction of jacking oil system,
– change of HP and IP cylinder supports, eliminating misalignment due to the temperature changes etc.

2. Detailed problems

Modern electricity system determines specific requirements to be met by turbines. These are:

– possibility of operation at various loads in the range from no-load to the maximum output, possibility of frequent shut-downs and starts and in extreme case possibility of daily two shift-operation (so-called "thermal flexibility"),

– dynamic stability i.e. operation in various conditions at possibly lowest vibration level,

– possibly small amount of work during overhaul, with trends to extend the operation period between subsequent major overhauls from 3 to 4 years,

– high reliability.

The purpose modifications of turbines TK120 and TK200, carried out by Zamech, was to meet the above mentioned requirements.

2.1. Thermal flexibility

The fulfillment of this requirements can be obtained by:

2.1.1. Application of double-shell cylinders

This allows to reduce the thickness of each casing walls and flanges due to the pressure difference reduction on both side of wall and to reduce the size of the joining bolts. Thinner walls allow to increase the speed of heating, and therefore consequently quicker start and loading of the turbine. Originally in the TK120 turbine only the HP cylinder was of double-shell design. As a modification, a double-shell cylinder was used in the IP part.

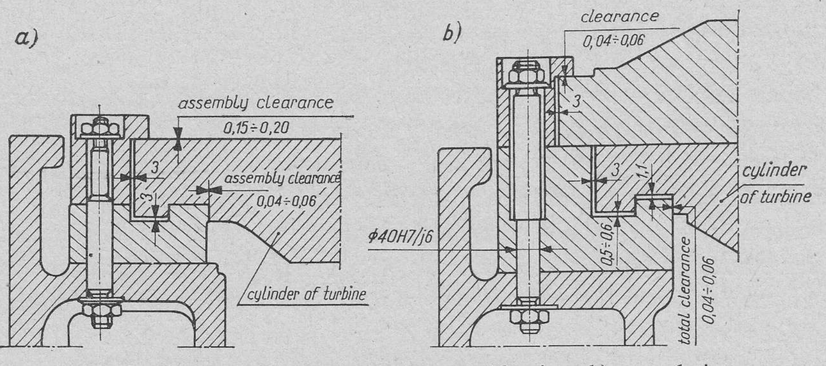

Fig. 6. Cylinder support; a) before modification, b) new design

Double-shell cylinders have been used as well in HP and IP parts of the 200 MW turbine. Simultaneously their supports have been changed in order to eliminate cylinder misaligment.

In the present design HP and IP cylinders are supported exactly in the centre line of the turbine, with palms integrally incorporated into the upper parts of the cylinders.

The original solution and the new one are shown in Fig. 6. The reduction of flange size and thickness allowed to eliminate flange heating during the start and loading of the turbine (see Fig. 7).

For inner cylinder the 21HMF material has been used; it is better for handling during cast repairing and heat treatment processes and less sensitive to the crack generation, than the 17HMF material, applied formerly.

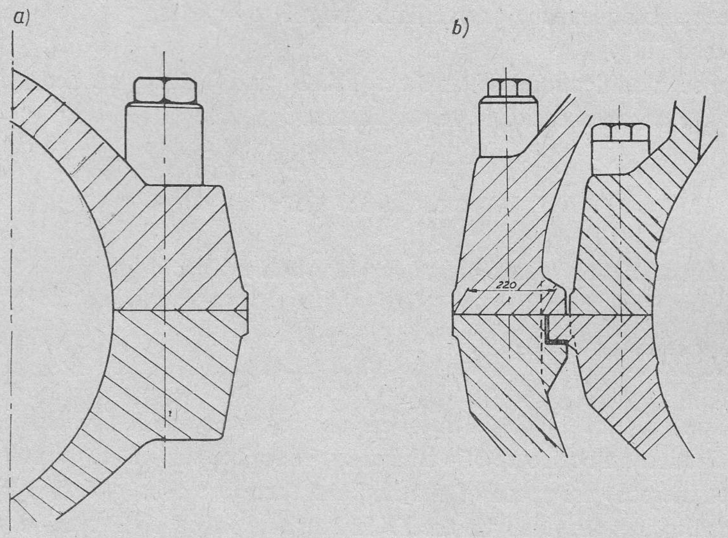

Fig. 7. Cylinder flange; a) before modification, b) new design

2.1.2. Modification of turbine governing system to meet the requirement of frequent starting and loading

The boilers applied in boiler-turboset units with TK120 and TK200 turbines did not require steam flow through reheater during the start.

In the starting system only one HP reducing and desuperheating by-pass was provided, for dumping live steam during the start-up of the turbine.

The governing systems of both these turbines had such control valve opening characteristic, that starting up of the turbine took place at fully opened IP control valves. This system was sufficient from the point of view of the boiler requirement, but longer operation of the turbines proved, that from the point of view of turbines such lack of control of reheat steam admission to the IP cylinder had a negative influence. During the standstill of the turbine much quicker cooling of boiler and steam piping and particularly of reheat steam piping takes place.

After a certain period of standstill, temperature of steam supplied during initial stage of the following start-up is consiserably lower than that of the rotor and IP cylinder.

This causes a large temperature difference across the cylinder wall and, as a result, its deformation and negative elongation (contraction) of the IP rotor, which in an extreme case may cause a reduction of axial clearances beyond the permissible limits and even make starting the turbine again impossible.

For that reason the starting-up system as shown in Fig. 8 is applied at present; it is equipped with live steam reducing and desuperheating by-pass which admits the steam to the cold piping of reheat steam, and with LP reducing and desuperheating by-pass which bypasses entirely or partially the hot steam from the reheater before IP cylinder to the condenser. This system is known as a two-stage by-pass starting system. It enables accomodation of steam condition to the actual thermal state of the IP part.

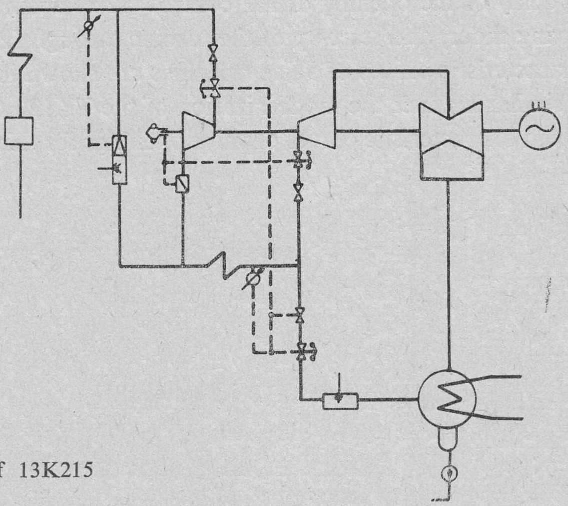

Fig. 8. Starting up system of 13K215 turbine

At the beginning of the production of TK200 turbines the adaptation of existing governing system for such kind of starting up diagram system was made in such a way that the interceptor stop valves were used as a control valves for steam admission control to the IP part (see Fig. 9).

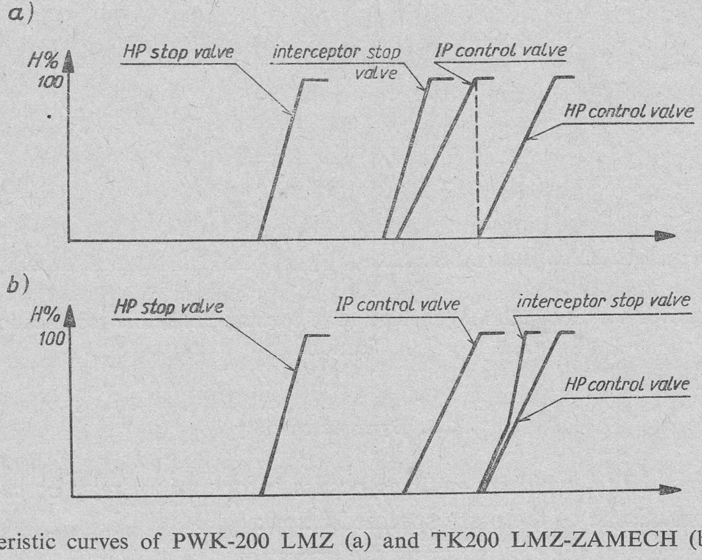

Fig. 9. Characteristic curves of PWK-200 LMZ (a) and TK200 LMZ-ZAMECH (b) turbine valve openings

The complete modification of TK200 turbine governing system consists in separation of HP and IP control valves relay gear in two separate relay gears, and introduction of LP reducing and desuperheating by-pass. This solutions enables:

- reintroduction of the IP interceptor valve original function,
- simultaneous opening of the HP and IP control valves,
- delay of the opening of HP control valves against the IP control valves (by means of starting slider) and start-up of the turbine through IP and LP cylinders only.

Characteristic curves of valve openings are shown in Fig. 10.

In similar manner the modernization of the TK120 turbine governing system has been arranged. Characteristic curves of valve openings for this turbine are shown in Fig. 11.

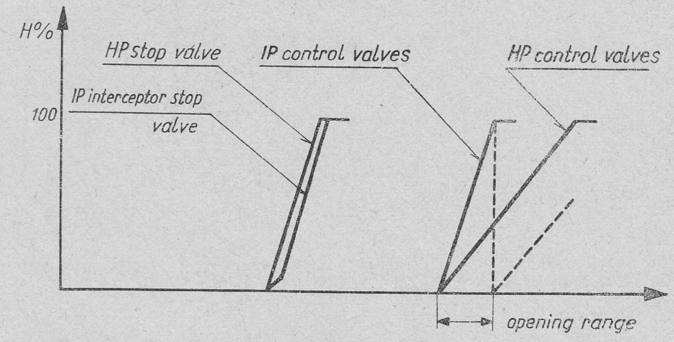

Fig. 10. Characteristic curves of 13K215 turbine valve openings

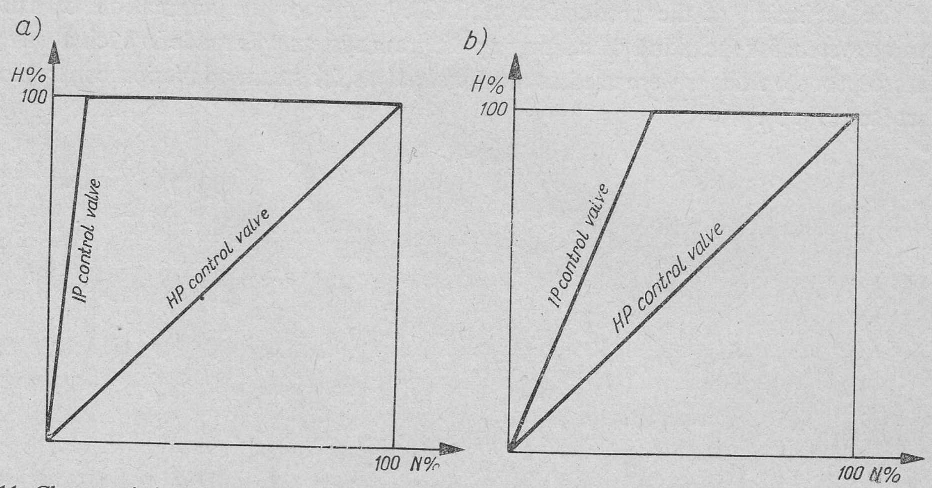

Fig. 11. Characteristic curves of 120 MW turbine valve openings; a) before modification, b) after modification

2.2. Dynamic stability

Dynamic instability, which sometimes occurs in operation, may be caused by many different reasons. Some of them are specified below:

- misalignment of the shafts during the operation,

– instability of bearings,
– instability of the rotor, caused by glands.

With respect to the dynamic stability the TK120 and TK200 turbines are principally different. TK200 turbine proved to be highly stable during operation and for this reason no new solution was introduced during the process of this turbine modification.

On the other hand many troubles occured with unstable running of TK120 turbines, leading sometimes to the shut-down and necessitating the correction of the turboset.

For this reason particular attention was drawn to this problem during modification.

2.2.1. Misalignment of the shaft-line

The research, carried out by Zamech and Thermal Technique Institute in Łódź has shown [1, 2, 3] that reasons of misalignment of shaft-lines were:
– small rigidity of LP cylinder,
– thermal distortions of IP cylinder,
– thermal deformation of the foundation.

The LP cylinder design was entirely changed during the modification. The rigid, so called "case-type" design of LP cylinder supported on the whole rim around, was introduced. The inner part of the LP cylinder is fixed in a way ensuring free thermal expansion.

Fixpoint of the whole turbine was placed at the center line of inlet to the LP cylinder.

Simultaneously, during the designing of the new IP double-shell cylinder the method of its connection with LP cylinder was changed. Application of double-shell IP cylinder, as mentioned above prevents its unpermissible thermal deformation.

As for the foundation problems, the new technical requirements for design and construction of the turboset foundation initiated by Zamech were elaborated. This highly improved the quality of recently constructed foundations.

One of the solutions was also the application of thermal shields in this areas of foundation which are exposed to the heat from hot parts of the turbine and piping.

2.2.2. Instability of bearings

This feature is known to turbine manufacturer and to the operating staff in power stations as well. In the case of TK120 thermal distortions of the foundation and the design of shaft-line, in which the whole turbine shaft-line was supported on five bearings (see Fig. 2) and two bearing were located close to each other in the central pedestal between HP and IP part, significant load change occured at the particular bearings during turboset operation.

The calculations carried out at the Research Department of Zamech showed that in certain cases bearing No. 2, counting from the front of the turbine, can become completely unloaded whereas bearing No. 4 can be unloaded partially, up to 50% of nominal-load.

As a result the oil-whip and unstable dynamic behaviour have occured. Bearing support system did not also ensure proper margin of the critical speed of the IP rotor. The bearing system of modified turbine was completely changed (see Fig. 3). Four-bearing system was applied, and the former bearing No. 4 was moved from IP rotor to the LP rotor.

2.2.3. Gland influence

The unstable work of the rotor in the glands was not observed in Zamech practice but with regard to the TK120 turbine significant influence of operation of water glands on the dynamical behaviour of the turbine was noticed.

The water external closing glands in the HP and IP part of this turbine were replaced by a conventional and tested design of steam glands.

Steam seals with controlled pressure in the end of each outer gland in HP and IP part, analogically as in 200 WM turbine, have been applied. This also allowed to avoid the cold water supply to the very hot rotor during a start-up following a short shut-down.

2.3. Reduction of work to be done during overhauls

One of the most important factor extending the total time-period of major overhaul and increasing labour during overhauls were large deformations of the turbine cylinders. They resulted in:

– leak in the joint faces of the cylinders parts (horizontal or vertical),

– distortions in free thermal expansion of turbine, asymmetrical expansion of left- and right-hand sides of the turbine, palm distortion, and blocking on the transverse keys etc.,

– rotating part seizing in the elements of stationary part,

– deteriorated dynamical state.

Characteristic behaviour of the single-shell design of high temperature cylinders is their very large deformation during the operation, especially in transient conditions.

Unknown are to us turbines of single-shell cylinder design in HP and IP parts which after one or two years of operation would not require serious works, opening of the cylinders for the purpose of correction because of deformation. These deformations may be smaller or larger. In extreme case they require, after some years of operation, the removal of the cylinder from foundation in order to carry out the correction by machining. This must be done especially for turbines which run frequently in transient conditions or in two-shift operation. In contrary to this, a double-shell cylinders design has even after some years of operation very small distortions, which even do not require correction of the joint surfaces of cylinder by scraping.

The application of double-shell cylinders in modified turbines and abandoning of flange heating had also another aspect.

Not only improvement of turbine thermal behaviour was obtained, resulting in higher flexibility of operation, but also significant reduction of labour and the time of duration of overhaul was possible.

Another feature of the original design of TK120 turbine were radial steam inlets to the HP cylinder. As a result dismantling of the inlets was required during overhauls, since otherwise opening of the cylinder was impossible.

At present paralell vertical inlets version, applied in modified turbines, dismantling of the cylinders without dismantling of inlet admission pipes is possible.

To the bearings of the TK200 turbine the jacking oil system was applied, ensuring less wear and therefore affecting positively, together with other features, the increasing of time-period between the overhauls.

2.4. Results of modification

Modified TK120 turbine (recent symbol 13K125) has been manufactured and recently is being erected in the Siekierki Power Plant in Warsaw. With regard to this turbine we can speak yet about expected results.

14 modified TK200 turbines, recent symbol 13K215, are already in operation; further are under erection or manufacturing.

Extensive research work already carried out in P. S. Kozienice and P. S. Pątnów, made full evaluation of results of modification possible. As achieved results we can specify:

2.4.1. Easy co-operation and adaptation to any boiler type

The modified turbines operate in boilter-turbine units for hard coal with boilers of various designs and characteristics. Two turbines are in operation with the boilers for residual oil (mazout). In all cases, the turbine governing system and steam dumping system operate correctly, enabling many variations of turbine starting up procedure to adopt to optimum thermal conditions.

Application of non-return valves on the HP cylinder outlet allows starting through IP and LP parts and the pressure control behind the reheater in the range of 3 up to ca 12 ata during the start-up of the turbine. Additional by-pass of non-return valves permits early heating up of HP cylinder from reheat cold line.

2.4.2. Starting times

The modification of design of the HP and IP cylinders, considerably thinner walls as well as other introduced features made possible quite a substantial reduction of starting times. 13K215 turbine is fully suitable for two-shift-operation. In Table 2 the starting times of TK200 and 13K215 turbines are given for comparison.

Remarkable is a relatively long time of cold start caused by very slow heating of outer HP and IP cylinders by steam. During starting up of first 13K215 turbine heating of the outer cylinder through steam admission to the space between inner and outer cylinder was

Table 2

Turbine type	Starting time in minutes			
	after short shut-down	after ca 8 hours shutdown	after ca 36 hours shut-down	cold start
TK200	50	115	295	400
13K215				
a) estimated	35	75	100	340
b) achieved	40	60	120	180
c) recommended by the Institute of Energetics	40	50	120	165

applied. This allowed the faster and controlled heating of outer shells of the cylinder. It also improved operating conditions of inner shells of the cylinders, to which on both sides the heat is admitted.

Certain elongation of starting time after the shut-down of $30 \div 36$ hours results from the fact that the boiler is cooled much faster than the turbine.

During the starting after twenty-four hours and longer shut-down the limiting criterion for the starting time is the permissible speed of increase of saturation temperature in the drum, which can not be higher than 1.5°C/min.

In consequence at slow rate of pressure rise in the boiler the power increase is limited by turbine governing valve flow capability. Starting time after short shut-down depends in principle on manipulative ability of turbine and boiler operators.

2.4.3. Other effects of modification of 13K215 turbine

Application of double-shell cylinders particularly in HP part of 13K215 turbines has allowed the increase of maximum permissible pressure in the governing wheel chamber.

In effect, using nominal boiler output of 650 t/h the turbines obtain continous rating of 215 MW. With the boiler output reserves used, a possibility of obtaining the maximum power (peak) up to appr. $218 \div 220$ MW exists.

During opening of cylinders on two different turbines, which was done after appr. 1.5 years of operation, it was noticed that no correction of cylinder joint facings is needed. A gap after unbolting was less than 0.2 mm. Formerly in single-shell cylinders the gaps reached the value of ca 1.5 mm and more at the same period.

It allows to draw the conclusion that the period between overhauls can be succesfully extended up to 4 years or even more.

97% availability was obtained already in the first year of operation of 13K215 turbines, which fully confirmed correct direction of modifications.

2.4.4. Effects of modification of 13K125

A considerable increase of availability and dynamic stability is expected with new 13K125 design.

3. Research and development activities

Obtainment of positive results in solving operating problems depends on possesion of high skilled staff of specialists and the adequate research basis.

Zamech beside their own Research Center base their development on co-operation with other Polish research institutions, namely:

– IMP PAN (Institute of Fluid-Flow Machinery of the Polish Academy of Sciences) – in the domain of flow problems in LP part of condensing turbines, particularly of two-phase medium flows.

– Politechnika Śląska (Technical University of Silesia) – in the domain of temperature and stress distribution in high temperature elements.

– ITC Łódź (Thermal Technique Institute – Łódź) – in turbine operation research (thermal, dynamic behaviour, and governing system research) and turbine HP and IP stage research.

– Politechnika Warszawska (Warsaw Technical University) – in the domain of strength calculation methods.

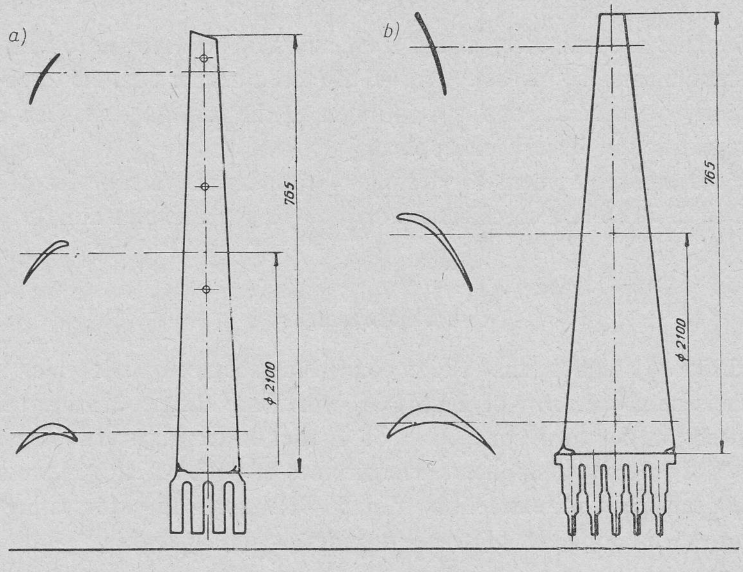

Fig. 12. Comparison of the last stage moving blade of old and new type for 13K215 turbine; a) original design, b) new design

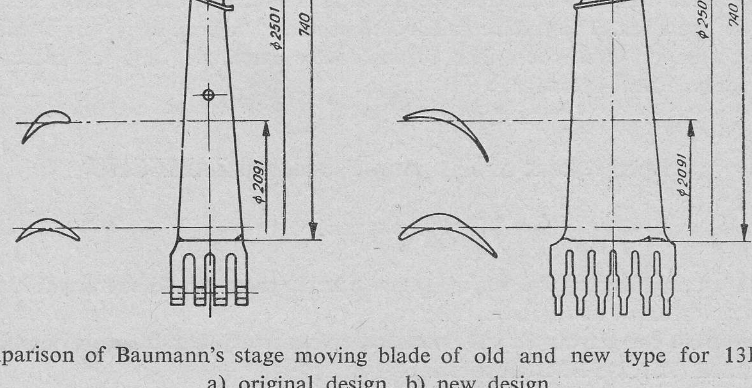

Fig. 13. Comparison of Baumann's stage moving blade of old and new type for 13K215 turbine; a) original design, b) new design

– Politechnika Łódzka (Łódź Technical University) – in the domain of the turbine stage research and many other organizations.

As an example, we should like to present recently finished and prepared for introduction to the 13K215 turbine the new design of LP part, which can be also applied in turbines already in operation.

Figs. 12 and 13 present the comparison of moving blades of the two last LP stages of original and modified version.

Main differences are resonably higher frequencies of new moving blades and lack of lacings (free-standing moving blades). Also, on the aerodynamic side, the three-dimensional flow is differently organized. For the diaphragm of the last stage profiled guide blades with moisture extraction have been applied.

The basic research equipment for testing of rotating moving blades of the last LP stages is, built in ZAMECH, a special stand driven by a condensing steam turbine of 8 MW rating.

4. Final remarks

We should like to mention, that beside condensing steam turbines which are the basic production, the second speciality of ZAMECH-works are district-heating turbines. They are based entirely on our own conception of district heating system, and also on our design solutions of different components. The turbines of both types, backpressure turbines and condensing turbines with extraction, from 50 MW up to 150 MW rating are used.

Further quick development of these turbines is anticipated.

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Supplement (inserted at the reading a proof in March 1976)

The new 13K125 turbine installed in the Siekierki Power Plant in Warsaw, has been already about 1 year in operation. The turbine fulfilled all estimated figures. It is very stable in transient conditions, the vibration level is less than 10 μm (double amplitude), and test results have shown its suitability for two shift-operation.

Energetyczne turbiny parowe produkcji ZAMECHU

Streszczenie

ZAMECH jest producentem i głównym dostawcą turbin parowych dla energetyki krajowej i generalnym dostawcą w zakresie maszynowni.

Produkcja turbin energetycznych jest oparta na dokumentacji konstrukcyjnej opracowanej przez AEI (Anglia), LMZ (ZSRR) i BBC (Szwajcaria).

Zebrane doświadczenia produkcyjne i eksploatacyjne stały się podstawą do przeprowadzenia własnych prac konstrukcyjnych w celu modernizacji turbiny AEI-120 MW i prac nad zmianą charakterystyki eksploatacyjnej turbiny LMZ-200 MW.

Uzyskane rezultaty zostały potwierdzone w eksploatacji.

Энергетические паровые турбины производства завода ЗАМЕХ

Резюме

ЗАМЕХ является изготовителем и главным поставщиком паровых турбин для отечественной энергетики и генеральным поставщиком турбоагрегатов.

Производство энергетических турбин основывается на конструкционной документации, разработанной фирмами АЭИ (Англия), ЛМЗ (СССР) и Броун-Бовери (Швейцария).

Накопленный производственный и эксплуатационный опыт стал основой для выполнения собственных конструкторских работ с целью модернизации турбины АЭИ-120 Мвт и работ, направленных на изменение эксплуатационной характеристики турбины ЛМЗ-200 Мвт.

Полученные результаты оправдались в эксплуатации.