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ГИДРОФОРУМ

НАУЧНО-ТЕХНИЧЕСКАЯ КОНФЕРЕНЦИЯ

на тему

ПРОБЛЕМЫ ГИДРАВЛИЧЕСКИХ ТУРБОМАШИН

Гданьск-Владыславово, 24-27 сентября 1985 г.

PRACE INSTYTUTU MASZYN PRZEPŁYWOWYCH

1989 Zeszyt 90-91

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Present State and Prospects of Development of Water-Power Engineering in Poland with Special Regard Paid to Demand for Water Turbines

The paper deals with the present state of water power plants in Poland against the background of technical water-power resources of rivers and the possibility of development of water-power engineering up to the year 2000. Next, an analysis was made of the types and quantities of water turbines necessary for the above development of water power plants in Poland.

1. Introduction

Technical water-power resources of the Polish rivers are small and amount to 12.1 TWh/a [1], supplemented by about 1.2 TWh/a within the so-called small hydro power. These low resources result from the predominance of lowlands in our country which do not create natural conditions for obtaining high heads. Relatively small precipitation (annual average about 600 mm) causes that our rivers are not abundant in water. The latter feature is deteriorated by insufficient volume of large storage reservoirs which, if suitably developed, could permit better utilization of large flood waters.

On the other hand, the basic sources in the national electric power system are the large thermal power stations fired with hard and brown coal. These power stations are fitted with large power units with steam turbines characterized by low controllability. This controllability deficiency of the basic source of electric energy in the electric power system will be deepened by the nuclear power plants which will soon be included in the national system. In contradistinction to the nuclear power plants, water turbine sets are the most elastic sources of electric energy, characterized at the same time by very high efficiency and availability which was described in detail by the author in a paper presented at Hydroforum'73 [2].

The general trends in development of the Polish water power engineering can be summarized as follows:

— One should aim at the quickest utilization of national water-power resources in order to maximally relieve the fuel balance by as large as possible production of "clean" electric energy derived from water power plants which do not put a burden on the natural environment.

— The water power plants should be as far as possible of peak character and should act as regulation/intervention power plants and thus produce the most valuable type of electric energy.
— Since the demand of the national electric power system for the above mentioned types of power and electric energy cannot be covered by even the most intensive development of water-power plants which operate on natural water supply, a planned and consequent extension of pumped-storage power plants [3] becomes necessary.

Basing on the research and design work carried out up to the present, the possibilities of development of the Polish water power generating industry will be presented, including the division into four characteristic groups of hydro-plants which already exist and which will be completed up to the year 2020.

2. Present State of Water Power Supply Industry in Poland

At the end of 1984, 119 hydro-electric plants (in abridged form HEP), of total installed power 2008 MW, were operating in the professional power supply industry. Their total production in that year was 3352 GWh, of which 2107 GWh came from pumped water. Consumption for own needs amounted to 0.90 per cent of gross output. As related to the total installed power in the national power plants — both professional and industrial — the participation of HEP amounted to 6.96 per cent, whereas with respect to the annual gross output the HEP generated 2.49 per cent of electric energy produced in this country. For documenting the economic advantages of HEP, a few indices obtained in 1984 are brought forward.

The average cost of producing 1 MWh in HEP amounted to 77.8 per cent of 1 MWh cost in thermal power plants, and for HEP Włocławek this ratio had the lowest value, namely 16.5 per cent. Average employment in HEP was 0.8 worker/MW, whereas in the thermal power plants — 2.1 worker/MW. The ratio of mean available power of December to the installed power in thermal power plants was 81.4 per cent, whereas in hydro-electric plants it was 96.8 per cent.

Polish public utility hydro-electric plants can be divided into three power groups, as shown in Table 1 [4] below.

The total number of turbines installed in the public utility hydro-electric plants is 264; these are 167 turbines of Francis type including 12 large reversible units, and 97 Kaplan turbines. The oldest and still operative is a Francis turbine built in 1898 in the Struga hydro-electric plant, of 250 kW power at 14 m head, manufactured in 1898 by the Schichau works in Elbląg. 158 turbines were installed before 1930, so they have been working for over 55 years.

For comparison, we present the participation of hydro-electric plants in the total power installed in the system in Poland and in other socialist countries: Romania 22.3 per cent, Bulgaria 20.4 per cent, Czechoslovakia 15.0 per cent, USSR (connected systems of the south) 9.3 per cent, German Democratic Republic 7.7 per cent, Poland 6.9 per cent and Hungary 0.8 per cent.

Table 1

Groups of hydro-electric plants	Range of installed power [MW]	Number of hydro-electric plants in group	Total power installed [MW]	Participation in total power of hydro-electric plants [%]	Remarks
I	> 50	7	1 756	87.5	State network power plants under control of State Power Board, including 3 pumped-storage power plants of total power 1330 MW
II	5÷50	10	128	6.4	Power plants of medium power
III	⩽ 5	102	124	6.1	Small hydro-electric plants
Total		119	2008	100	

For full illustration of the state of the water-power engineering in Poland one should briefly characterize plants which are operating outside the public utilities. Of these the pronounced majority are plants in which the production facilities such as grinding rolls, sawmill frame sawing machines, etc. are driven directly by water turbines. It is estimated that at present about 150 of such plants are operating; among them are 30 plants in which the whole or a part of the turbine power is used for production of the electric energy.

3. Possibilities of Development of Water-Power Engineering in Poland up to the Year 2020

3.1. Preliminary remarks

It should be realized that a significant number of new hydro-electric plants will be constructed while building multi-purpose water reservoirs or stages of fall on rivers, dictated by the needs of the general water economics of the country. In other words, the building of the majority of new hydro-electric plants (apart from pumped-storage power stations which will be built purely for energy production reasons) will depend on building plans of basic water economics objects, and therefore it is difficult to determine at present the time of completion of these hydro-electric plants. In consequence of this fact, in the considerations below, the hydro-electric plants which most probably will be built up to about the year 2020 will be discussed, and the suggestions will be based on the hitherto carried out research and design work both within the scope of power engineering and water economics departments. Development of hydro-electric plants will be considered with the division into the following groups:

A. Hydro-electric plants at low-head stages of fall on larger rivers.
B. Low-head hydro-electric plants at multi-purpose reservoirs.
C. Small hydro-electric plants.
D. Pumped-storage power stations.

3.2. Hydro-electric plants at low-head stages of fall on larger rivers

With reference to these hydro-electric plants it should be stressed that the group encompasses basically hydro-electric plants on the Vistula and Odra rivers and possibly on the Narew and Bug rivers, provided that such stages are to be built during the time under consideration. Hydro-electric plants of this group are characterized by relatively large annual production which may be of significance in the national fuel and energy balance. The principal aim as regards these hydro-electric plants should be their implementation in the form of compact cascades with the power plants in the cascade started and stopped simultaneously. Owing to the above it will be possible to increase the installed power of the hydro-electric plants and, at the same time, to increase their peak character to such an extent that all the hydro-electric plants of a given compact cascade will constitute, so to say, a large peak power plant centrally controlled depending on temporary needs of the system. The cascade may have flow equal to zero, in which case the first stage reservoir accumulates water flowing into the cascade while from the lower balancing stage a quantity of water determined by the water right is discharged.

Among the objects of this group the hydro-electric plants on the Lower Vistula cascade [5,6] are the most important ones. Considering the production capacities exceeding 4000 GWh/a (saving 2.5 million tons of power coal per year) the Lower Vistula cascade should be an interdepartmental investment project carried into effect consistently and according to the plan. This was many times postulated by the government department of the power industry and the scientific and technical associations, and recently this proposal was placed among the postulates of the 20th Congress of Polish Technicians [7]. In February 1979 the Presidium of the Cabinet ordered the department of power industry to build the whole Lower Vistula cascade The department set immediately about building the second stage of this cascade including a power plant. The object, which was the second after Włocławek, was located in Ciechocinek. At the beginning of the eighties the work was stopped due to economic difficulties. It is expected that the whole Lower Vistula cascade together with the existing Włocławek stage will comprise 8 stages, and their total power will amount to about 1400 MW. The power plants of this cascade will be equipped with 6 bulb turbine sets each, with the power ranging from about 23 to 38 MW and the turbine runners will have a diameter of $6 \div 7$ m. The approximate characteristics of hydro-electric plants of the Lower Vistula cascade are specified in Table 2.

Table 2

Approximate technical data of hydro-electric plants on the Lower Vistula cascade

Name of plant	Statical head [m]	Total power [MW]	Annual output [GWh]	Quantity of turbine sets [pcs]	Building order	Remarks
Wyszogród	8.0	164	420	6	V (or VI)	Building dependent on the completing of the sewage treatment plant for Warsaw
Płock	6.5	137	350	6	III	
Włocławek	11.3	160	650	6	I	Existing
Ciechocinek	8.5	163	475	6	II	Building interrupted
Solec Kujawski	7.8	192	530	6	IV	
Chełmno	8.0	160	502	6	V (or VI)	
Opalenie	10.0	204	660	6	VII	
Tczew	9.0	230	683	6	VIII	
Total	72.1	1410	4270	48		

On the Upper Vistula a cascade of navigation stages is under construction and the first newly built power plants in this cascade (apart from two existing ones) should be: a 5 MW power plant at the existing Łączany stage, and a 3 MW power plant at the Niepołomice stage. The new hydro-electric plants on the Upper Vistula cascade should be also equipped with tubular turbine sets of $1 \div 3$ MW power; the turbine runners will have diameters of $2.5 \div 3.5$ m.

The same type of power plant should be built at the modernized navigation stages on the Odra river and at the subsequent stages of the Odra waterway, of which the first to be built will be the stage at Malczyce. A power plant of 6.5 MW is being designed for this stage.

3.3. Low-head hydro-electric plants at multi-purpose storage reservoirs

For hydro-electric plants of this group an important recommendation is to increase the installed power of such peak power stations in places where there exists a possibility for building below surge reservoirs. Furthermore (if the head is sufficiently high and the capacity of the surge reservoir permits) — to install a pump unit in the power plants with a compensating power plant to be installed at surge reservoir dam. A classical example of such a system are the Czorsztyn and Sromowce Wyżne Hydro-Electric Plants on the Dunajec river, which are now under construction. In the Czorsztyn Hydro-Electric Plant, for the first time in Poland, two reversible Deriaz turbines, each of 45 MW power, will be installed.

There are but a few locations in our country where large multi-purpose storage reservoirs will be made at which peak power plants of system type might be installed. In the Vistula river basin these are Niewistka and Krasiczyn on the San river and Jazowsko or Tylmanowa on the Dunajec river, whereas in the Odra river basin, the reservoir Wielki Wrzeszczyn or Pilichowice II on the Bóbr river. All the remaining multi-purpose reservoirs which should be built in our country in order to provide a suitable amount of water for municipalities and industry — will allow installing power plants with power outputs not exceeding 20 MW, and in majority of cases these will be low power plants with outputs no higher than 5 MW.

Larger power plants in this group, in which the pump unit can be used, will be equipped with $2 \div 3$ reversible turbines of Francis or Deriaz type, depending on the head which can be obtained. Power outputs of these turbines will range from a dozen or so to several dozens of MW.

3.4. Small hydro-electric plants [7,8]

In consequence of recommendations of resolution No 192/81 of the Council of Ministers dated 7th September, 1981, on development of small water power plants, a specification was worked out of small hydro-electric plants — of output not exceeding 5000 kW — in the respective provinces that could be commissioned within the period 2000-2020, based on the existing dams or those built for other than energy production purposes [9]. The above specifications comprise 1026 plants of total power output of 205 MW and annual output on the order of nearly 1000 GWh. It is assumed that these small hydro-electric plants will be built by investors of 3 economic sectors, i.e. the state, co-operative and private sectors.

Structures and implementation of the complete electromechanical equipment needed for these hydro-electric plants have been developed within the governmental research and development program PR-8 [10].

At present there are tens of small hydro-electric plants under construction, and a significant number of them makes use of Francis turbines left there from former mills, sawmills and factory power stations.

3.5. Pumped-storage power plants [2,3,7,11]

As it has been already mentioned in the introduction, a consequent and planned building of pumped-storage power plants is a necessity arising from a need for ensuring safe and correct operation of the whole national electric power system as well as economical and complying with international agreements exchange of energy with neighbouring countries, and especially in the prospect of connecting Poland's own nuclear power stations to the system in the nearest future. In order to correctly plan the development of the domestic productive base, one has to take into account also the dynamic properties of the system such as its adjustability, suitable quantity of intervention power and permanent warranty of quality of the energy supplied. To meet these requirements, the system should have a relatively high share — of the order of $10 \div 12\%$ — in the peak power of the pumped-storage power stations, and a certain part of these stations should be outside the "static energy balance of the system" such as e.g. the pumped-storage power plant Dinorwic in England. In modern electric power systems pumped-storage power stations are basic warrantors of safe and correct operation of these systems.

Apart from the three existing pumped-storage power plants there is the Młoty 3×250 MW Power Plant under construction, its building, however, having been suspended for several years. It is anticipated that this power plant will be put into operation in 1994. Reversible Francis turbines with runners of 4375 mm diameter, and rated speed of $333.3\ s^{-1}$ will be installed there. The maximum net head in the turbine operation will be 270.50 m. The above turbines together with ball valves at inlet (diameter 3200) will be imported within the scope of Czechoslovak-Japanese co-operation.

At present the problem of selection of the sequence of constructing the next pumped-storage power stations is studied, with the following power stations taken into consideration:

— Niewistka of power up to 1000 MW with the lower reservoir on the San river;
— Kadyny of power on the order of 1000 MW for which the Vistula Lagoon will be the lower reservoir;
— Sobel of 1500 MW power with the lower reservoir on the Dunajec river below Czorsztyn; this power plant will probably operate in the weekly compensation cycle;
— Rożnów II of 750 MW power for which the existing reservoir of the Rożnów power plant on the Dunajec river will constitute the lower reservoir;
— Pilchowice II of power on the order of 700 MW, on the Bóbr river.

The choice will depend on constructional, hydrotechnical and also system considerations.

4. Preferred Types and Designs of Water Turbines

It can be concluded based on the above considerations which types of water turbines are most suitable for the conditions in Poland and should be given special attention in both the research and development work and in the pre-design studies. The other problem connected concerns the scope of production of individual turbine types by the domestic industry.

Tubular turbines are the most important group of water turbines necessary for the future hydro-electric plants. They should be considered in two sub-groups, namely large bulb turbines for stages on the Vistula and Odra rivers, and tubular turbines for small water power plants. As regards bulb turbines for the Lower Vistula cascade, which diameters will be of the order of $6 \div 8$ m, and which number necessary for full implementation of this cascade is 42 pieces, it should be borne in mind that within the scope of preparations for building the hydro-electric plant in Ciechocinek, steps have been taken in order to start production of turbines in the ZAMECH Mechanical Works in Elbląg, in co-operation with a consortium of foreign firms, whereas production of generators for these turbines has been offered by DOLMEL in Wrocław. The remaining low-head stages on the Upper Vistula and Odra rivers will be equipped with tubular turbines of $3 \div 4$ m diameter, the number of which within the prospect considered here is estimated to be about 20 pcs. Turbine sets for these hydro-electric plants should also be manufactured in the above mentioned works. To ensure a possibly correct and fast implementation and operation of this type of turbine sets one should postulate construction of the first power plants at the existing water stages, e.g. at the Łączany weir on the Upper Vistula. For this power plant the first turbine sets of this type, which will be of middle size, should be manufactured.

Tubular turbines for small water power plants are manufactured at the Power Industry Repair Works in Gdańsk. It has been assumed based on [10] that the above production will include the following:
— tubular turbines, type S, with single bent suction pipe,
— vertical tubular turbines, type Z,
— vertical, bell type turbines with open inflow.

For very low heads of the order of $1.5 \div 4.0$ m "Energoprojekt" has worked out a design for installing bell turbines in concrete siphon pits.

For larger medium-head hydro-electric plants up to about 25 m head, Kaplan turbines will be installed, whereas in places where it is necessary to use pump units with heads over 30 m — reversible Deriaz turbines or reversible Francis turbines will be used. It is assumed that the demand for this type of turbines in the period considered will amount to a dozen or so machines. For small water power plants the DOZAMET works produce vertical Kaplan turbines for open pits with runner diameters from 1550 to 2300 mm. These turbines for very low heads can be installed in siphon pits.

Application of imported reversible Francis turbines has been adopted in large pumped-storage power stations based on very good operation experience gained in power plants at Solina, Żydowo, Żarnowiec and Porąbka-Żar. Most likely in the considered period the demand for these turbines, including the power plant at Młoty, will amount to 15 sets.

For the smallest installed powers in small hydro-electric plants — from a few to several dozen kW, i.e. such where the problem of turbine efficiency is not taken into account — a series of 5 sizes of cross-flow turbines also called Banki-Michell turbines has been worked out in our country. Turbines of this type are manufactured by the Power Industry Repair Works in Gdańsk.

Governors for small water turbines are made in two versions, namely mechanical-hydraulic by the Industrial Automatics Works in Ostrów Wielkopolski, and electro-hydraulic — by the Institute of Automatics of Energy Systems in Gdańsk in co-operation with the Power Industry Repair Works in Gdańsk.

Concluding these considerations — attention should also be paid to the necessity of extending scientific — research work concerning:
— solutions and operation of tubular turbines,

— investigations of reversible turbines, especially within the scope of problems connected with fatigue effects in selected elements of machines,
— working out and implementing in the turbine design and construction offices modern methods of computer-aided design,
— analysis of the necessary scope of modernizing those hydro-electric plants in service which have been working for over 50 years.

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Stan obecny i perspektywy rozwojowe hydroenergetyki w Polsce ze szczególnym uwzględnieniem zapotrzebowania na turbiny wodne

Streszczenie

Skromny potencjał energetyczny polskich rzek, który wliczając rzeki nadające się dla małych elektrowni wodnych wynosi 13,3 TWh rocznie, oraz niska sterowalność systemu elektroenergetycznego w Polsce pociągają za sobą konieczność budowania elektrowni wodnych jako elektrowni szczytowych mających ułatwić sterowanie systemem i zapewnić jego niezakłóconą pracę. Przewiduje się, że do roku 2020 elektrownie te będą rozwijane w następujących czterech grupach:

I — elektrownie wodne niskospadowe na stopniach wodnych zbudowanych na Wiśle i Odrze;

II — elektrownie wodne średniospadowe budowane nad dużymi wielozadaniowymi zbiornikami wodnymi;

III — małe elektrownie wodne;

IV — elektrownie pompowe potrzebne dla zapewnienia prawidłowej i bezpiecznej pracy systemu elektroenergetycznego oraz regulacji wymiany energii z sąsiednimi krajami.

W grupie I będą stosowane głównie duże i średnie turbiny rurowe, w grupie II — turbiny Kaplana albo, tam gdzie będzie potrzebny zespół pompowy, odwracalne turbiny Deriaza lub Francisa. W grupie III będą wykorzystywane różne wersje rurowych turbin Kaplana oraz turbiny przepływowe.

W końcowej części referatu przedstawiono główne tematy prac badawczych mających na celu zapewnienie dalszego rozwoju elektrowni wodnych w Polsce.

Нынешнее состояние и перспективы развития гидроэнергетики в Польше с особым учётом требований относительно гидротурбин

Резюме

Скромный энергетический потенциал польских рек, который, включая реки пригодные для малых гидроэлектростанций, составляет 13,3 Твтч в год, а также низкая управляемость электроэнергетической системы в Польше способствуют необходимости строения гидроэлектростанций как пиковых электростанций, позволяющих облегчить управление системой и обеспечить её невозмущённую работу. Предусматривается, что в период до 2020 года эти электростанции будут развиваться в следующих четырёх группах:

— низконапорные гидроэлектростанции на водяных ступенях на Висле и Одре;

— средненапорные гидроэлектростанции создаваемые на берегах водных резервуаров различного предназначения;

— малые гидроэлектростанции;

— насосные электростанции, необходимые для обеспечения правильной и безопасной работы электроэнергетической системы, а также регулирования обмена энергией с соседующими странами.

В группе I будут применяться в основном большие и средние прямоточные турбины, в группе II — турбины Каплана или, там, где будет необходим насосный агрегат, отвратимые турбины Дериаза или Френсиса. В группе III будут использовываться различные виды пряпоточных турбин Каплана, а также проточные турбины.

В заключительной части реферата представлены основные темы исследовательских работ служащих обеспечению дальнейшего развития гидроэлектростанций в Польше.