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90-91

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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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НАУЧНО-ТЕХНИЧЕСКАЯ КОНФЕРЕНЦИЯ

на тему

ПРОБЛЕМЫ ГИДРАВЛИЧЕСКИХ ТУРБОМАШИН

Гданьск-Владыславово, 24-27 сентября 1985 г.

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1989 Zeszyt 90-91

ZDZISŁAW REYMANN, KAZIMIERZ STELLER, JERZY LITOROWICZ

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Activities of the Polish Academy of Sciences' Institute of Fluid-Flow Machinery Concerning Development of Small Water Power Plants

The paper reviews the work of the Institute's Department of Fluid Dynamics concerning low-power water turbines. The investigations were carried out between 1981 and 1985 and were supported by the Government-Sponsored Program PR-8.

1. Introduction

Work on small water power plants carried out by the Polish Academy of Sciences Institute of Fluid-Flow Machinery concerned low- and medium-head water turbines of 2 to 200 kW power. Investigations concentrated on Banki-Michell turbines, "weirside" siphon propeller turbines and on pumps (helicoidal, diagonal and axial-flow) adapted for turbine operation. The work was carried out mainly* within the frame work of the Government-Sponsored Program PR-8 "Complex development of power engineering" [1] and comprised:
- theoretical analyses and design studies,
- building of model machines and experimental studies,
- designing and constructing of prototype machines,
- dissemination of developed solutions and implementation activities.

The solutions developed have been implemented in co-operation with the Power Industry Repair Plant in Gdańsk manufacturing Banki-Michell turbines, the Gdańsk Section of the Institute of Systems Automation involved in governors for these turbines, and the Power Industry Measurement and Investigation Works, Section in Gdańsk disseminating the results in the country. Among other contacts, special mention should be made of the Main Office of Studies and Power Engineering Design in Warsaw, the Research and Development Centre "Chemkop" in Cracow, the Ship Electrical and Automatics Installation Works in Gdańsk, and also of foreign partners with which the Institute co-operates basing on signed agreements.

* Investigations concerning siphon turbines were carried out outside the PR-8 program.

In this paper some of the more important results concerning the construction of low-power water turbines that were obtained during the years 1981-1985 by the Department of Fluid Dynamics of the Institute are presented. Also an information on plans for the future years is given.

2. General Assumptions

Hydroenergy resources of Poland are rather small. This state results mainly from the lowland shape of most of the country and from relatively small rainfall. In consequence the heads are low and flow intensities are small; about 2/3 of the dams have heads of $H \leqslant 5$ m and flows of $Q < 10$ m^3/s. These conditions are not favourable for the development of water power plants. At the most they can be used for small water power plants. Though energy production of these plants is of rather small significance, it is very important with regard to environmental protection and water economy.

In order to utilize small flows at low heads several types of turbines may be used. These may be centripetal-axial flow (Francis), diagonal (Deriaz) or axial flow (Kaplan) turbines. Also turbines of special construction can be used, e.g. reaction turbines with Reiffenstein guide apparatus, Banki-Michell turbines or siphon turbines.

For low heads, horizontal tubular turbines with Kaplan runners are recommended. However, because of the small power of the turbines (from several to several tens kW), and the need to adapt them to existing hydrotechnical structures, other solutions must be taken into consideration.

Taking into account the needs and production abilities, and also the general development of small power plants in the world, the authors listed types of turbines which in their opinion* should be preferred for the lowest heads (Table 1). Some of

Table 1

Type of turbine	Head [m]	Flow [m^3/s]	Power [kW]
Diagonal and axial flow in Reiffenstein system	1.5 ... 5	0.2 ... 1.2	2 ... 50
Banki-Michell	1.5 ... 5	0.2 ... 2.5	2 ... 85
Siphon, high-speed	1.5 ... 3(5)	0.4 ... 4.5(6)	4 ... 80(200)
Tubular horizontal — S art	1.5 ... 5	1.0 ... 10	12 ... 400
Tubular horizontal — elbow	1.5 ... 5	0.5 ... 5	6 ... 200

* It should be explained, that the proposals presented here differ from those of the Office of Power Engineering Studies in Warsaw presented in the "Materials for the program of domestic production of

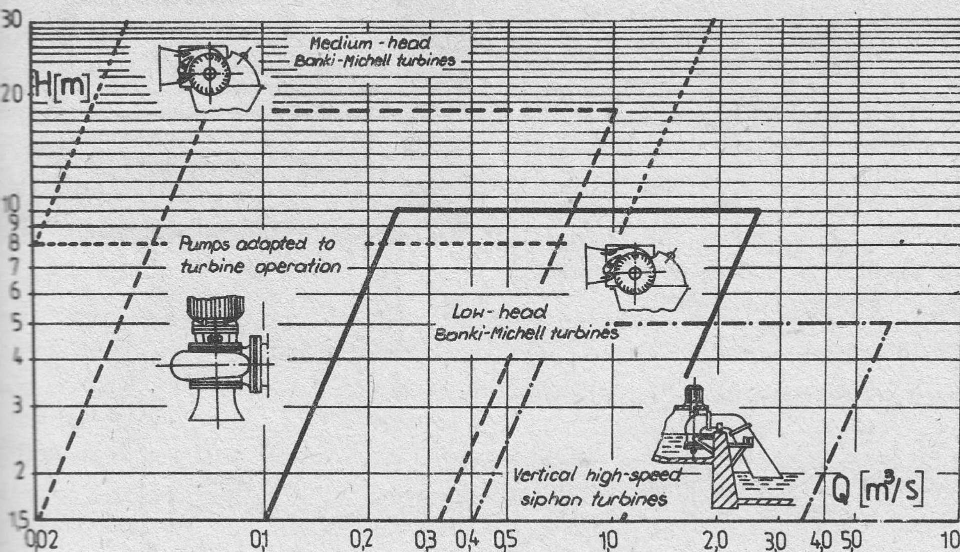


Fig. 1. Ranges of application of small-power water turbines developed at the Institute of Fluid-Flow Machinery

The listed turbines have already been worked out or are being designed. A low-head series of types of Banki-Michell turbines (Institute of Fluid-Flow Machinery) and also several successful constructions of Kaplan turbines (Technical University of Gdańsk) have been finished. Documentation of tubular turbines (Technical University of Gdańsk) and principles of building siphon turbines and turbines based on components of high-speed impeller pumps (Institute of Fluid-Flow Machinery) are in preparation.

Fig. 1 shows ranges of application of low- and medium-head turbines of small power which have already been developed or are being developed at the Institute of Fluid-Flow Machinery in Gdańsk.

3. Completed Work

Low-head series of types of Banki-Michell turbines

The Banki-Michell turbines are two-stage turbines. Water flows twice through the grid of blades, once from the outside towards the centre where the bladeless space is situated, and the second time — from the centre to the outside where the outlet space is situated (Fig. 2). In order to use the turbine effectively under conditions of variable flow, both the runner and the guide vane are divided into two unequal parts (Fig. 3). By appropriate setting of the divided guide vane water flows through 1/3, 2/3 or full width of the turbine runner.

small power plant turbines" [2]. The differences concern both the type and the scope of utilizing the proposed types of turbines.

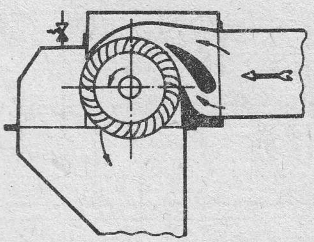


Fig. 2. Schematic of a Banki-Michell turbine (principle of operation)

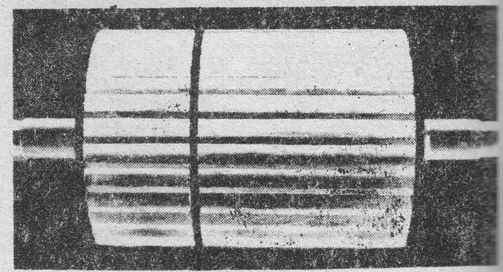


Fig. 3. Model Banki-Michell runner

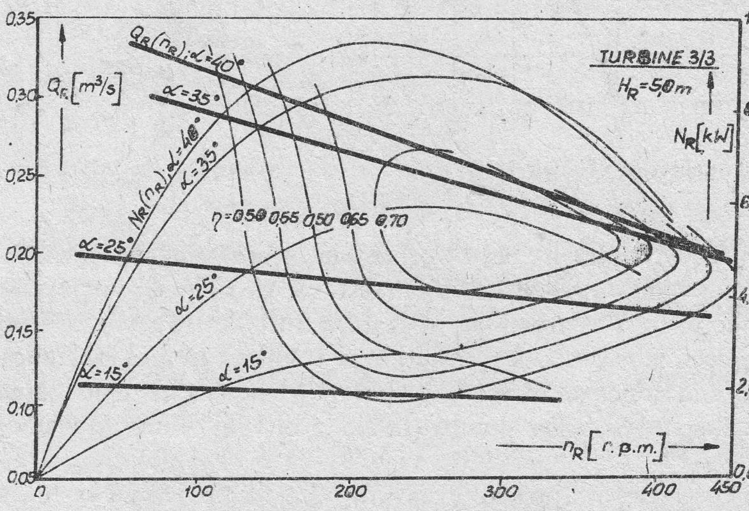


Fig. 4. Set of iso-efficiency curves for the model low-head Banki-Michell turbine

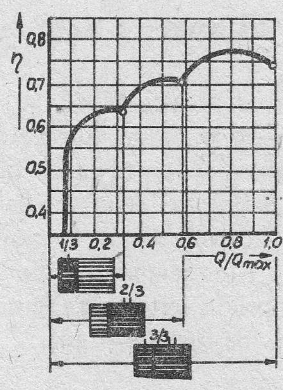


Fig. 5. Efficiency curve of the model low-head Banki-Michell turbine

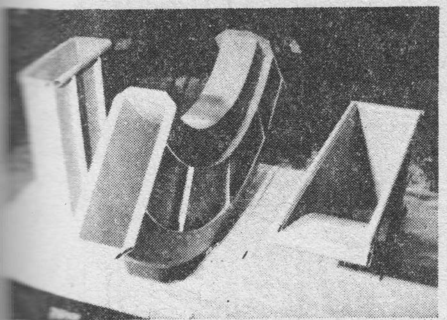


Fig. 6. Model suction tubes

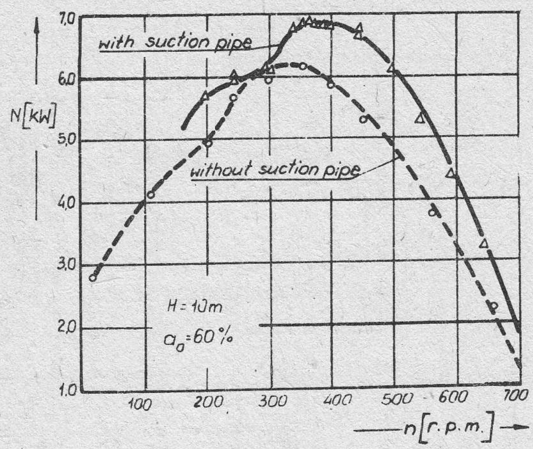


Fig. 7. Power delivered by the model turbine with and without suction tube

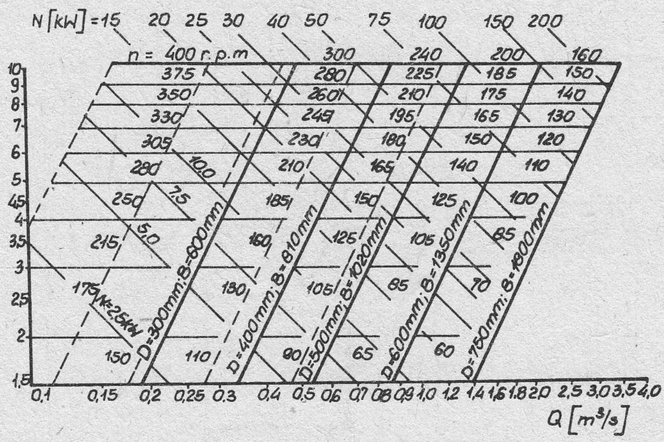
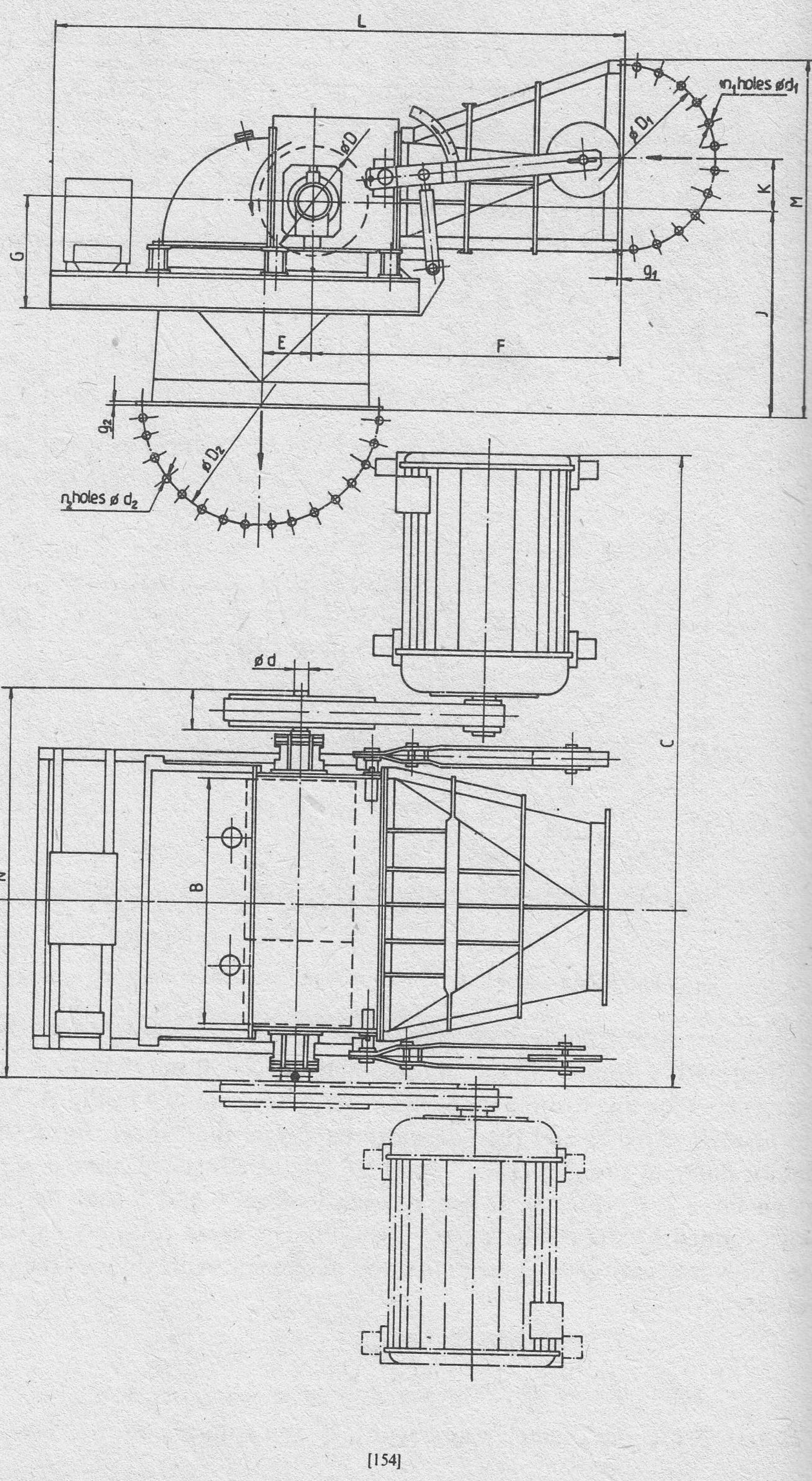


Fig. 8. Nomograph for low-head Banki-Michell turbines

The development of the series of types was based on investigations of a model turbine fitted with a runner of 300 mm diameter and 400 mm width. A set of iso-efficiency curves for this turbine in (Q, n) co-ordinates is shown in Fig. 4. The curves relate to head $H = 5.0$ m and the full width supply of the runner. Based on curves obtained for different supplies (1/3, 2/3 and 3/3 Q), the efficiency curve $\eta = f(Q/Q_{\max})$ was drawn for $n = n_n$ (Fig. 5). It can be seen in Figs 4 and 5 that the maximum efficiency attained by the model was $\eta_{\max} = 0.77$. The rated rotational speed $n = n_n$ and rated flow intensity $Q = Q_n$ were in good agreement with values predicted using the formulae:

$$n = 40\frac{\sqrt{H}}{D} \quad \text{and} \quad Q = 0.85\, DB\sqrt{H},$$

where D and B are the diameter and width of the runner, respectively, and H is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Turbine							Asynchronous generator			C	Appr weight
Type	Runner diameter D mm	Active width runner mm	Water head m	Flow intensity m^3/s	Power kW	Speed r.p.m	Type	Power kW	Speed s.p.m	mm	kg
NSH-400/810	400	810	3	0,46	10	165	SDf-225 S 8	18,5	750	2076	1250
			4	0,51	15	190					
			5	0,55	20	210	SDf-280 S 8	37	750	2263	1550
			6	0,59	25	230					
			7	0,64	32	250					
			8	0,68	39	270	SZDc-158 ch	75	750	2607	2350
			9	0,72	46	285					
			10	0,75	54	300					
NSH-600/1350	600	1350	3	1,15	25	110	SZDc-158 ch	75	750	3391	3500
			4	1,35	39	125					
			5	1,5	54	140	SZDc-158 d	125	750	3391	3600
			6	1,65	71	155					
			7	1,75	86	170					
			8	1,85	106	180	SZDc-178 c	160	750	3532	4700
			9	1,95	126	190					
			10	2,05	147	200					
NSH-750/1800	750	1800	3	2,0	43	90	SZDc-158 ch	75	750	3808	4650
			4	2,2	63	100					
			5	2,5	90	115	SZDc-178 c	160	750	3949	5850
			6	2,65	114	125					
			7	2,85	143	130					
			8	3,0	172	140	SZDc-198 c	250	750	4112	6750
			9	3,2	206	150					
			10	3,4	243	160					

Type [illegible] turbine	Dimensions																
	E	F	G	J	K	L	M	N	d	l	D_1	D_2	d_1	d_2	g_1	g_2	n_1	n_2
[illegible]/810	167	1100	450	972	185	2248	1535	1396	58	120	705	810	26	26	15	15	20	24
[illegible]/1350	268	1717	605	1138	281	3148	1957	2225	85	210	1020	1320	30	27	15	15	24	32
[illegible]/1800	243	1812	522	1083	422	3577	2193	2647	136	220	1320	1730	30	30	24	20	32	40

Fig. 9. Characteristic parameters of turbines NSH-400/8100, NSH-600/1350 and NSH-750/1800

the head. It should be stressed that the turbine efficiency depends also on the wi
of the supplying stream and on the head. Decrease of the active width B and in-
crease of the head H result in a lower efficiency η. This last observation coinci
with the results of Johnson et al. [3].

During the model tests the control moments and overspeeding velocities we
also measured, the best guide vane angles and the number of runner blades we
selected, the effectiveness of pressure controlling in the space behind the runner an
the effectiveness of operation of straight- and curvilinear suction tubes of recta
gular and circular cross-section were evaluated (Fig. 6). It was observed, amo
others, that pressure control on the suction side should be independent of the hea
and water flow intensity, and that suction tubes had an advantageous influence o
the conditions of turbine operation. The gain obtained by using a suction tube at 10 m
head and supply stream width of 150 mm is shown in Fig. 7. The gain is significa
for this reason supplementary investigations of the conditions of Banki-Miche
turbine installation were started.

Based on the results of model test the principles of building a series of typ
consisting of five sizes were worked out. A nomograph indicating the operati
parameters and characteristic quantities of low-head turbines is presented in Fig.
Detailed information concerning three sizes for which a construction documentati
was worked out at the Institute of Fluid-Flow Machinery are given in Fig. 9.

Governors for Banki-Michell turbines were developed by three centers: the In-

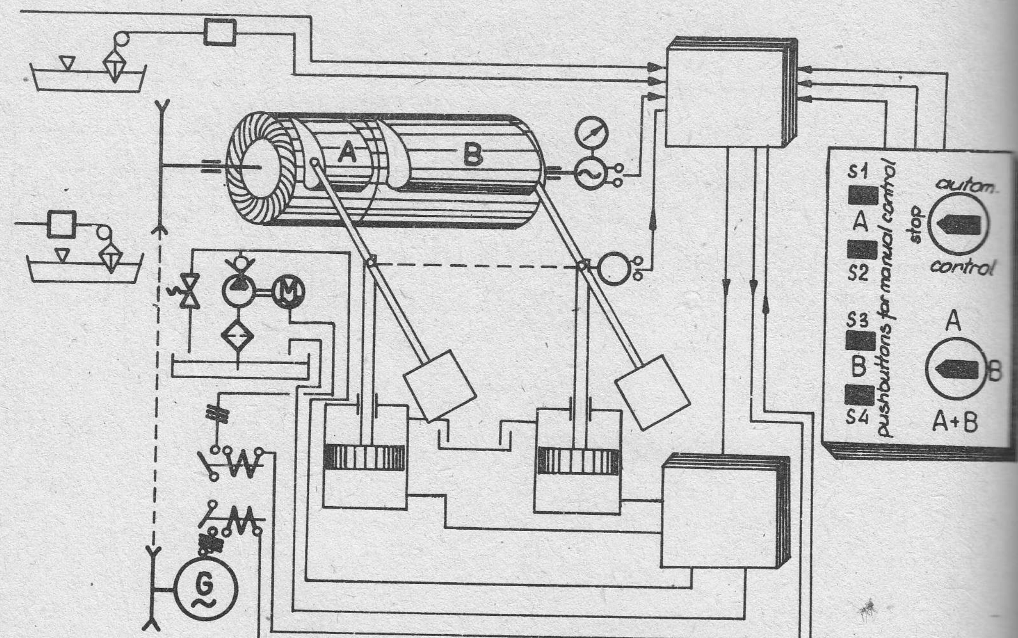

Fig. 10. Schematic diagram of the control of a Banki-Michell turbine operating in conjunction with a
asynchronous generator

stitute of Power Systems Automation the Research and Development Laboratory of Chemical Resources and the Institute of Fluid-Flow Machinery.

Here we shall present in a short form only the electrohydraulic governor RTBA developed by the Gdańsk Division of IPSA and installed at the Osowo Lęborskie Power Plant [4].

The control system (Fig. 10) consists of two independent hydraulic servo-motors with a power supply unit, two guide vane angle transformers, a rate generator, electronic governor, relay control system and a system for headwater measurement.

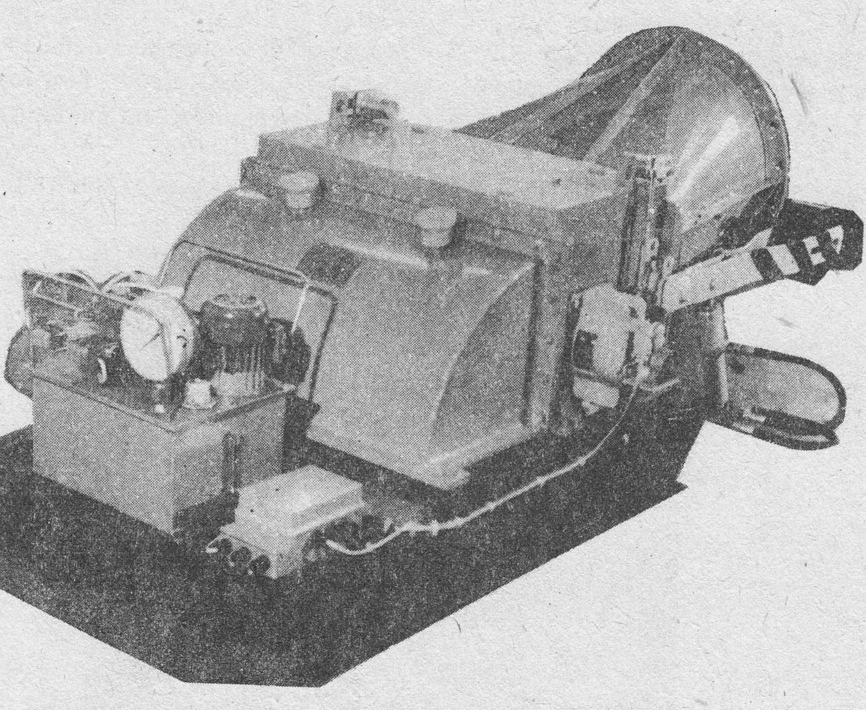

Fig. 11. Turbine NSH-400/810 with the electrohydraulic governor designed for operation at $H = 4.0$ m, $Q = 0.64\ m^3/s$, $n = 185$ r.p.m. and $P = 18.5$ kW

The guide apparatus is opened and closed by electric signals from the headwater (float sensor), turbine shaft speed (rate generator), and electric network voltage (voltage at the divider coil). The signal controlling opening of the guide apparatus activates the oil pump and the oil flows below the piston of the appropriate servo-motor. The guide is closed by draining oil to the tank under the weight acting on the servo-motor piston.

The turbine set can be controlled manually or automatically, both during starting and stopping — e.g. due to voltage decay in the grid, excessive headwater level drop or turbine set loading.

The turbine NSH 400/810 and the electrohydraulic governor RTBA installed in the water power plant at Osowo Lęborskie are shown in Fig. 11. The turbine operates there since January 1985. The RTBA governor adjusts the guide vanes depending on water inflow, stops the turbine if interference appears, and starts it when the interference is removed.

4. Work in Progress

Medium-head series of types of Banki-Michell turbines

The design of this series of types is based on the following assumptions:

— the turbines should work at 7 to 30 m heads and flow intensities of 0.02 to 2.0 m^3/s,
— the required range of hydraulic parameters should be covered by four turbine sizes,
— for small widths of the supply stream, undivided runners and guides apparatuses are recommended.

The design is based on model tests with a runner of 300 mm diameter and 150 mm

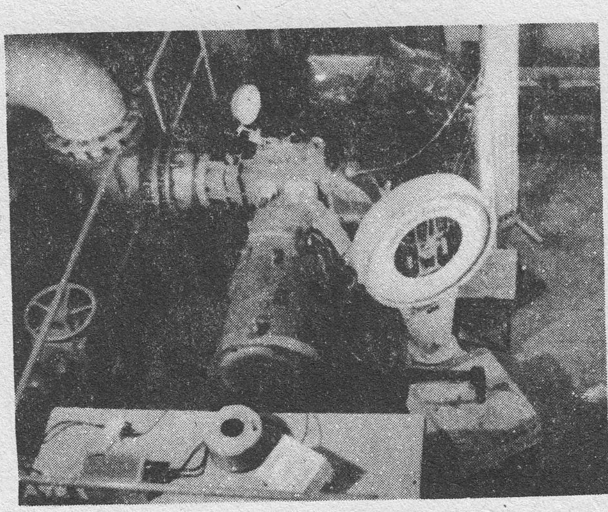

Fig. 12. Medium-head Banki-Michell model turbine on test stand

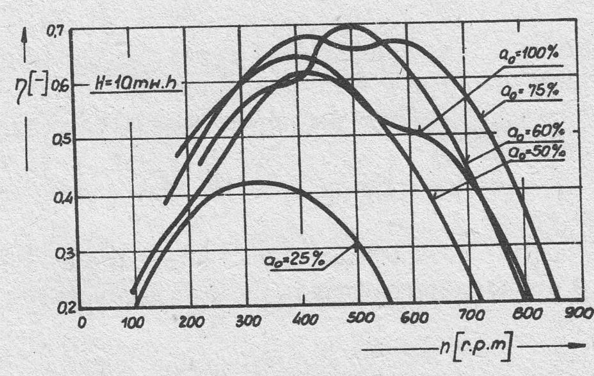

Fig. 13. Characteristics of medium-head Banki-Michell turbine

width (Fig. 12). First tests showed an undesirable deformation of efficiency curves (Fig. 13). Removal of these effects required changes in the turbine flow system. These consisted in changing the shape of the inlet and the runner itself.

Work on documentation of this series of types is still in progress.

Adapting impeller pumps to turbine operation

In order to lower the cost of manufacturing of water turbines, especially for low heads and small flow intensities, work was started on adaptation of products of the

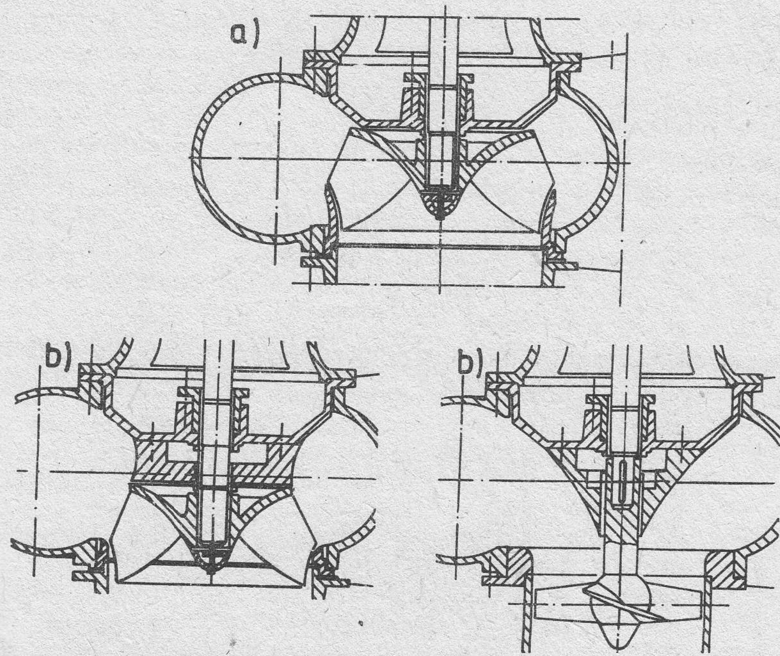

Fig. 14. Adaptation of helicoidal pumps for turbine operation;a) initial state, b) after modifications

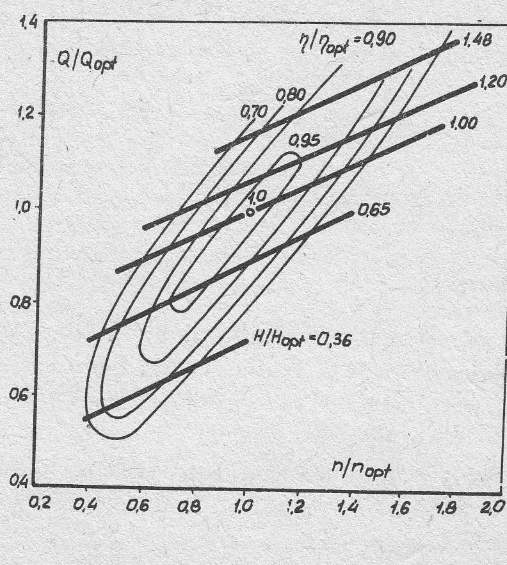

Fig. 15. Characteristic curves of a helicoidal pump working as a water turbine

domestic pump industry. The work consists in adapting diagonal and axial flow pumps manufactured by the Warsaw Pump Works and helicoidal pumps of the Leszno Pump Works to turbine operation. An example of such an adaptation is the helicoidal pump shown in Fig. 14. The changes consisted in using a different impeller (with mixed or axial flow) and in its different setting in the spiral casing of the pump.

It should be mentioned that there are no control components (except a gate or butterfly valve). Therefore these machines are characterized by steep performance curves (Fig. 15) and cannot be used in variable conditions. This means that they should not be used where flow rate variations are large.

Siphon turbines

Interest in siphon turbines resulted from the following considerations:

— demand of socialized and private economy units; for example — an application of the Power Engineering Office at Słupsk, submitted — in agreement with the province authorities — to the co-ordinator of problem 2.5 of the Government-Sponsored Program PR-8, and also questions directed to the Small Water-Power Plant Consulting Office at Gdańsk-Oliwa,

— world trend of small water-power plant development, especially work on siphon turbines started by various firms abroad.

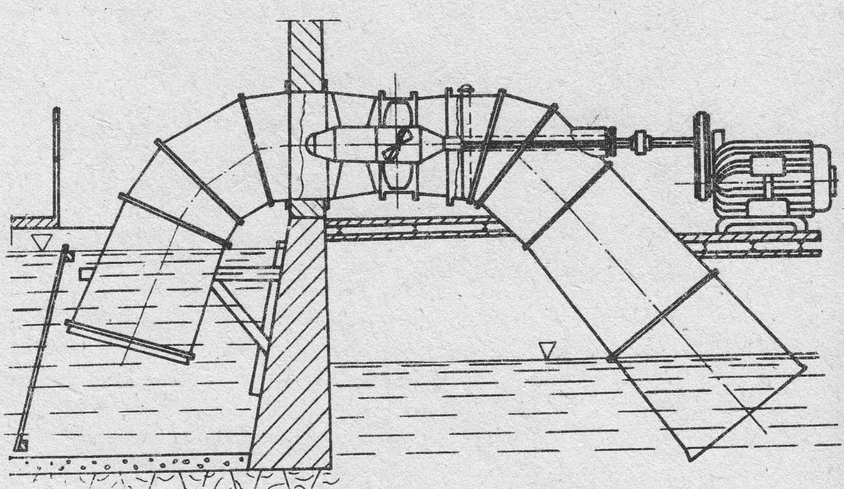

Fig. 16. Schematic of a horizontal siphon turbine

It is assumed that siphon turbines should complement the already developed series of types of Banki-Michell turbines and the series of tubular turbines now under development.

They may be used for building automated micro power plants at existing or newly built dams (Fig. 16). Working as high-speed "weir-side" turbines they should be adapted to operation in the following conditions:

head .... from 1.5 to 3.0 (max. 5.0) m
flow rate .... from 0.4 to 4.5 (max. 6.0) m^3/s.

For these requirements a model siphon turbine was developed [1]. This model will undergo complex laboratory tests. Results of these investigations and assumptions for developing a whole series of types of these turbines will be presented in the next year.

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Działalność Instytutu Maszyn Przepływowych Polskiej Akademii Nauk na rzecz rozwoju małych elektrowni wodnych

Streszczenie

Artykuł zawiera przegląd działalności Zakładu Dynamiki Cieczy IMP PAN w dziedzinie roz małych elektrowni wodnych. Badanie prowadzono głównie w latach 1981-1985 w ramach progra rządowego PR-8 „Kompleksowy rozwój energetyki".

Na początku podaje się ogólne wskazówki dla projektowania małych elektrowni wodnych. D omawia się badania zakończone i aktualnie prowadzone.

Do prac zakończonych należy typoszereg niskospadowy turbin Banki-Michella. W artykule po się wyniki badań modelowych (rys. 4 i 5). Badania pokazały dość dużą sprawność turbin, równą η = 0, oraz użyteczność rur ssących. Na rysunku 8 przedstawiono nomogram dla tego typoszeregu a rysunku 11 — turbinę prototypową.

Prace prowadzone aktualnie dotyczą m. in. typoszeregu średniospadowych turbin Banki-Mich (rys. 12), adaptacji pomp wirowych do pracy turbinowej (rys. 14) oraz turbin wodnych lewarowych (rys.

Prace prowadzone w Zakładzie są planowane głównie z myślą o zaspokojeniu potrzeb gospoda narodowej i wykorzystaniu mocy produkcyjnych w dziedzinie budowy elektrowni wodnych.

Деятельность Института проточных машин Польской Академии Наук направлённая на развитие малых гидроэлектростанций

Резюме

В статье дан обзор деятельности Отдела динамики жидкости Института проточных ма ПАН в области развития малых гидроэлектростанций. Исследования проводились в основ в 1981-1985 г. в рамках правительственной программы PR-8 ,,Комплексное развитие энергети

В начале даются общие указания для проектирования малых гидроэлектростанций. За обсуждаются результаты завершённых и актуально проводимых исследований.

К завершённым работам зачисляется низконапорный типоряд турбин Банки-Мичелла. В ста представлены результаты модельных исследований (рис. 4 и 5). Исследования показали дово высокое значение к.п.д. турбин, достигающее $\eta = 0{,}77$, а также полезность применения отсас ющих труб. На рис. 8 представлена номограмма для этого типоряда, а на рис. 11 — прото турбины.

Сейчас проводимые работы касаются м.пр. средненапорного типоряда турбин Банки-Мич (рис. 12), приспособления роторных насосов к турбинной работе (рис. 14), а также гидроту со сифонным питанием водой (рис. 16).

Работы проводимые Отделом динамики жидкости запланированы с мыслей об удовлетвор нужд народного хозяйства и использовании производственных ресурсов в области стро гидроэлектростанций.