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Poland*

Power System Aspects of Peak Loading of Great Steam Power Generating Units on the Basis of Polish Operating Experience

1. Introduction

The increase of the Polish power system has been accomplished since 1960 with the aid of 120 MW and 200 MW steam power units, with interstage steam reheaters. The present participation of these power units in the system can be considered as equal to 55 p.c. and is expected to achieve ca 60 p.c. by 1975. Nearly the whole capacity installed is placed in steam power generating units, and only 5 p.c. is placed in hydro-plants. The prevailing participation of steam power generating units will be maintained also in future.

It should be emphasized that with increasing period of operation of these units in power system, also according to disposed amount of fuel, an annual utilization time of turbosets of nominal capacity will keep a decreasing trend [9]. It means that when these power units operated as base-load units in the first $5 \div 6$ years of operating period, they will occupy the intermediate region of annual load diagram after this period, and replace peak-loading stations by 15th year of utilization. Nowadays these great steam power units are installed as intermediate loading plants from the beginning.

This process of variable loading conditions of great power blocks against time will be especially significant with the increasing participation of very great power units and with introducing nuclear power plants into the power system. New units will replace the old ones, considerably less efficient.

On the basis of this consideration it is justified that comparatively great steam power units, here 120 MW and 200 MW ones, will be replaced by more efficient units and forced therefore to meet peak loads of the power system considered.

It is expected in Poland that special peak loading power stations (like gas-turbine plants, pumped storage stations and other) will not be able to meet all the future power system peaking requirements. For this reason a part of peaking capacity must be covered by great steam power units. However the present base-load power units are not accomodated to this kind of loading.

The main parameters of Polish steam power sets of 120 MW and 200 MW lignite-fired, are listed in Table 1.

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* Technical University, Poznań, and Western Electricity Generating Board.

Table 1

Main parameters of Polish steam power blocks of 120 MW and 200 MW, lignite-fired

Nominal output of power block	Boiler				Turbine		
	type	steam output	steam pressure	steam temperature	type	steam pressure	steam temperature
[MW]		[t/hr]	[atn]	[°C]		[ata]	[°C]
120	OP-380b	380	136/26,3	540/540	TK-120	127/25.3	535/535
200	OP-650b	650	139/26	540/540	TK-200	130/22.1	535/535

Remarks: Parameters of the electrical generators are the following – 150 MVA, 13 800 V, and 235 MVA, 15 750 V.

It should be emphasized that technical and economic experience was acquired on steam power units fired by lignite of the following characteristic:

– average heating value 2150 kcal/kg
– humidity $50 \div 55$ p.c.
– average ash contents $5 \div 12$ p.c.

The present installations of steam power sets are only partly accomodated to meet a varying system load.

2. Accomodation of steam power units of 120 MW and 200 MW nominal capacity for meeting variable system load

Accomodation of great steam power units for meeting varying system loads shows in the following features:

– accomplishment of a safe and normal starting conditions under different thermic states of a turbo-set, taking into account a short starting time,

– possibility of meeting very large load gradients.

Starting time of a steam power block and the way of its loading are limited by an irregular temperature distribution, especially in the thick structural elements.

Thermal stresses in the constructional materials depend mainly upon a difference of temperatures. During starting process an irregular distribution of temperatures develops, causing the additional stresses and clearances between moving and steady elements of turbine. During this thermic state a difference of temperatures between the casing and the rotor causes a change of axial clearances in the blade system and in the stuffing box as well, depending on the intensity of metal heating and construction of the components. In the same way the radial clearances develop due to the difference of temperatures between the upper and the lower parts of the turbine casing.

In this case a deflection of rotor shaft is often observed.

A necessity of keeping these constructional clearances in the admissible limits defines the starting conditions of steam turbine.

An experience with turbine operation over the transient thermal conditions has shown that the elements influenced most by thermal stresses are: the inlet part and the rotor of the turbine.

The results of these experiments have been confirmed in practice by lower availability and more numerous repairs of these elements. The damages to turbines without adjustment to loading at variable rate are usually in the form of fissures, deformations and seizures of these elements [5, 8].

The highest parameters and thickest walls of casing are in the inlet part of the HP cylinder (valve and nozzle cells, governor housing with collar junction) and therefore it suffers the greatest thermic stresses, especially during starting and loading conditions.

It is known that these fissures of inlet elements are observed mainly in the turbines with a quantitative regulation of steam flow and for the single-coat construction of turbine casing.

A heating process of inlet part is especially irregular and rapid during starting operation. The temperature gradient of nozzle and valve cell achieves ca 8 deg/min, and in the case of starting-up or shut-down operation (e.g. after holidays) is equal to 10÷15 deg/min, exceeding twice the admissible values (see Table 2), [8].

Table 2

Admissible temperature gradients for great steam turbines during starting-up operation

No.	Element of turbine constructional system	Ranges of metal temperatures			
		below 200°C	200–400	400–500	above 500°C
1	2	3	4	5	6
	Temperature gradient (deg/min)				
1	Pipeline of inlet steam	8÷6	6÷4	4÷3	2
2	Pipeline of reheat steam	10÷8	8÷6	6÷5	4
3	Pipeline of IP cylinder	16	12	9	6
4	Pipeline of HP cylinder	10	8	6	4
5	HP valves	5	4	3	2
6	IP valves	8	6	4	3
7	Control valves	8	6	4	3
8	Turbine casing	4	3	2	2
	Temperature difference (deg)				
9	On the width of collar junction of turbine	with collar heating			50
		120	110	110	100
10	Collar junction and screws of turbine casing	with screw heating			20
					40
11	Upper and lower part of turbine casing				35÷50
12	Left and right collar junction of turbine casing				10
13	Upper and lower collar junction of turbine casing				10

Ring junctions, the most solid elements of the front part of a turbine casing, are heated very slowly and unevenly, especially after long shut-down operation of the turbo-set. This process sets limitations upon the admissible extension of the casing.

At the same time occur the relative extensions of rotor, the seizures of the blade ring or the stuffing box.

It was proved during the research of many steam turbines that also in case of slow loading the temperature difference between the casing and the collar junction equals up to $170 \div 200$ deg, much more then admissible limits.

Similar processes are observed in the inlet part of an IP cylinder with interstage reheating.

A lack of by-pass arrangement for the reheated steam before its admission to the IP cylinder and IP pipelines leads to a deformation of the front part of turbine casing.

After long-time shut-down, the inlet temperature of the IP cylinder is about 200 deg lower than the casing temperature, especially during the first period of starting operation. A great difference of metal temperatures occurs also at the width of collar junction of the IP casing and reaches 200 deg.

A lack of axial and radial fitting margins becomes very dangerous for a turbine rotor.

During the speed increasing after a short shut-down a steam is cooled by the inlet pipelines leading governor control valves, or its temperature drops due to the expansion and throttling process; in this case a dangerous diminution of turbine rotor dimensions occurs.

During the starting operation after longer shut-down an extension of the rotor takes place, especially due to a great increase of the inlet steam temperature or a rapid turbine loading.

Table 3

Constructional adjustments to variable loading conditions of Polish 120 MW and 200 MW steam turbines

No.	Kind of constructional changes	Steam turbines	
		120 MW	200 MW
1	Starting-up bypass devices and reduction cooling stations of turbine*		
	1.1. Bypass starting equipment of reduction cooling station of HP cylinder	×	
	1.2. As above, but of IP and LP cylinders	×	
	1.3. Bypass of the whole turbine with reduction cooling station	×	
	1.4. Drain-cooling sections of condenser	×	
2	Turbine control system and thermic stress reduction		
	2.1. Simultaneous opening of HP and IP valves, total opening at 50 p.c. of nominal output	×	×
	2.2. Relationship between a position of the IP control valves and position of the speed governor; extension of control range of the speed governor in connection with total closing of HP and IP control valves		×
	2.3. Adjustment of admission turbine system of stuffing — box steam supply		×
	2.4. Steam heating of collar junctions and IP casing screws	×	×**
	2.5. Application of double coating HP casing		×**

Remarks:*200 MW turbines are equipped with these arrangements. **Only in new constructions.

In the case of a casing deformation or a temporary rotor deflection (e.g. when the turning gear motor is switched off before the start-up), steady distortions of the rotor may take place. This is very dangerous and leads to a serious damage to the turbine.

Admissible temperature gradients during start-up of a steam turbine for the different metal temperatures are listed in Table 2.

Investigations carried out with regard to this problem have led to some constructional modifications, applied with the main aim of equalization of thermic stresses, especially during the starting operation and loading at a variable rate.

The main constructional modifications applied in great steam turbines of 120 MW and 200 MW nominal capacity are listed in Table 3.

These modifications were made for the following purposes:

– The bypass starting device of the whole turbine enables maintaining admissible temperature gradients in the respective parts of the turbine casing and leads a steam flow through an interstage reheater, bypassing a turbine.

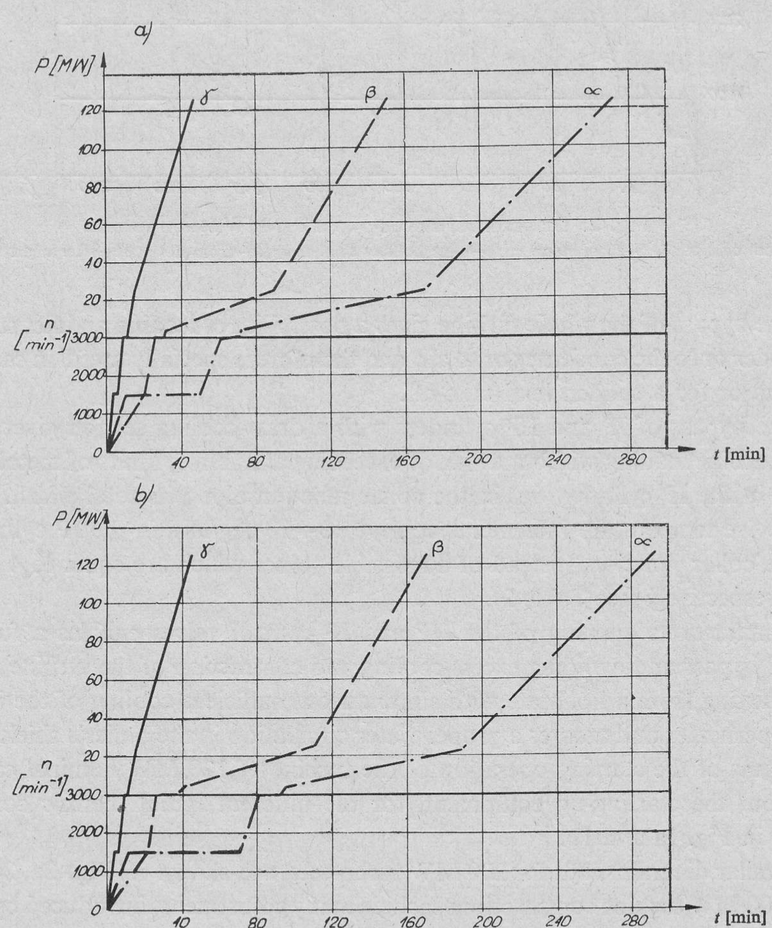

Fig. 1. Diagrams of starting up a 120 MW steam turbine: a) with equipment for start-up, b) without equipment for start-up

α – from cold state, β – from warm state – after holiday shut-down, γ – from hot state – after night shut-down

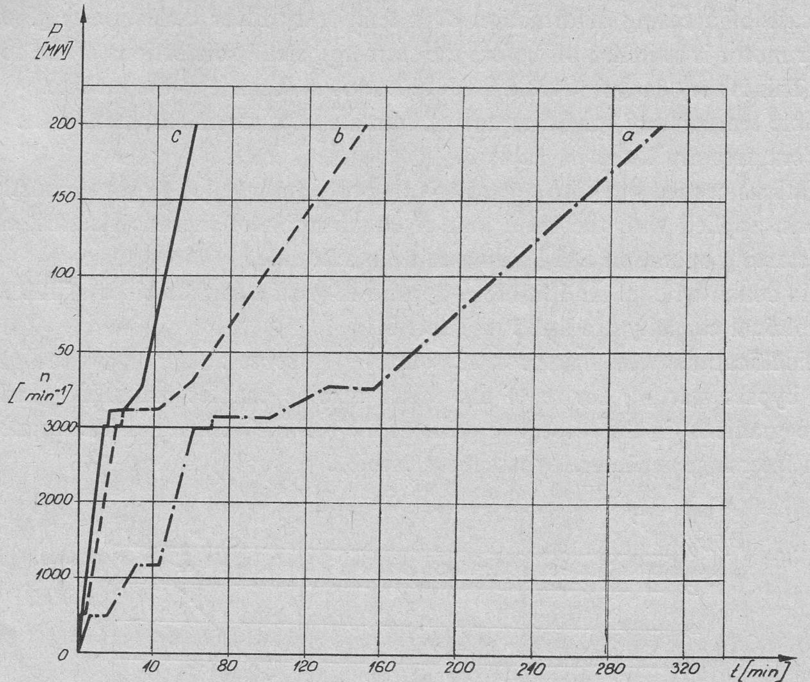

Fig. 2. Diagrams of starting up a 200 MW steam turbine
a—from cold state, *b*—from warm state—after holiday shut down, *c*—from hot state—after night shut-down

— The bypass of the whole turbine gives a possibility of leading an inlet steam through the expander or to the condenser or to air, and therefore is specially useful in case of a turbo-set failure or for a sudden load take-off.

— The bypass of IP and LP cylinders with a draw-cooling section gives a possibility of quick turbine loading without a risk of exceeding admissible limits of metal temperature gradients in the IP cylinder and in the collar junction along its total width. Without the bypass device temperature increments achieve $10 \div 12$ deg/min in the IP cylinder and 200 deg in the collar junction, instead of admissible values which are equal to 4 deg/min and 100 deg, respectively (see Table 2).

— Simulatenous opening of the HP and IP control valves enables a full utilization of the HP bypass and avoiding excess cooling and contraction of the turbine rotor. It also enables starting from a hot state with simultaneous sufficient cooling of the interstage re-heater, superheater and assures a proper water circulation in the boiler's shield.

Diagrams of the starting operation of the turbine of 120 MW nominal capacity, with and without the starting-up equipment, for the different initial thermic conditions, are presented in Fig. 1a and 1b.

The similar diagrams, but for 200 MW turbo-sets, are shown in Fig. 2a, 2b and 2c, [8].

New 200 MW turbine constructions include many adjustments introduced by the factory. According to this, a new turbine 13K215 is adjusted and operated at a variable load and frequent shut-downs (about 150 start-ups per year). The casing of this turbine consists of two parts — the external and the internal one. The both parts are made of cast iron.

A three-zone pressure distribution system unloads the external casing and enables preserving admissible stresses, thus acting against the creeping of metal at the relatively thin walls of the internal casing.

The IP casing consists of two parts, with vertical division surface – the front part is casted and the back part is welded. Front wall is double-coated. This kind of construction assures a great thermic elasticity of turbine.

A parallel-opening system of the HP and IP control valves, mainly for the starting operation, is a rule in the turbine control system. The reduction cooling station operates during the start-up of the turbine and constitutes the bypass device for the IP and LP cylinders. Starting of the turbine is possible from the each thermic state of turbo-set.

A boiler operation is also possible at the load take-off and when fulfilling auxiliar needs of a power plant.

3. Power and economic effectiveness of the operation of units at variable loads

An analysis below is based on the results of the operation and on statistics. Guaranteed and measured characteristics of the OP-380b and OP-650b boiler efficiency, as well as the unit heat consumption characteristics for 120 MW and 200 MW power turbines, are applied as the initial data. They are shown in Fig. 3. Taking into account these data we can define net and gross characteristics of the unit heat consumption of the considered power blocks (boiler, turbine and generator together), as it has been shown in Fig. 3 [9].

3.1. Unit fuel cost of a power block

The daily load demand of a power system is the main factor defining wide load variations of a power block, especially during morning and evening peaks, and also over night minimum-load period.

The typical loading diagrams for 120 MW and 200 MW turbo-sets over a year are given in Fig. 4. For these loading diagrams we define the fuel costs, taking into account the following fuel prices:

lignite: $C_b' = 45{,}3$ zł /Gcal, with heating value of 2150 kcal/kg,

starting oil: $C_c'' = 200$ zł/Gcal at the calorific value of 9500 kcal/kg.

A participation of the oil during a starting is assumed at the level of 30 p.c. for a 200 MW unit, and 25 p.c. for 120 MW block. The technical load minimum is assumed at the level: $P_{0(120)} = 80$ MW, $P_{0(200)} = 140$ MW.

The characteristics of the total heat consumption and starting heat losses, are given in Fig. 5 and 6 [2, 4, 6].

Unit fuel costs for the considered power blocks are shown in Fig. 7, for the different variants of system loading, according to the diagrams given in Fig. 4. This characteristics is a function of the daily utilization factor of the block nominal capacity.

It can be stated, when analyzing the run of this characteristics in Fig. 7, that the daily unit fuel cost with shut-downs of power blocks is much higher than for the continuous operation. Maximal differences reach up to 25 p.c.

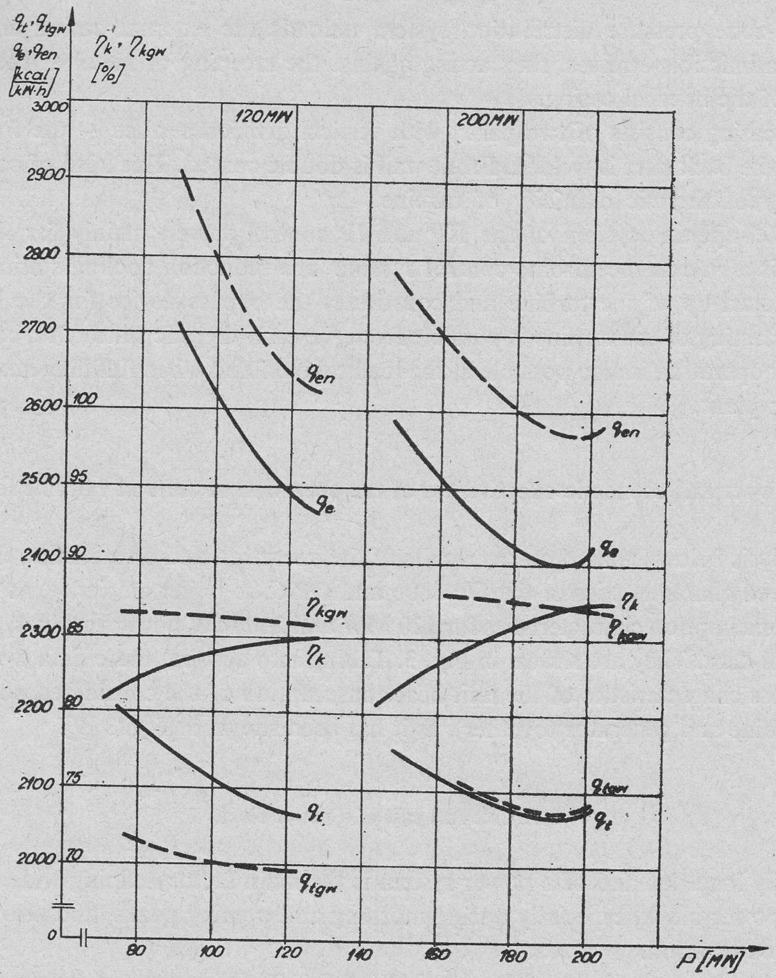

Fig. 3. Guaranteed and measured curves of boiler efficiency (η_k) and unit heat consumption of turbo-set (q_t), unit heat consumption – net (q_{en}) and gross (q_e) for 120 MW and 200 MW blocks

Annual unit fuel cost is defined as below:

$$k_v = \frac{K_{rv}}{A_r} = \frac{K_n \sum_i T_{ni} + K_0 \sum_i T_{0i} + K_u \sum_i n_i}{P_n \sum_i T_{ni} + P_0 \sum_i T_{0i}}, \tag{1}$$

where K_{rv} – annual fuel cost of a power block [zł/year], A_r – annual energy output of a power block [MW·hrs/year], k_v – annual unit fuel cost [zł/MW·hr], K_n – fuel cost at a nominal loading [zł/MW·hr], K_0 – fuel cost at a technical minimum [zł/MW·hr], K_u – starting cost of a power block [zł/start], T_{ni} – number of hrs with a nominal loading [hrs], T_{0i} – number of hrs with a technical minimum [hrs], n_i – number of starts, P_n – nominal loading [MW], P_0 – technical minimum loading [MW], $i = 1, 2, \ldots, k$ – number of the typical loading diagram.

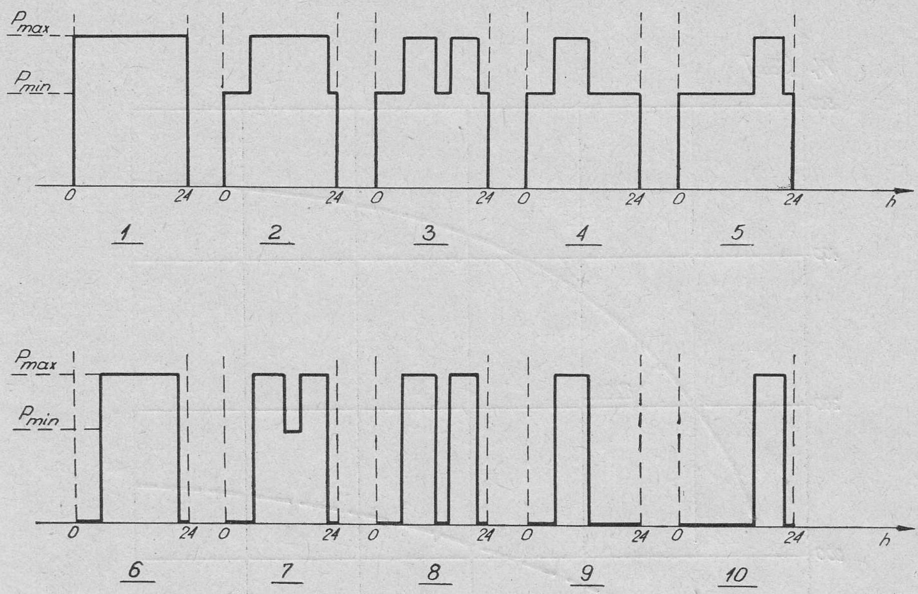

Fig. 4. Variants of daily load diagrams for 120 MW and 200 MW power blocks

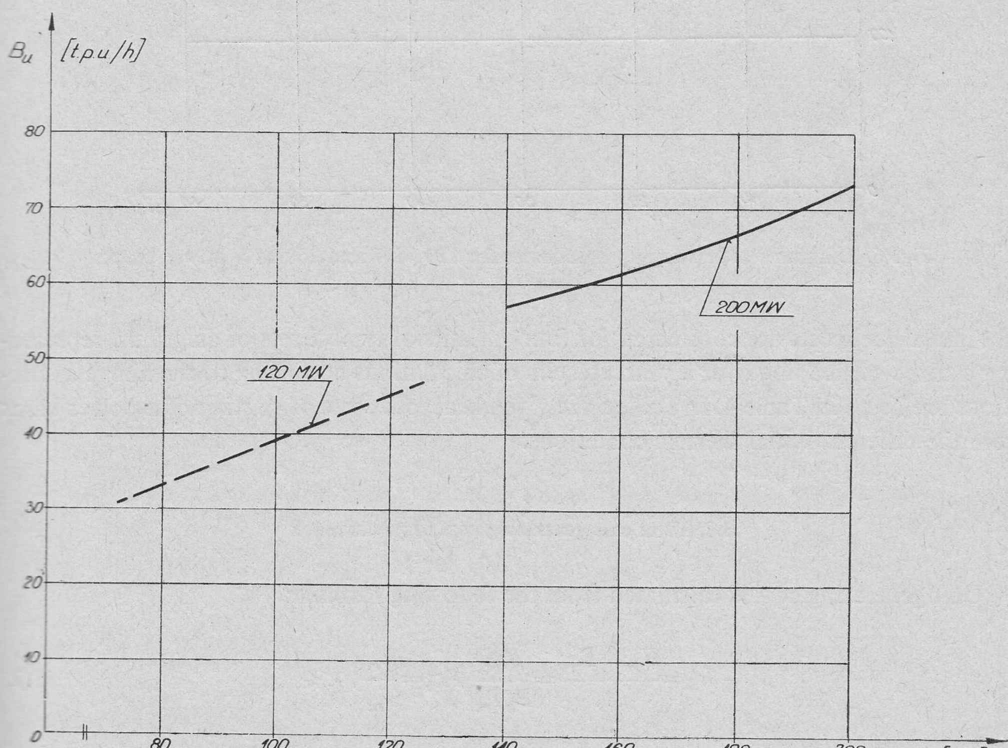

Fig. 5. Diagrams of fuel consumption of 120 MW and 200 MW power blocks (in conventional fuel – 1 kg – 7000 kcal)

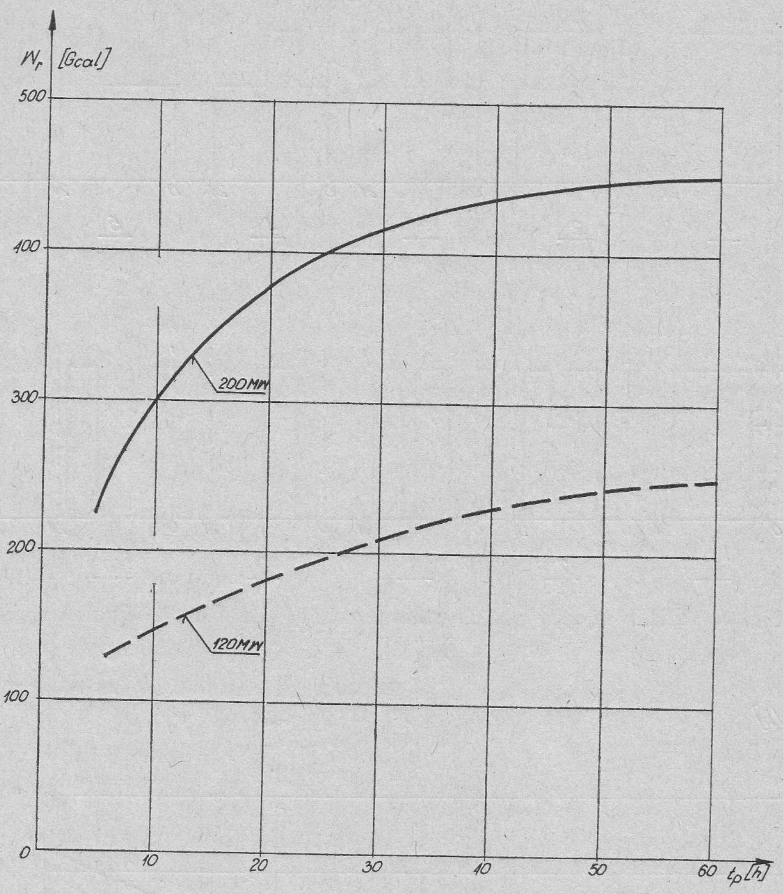

Fig. 6. Diagrams of starting-up heat losses for 120 MW and 200 MW power blocks

Annual fuel costs are considered for four variants of typical sets of diagrams, representing a turbo-set loading over a year. Results of calculations according to the above assumptions are listed in Table 4. In Table 5 are given heat loss costs of starting of a power block from the different initial thermic conditions.

3.2. Total unit generating cost of power block

Unit generating cost is calculated from the following formula:

$$k_w = \frac{K_{rc}+K_{rv}}{A_r} = \frac{K_{rc}}{P_n T_{rn}} + k_v = \frac{k_c}{T_{rn}} + k_v, \tag{2}$$

where K_{rc} – annual fixed operating cost [zł/year], k_c – unit annual fixed operating cost [zł/year], $T_{rn} = A_r/P_n$ – annual utilization time of the nominal capacity [hrs/year]. For the power blocks considered the following values of the unit fixed cost k_c are defined on

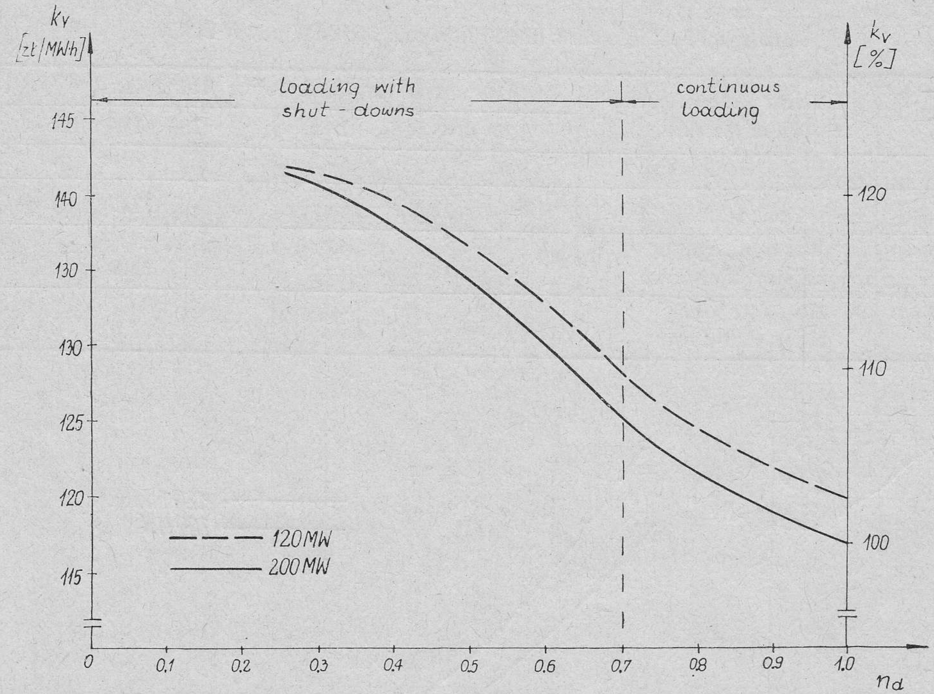

Fig. 7. Diagrams of unit daily fuel cost (k_{vd}) versus average daily utilization coefficient $n_d = P_{da}/P_n$

Table 4

Calculation of daily and annual fuel costs for four variants of representative load diagram sets

No. of typical load diagram (see Fig. 4)	Annual fuel costs K_{rv} (10^6 zł/year)								Unit annual fuel cost k_v (zł /MW·hr)							
	120 MW				200 MW				120 MW				200 MW			
	v.1	v.2	v.3	v.4	v.1	v.2	v.3	v.4	v.1	v.2	v.3	v.4	v.1	v.2	v.3	v.4
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	12.6				20.5				120				117			
2	34.8				56.6				123				120			
3	52.3	52.3			85	85			124	124			121	121		
4		20.9				34				127				124		
5		20.4				33.2				128				125		
6			17.6				28.7				127				125	
7			38.3				62.8				129				127	
8			15.4				25				135				132	
9				16.9				28.1				139				139
10				17.1				28				142				142
Total	99.7	93.6	71.3	34	162.1	152.2	116.5	56.1	123	126	130	142	120	123	127	140

Remarks: Annual utilization time for the particular variants: $T_{rn1} = 6740$ hrs/year, $T_{rn2} = 6204$ hrs/year, $T_{rn3} = 4585$ hrs/year, $T_{rn4} = 2000$ hrs/year.

Table 5

Starting-up heat loss costs of 120 MW and 200 MW power blocks

Item	Thermic state of turbo-set before starting up	Heat loss cost (10^3 zł /start) for:	
		120 MW turbo-set	200 MW turbo-set
1	2	3	4
1	Cold state	22.925	37.8
2	Warm state after holiday shut-down	18.8	34.86
3	Hot state after night shut-down	12.83	23.52

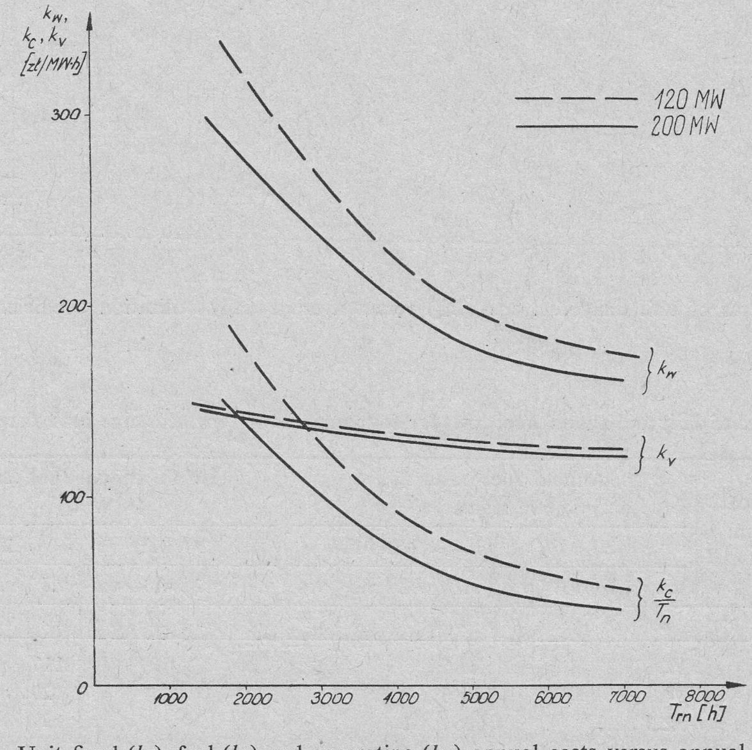

Fig. 8. Unit fixed (k_c), fuel (k_v) and generating (k_w) annual costs versus annual utilization time T_{rn}

the basis of the operation statistics:

$$k_{c(120)} = 357 \cdot 10^3 \text{ zł/MW} \cdot \text{year}, \quad k_{c(200)} = 275 \cdot 10^3 \text{ zł/MW} \cdot \text{year}.$$

These fixed costs take $35 \div 50$ p.c. of toal generating cost.

The unit generating costs are calculated from the formula (2) taking into account the above assumptions and fuel costs defined before. Results of these calculations are shown in Fig. 8. On the basis of these curves it can be stated that:

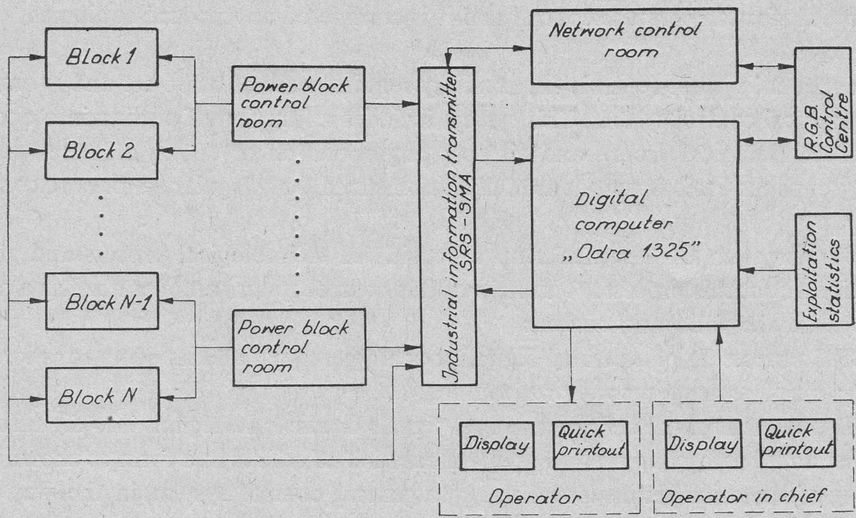

Fig. 9. Diagram of a steam power plant control system scheme using a digital computer

– fixed operation costs have an important significance for small values of the annual utilization time of the nominal capacity of a power block,

– 200 MW power block is more economic than a 120 MW one (higher efficiency, lower starting cost), and therefore its characteristics lies lower.

4. Automatic control system of starting great steam turbines and variable loading conditions

Electric power generation in Poland will be controlled by a computer system. At the beginning of the Polish system automation the following undertakings are foreseen:

(i) automatic control of starting operation of a steam power turbine (ASURT), concerning:

– regulation of the turbine speed,

– rising the turbine load,

– sequential control of an auxiliary equipment.

(ii) automatic processing of digital and analogue information, measurements, recording and data transformation realized by CRPD system.

A control system, called ASURT, realizes the following functions:

– Speed control, according to the fixed time programs, chosen by an operator in connection with thermic conditions before starting the turbine,

– Load control of a turbo-set, which corresponds to a constant heat exchange rate rule concerning the turbine metal. A computing device gives a signal of steam flow demand, corresponding to the heat exchange rate between steam and turbine or in metal as well,

– Taking-off the turbo-set load during a shut-down operation is realized at the defined unloading rate and adequately to the turbine parameter values. During all stages of starting functions acts a speed signalling and security system; this includes also an additional equipment for temperature control and it is considered as standard equipment of each large turbo-set,

– Sequential system controls the auxiliary requirements of turbo-set and is organized as a hierarchical control system. This system includes a function of putting into operation particular technological groups and also starting operation or taking off turbo-set load. In these groups the basic functions are fully automatized, but singular actions are controlled manually.

A control system CRPD checks up a considered technological process and gives an information about this process. With help of this control system an operator has a possibility to realize the following actions:

– CRC processing of a defined digital or analogue signal and its demonstration in the form of : measurement, record or signalling,

– PD treatment of the defined analogue signals or two-state signals into digital signals, creation of data bank, computation and transmission of results in a form as shown above. Processing of operation results is realized by a general control system, in the way shown in Fig. 9.

In this case the main operation functions are processed by a central computing unit (a Polish computer of third generation – Odra 1325), installed in a power plant. It is a great help for the power plant operator.

5. Conclusions

In this paper some main aspects of great steam power block have been discussed, especially the problems of operation at variable loads. It was shown that:

– great steam turbines must be adjusted to a loading with a variable rate to overcome the thermal stresses or to equalize them during loading of a turbo-set,

– these modifications should equalize the great temperature gradients, especially during starting up operation of a steam turbine,

– economic effectiveness depends mainly upon the way of power block loading over day or year,

– right control of all processes occurring during the starting, shut-down and variable loading operation is usually realized using special sequential and differential system and a digital computer.

References
(all in Polish)

[1] Z. Budzyński, L. Cwynar, S. Markowicz, *Starting up operation research of the 120 MW power block, installed in Konin steam power plant.* Instytut Energetyki, Warszawa 1964.

[2] W. Charzyński, *Choice and perfectioning of practical calculation and measurement methods of power block starting losses.* Instytut Energetyki, Warszawa 1972.

[3] L. Cwynar, *Practical method of heat loss calculations, connected with shut-down operation of turbo-set.* Biuletyn Instytutu Energetyki, Energetyka 4/1965.

[4] L. Cwynar, *Methods of starting loss computation and its interpretation by the Polish Power Generating Boards and Power Control Centre.* Instytut Energetyki, Warszawa 1965.

[5] F. Czudejko, A. Krawet, *Actualisation of starting-up instruction of 120 MW turbo-sets.* „Energopomiar", Gliwice 1969.
[6] F. Czudejko, Cz. Folwarczny, *Influence of shut-down and starting-up operation on heat losses*, Energetyka 8/1970.
[7] F. Czudejko, J. Pawlik, *Guide lines to operating instructions of 200 MW steam power blocks.* „Energopomiar", Gliwice 1970.
[8] F. Czudejko, J. Rzepecki, *Definition of constructional turbine nodes deciding on temperature and thermic stress distribution and way of starting-up and loading of steam turbine.* „Energopomiar", Gliwice 1971.
[9] S. Góra, K. Kosobudzki, *Operation of great steam power blocks at variable load.* VI Konferencja Nauk.-Techn. Wydz. Elektr. Politechniki Poznańskiej, 1972.

Ocena obciążania szczytowego wielkich parowych bloków energetycznych z punktu widzenia systemu energetycznego, na podstawie polskich doświadczeń eksploatacyjnych

Streszczenie

W artykule omówiono energetyczne i ekonomiczne aspekty pracy wielkich parowych bloków energetycznych podczas zmiennego obciążenia systemu energetycznego. Przeanalizowano również zagadnienia związane z rozruchem i wyłączaniem turbin, a w szczególności:

— charakterystyki rozruchowe wielkich turbin parowych, ich wyposażenie oraz zmiany konstrukcyjne dla pracy przy zmiennym obciążeniu,

— wpływ czasu pracy na charakterystyki siłowni, a przede wszystkim na ich sprawność i jednostkowy pobór ciepła,

— techniczne i ekonomiczne czynniki charakteryzujące siłownię (koszty paliwa na rozruch i wyłączanie, dzienne i roczne jednostkowe koszty paliwa, całkowity koszt produkcji energii itd.).

Opisano również układ komputerowego systemu sterowania pracą siłowni i sterowanie turbiną parową podczas rozruchu i obciążania.

W końcu przedstawiono propozycje sposobu pracy parowego bloku energetycznego.

Оценка пиковой нагрузки больших паровых энергетических блоков, с точки зрения энергетической системы, на основе польского эксплуатационного опыта

Резюме

В статье обсуждаются энергетические и экономические аспекты работы больших паровых энергетических блоков при переменной нагрузке энергетической системы. Анализируются также вопросы, связанные с пуском и отключением турбин, а особенно:

— пусковые характеристики больших паровых блоков, их оборудование и конструкционные изменения для роботы на переменном режиме,

— влияние времени работы на характеристики силовой установки, а прежде всего на их к.п.д. и удельный расход тепла,

— технические и экономические факторы, характеризующие силовую установку (стоимость топлива, употребляемого для пуска и отключения, суточная и годовая удельная стоимость топлива, полная стоимость производства энергии и т.п.).

Описываются также системы управления работой силовой установки при помощи ЭВМ и управление паровой турбиной во время пуска и нагружения.

В заключении даются предложения, касающиеся принципов работы энергетического блока.

ment. The best way of solving Volterra's integral equations is to apply the method of finite sums [9]. Thus we have to choose a sufficiently small time interval Δt and to construct a set of points

$$t_i = i\Delta t \qquad (i=0,1,2,\ldots).$$

To the right side integral of the equation (24) we apply now any formula of the numerical integration in which the value of the integrated function does not appear at the right end of the integration range. If we use the method of rectangles for calculating the integral

$$\int_0^{t_{n+1}} F(\vartheta)\,d\vartheta = \sum_{i=0}^{n} \Delta t\, F(t_i),$$

while $t=t_{n+1}$ in the equation (24), we obtain the following result

$$\sum_{i=0}^{n} K_{n+1,i}\,\dot{q}_{\mathrm{dop},i}\Delta t = f_{n+1}, \tag{25}$$

where

$$\dot{q}_{\mathrm{dop},i} = q_{\mathrm{dop}}(t_i),\; K_{n+1,i} = K(t_{n+1}, t_i),\; f_i = f(t_i).$$

From the equation (25) it can be found that

$$\dot{q}_{\mathrm{dop},n} = \frac{f_{n+1} - \sum\limits_{i=0}^{n-1} \Delta t K_{n+1,i}\,\dot{q}_{\mathrm{dop},i}}{\Delta t K_{n+1,n}} \tag{26}$$

$$(n=0,1,2,\ldots).$$

5. The method of analysing the heating process in non-insulated elements

In the previous part of our paper we have presented the analysis of a permissible heat flux, after assuming that the outer area is being insulated. This, however, limits the range of the applicability of the presented method. Usually, the problem of determining the boundary conditions on the non heated area, particularly in case of turbine, is very complicated. The complications result from the complex geometry of elements as well as from the difficulty in determining the thermo-dynamic and kinematic parameters of the flowing vapour. The simplifications of geometry and the application of the formulae known for these geometries, which define the value of the heat penetration coefficient, may lead to serious errors, especially for non-stationary phenomena which we have to deal with during the starting process. These difficulties can be eliminated if we assume that the temperature of a given point (or of the area) is known during the starting period. The point at which the temperature is measured should as far as possible from the heated area. For the model under consideration, the temperature field is described by the equation (4) and the equations of the initial and boundary conditions have the form

$$-\lambda \frac{\partial T(\vec{r}, t)}{\partial n} = \dot{q}(\vec{r}, t), \qquad \vec{r} \in A_w, \tag{27}$$

$$T(\vec{r}_a, t) = T_a(t), \tag{28}$$