OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

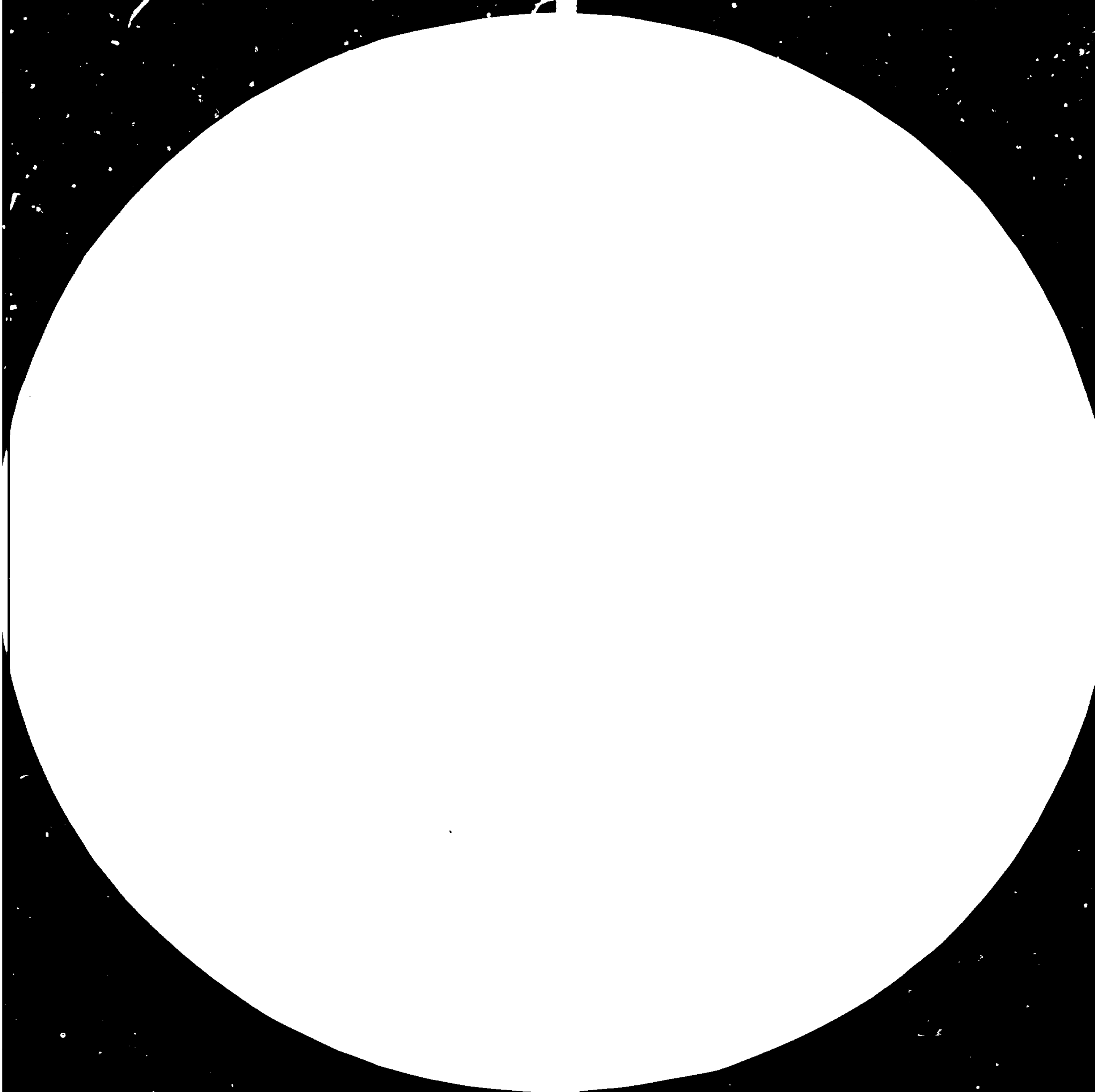
Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

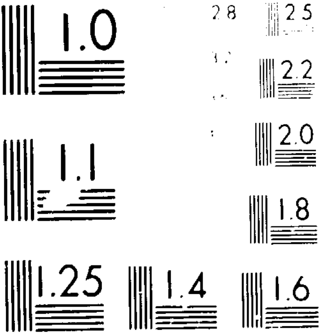
CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org




1.0
2.8
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

09668

Distr.
LIMITED

ID/WG.305/31
9 May 1980

ENGLISH

United Nations Industrial Development Organization

Seminar-Workshop on the Exchange of
Experiences and Technology Transfer
on Mini Hydro Electric Generation Units

Kathmandu, Nepal, 10-14 September 1979

MODERN WATER TURBINE TECHNOLOGY
FOR SMALL POWER STATIONS*

by

Timo Salovaara**

---

* The views expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO. This document has been reproduced without formal editing.

** Mr. Timo Salovaara, Oy Tampella Ab, Tampere, Finland.

80-39215

Background of Development in Finland

Low heads (waterfalls) are a typical feature in hydro power station construction in Finnish circumstances. Most of the heads are lower than 10 m (33 ft.). The head range of big power stations is 10-25 m (33 to 82 ft.). Due to this, the manufacturing of water power machinery is concentrated on types for low heads.

In the beginning of this century, the Francis-turbine was the most common type. Usually there was a horizontal shaft in the machine and to increase its speed, several runners were placed on the same shaft. By the end of the 1920's, practically all power stations, with the exception of the smallest ones, were being furnished with vertical Kaplan-turbines. New technology was not introduced again until the 50's when the need arose to decrease the construction costs of small, low-head power stations. To accomplish this, these power stations began to be equipped with tubular Kaplan-turbines more than 20 years ago. The relatively high price of electrical energy and state support for many flood control projects made it possible to continue constructing small power stations in the 60's and beginning of the 70's, despite the low oil price. As a result, Finnish hydro technology is both modern and well-proved today, just as interest in small hydro power stations has begun to redevelop in different parts of the world.

Water Turbine as Part of the Power Station

In a small hydro power station, the turbine and other mechanical equipment usually form a rather small part of the total costs. A typical value is 10-30%. The total cost of the machinery, including electrical equipment, hardly ever rises to 50% of the total investment. It is nonetheless of essential importance to the profitability of the project to choose machinery most suitable for keeping construction costs low. The investment in a hydro power station must be totally paid back by selling energy produced by the turbine. A simple calculation shows that the mean efficiency of the turbine has a considerable influence on the pay-back time and economy of the project.

Several attempts to decrease machinery costs by designing simplified standard turbines have been made. According to our experience, the economically optimal solution is only seldom found this way. It seems better to strive for a technically reasonably advanced solution by assembling a partly-customized turbine incorporating certain standard components. This approach also permits the price of the machinery to be kept within reasonable limits.

The service life of a hydro power station is very long, in most cases 50-80 years. This sets very high demands on the reliability and durability of the machinery. The design should be directed at simple and straightforward details. Parts needing regular maintenance should be avoided. Extensive use of corrosion-resistant materials is an absolute must.

Turbine Types

In small low-head power stations, a tubular turbine with horizontal shaft is usually used. In small machines, the draft tube is bent, allowing the generator to be placed outside the waterway (Fig. 1). The turbine runner and generator are usually located above the tailwater level. This is an important safety factor which at the same time makes maintenance of the plant easier and construction costs lower.

In such a turbine, there is usually a Kaplan-runner with adjustable blades. Fixed guide vanes connected to a butterfly valve operating as a shut-off device can be used as a guide apparatus. Alternatively, a distributor with adjustable wicket gates can be used, with the butterfly valve omitted or replaced by stoplogs or a simple bulkhead gate. The typical head range for such a turbine is 3-20 m (10 to 65 ft.) and discharge 5-60 m^3/s (180 to 2100 cu.ft./sec.). When the discharge exceeds 80-90 m^3/s (3000 cu.ft./sec.), a bulb-type turbine may become feasible (Fig. 2).

The lower limit for the turbine size will be determined by the fact that the bulb must be accessible for maintenance. A bulb-type turbine is always provided with adjustable wicket gates and Kaplan-runner. The straight waterway gives this type very good efficiency and high discharge capacity.

In some cases, it is profitable to use a tubular turbine with vertical shaft (Fig. 3). The head range can be extended upwards to about 25 m (32 ft.), since the runner can be submerged below the tailwater level to avoid cavitation.

A common feature of all tubular turbine types is a straight and compact waterway allowing a very small sized powerhouse and simple form of concrete structure. In small tube-type machines, the waterway consists mainly of the steel plate construction of the turbine.

In some cases, the head of a small power station is so high that a tubular turbine cannot be used. The Francis-turbine is still competitive from a head of about 25 m (82 ft.) upwards. If there is a long penstock in the power station, the use of Francis-turbine is also recommended for lower heads. In a runaway situation, the speed and discharge of this turbine remain relatively low and an excessive pressure rise in the penstock at shut-down is avoided. The construction with a horizontal shaft is the most common also in Francis-turbines, the discharge being smaller than about 30 m^3/s (1000 cu.ft./sec) (Fig. 4).

Hydraulic Characteristics of the Turbines

The characteristic efficiency curves of some turbine types are shown in Fig. 5.

As a general statement about axial flow turbines, it can be said that machines provided with adjustable Kaplan-runners can be used at a wide range with part load and overload thus maintaining good efficiency. With a fixed blade propeller turbine, use outside the optimum range, means vibrations, noise and poor efficiency.

In hydro power projects, extensive model turbine tests are usually an important part of the planning work of the plant. In small plants, this method cannot be adapted to each power plant due to its high costs. For this reason, our company has made a great number of universal model tests, the results of which can be interpreted for each different case. Model tests for tubular turbines were started in our hydraulic laboratory in 1956. In addition to efficiency and cavitation properties, a great number of other questions necessary for design work have been cleared up in these tests.

Choice of Turbine Type

If the power station is located in a place with big flow variations, it is advisable to choose a turbine with a fully-adjustable runner and distributor. This type with its flat efficiency curve can make use of any flow at a range 15-110% of its nominal capacity. If the plant has sufficient regulated reservoir capacity for peaking operation or if the plant is furnished with two or more machines, a "semi-Kaplan" furnished with Kaplan-runner and fixed vanes is usually the most suitable type. A fixed propeller turbine can be used only in places where continuous or intermittent full-load operation is possible, i.e. where a constant rate of flow can be maintained. Experience has shown, however, that in small power stations there are often sizable water level variations. These variations may be especially harmful in harsh winter conditions as there is a risk of breaking the ice cover of the river. The trashrack of the power station is easily clogged by loose ice and this causes disturbances in the operation of the plant. Accordingly, this type of turbine has its limitations vis-a-vis small hydro power applications.

Mechanical Properties of the Turbines

The stationary parts of small turbines wholly consist of fabricated steel plate structures. Improved surface treatment methods are continuously developed for these to decrease the need for maintenance.

In practice, trouble-free operation of the turbine depends on the operation of the seals and bearings. Special attention has been paid to these points. Inside the waterway, only water or grease lubricated journal bearings are used. Outside the waterway, self-aligning roller bearings lubricated with oil led from the governing system are used. Stainless steel is used for many moving parts, e.g. shaft sleeves and wicket gate trunnions. The runner blades are, without exception, made of stainless steel as in many cases is the runner chamber as well.

The turbines are assembled in the workshop into components as big as can be transported. In many cases, an almost complete turbine can be transported. In this way, erection work at site can be considerably accelerated.

Governing and Control Equipment

In many cases, no speed governor is needed because the power plant is intended to operate only connected to a large system. In this case, only equipment for load control is needed. If there is a need to feed into an isolated system, e.g. as a stand-by power source, the turbine can be furnished with a mechanical-hydraulic governor. From about 5000 kW output upwards, an electronic governor is used which provides better accuracy and stability in speed governing. As power source of the governor servo system, a pressure oil unit is used. A relatively low hydraulic pressure is used to afford a long service life for the components of the system. The governing system usually includes a pressure tank which stores energy for shut-down of the turbine in emergency cases. In addition to this, the butterfly valve or the distributor of the tubular turbine is made self-closing by means of a counterweight.

In case of a failure, the runaway speed of the turbine may exceed the nominal speed by 100-180%. The turbine and generator are designed to withstand full runaway speed for a short time. Generally, it is not recommended to use a clutch for disconnecting the generator because the turbine is the more critical and also more expensive component in runaway conditions.

Use of Gear as Speed Increaser

The speed of a low-head turbine is usually low and it is often advantageous to increase the generator speed by using a gear. This permits the use of standard generators. The generator speed is usually set between 600-1200 rpm depending, among other things, on turbine output and runaway speed. The mechanical losses of the speed increaser can to a great extent often be compensated for by choosing an optimum speed for the turbine independent of the synchronous speed of the generator. At present, the upper limit for economical use of the gear is an output of about 2000-3000 kW.

Replacing of Old Turbines by Modern Units

When old power plants are put into use again, the powerhouse is not often usable anymore. A new powerhouse can then be designed, fitting modern turbines together with existing dam structures. In many cases, the existing Francis-turbine with horizontal shaft can be replaced by a tubular turbine with only slight modifications in the power plant structures. At the same time, the output of the plant can be considerably increased.

Summary

Experience obtained from extensive research and development work, as well as from a great number of delivered small water turbines, makes it possible for us to offer competitive water turbine technology for export. The principle of fashioning tailor-made units using mostly standard components has also proved to be advantageous when replacing old water turbines by modern ones.

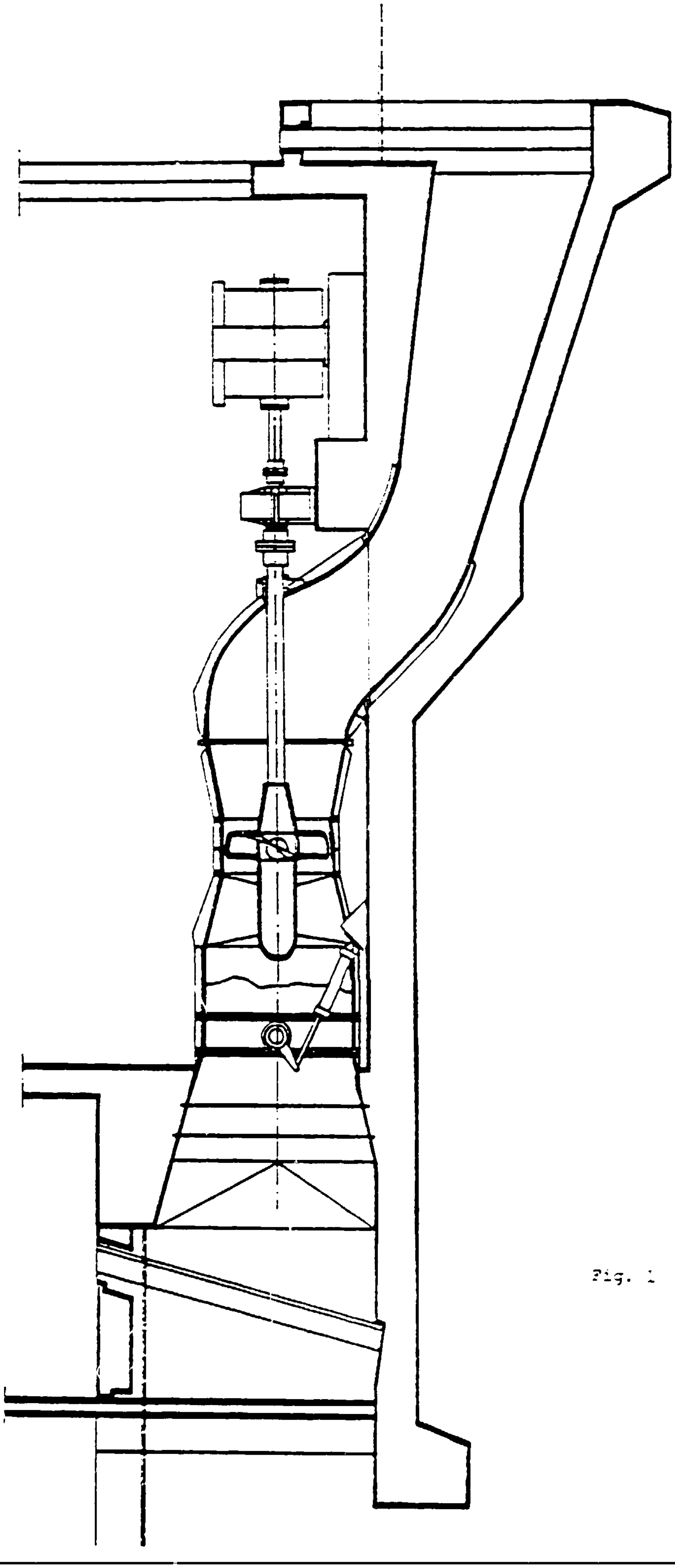


Fig. 1

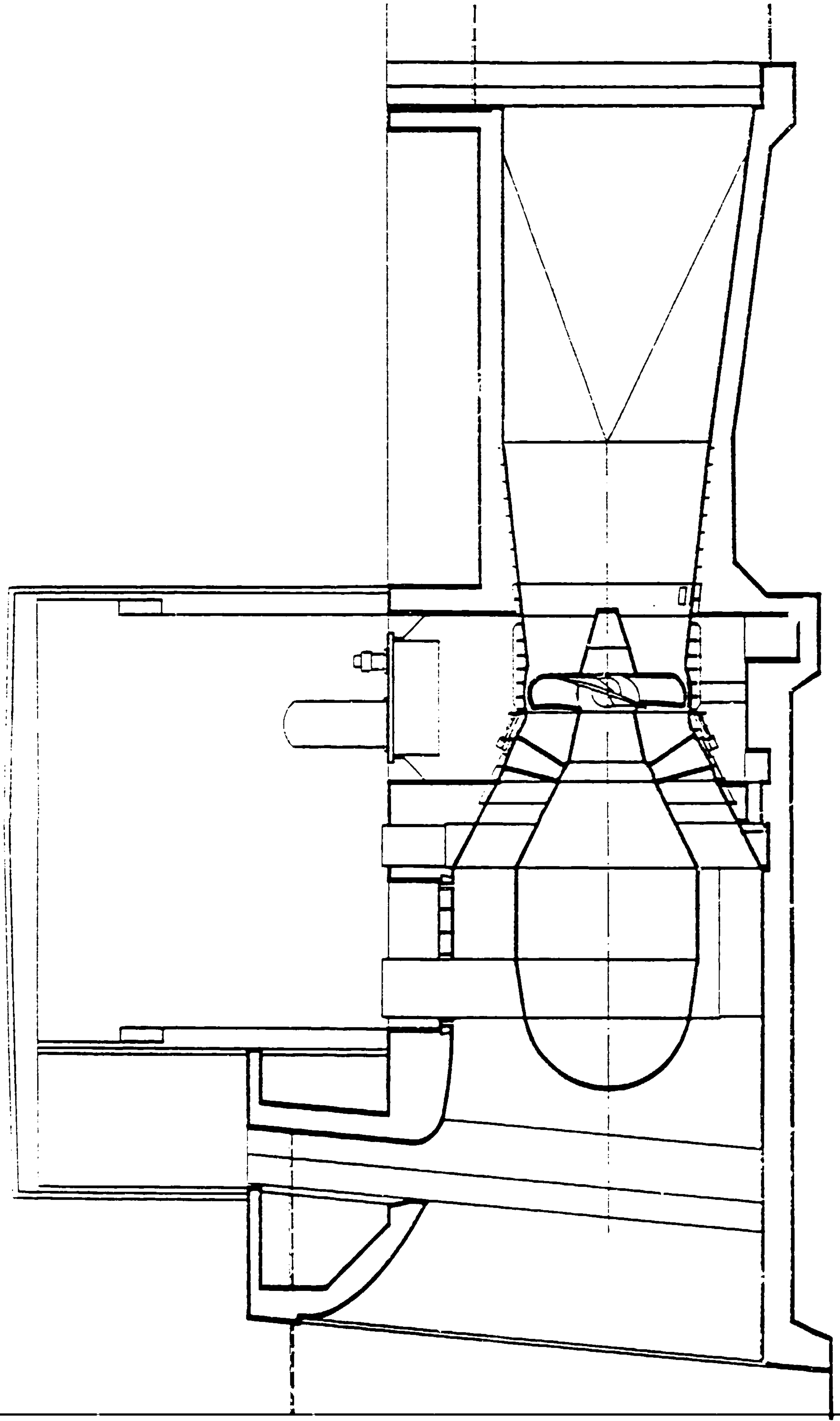


Fig. 2

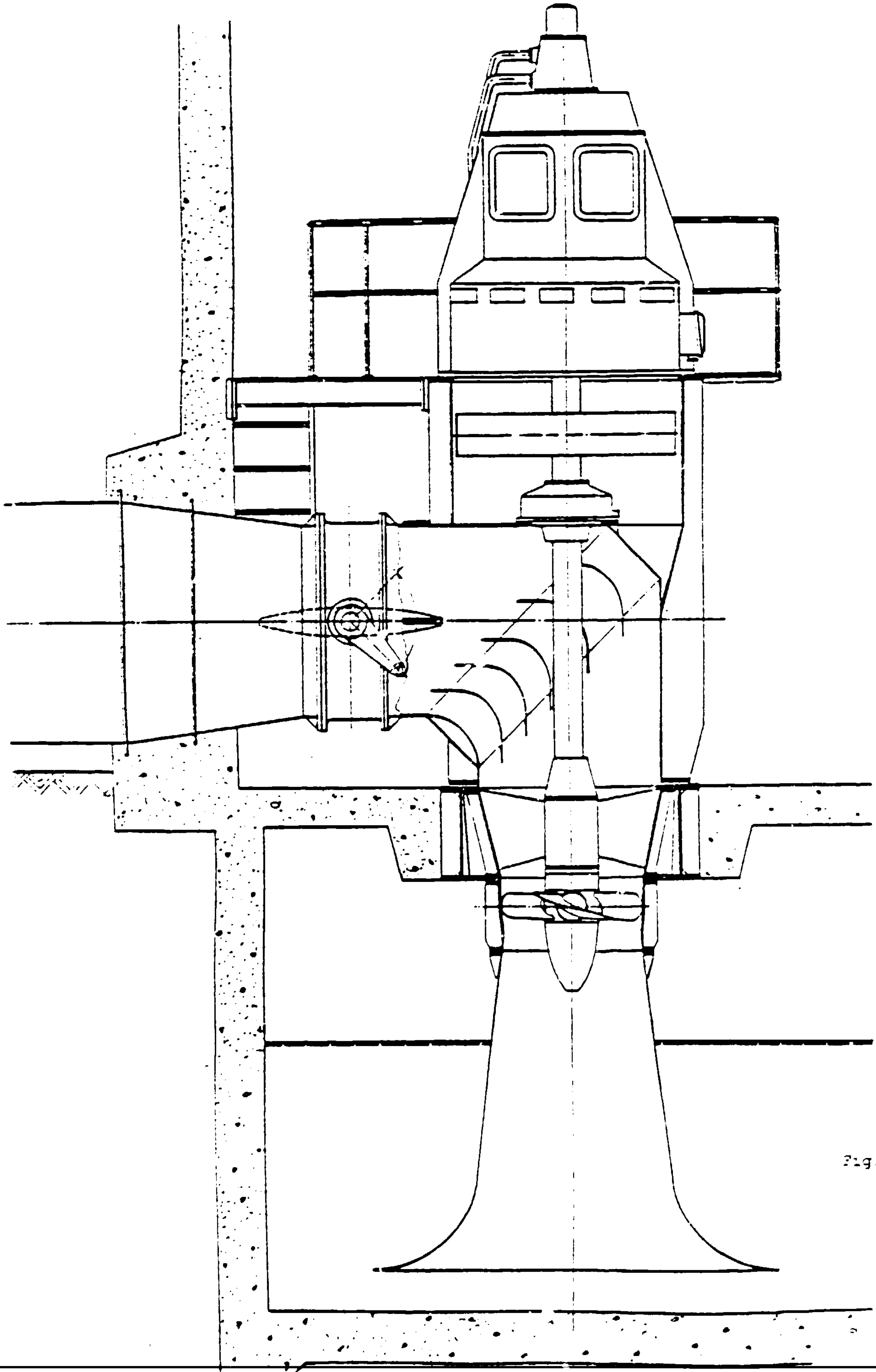


Fig. 3

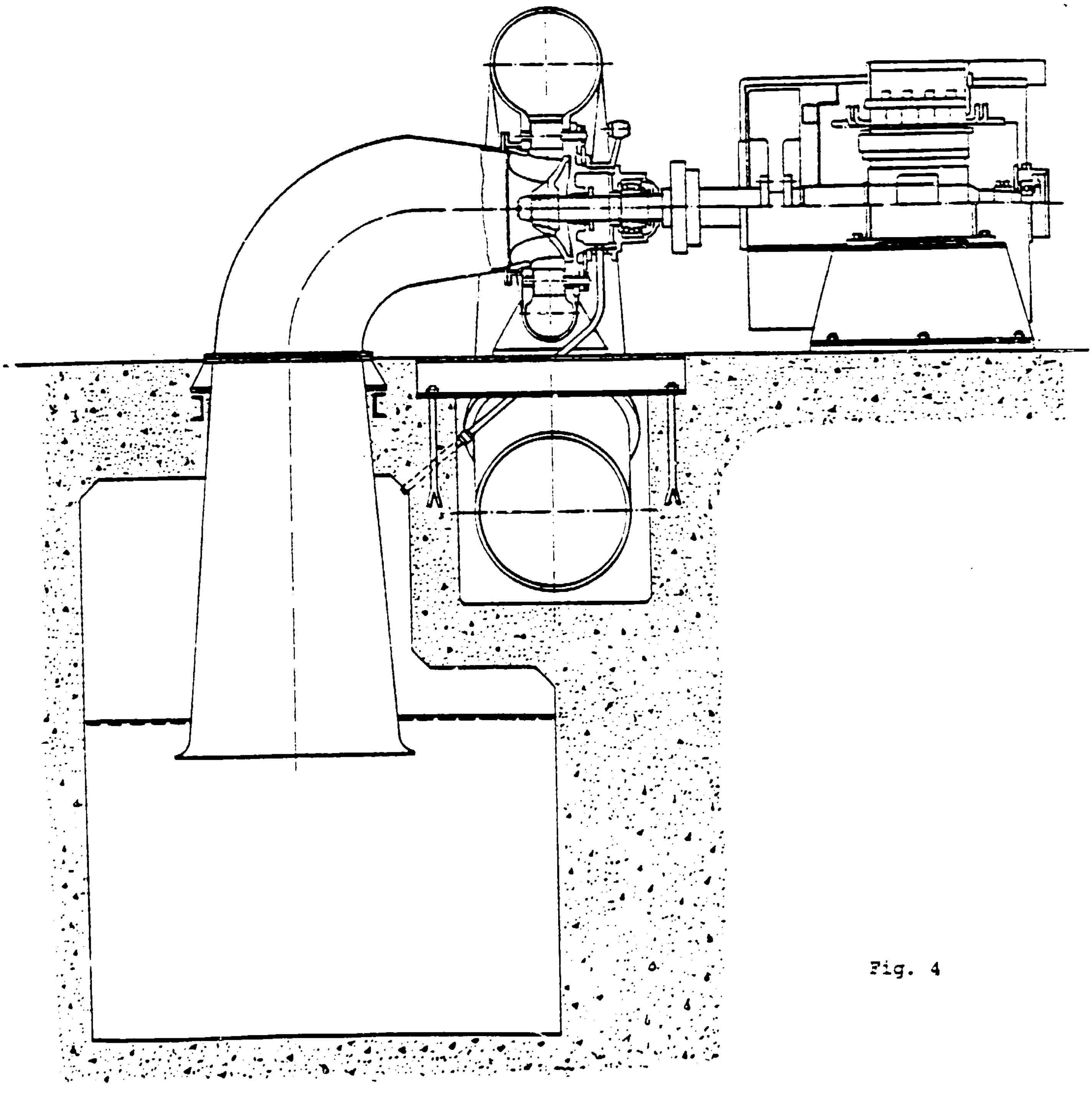


Fig. 4

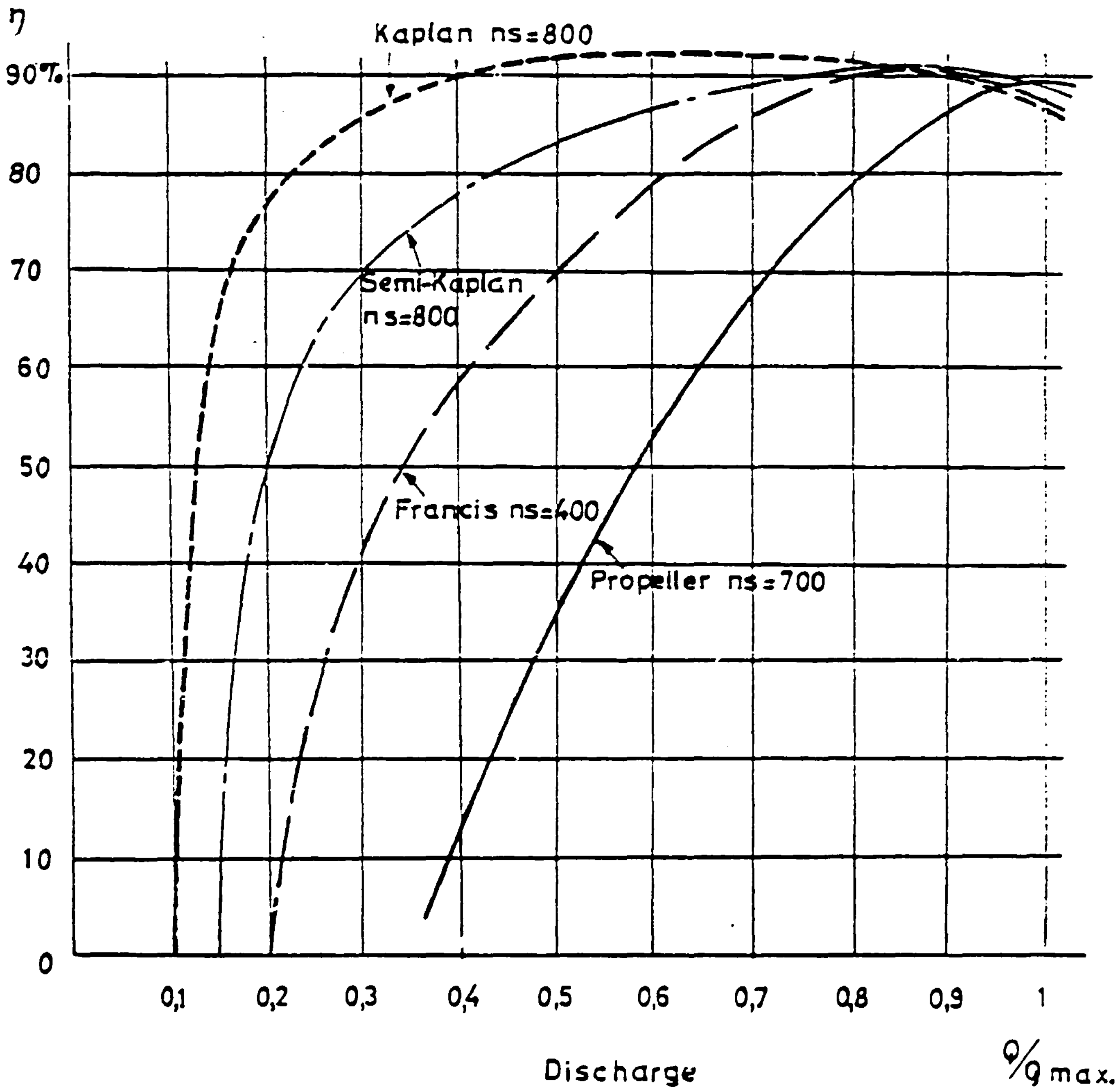

η
90%
80
70
60
50
40
30
20
10
0
Kaplan ns=800
Semi-Kaplan
ns=800
Francis ns=400
Propeller ns=700
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1
Discharge
Q/Q max.

Fig. 5