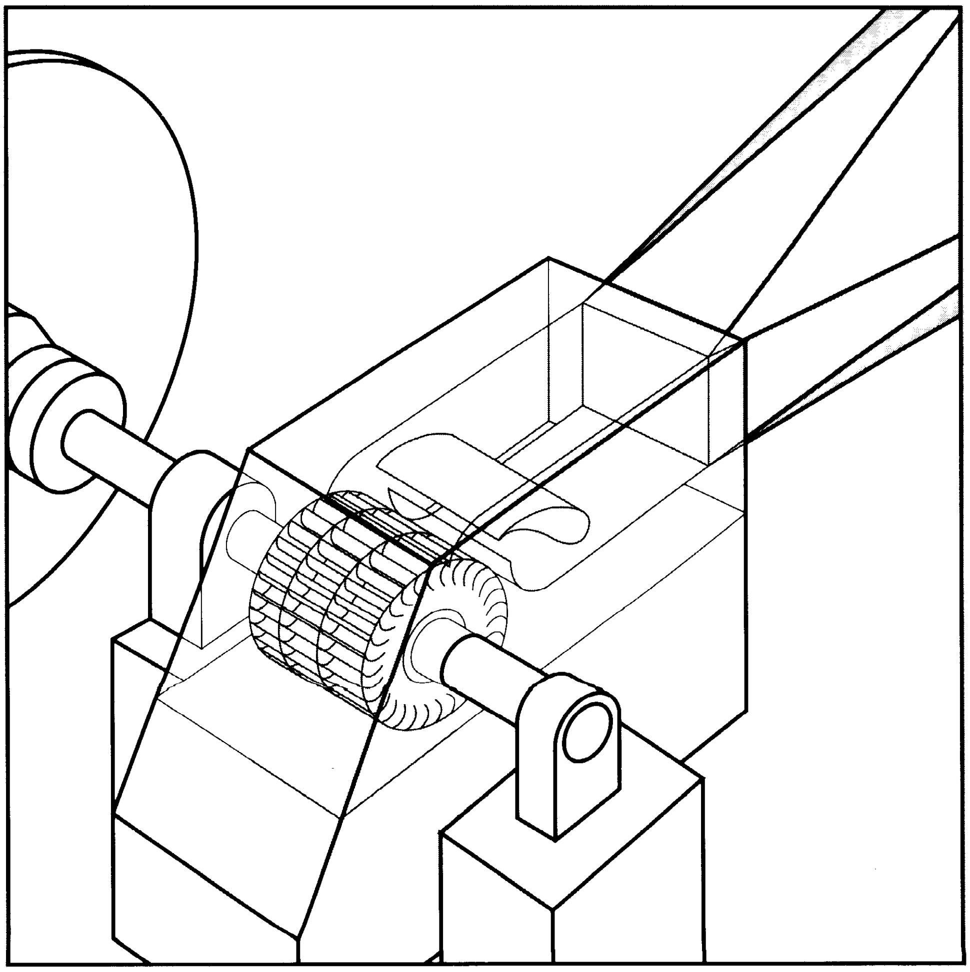
MHPG Series

Harnessing Water Power on a Small Scale

Volume 3

Cross Flow Turbine Design and Equipment Engineering

Krishna Nakarmi, Alex Arter, Rolf Widmer, Markus Eisenring



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Volume 3

Cross Flow Turbine Design and Equipment Engineering

Volume 1: Local Experience with Micro-Hydro Technology

Volume 2: Hydraulics Engineering Manual

Volume 3: Cross Flow Turbine Design and Equipment Engineering

Volume 4: Cross Flow Turbine Fabrication

Volume 5: Village Electrification

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Finally, we thank Silvia Ndiaye for proof-reading and Werner Fuchs, head of publishing at SKAT, for editing and designing this publication.

the authors
St. Gallen, February 12, 1993

F	F/(1-F)
0.0035	0.0035
0.0120	0.0122
0.0408	0.0425
0.1292	0.1484
0.3412	0.5180
0.6439	1.8080
0.8632	6.3107
0.9566	22.0265
0.9872	76.8799
0.9963	268.3373

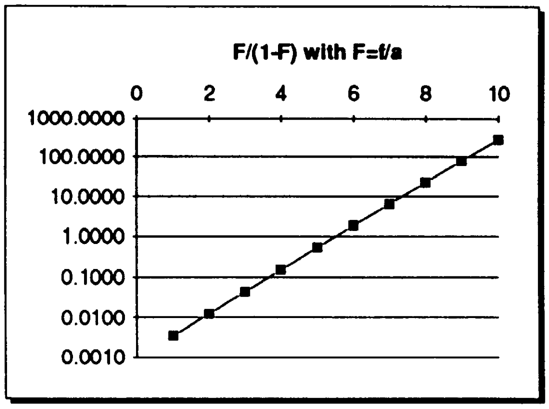


Fig 2: the logistic curve after the Fisher - Prey transformation

The application of this formula is correct when there is no competition, e.g. in case of a market niche.

A successful competition which is stronger than the confirmed technology, will replace the old one insofar as the market niche is conquered. This conquest follows a logistic curve since the rise of the one means the fall of the other. Therefore the loser in the F/(1-F) scheme is drastically reduced following a descending straight line.

t	f1(t)	f2(t)
1	0.0035	0.0000
2	0.0120	0.0000
3	0.0408	0.0000
4	0.1292	0.0000
5	0.3412	0.0000
6	0.6439	0.0000
7	0.8632	0.0001
8	0.9566	0.0002
9	0.9872	0.0008
10	0.9963	0.0027
11	0.9989	0.0093
12	0.9997	0.0317
13	0.9999	0.1024
14	1.0000	0.2848
15	1.0000	0.5816
16	1.0000	0.8291
17	1.0000	0.9442
18	1.0000	0.9834
19	1.0000	0.9952
20	1.0000	0.9986

F	F/(1-F)
0.0035	0.0035
0.0120	0.0122
0.0408	0.0425
0.1292	0.1484
0.3412	0.5180
0.6439	1.8079
0.8632	6.3073
0.9564	21.9103
0.9864	72.4835
0.9936	155.5188
0.9897	95.6599
0.9680	30.2880
0.8975	8.7559
0.7152	2.5107
0.4184	0.7194
0.1709	0.2061
0.0558	0.0591
0.0166	0.0169
0.0048	0.0048
0.0014	0.0014

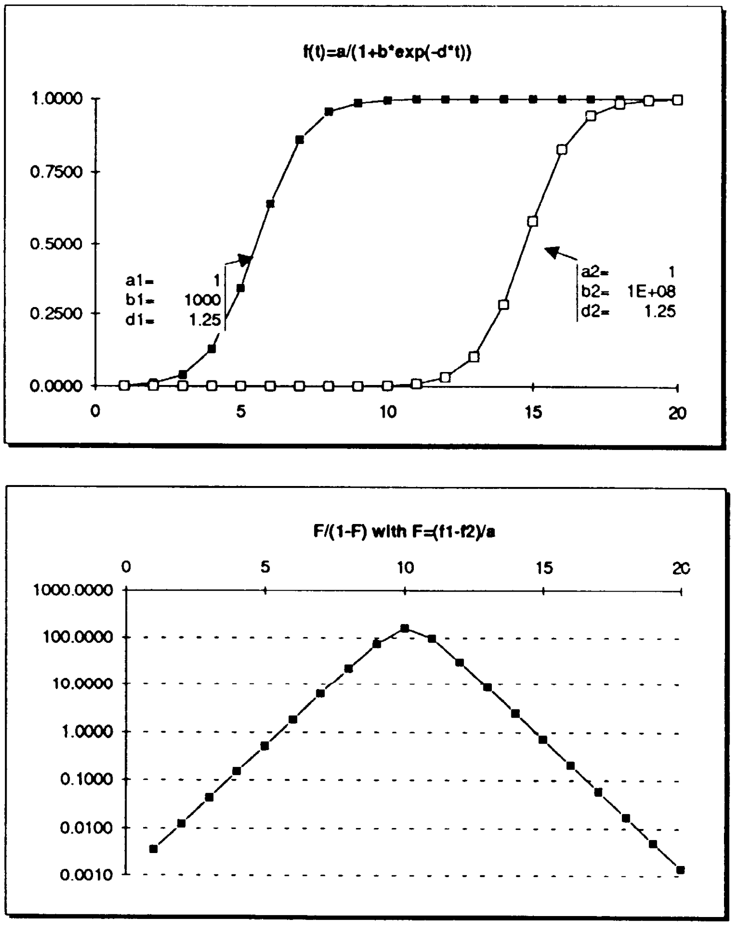


Fig 3: the logistic curve for a life cycle (phase in and out)

Instead of a Foreword

The cover of this book already makes it clear that this publication is not simply an additional book on cross flow turbines. It represents the feasible reply to the need of a satisfactory turbine which can be manufactured without the use of a foundry: **the T12 turbine.**

These lines shall throw some light on the question whether this is the best of all answers. Three aspects regarding the "development of the cross flow turbine" are presented hereafter as if they were seen through a zoom: first a somewhat abstract view of the life cycle of technologies in general, or expressed in a simpler manner: "When has a device / equipment reached the point where no significant improvement can be realized"; furthermore a view on a series of patent specifications regarding the cross flow turbine and brillant (sometimes less) ideas on possible improvements of this kind of turbine; and finally a view on the development of the turbine of the Txx series at BYS in Nepal.

The objective of this exercice is in no way to prevent resourceful persons to improve the T12 turbine, but to make them hesitate to change tested technologies without careful consideration of the subject. Many "improvements" were already proposed and tested, but they did not prove successful in the long run. Moreover, the creative potential of each product - and this applies also to the cross flow turbine - is limited and there is the moment when it is not worthwhile any more to invest money in improvements.

We will further make a disgression on a somewhat more abstract level [1]. Everybody knows sufficiently that technologies and products have their life cycle: at the beginning they are new, pioneering and attractive, they come in replacement of an older and weaker solution, they are accepted and used by most people after a certain time and are finally replaced by another new and pioneering solution.

It is however surprising to see that the rise and fall of a technology always happens in a similar way which can be represented with a simple mathematic scheme: the logistic curve.

the logistic curve
example

t	f(t)
1	0.0035
2	0.0120
3	0.0408
4	0.1292
5	0.3412
6	0.6439
7	0.8632
8	0.9566
9	0.9872
10	0.9963

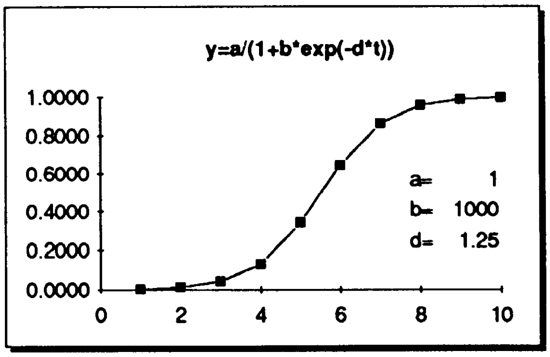


Fig 1: the logistic curve

This curve describes nothing else than a hesitating rise ending in saturation. It is often easier to represent this process in another way so that the curve appears as an inclined straight line which is called a Fisher Prey transformation:

A good example of such a displacement process is the global energy market: wood, coal, oil, gas, nuclear energy etc. fought and still fight to have a priority status on the energy market. The following curves show how precise logistic curves are.

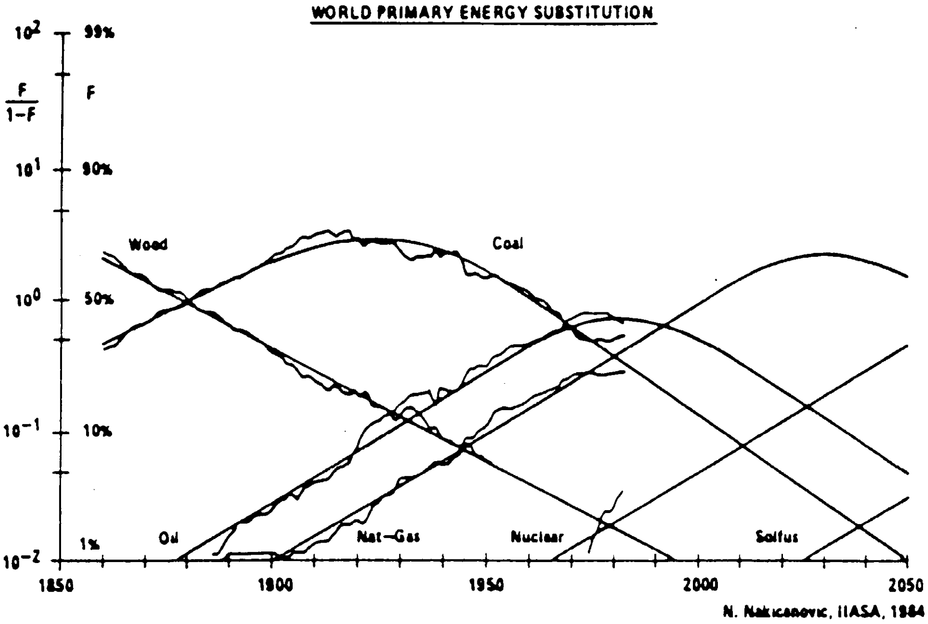


Fig 4: the primary energy market substitution analysis, originally made in 1974 has been here adourned with data to 1982. The lower than expected penetration of natural gas is signal for a fast growth in the next future. As the past shows, deviations are always reabsorbed elastically. Reported are market shares.

Furthermore it is surprising to note that the the arrival of competition is cyclic and, in the case of products, always comes after an innovation thrust which also follows a logistic curve.

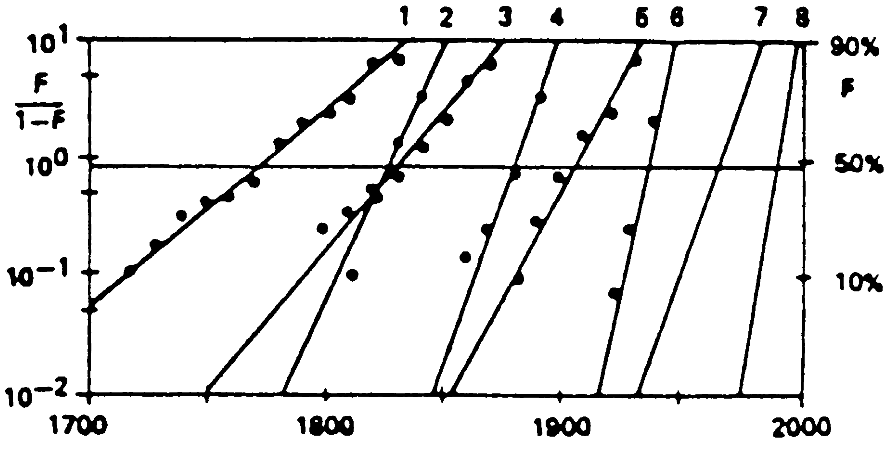


Fig 5: Cumulative number of inventions and innovations, in the waves identified and quantified by Mensch (1975). The "populations" in each wave are treated as in the case of objects filling a niche. The excellent fitting confirms the underlying hypothesis that innovations are not the consequence of a stochastic process, but they fill a precise market demand, a niche. In the case of inventions, only those that went into a successful innovation are counted. Invention waves are marked with odd numbers and innovation waves with even ones. The last wave, without data points, is calculated from the regularities of the previous ones (Marchetti, 1981).

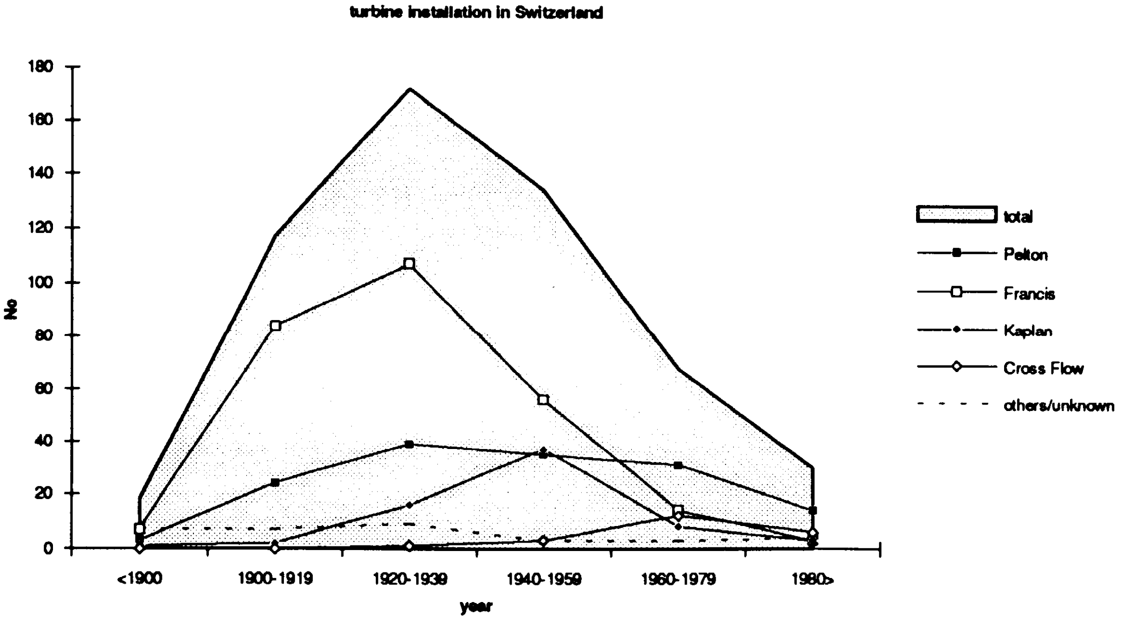
There are some other surprising facts:

- The quantity of statistic data to be studied does not matter (the regional results are the same as the global ones, short periods give the same results as long ones).
- The complexity of the relations do not matter either (availability, customers' trend...).
- In the absence of competition, any product can at best saturate a niche . When there is a competition it will always lose in the long run (there is always a better one!).
- The trend of declining is irreversable (no come back!)
- The creative phase of an established product is over.
- Manipulation of the niche has little influence on the "life cycle" of a product.
- The rise of a new "competitor" is foreseeable. It is not possible to know which product will rise, but when it will arrive on the market.

Does the aforesaid apply to cross flow turbines?

Can we draw any conclusions for the cross flow turbine? Is its time over or just beginning? Is it worthwhile to invest in its further development? Hydro power (turbines in general) is competing with other energy technologies (oil, nuclear, solar energy etc.) and, additionally, the cross flow turbine is in competition with other turbine types (Pelton, Francis turbines etc.). For the application range of the cross flow turbine (< few 100 kW), the market niche is again restricted to the MHP range.

In following what has been explained above we could try to indicate an answer in considering the MHP niche in Switzerland. We simply observe the statistical data [2] of turbine installations during this century. Most of these plants are working today, therefore the data do not show the *displacement* from the niche but the owner's buying decision to *add* the currently best turbine.



The presented curves show first the number of installed turbine types over their year of installation, then the cumulative number of turbines (showing the saturation of the niche) and finally a F/(1-F) scheme.

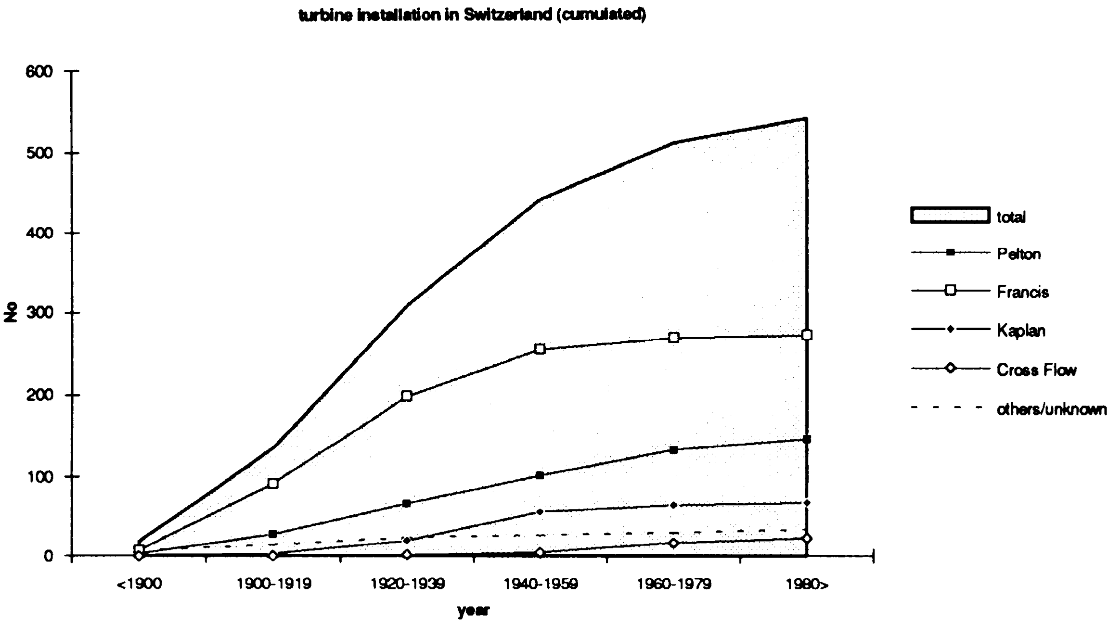


Fig 5a: SHP (<300 kW) installed in Switzerland during this century.

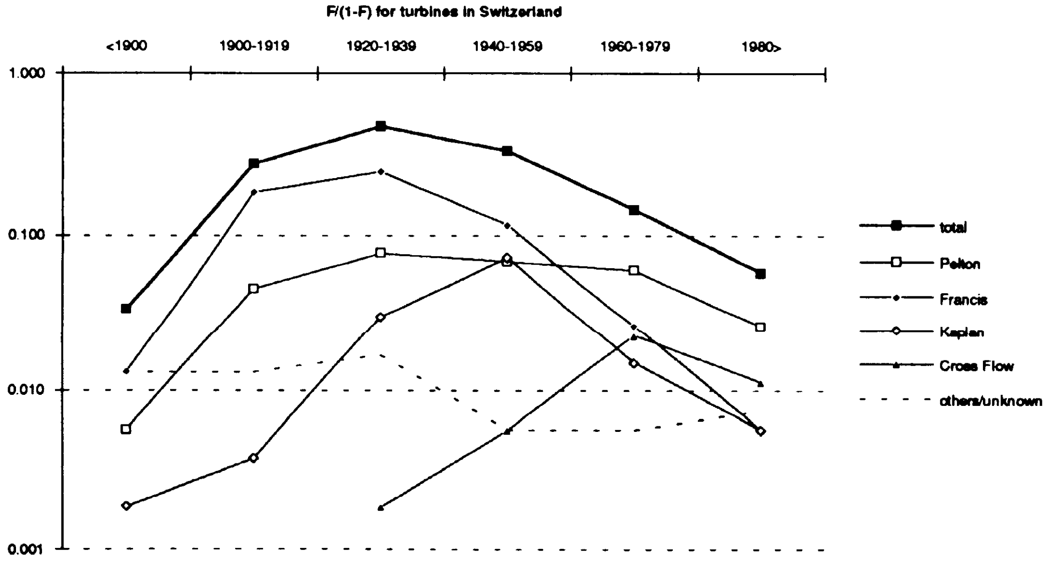


Fig 5b: F/(1-F) for turbine installations in Switzerland.

It appears clearly that the number of installed turbines is decreasing, which could be interpreted as "the MHP technology is not competitive"; the various turbine types are challenging each other, one after the other having its rise and decline. The cross flow turbine appears to be the last to conquer its market niche, but due to the shrinking niche its also on the decline. An explanation why it could enter a 'dying' market at all could be its good cost-effectiveness in certain applications.

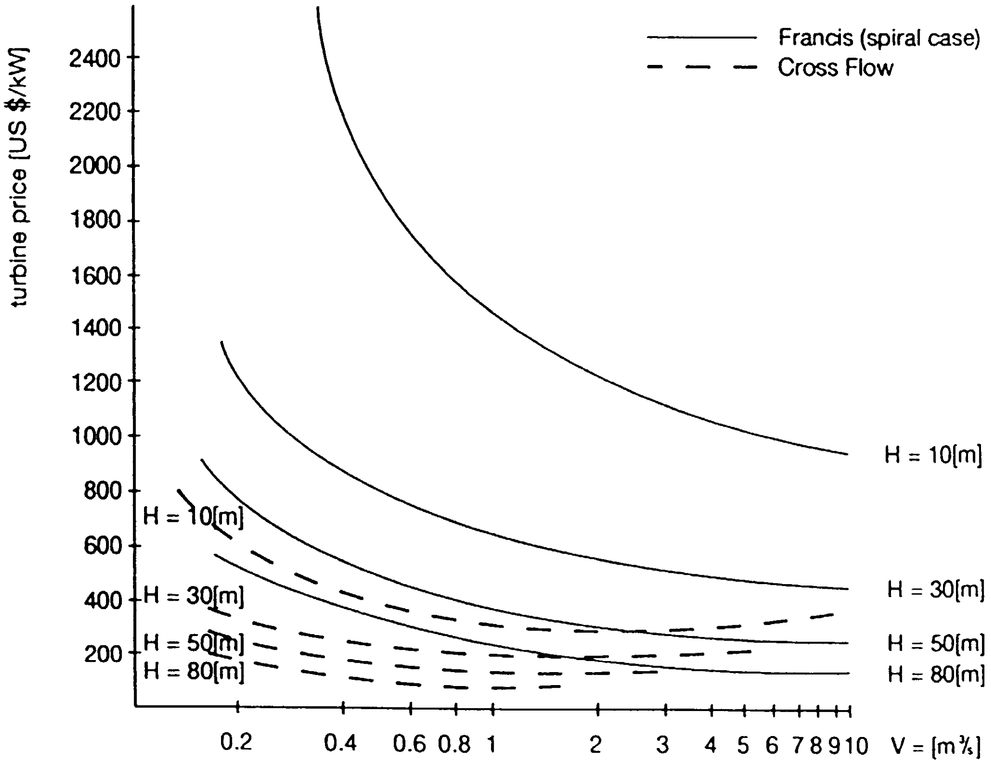


Fig 6: cost advantage of the crossflow turbine for low head and small flow [3].

References:

[1] Cesare Marchetti, 'Stable Rules in Social and Economic Behaviour'
bollettino ingegneri, No 6, 1988

[2] 'Kleinwasserkraftwerke der Schweiz, Teil III'
Eidgenössisches Verkehrs- und Energiewirtschaftsdepartement, Bundesamt für Wasserwirtschaft.

[3] A. Arter, 'Do Cross Flow Turbines Have a Future'
Small Hydro 1992, Conference Papers, Water Power & Dam Construction

The following three pages show a series of arbitrarily chosen pictures, illustrating the avalanche of creative ideas in the first twentyfive years after the invention of the crossflowturbine (1903 A.G.M. MICHELL, further development >1917 by Prof. E. BANKI).

Aug. 4, 1925.

E. BÁNKI

WATER TURBINE

Filed Feb. 21, 1925

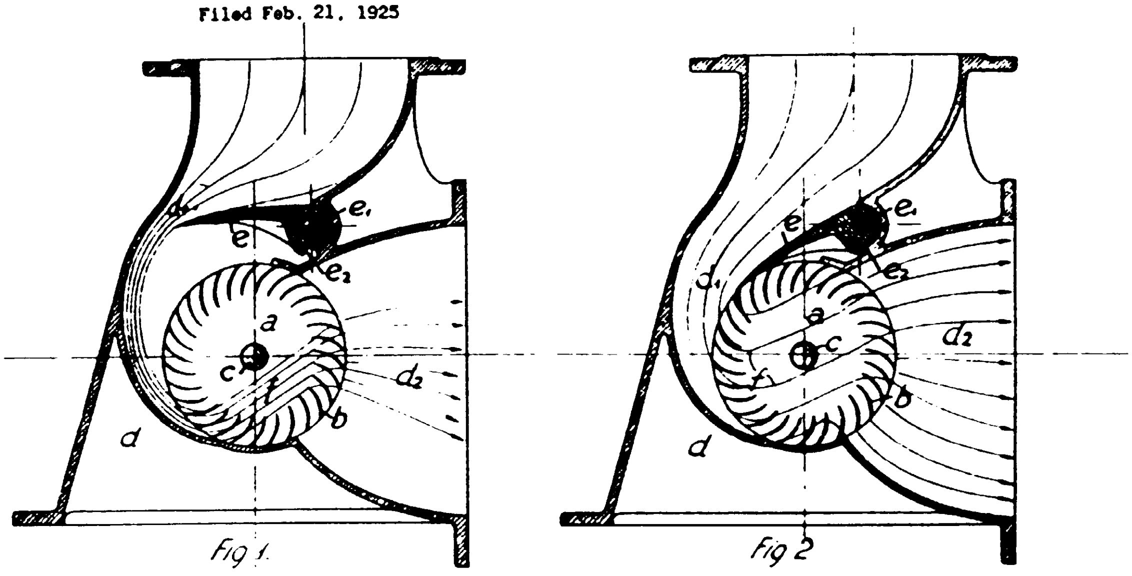


Fig 1. Fig 2

Inventor
Elemér Bánki
by
his attorney

Fig. 1

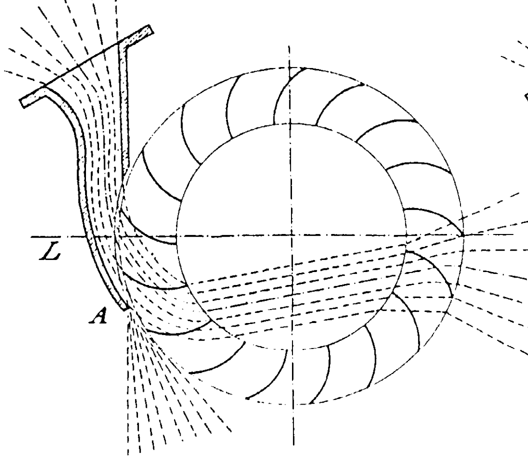
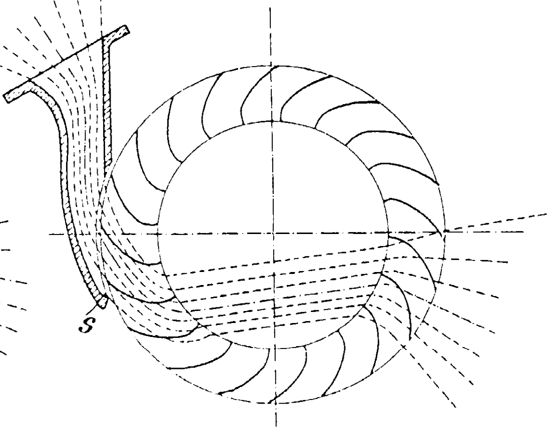


Fig. 2



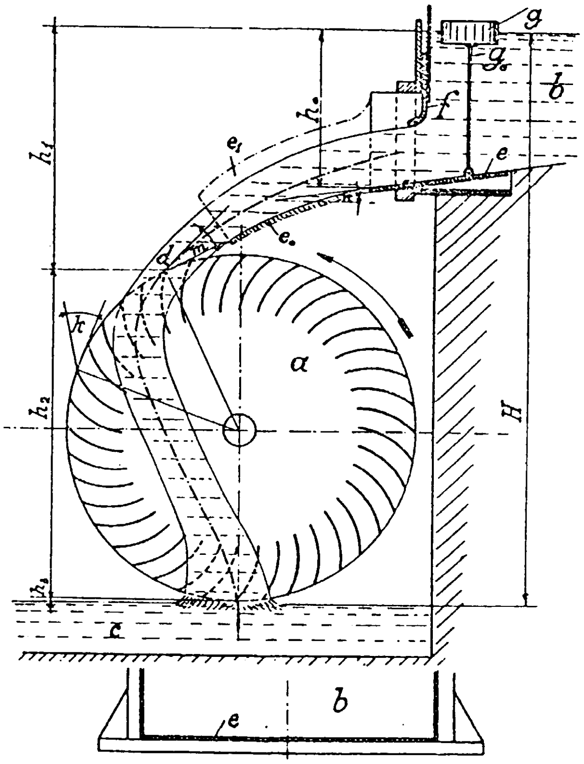
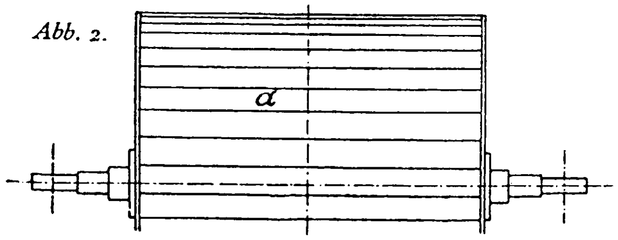


Abb. 2.



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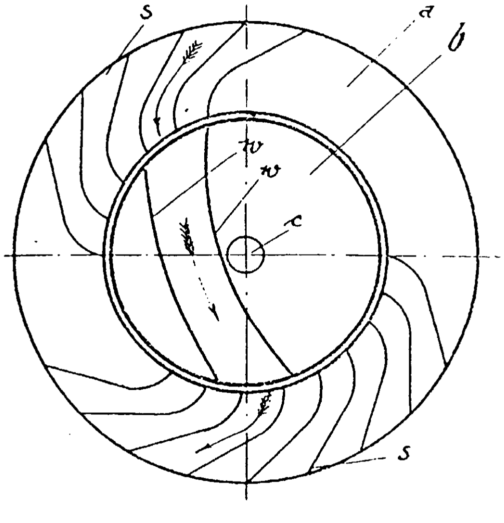

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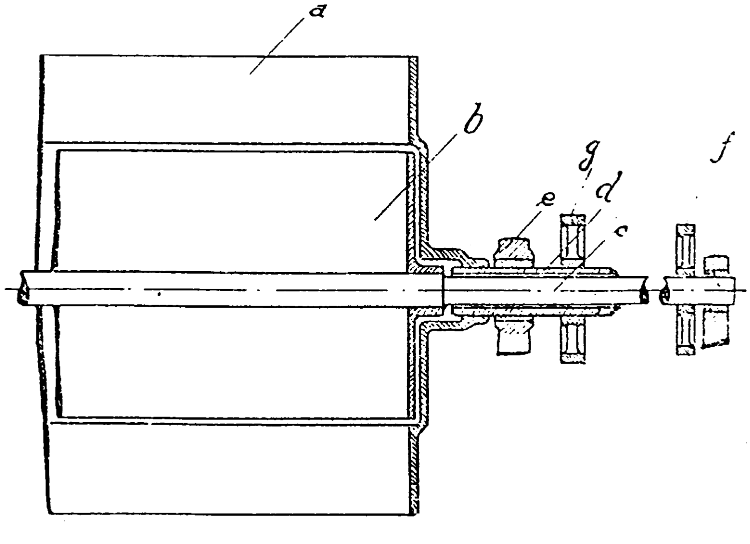


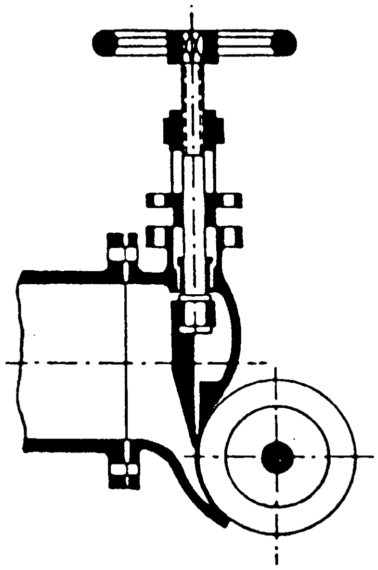


Fig. 21.
Regulierung durch Schieber.

Fig. 3.

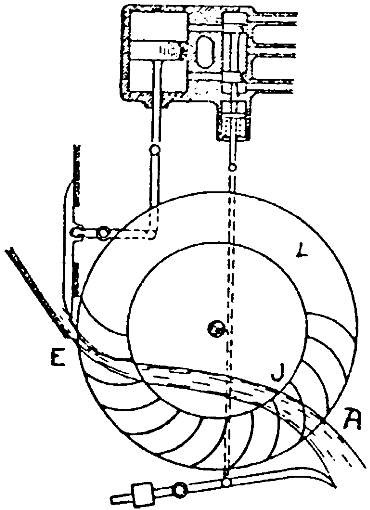


Fig. 4.

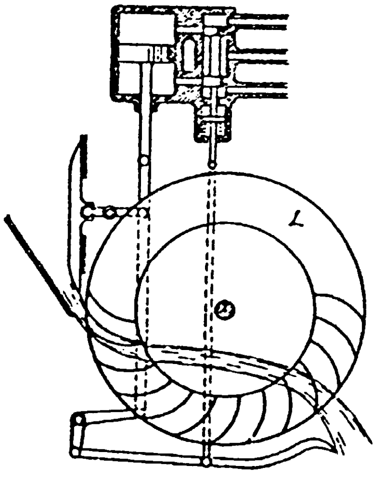
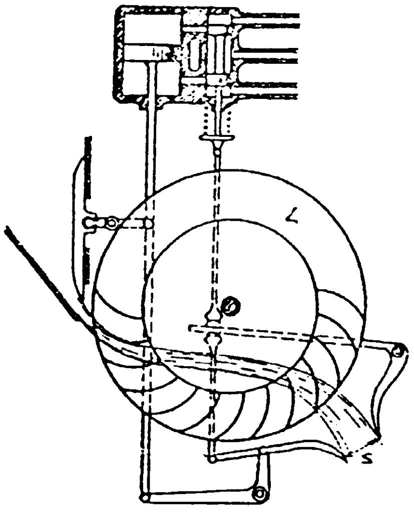


Fig. 5.



A Brief History of the BYS' Txx Turbine Series Development

In 1960 the Swiss technical co-operation agency Helvetas established the first mechanical workshop in Nepal, to create a minimal industrial infrastructure needed to execute repair works for equipment used in its other projects. Already 1964 a mechanical training centre was incorporated as no skilled manpower was available throughout the country.

Today this company has 170 employees and is among the biggest enterprises in Nepal, named BYS (Balaju Yantra Shala P (Ltd.)).

In the late sixties the company started to develop a simple water turbine. SKAT, the Swiss Centre for Appropriate Technology is collaborating with BYS mainly in the field of micro hydro power (MHP) technology.

Initial MHP Concept

It was observed that locally produced water mills were properly working but were not powerful enough to drive rice husking machinery. A large number of Nepalese farmers knew that in India diesel engines were available to drive small flour mills and rice huskers. Upon farmers pressure, the Nepalese Agricultural Development Bank (ADB-N) started granting loans for diesel mills. At this time BYS came up with the idea to produce turbine driven mills. A Swiss turbine manufacturer was approached to furnish BYS with the technical drawings for a propeller turbine. There was no foundry in Nepal, therefore the design had to be adapted but by people never having designed any turbine. The blade profiles of the runner could not be produced with the machinery in BYS. However, a few prototypes at probably half the efficiency of the original design went into operator and marked a break through in the sense, that it became public that rice hullers could be driven with hydropower.

Development of the Cross Flow Turbine Concept

By analysing the difficulties to locally produce propeller turbines, it became clear, that a suitable turbine should fulfil the following criteria:

- The machine must be a welding construction to avoid foundry technology.
- The turbine must be made up of components of not more than 60 kg weight to allow transportation by manpower to remote areas.
- The adaptation of the turbine size to different head and flow data should be simple.
- The machine should incorporate a flow regulating device to adjust the output to the consumer load.
- It must be possible to produce the machine locally.

A turbine satisfying the above criteria did simply not exist at that time, furthermore none of the approached European turbine manufactures joined hands to develop the simple design required. Among the known types the cross flow turbine was the most simple from the construction point of view and therefore selected for further adaptation.

The most important features of this model are:

- cast parts are not required, the whole machine can be executed as a welding construction.
- the runner blades do not requires any three dimensional shaping but can be produced out of simple pipe sections.
- the machine can be adapted to head and flow conditions by simply varying the runner length.

Development History of Txx Design

The following chart represents the various development phases marked by different turbine models with breakthroughs achieved (👍) and setbacks suffered (👎). The axis are 'time' versus 'improvement' which is

characterized by:
- Plant reliability and life
- Product quality
- Standardisation
- Plant Safety
- Range expansion / output
- Local skill level
- Technology dissemination
- Convenience

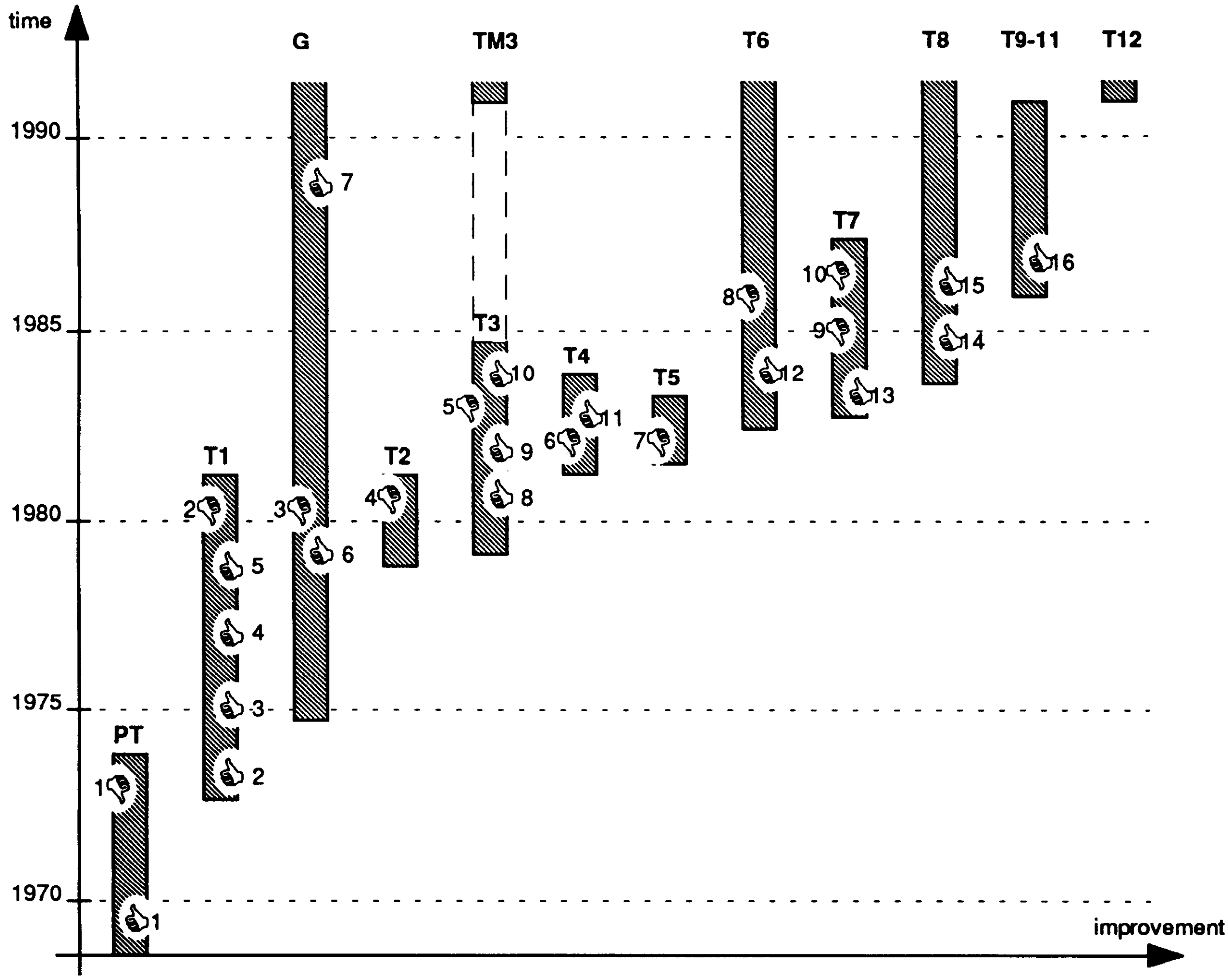


Fig 7: SKAT/BYS Turbine Development history.

Legend	👍 **Progresses**	👎 **Setbacks**
PT Propeller turbine	1 - driving rice huller / oil expeller with a propeller turbine	1 - ill-suited designed propeller turbine, difficult flow regulation
T1 Cross flow turbine model T1	2 - first cross flow turbine driven mill installation 3 - first "cross flow - mill" financed by Agriculture Development Bank Nepal (ADB/N), so far the bank granted loans for diesel sets only 4 - first order for a village electrification project from the government at hand 5 - test rig to measure turbine and governor performance completed	2 - loosing complete station due to landslide
G Turbine governor	6 - governor prototype operating 7 - fully automatic control	3 - control system damage due to governor failure
T2 Low-cost turbine		4 - low cost turbine, no market acceptance
T3 Compact design cross flow model T3 and successor TM3.	8 - systematic model test for the optimisation of runner geometry for the more compact T3 design 9 - standardisation of fabrication 10 - installation with a head of 80 m completed	5 - under designed bearing concept, short life span
T4 First cross flow for governor operation	11 - first village electrification project completed equipped with a T4 turbine including governor	6 - fatigue failure in equipment base frame
T5 Big size cross flow		7 - design office comes up with a machine size not manageable in the workshop
T6 High discharge cross flow model T6	12 - winning tender against international competition	8 - loosing contracts in international competition due to image problem
T7 Circular wing cross flow model T7	13 - plant with two units running in parallel completed, synchronisation problem solved	9 - alternator damage due to improper lightning protection 10 - runner failure
T8 Standard design model T8	14 - first standard design, range of application defined 15 - first unit with an output of more than 100 kW	
T9 High efficiency cross flow model T9	16 - first machine with exchangeable spare parts	

Table 1: SKAT/BYS Turbine Development history.

Brief Description of Cross Flow Turbine Models T1 - T12

The T1 Model:	is a hand regulated, straight forward design to mechanically drive a flat belt transmission for the operation of agro-processing machineries such as flour mills, rice huskers and oil expellers.
The T2 Model:	is an attempt to come up with a low-cost design. The expensive turbine housing is omitted to a large extent. It resulted in having water splashing all around the equipment, increasing the humidity in the mill house and spoiling the flour. This design is obsolete.
The T3 Model:	is a compact design, and the first machine with a butterfly valve for flow regulation. The bearing concept is under designend and not suitable for outputs higher than 20 kW.
The TM3 Model:	is a redesigned version of the T3 overcoming the flaws of its predecessor.
The T4 Model:	has a circular wing for flow regulation. It was the first turbine with automatic governor control used in a village electrification project.
The T5 Model:	is basically the concept of an enlarged T3 model. However the machine size was not adequate for the production facilities in Nepal. This design was obsolete.
The T6 Model:	is suitable for governor control, having a butterfly valve as the flow regulating device. The machine is much stiffer than previous designs, therefore it has a low vibration and noise level during operation. It is a good design for high specific discharge.
The T7 Model:	is the first model with fully machined turbine blades in order to increase the efficiency. But this advanced technology led to a runner failure due to fatigue stress problems. By now the T7 is an obsolete design.
The T8 Model:	replaced the T7 design. It is a fully tested machine with known characteristics. This allowed to define the application ranges and to standardise the design.
The T9-11 Model:	are test models for the following T12. With all performance tests where executed at the University of HongKong. The efficiency hill diagram in this book is the result of these tests. The design adheres to the concept of the T8 series with a modified hydraulic profile and secured quality control to guarantee the exchangeability of spare parts.
The T12 Model:	is collecting the past experiences, emphasizing longevity, rugged design. It uses a new concept to ventilate the jet (free jet approach) and is specially suited for flow control.

Conclusions Drawn from Past Experiences

Statistical data for Germany indicates that in the year 1875 the total installed capacity of all hydro power plants reached 118 MW. The average output per plant was 20 kW. 20 years later the total installed capacity had doubled however the average plant size had only risen to 28 kW.

In Nepal, 20 years after having started to promote locally developed hydropower technology it is a commonly shared feeling that progress has been slow, financial inputs substantial and socio-economic impact very limited.

If the ultimate goal of MHP activities are trouble free produced kWh, we may have to admit that the present achievements are moderate. If the objective is technology dissemination in its full complexity then the efforts in micro hydro development in Nepal reflect a great success.

Solving technology problems and coming up with adequate designs is important but in fact a minor issue considering the whole context.

Decisive are the following areas of involvement:

- Adapting technology to user requirements, creating a market in an environment of low purchasing power.
- Building up local skills in surveying, planning, installing and maintaining.
- Influencing government policy.
- If technology spreads, promotion of quality standards.
- Creating organisational set-ups allowing the gradual reduction of foreign inputs.

Recommendations for the Implementation of MHP Schemes

- Pilot projects should aim at finding technical solutions. Giving top priority to economical viability at an early stage is too ambitious. It is a great achievement if the income of a plant allows to cover operation and maintenance costs.
- Any activity not in collaboration with a motivated local partner is bound to have no long-term impact.
- "Learning by doing" has proven to be a useful approach.
- It pays to start with simple projects such as mechanical applications for direct drive of agro-processing machinery. These are not only less complex (against electrification projects) but in general more economical for the user.
- It is narrow minded to think a plant is completed the day it goes into operation. Impact monitoring is essential.
- In most cases flow data at a proposed site do not exist. Therefore to assess the flood risk and to properly size the plant, river flow measurement during at least one year are a must.
- If your get involved in MHPdevelopment aim at long-term activities.

1. Introduction

This publication "Cross Flow Turbine Design and Equipment Engineering" is Volume 3 in the Micro Hydro Power Group (MHPG) Series "Harnessing Water Power on a Small Scale". It consists of a complete set of master workshop drawings for the T12 cross flow turbine and includes information required to determine inlet width and number of intermediate discs for the turbine within its specific application range.

This publication is based on the experience which SKAT has made for many years in the field of Small Hydro Power Development. Some of their staff members worked in Nepal in the mechanical workshop BYS, (Balayu Yantra Shala (P) Ltd.). BYS was instrumental in the development of the cross flow turbines which started in 1973 with the first cross flow turbine T1. The R&D work at BYS culminated in the T12 cross flow turbine now successfully manufactured by BYS.

In 1990 GTZ financed the testing of the T12 turbine in the Fluid Mechanics Laboratory of the Hong Kong Polytechnic. The performance data established during this examination constitutes the basis for the calculations and nomograms used in this publication.

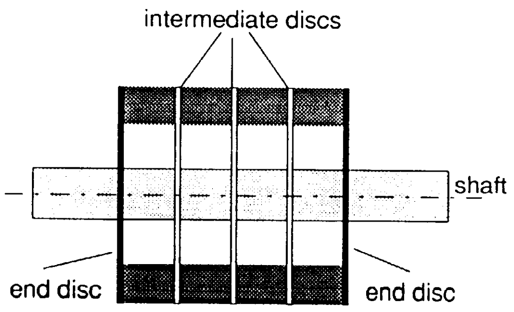
The T12 cross flow turbine design incorporates the latest results from development work and the experience gained from a whole range of turbine designs, both from Nepal and other countries. Earlier designs, such as T3 and T7, were also published by SKAT before. They were very simple turbines, designed for a small application range and for manufacture in small workshops with basic equipment. The T12 cross flow turbine is a more sturdy design and the turbine is built for durability. However the manufacture of the turbine requires higher standards of production engineering and quality control as well as more sophisticated production machines.

The T12 turbine can be adapted to a wide application range. For varying heads and flow rates the only parameters to be adjusted are the inlet width and the number of intermediate discs.

2. Nomenclature and Definitions

Hnet	Net head	[m]	Head available for the turbine (the geodetic head minus the total of all head losses *[penstock friction losses and other internal head losses]*), expressed as height of water column.
Q	Discharge	[l/s]	Flow rate of water flowing through the turbine.
$q_{11\,max}$	Unit discharge		= 0,92 for the T12 cross flow turbine (when the inlet valve is fully open).
b_0	Inlet width	[mm]	The inlet width b_0 represents the width at the inlet of the turbine housing (b_0 is 324 mm in the examples shown in this publication).
P	Power	[kW]	Power output available at the rotor shaft.
D	Rotor diameter	[m]	= 0,3 m for the T12 cross flow turbine.
h	Turbine efficiency	[-]	The design value can be estimated as 0,7 for the T12 cross flow turbine (the effective value for any given operating point can bee seen in Chart 10, Iso-Efficiency Graph).
n	Rotational speed	[min^{-1}]	Number of revolutions per minute of the turbine shaft (rpm).
n_{11}	Unit speed		= 40 for the T12 cross flow turbine.

Intermediate disc



3. T12 Turbine Size Selection

The T12 design can easily be adapted to a wide range of net head and discharge, simply by choosing the inlet width b_0 and the required number of intermediate discs. The required rotor shaft diameter must also be checked. Therefore, the following three parameters:

- inlet width b_0
- number of intermediate discs
- rotor shaft diameter

must be determined according to the steps explained hereafter.

STEP 1:

Take the design values for discharge [Q] and net head [H_{net}] from the engineering report for the turbine installation.

Fill in the blanks for H_{net} and Q:

H_{net} = ______ [m]

Q = ______ [l/s]

STEP 2:

Find the correct chart for the H_{net} and Q values (established in step 1) to determine the required number of intermediate discs.

On the following pages you will find various charts each covering a specific sub-application range of the T12 cross flow turbine. To determine how many intermediate discs are required for your T12 turbine enter the H_{net} and Q values from step 1 into the Charts 0 to 8. If the intersection point of the lines of values lies within the range of the white, non-dotted field or on its borderline, the number of the chart is identical with the correct number of discs required. Start at Chart 0 and continue until you have a chart in which the above requirements are met.

Note: **In case that you do not find any chart where the point of intersection of H_{net} and Q lies within the range of the white, non-dotted field, the T12 turbine design is not appropriate to your needs. You will have to choose another turbine model.**

Example: We have to determine the required number of intermediate discs for a net head H_{net} of 30,89 m and a discharge Q of 497 l/s. In Chart 3 the point of intersection of these H_{net} and Q values is found to be within the range of the white field and therefore the rotor must have 3 intermediate discs.

H_{net}	=	______	[m]
Q	=	______	[l/s]

no intermediate disc required

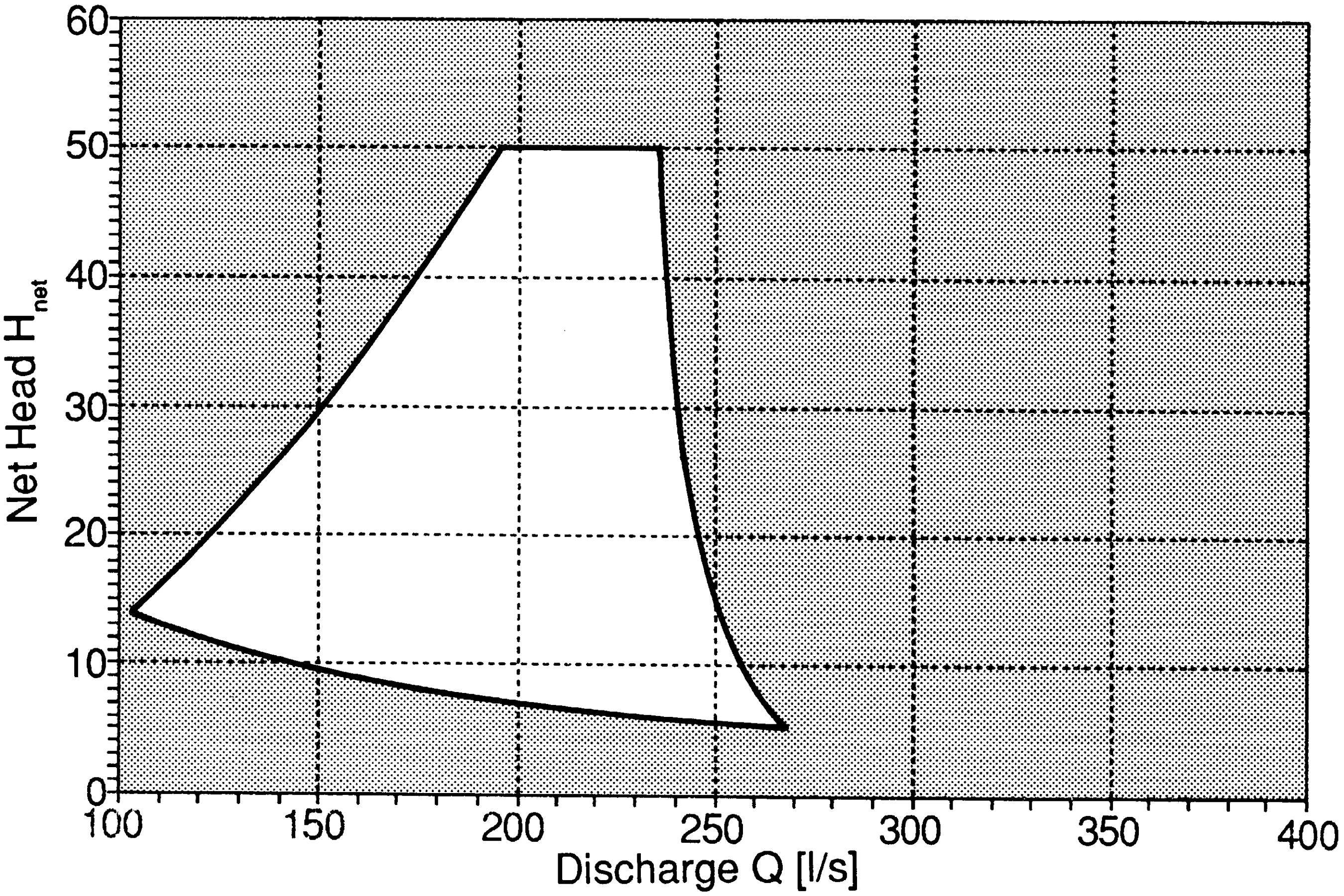


Chart 0: Application range for no intermediate discs on the rotor

If the point of intersection of the values H_{net} and Q falls within the range of the white, non-dotted field or on the borderline of the field, no intermediate disc is needed on the rotor.

H_{net} = ________ [m]

Q = ________ [l/s]

1 (one) intermediate disc required

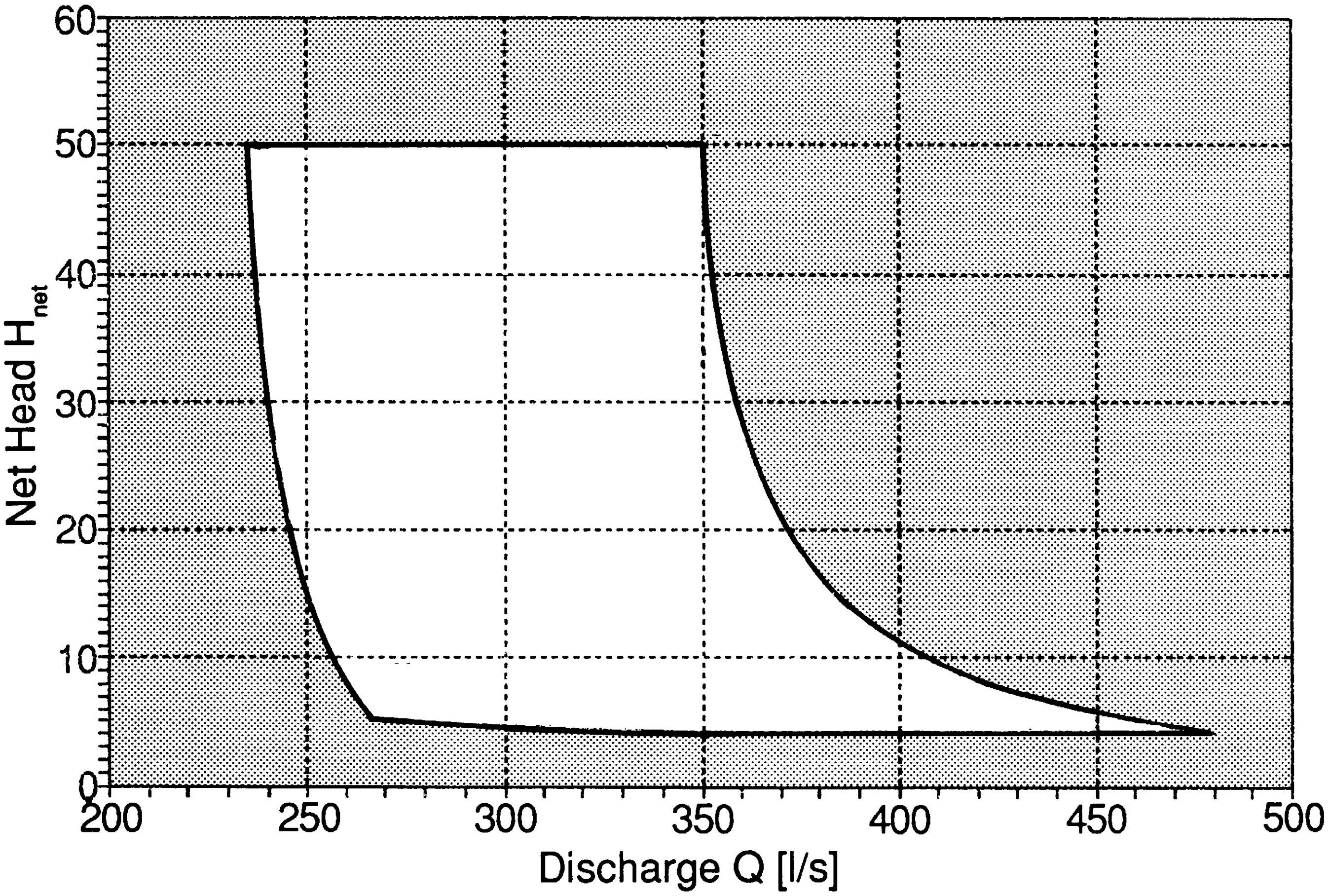


Chart 1: Application range for 1 intermediate disc on the rotor

If the point of intersection of the values H_{net} and Q falls within the range of the white, non-dotted field or on the borderline of the field, 1 intermediate disc is needed on the rotor.

H_{net} = ________ [m]

Q = ________ [l/s]

2 intermediate discs required

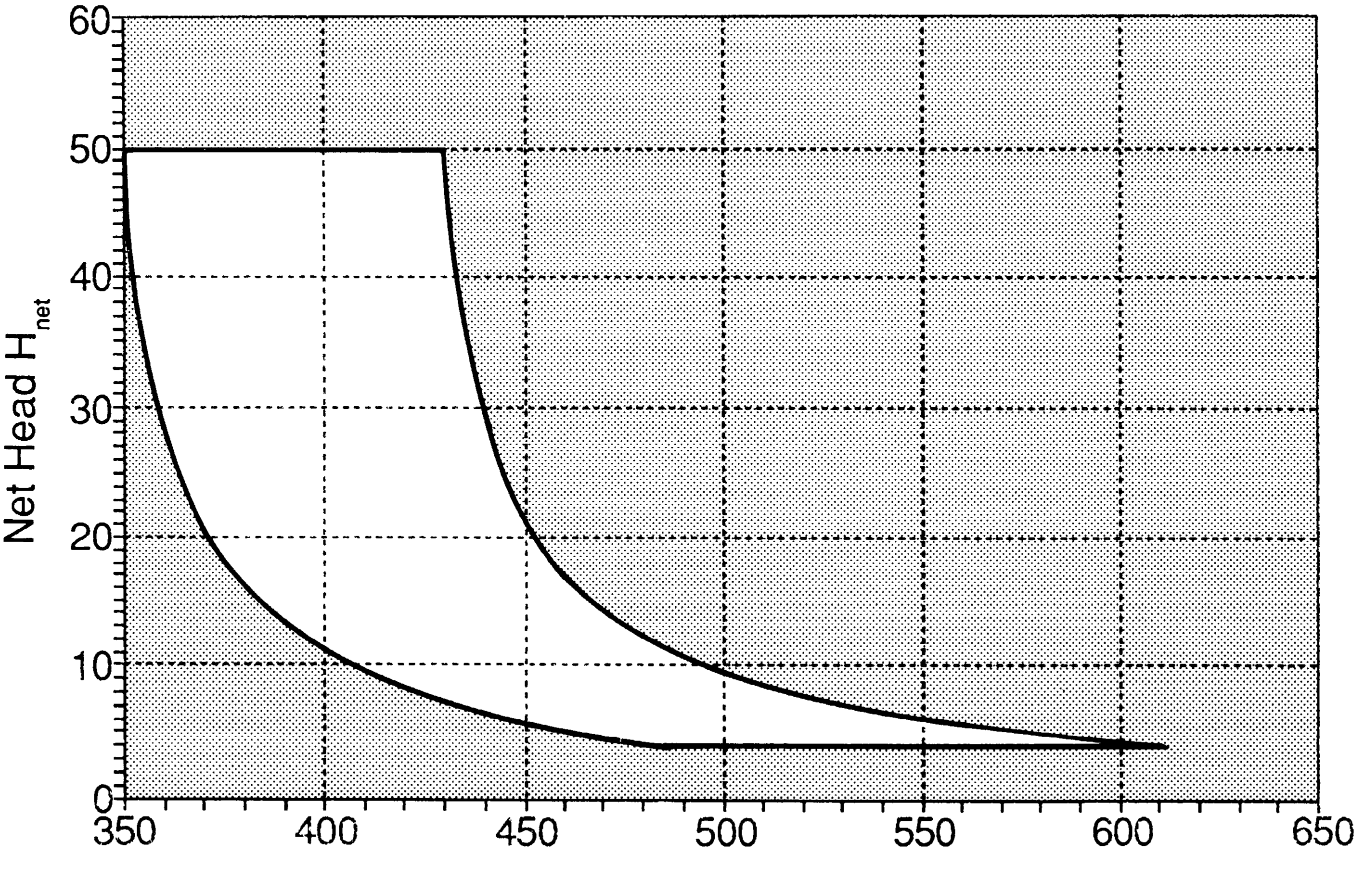


Chart 2: Application range for 2 intermediate discs on the rotor

If the point of intersection of the values H_{net} and Q falls within the range of the white, non-dotted field or on the borderline of the field, 2 intermediate discs are needed on the rotor.

H_{net} =	________	[m]
Q =	________	[l/s]

3 intermediate discs required

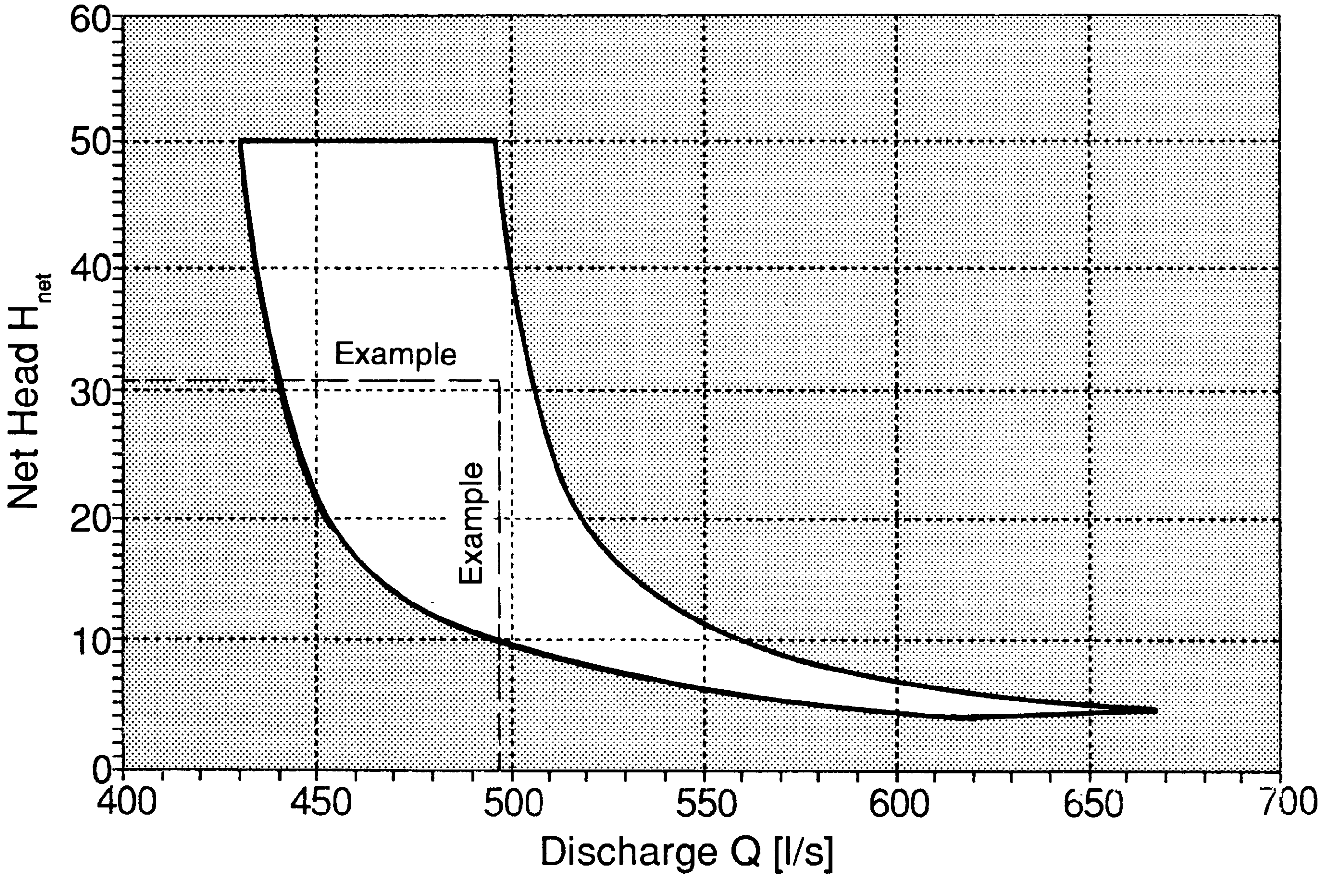


Chart 3: Application range for 3 intermediate discs on the rotor

If the point of intersection of the values H_{net} and Q falls within the range of the white, non-dotted field or on the borderline of the field, 3 intermediate discs are needed on the rotor.

H_{net} = ________ [m]

Q = ________ [l/s]

4 intermediate discs required

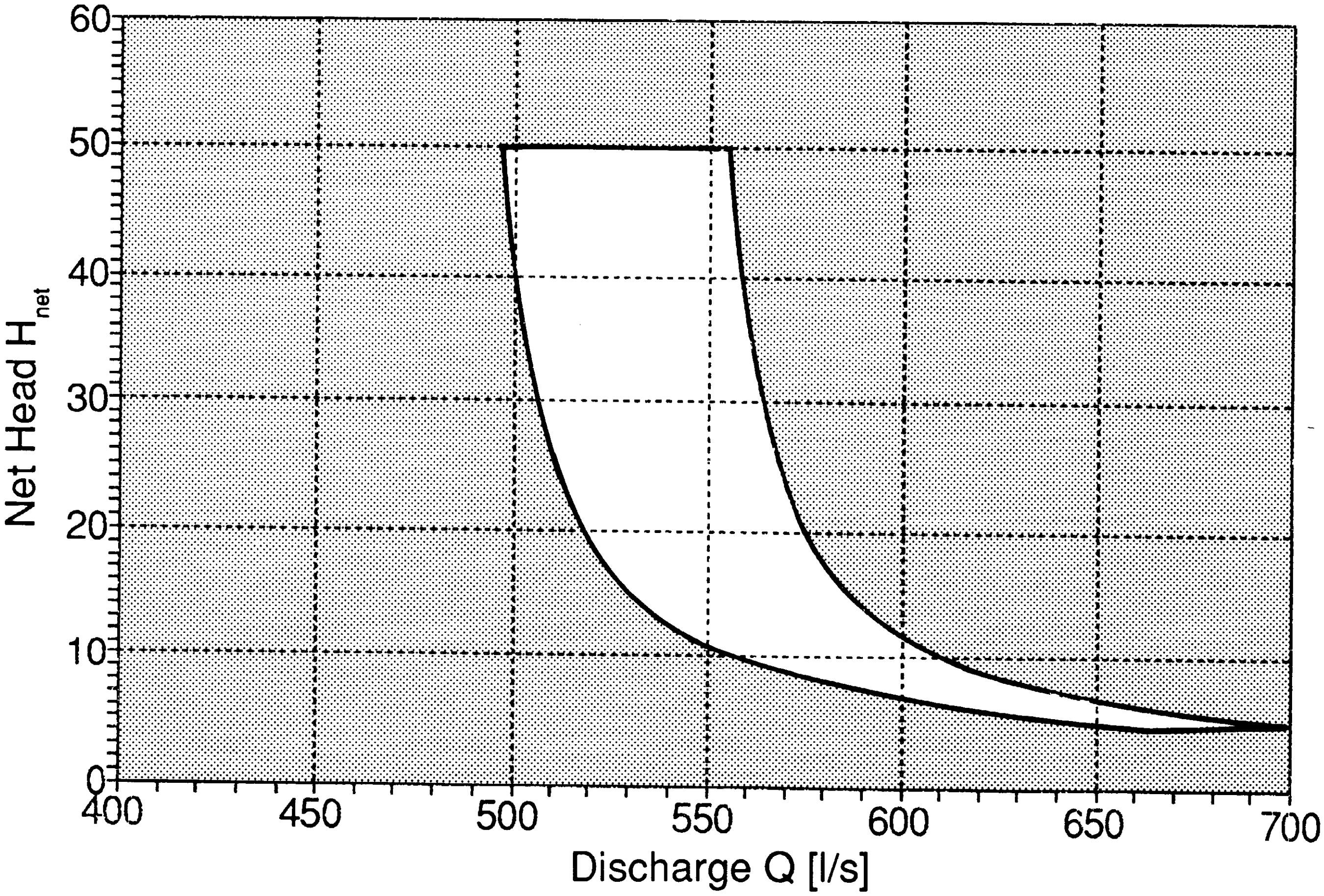


Chart 4: Application range for 4 intermediate discs on the rotor

If the point of intersection of the values H_{net} and Q falls within the range of the white, non-dotted field or on the borderline of the field, 4 intermediate discs are needed on the rotor.

H_{net}	=	________	[m]
Q	=	________	[l/s]

5 intermediate discs required

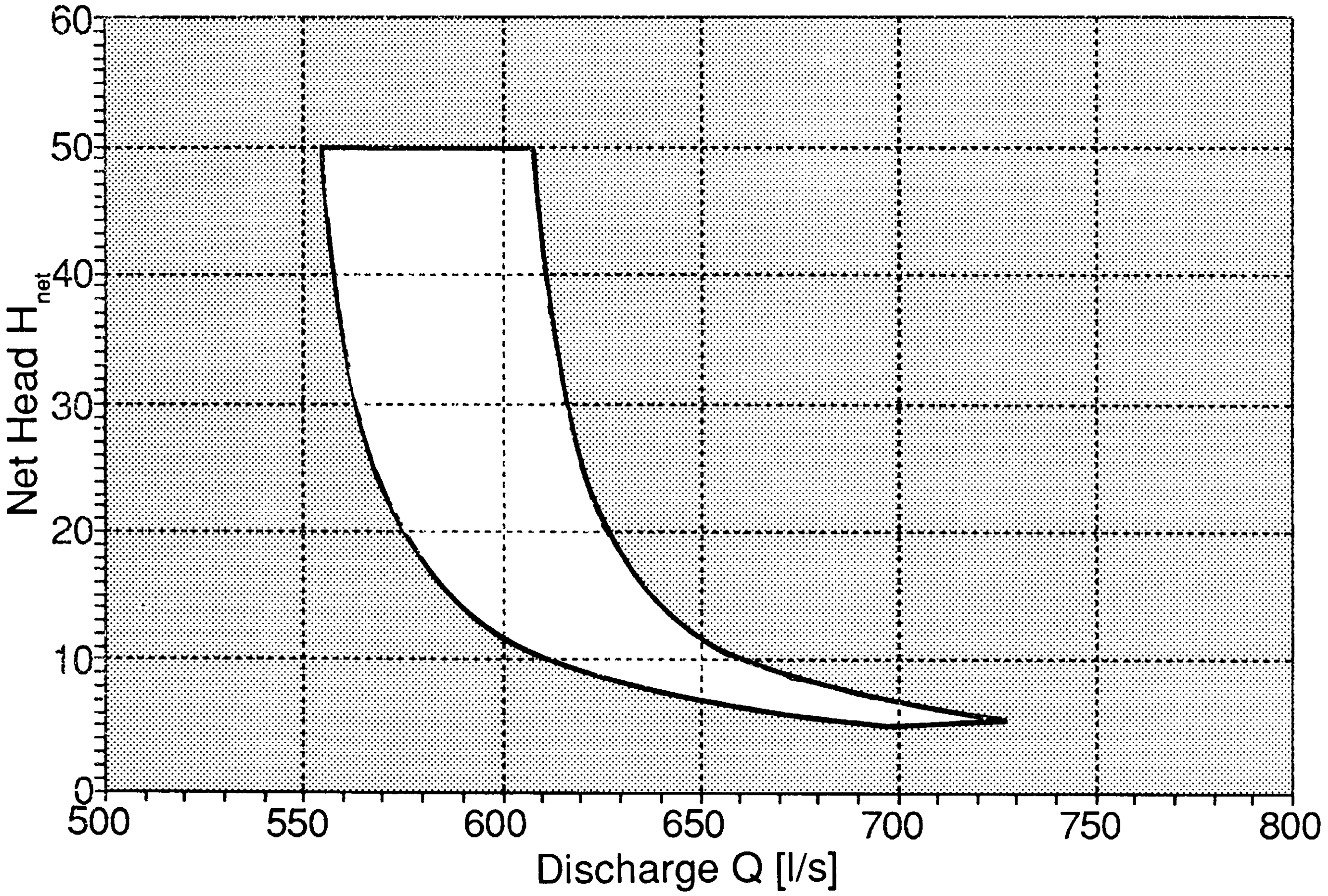


Chart 5: Application range for 5 intermediate discs on the rotor

If the point of intersection of the values H_{net} and Q falls within the range of the white, non-dotted field or on the borderline of the field, 5 intermediate discs are needed on the rotor.

H_{net} = ________ [m]

Q = ________ [l/s]

6 intermediate discs required

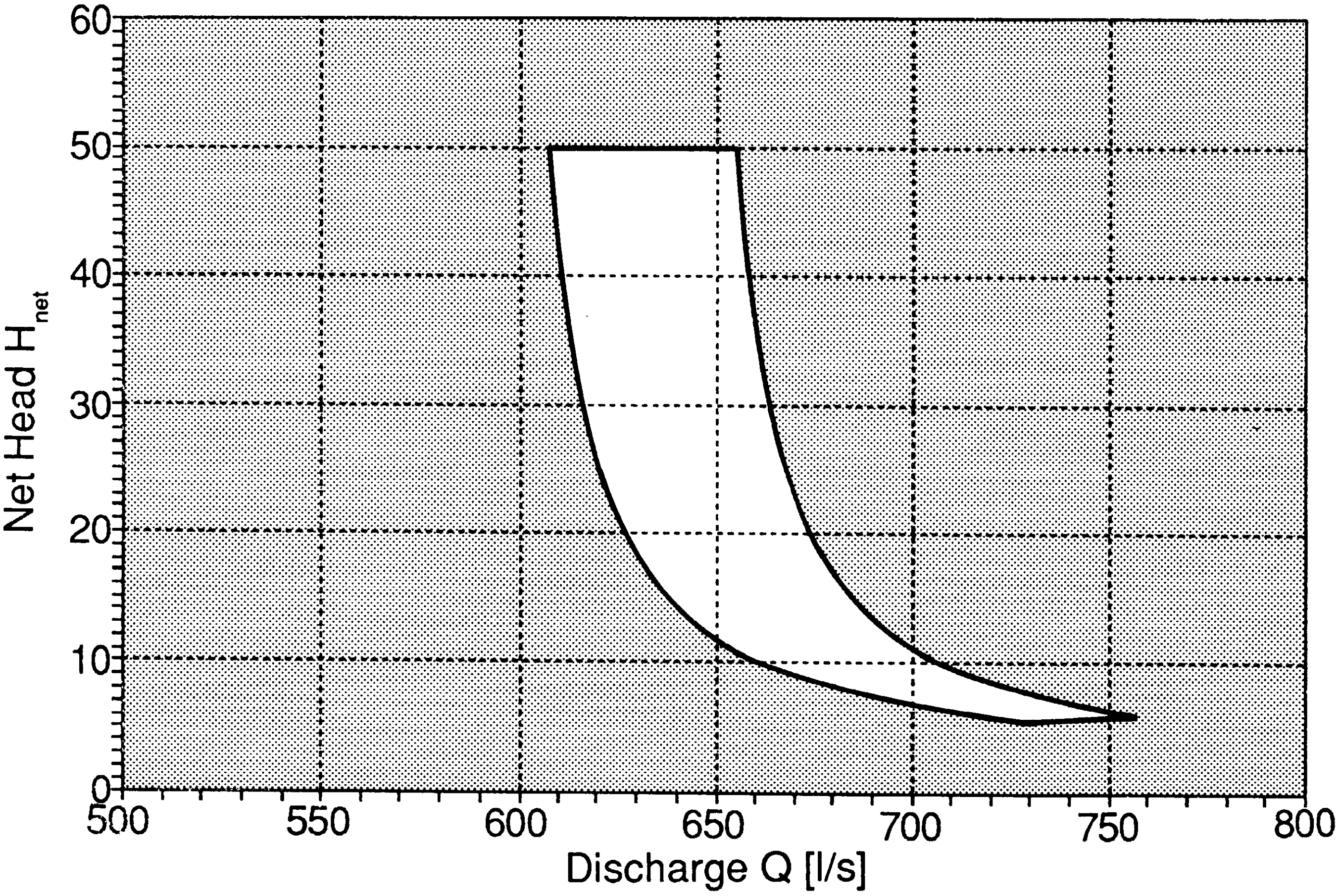


Chart 6: Application range for 6 intermediate discs on the rotor

If the point of intersection of the values H_{net} and Q falls within the range of the white, non-dotted field or on the borderline of the field, 6 intermediate discs are needed on the rotor.

H_{net} = ______ [m]

Q = ______ [l/s]

7 intermediate discs required

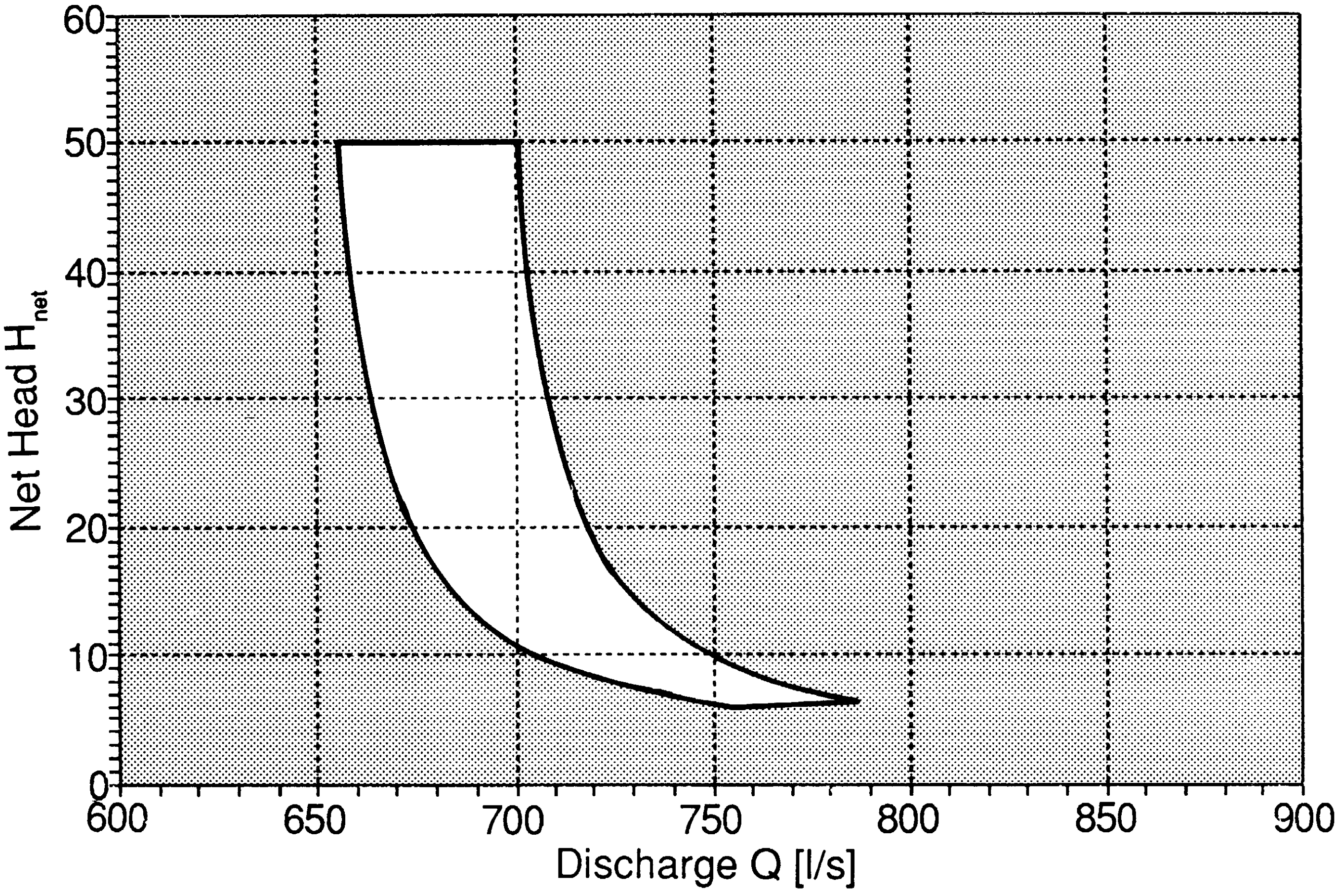


Chart 7: Application range for 7 intermediate discs on the rotor

If the point of intersection of the values H_{net} and Q falls within the range of the white, non-dotted field or on the borderline of the field, 7 intermediate discs are needed on the rotor.

H_{net} = ______ [m]

Q = ______ [l/s]

8 intermediate discs required

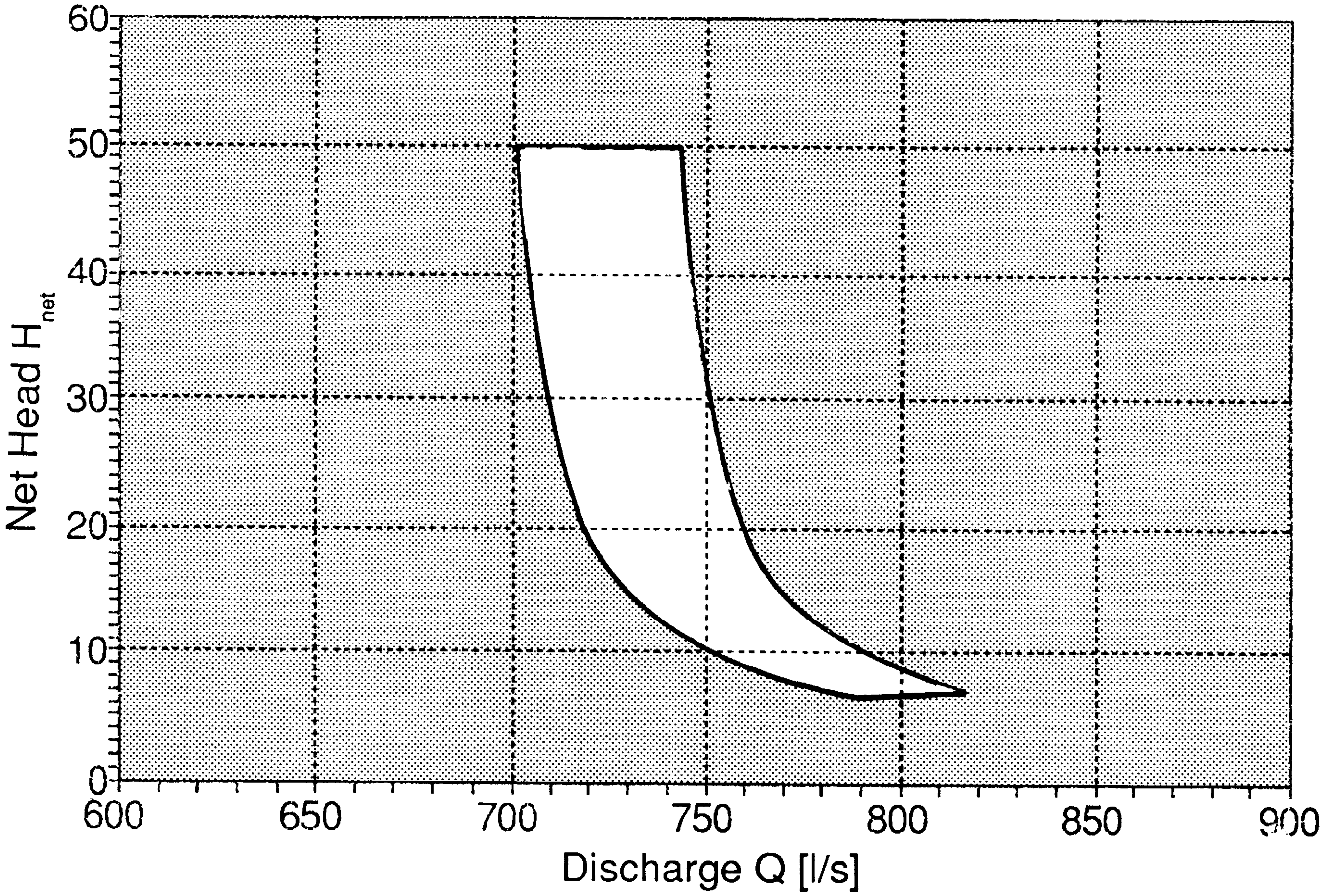


Chart 8: Application range for 8 intermediate discs on the rotor

If the point of intersection of the values H_{net} and Q falls within the range of the white, non-dotted field or on the borderline of the field, 8 intermediate discs are needed on the rotor.

STEP 3:

Determine the inlet width b_0

For every turbine installation the inlet width b_0 has to be defined. The net head H_{net} and discharge Q are the determining factors.

You can calculate the inlet width b_0 with the following formula:

The inlet width b_0 should generally be determined with an accuracy of plus/minus 1 mm.

To check whether the design points are within the limits you should check the inlet width with the nomogram 1. Enter the values for Q and H_{net} in the nomogram 1 as follows:

$$b_0 = 3.623 \cdot \frac{Q}{\sqrt{H_{net}}}$$

- Mark the value of the net head H_{net} (from step 1) on the scale at the left side.
- Mark the value of the discharge Q (from step 1) on the scale at the right side.
- Connect the marks on the two scales with a straight line.
- The required inlet width b_0 can now be read on the inclined scale in the centre at the point of intersection of the straight line and the inclined scale.

Note: Should any of the values for Q, H_{net} or b_0 be above or below the ranges indicated on the respective scales, the T12 turbine design is not suitable for this application, i.e. the T12 design is not appropriate for the given head and discharge.

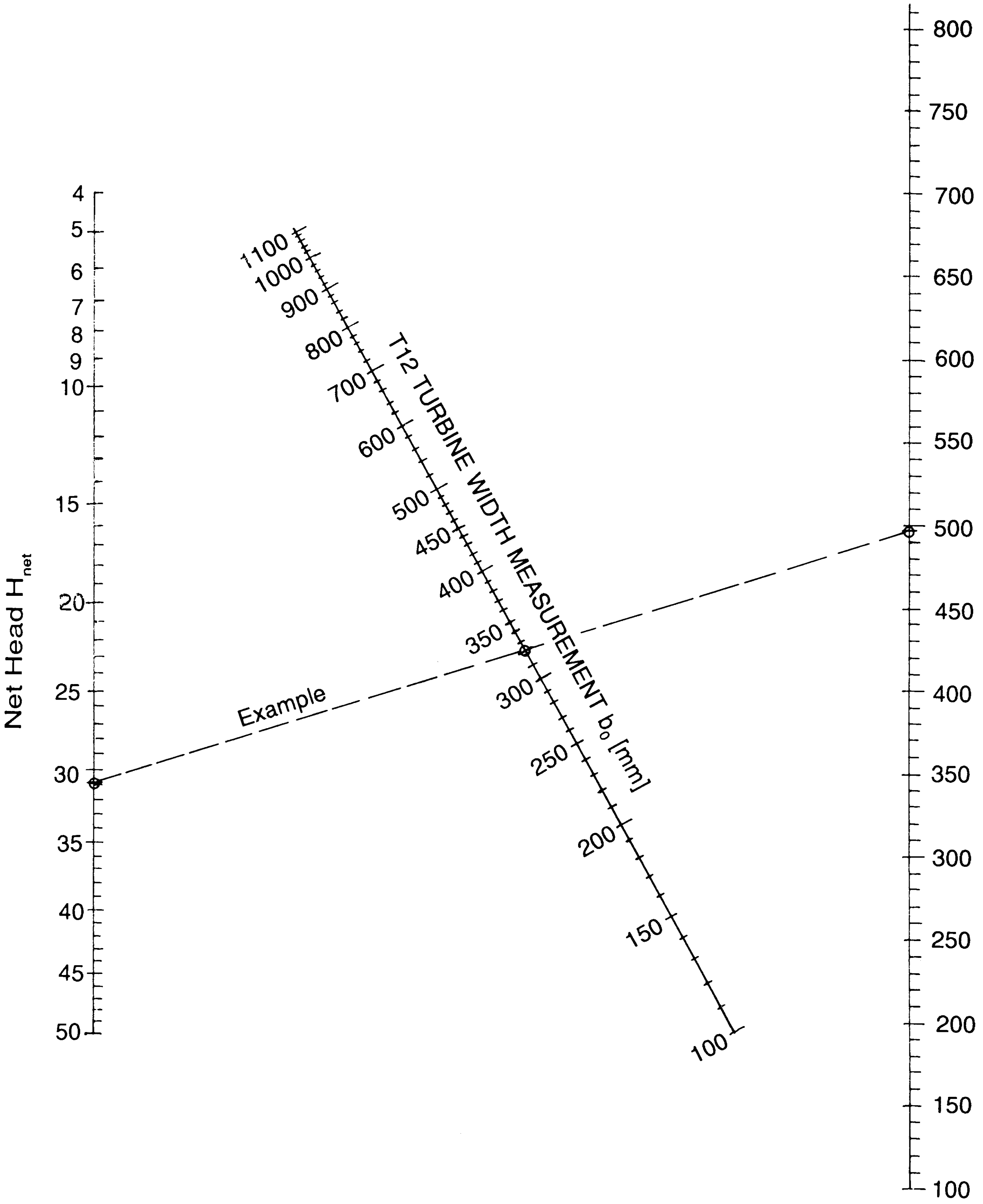
Example:

You wish to determine the required inlet width b_0 for the net head H_{net} of 30,89 m and the discharge Q of 497 l/s. The value calculated with the formula

$$b_0 = 3.623 \cdot \frac{Q}{\sqrt{H_{net}}} = 3.623 \cdot \frac{497}{\sqrt{30.89}}$$

amounts to 324 mm. This is an accurate measurement.

The nomogram 1 gives about the same value at the intersection point of the straight line between the marks for 30,89 m on the left hand side scale for the net head H_{net} and for 497 l/s on the right hand side scale for the discharge Q and the inclined scale for the inlet width b_0. All values are within the specified ranges.



Nomogram 1: Determination of the T12 inlet width b_0

Example: A net head H_{net} = 30,89 m and a discharge Q = 497 l/s indicates an inlet width b_0 of 324 mm.

STEP 4:

d-d line

The point of intersection of the values H_{net} and Q falls either below or above the d-d line shown in Chart 9.

intersection point below d-d line

Any transmission system between turbine and generator is permissible.

intersection point above d-d line

Additional bending stress on the rotor shaft due to forces created by e.g. belt tension is not permissible, therefore **no belt pulley on the rotor shaft is allowed.**

In case of a belt transmission, a separately supported pulley shaft would have to be coupled to the rotor shaft.

APPLICATION LIMITS OF THE T12
CROSS FLOW TURBINE DESIGN,
POWER OUTPUT, RPM AND d-d LINE

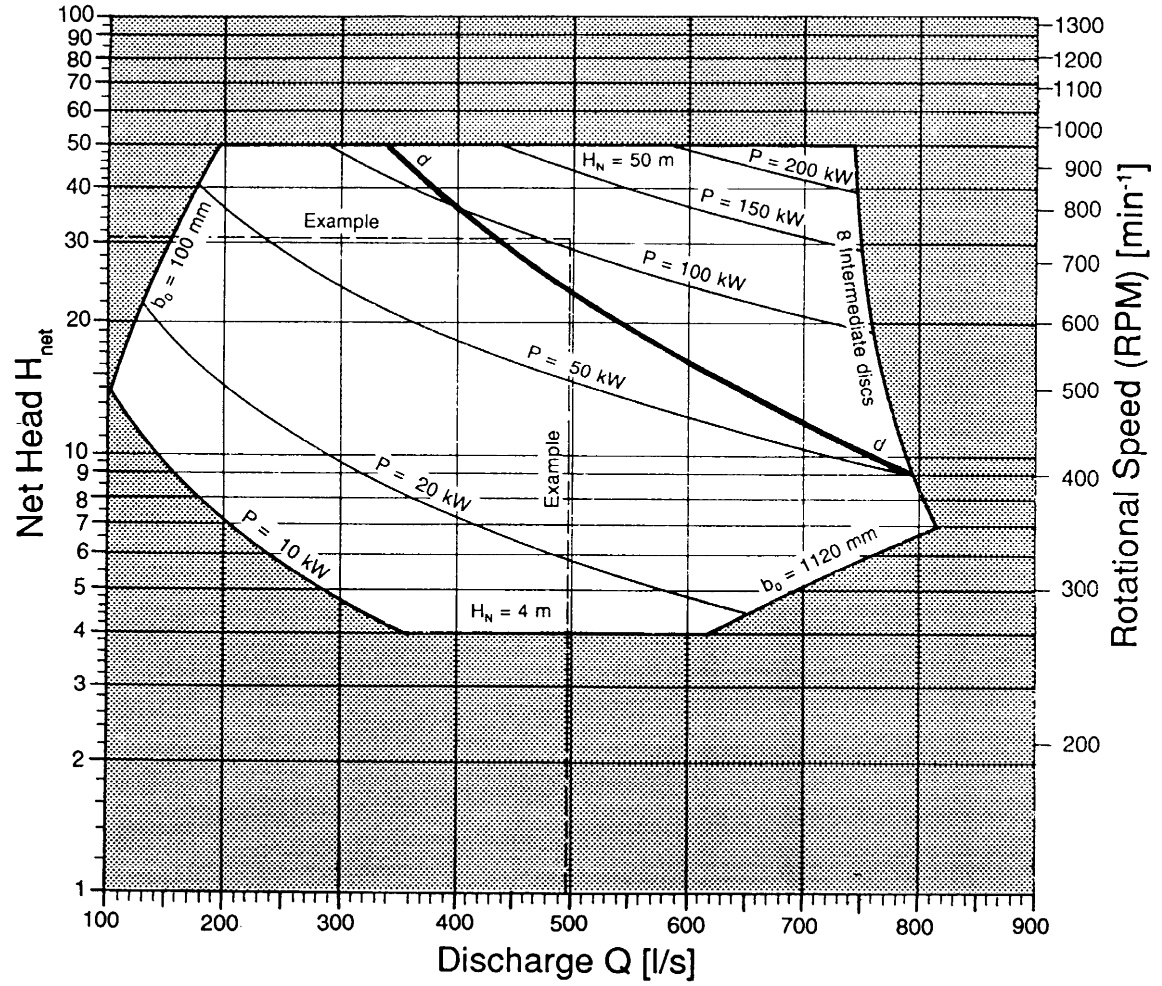


Chart 9: Net head or Rotational Speed versus discharge chart showing application limits, power output and d-d line

STEP 5:

How to modify the T12 Turbine master set drawings to the inlet width b_0 found in step 3

The dimensions in the attached set of T12 turbine workshop drawings are for a turbine inlet width b_0 of 324 mm (as calculated in the example). This dimension of 324 mm is the distance between the two side panels on the housing inlet (see section A-A on drawing T12/G1).

When you calculate the turbine width b_0 with your H_{net} and Q the resulting b_0 will (almost certainly) not be the same as the b_0 = 324 mm calculated in the example. You will have to adapt your workshop drawings to the dimension of b_0 that you found. All dimensions in the T12 master drawings marked with an asterisk = * have to be modified. Therefore, before manufacturing a T12 turbine, all dimensions marked with a * must be recalculated to correspond to your actual inlet width b_0.

Normally, this can be done with the following formula:

Dimension on master drawing (marked *)

\+ actual inlet width b_0 (step 3)

— Inlet width of master drawing (324 mm)

= Modified dimension

(see example 1 below)

The centre distance between the holes in the flanges of the housing needs to be recalculated. First calculate the overall distance between to two extreme holes. Then check what centre distance is indicated in the master set of drawings. Select the number of divisions so that the centre distance will be similar. It is not necessary that all centre distances are equal. Adjustments should be made using common sense. (see example 2 below).

Example 1: The overall rotor shaft length has to be calculated for an inlet width b_0 of 580 mm (dimensions on drawings T12/B1-1 and T12/B1-2). The master set of drawings being made for an inlet width b_0 of 324 mm gives the overall rotor shaft length of 872* mm. The overall rotor shaft length for an inlet width b_0 of 580 mm is therefore:

L = 872* + 580 - 324 = 1128 mm.

Example 2: The number of threaded holes and their centre distances for the fixation of the top cover has to be determined (see drawing T12/G3) for a turbine with an inlet width b_0 of 580 mm.

The master drawing there shows six holes with a centre distance of 81* mm and overall distance of 5* x 81* = 405* mm. According to the calculation of example 1, the new overall distance will be 405* + 580 - 324 = 661. The number of divisions can be calculated:

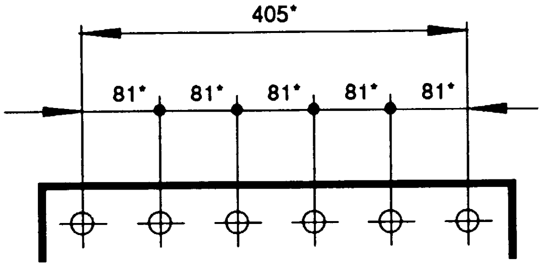
661/81 = 8.16 choose 8 divisions

This means 9 holes with 8 divisions. In order to have the divisions of, as near as possible, the same size we can make the 3 divisions on the right and the left side with a centre distance of 83 mm, whereas the remaining two divisions in the centre will be separated by a distance of 81,5 mm each.

This will add up to an overall distance of (6 x 83 mm) + (2 x 81,5 mm) = 661 mm.

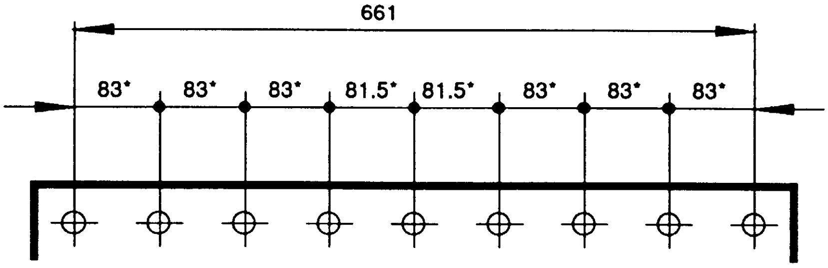
master drawing

b_0 = 324 mm



modified drawing

b_0 = 580 mm



4. Additional Information for Engineers

4.1. T12 Turbine Calculation

The formulae for the calculation of the turbine performance values are as follows:

Formula (1): **Inlet Width**

$$b_0 = \frac{1}{q_{11\,max} \cdot D} \cdot \frac{Q}{\sqrt{H_{net}}}$$

for T12:

$$b_0 = 3.623 \cdot \frac{Q}{\sqrt{H_{net}}} = 3.623 \cdot \frac{497}{\sqrt{30.89}}$$

$Q = D \cdot \sqrt{H} \cdot b_0 \cdot q_{11}$

b_0	Inlet width	[mm]
H_{net}	Net head	[m]
Q	Discharge	[l/s]
$q_{11\,max}$	Unit discharge = 0,92 for the T12 turbine	
D	Rotor diameter = 0,3 m for the T12 turbine	[m]

Formula (2): **Shaft Power Output**

$$P = \frac{Q \cdot H_{net} \cdot \eta}{102}$$

P	Power	[kW]
η	Turbine efficiency = 0,7 for the T12 turbine	[-]

Formula (3): **Turbine RPM**

$$n = \frac{n_{11}}{D} \cdot \sqrt{H_{net}}$$

for T12:

$$n = 133 \cdot \sqrt{H_{net}}$$

n	Rotational speed	[min^{-1}]
n_{11}	Unit speed = 40 for the T12 turbine	

Example:

We calculate the inlet width b_0, the power output P and the rotational speed n for a net head H_{net} = 30,89 m and a discharge Q = 497 l/s according to the above formulae as follows:

$$b_0 = \frac{1}{q_{11\,max} \cdot D} \cdot \frac{Q}{\sqrt{H_{net}}} = 3.623 \cdot \frac{497}{\sqrt{30.89}} \qquad = 324 \text{ mm}$$

$$P = \frac{Q \cdot H_{net} \cdot \eta}{102} \qquad = \frac{497 \cdot 30.89 \cdot 0.7}{102} \qquad = 105 \text{ kW}$$

$$n = \frac{n_{11}}{D} \cdot \sqrt{H_{net}} \qquad = 133 \cdot \sqrt{30.89} \qquad = 741 \text{ min}^{-1}$$

4.2. Application Limits

The application limits for the T12 cross flow turbine can be summarized as follows:

			lower limit	upper limit
H_{net}	Net head	[m]	4	50
Q	Discharge	[l/s]	100	820
P	Shaft power output	[kW]	10	250
b_0	Inlet width	[mm]	100	1120
Number of intermediate discs		[-]	0	8

Note: **These limits must be respected. Engineering considerations such as practicability, relative cost, tightness of inlet valve in closed position, opening and closing force on the inlet valve, strength of the rotor blades, strength of the connection of the side discs to the rotor shaft, diameter of the shaft etc. demand the respect of these limits.**

On Chart 9 curves are shown for various power outputs P. The corresponding formula is:

$$P = \frac{Q \cdot H_{net} \cdot \eta}{102}$$

The approximate rotational speed n of the turbine can be read from the vertical scale on the right side of chart 9. Its exact value is calculated with the following formula:

$$n = \frac{n_{11}}{D} \cdot \sqrt{H_{net}} = \frac{40}{0.3} \cdot \sqrt{H_{net}} \cong 133 \cdot \sqrt{H_{net}}$$

Example within the limits:

For a net head H_{net} = 30,89 m and a discharge Q = 497 l/s, the following values can be determined on the T12 application Chart 9:

- The point of intersection of the H_{net} and Q values is within the range of the white field, which means that the T12 design is appropriate.
- The shaft power output is just above 100 kW.
- The rotational speed n is about 740 min^{-1}.

Example outside the limits:

H_{net} = 6 m and Q = 200 l/s.

Although both H_{net} and Q are within the limits, the intersection point on Chart 9 lies outside the white, non-dotted field. Hence, **for this application a T12 turbine cannot be used.**

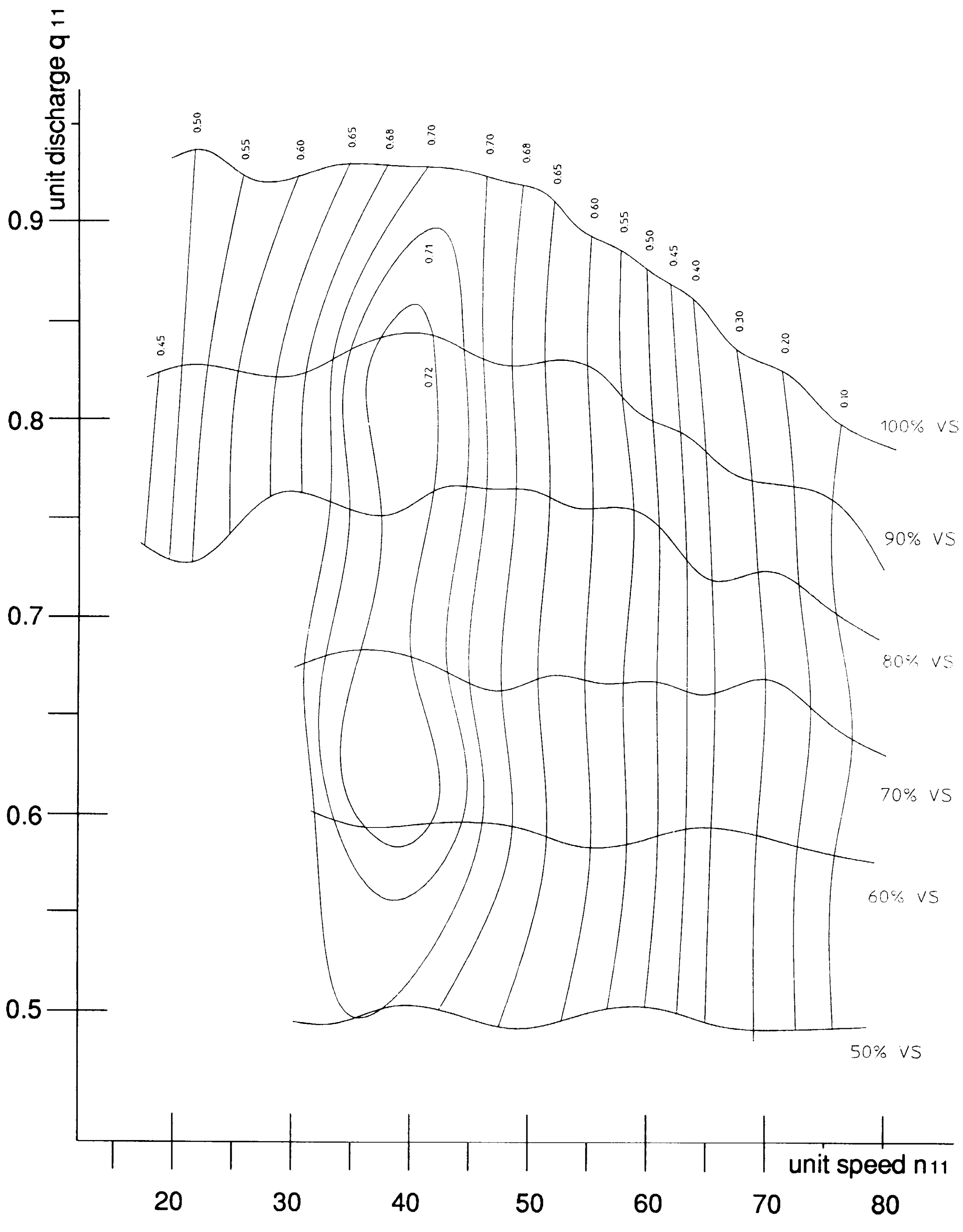


Chart 10: Iso-Efficiency Graph for the T12 Turbine

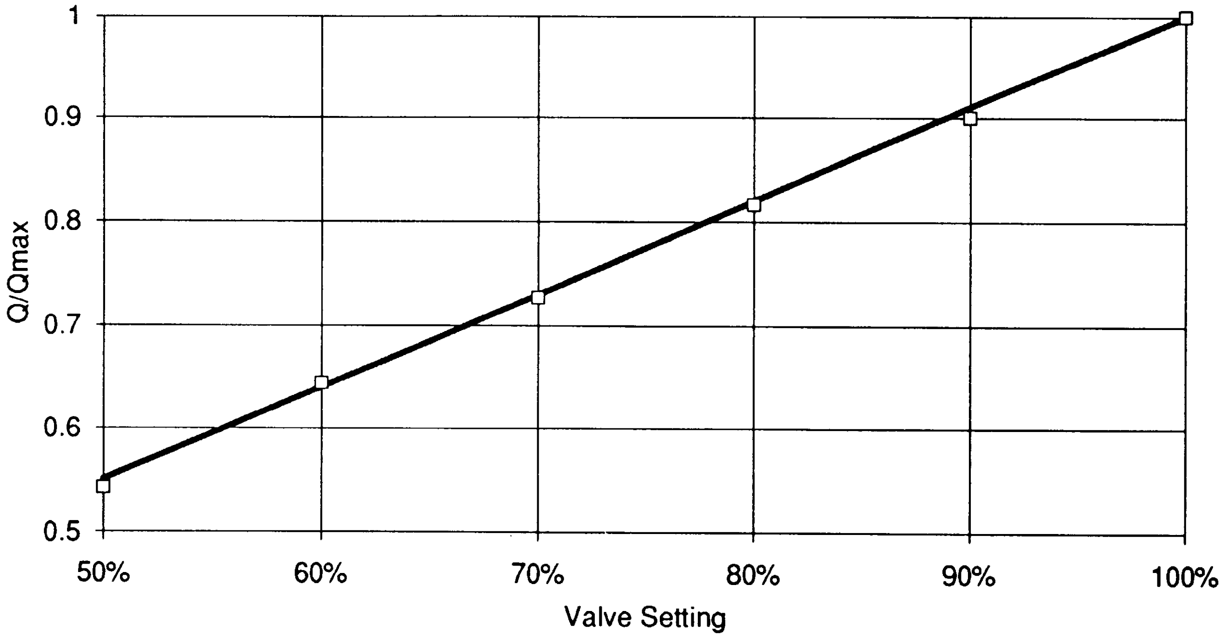


Chart 11: Relative Discharge Q/Q_{max} versus Valve Setting for the T12 Turbine

Q_{max} represents the maximum discharge at full valve opening. To fully close the inlet for a T12 turbine, the valve is rotated 20° from the fully opened position. The relation between the valve setting in % and in ° [degree] is the following:

$$\text{valve setting in \%} = \frac{100\%}{20^\circ} \cdot \text{valve setting in }^\circ = 5\frac{\%}{^\circ} \cdot \text{valve setting in }^\circ$$

A valve setting of 0% means fully closed and a valve setting of 100% means fully opened valve position.

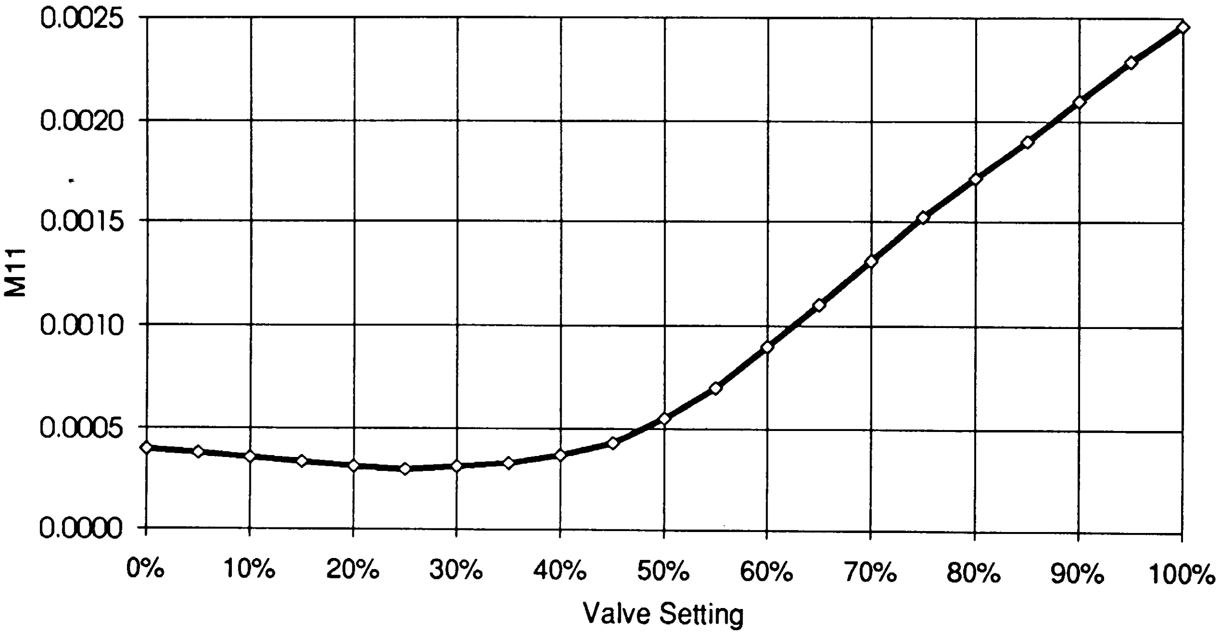


Chart 12: Specific Valve Torque M_{11} versus Valve Setting

The required torque to operate the turbine valve can be calculated with the formula

$$M = M_{11} \cdot b_0 \cdot \sqrt{H_{net}} \quad [\mathrm{Nm}]$$

whereas the value M_{11} is to be taken from Chart 12 (Specific Valve Torque M_{11} versus Valve Setting).

Example:

H_{net}	=30.89m
b_0	=324mm
Valve Setting	= 60% (=12° open)
read from Chart 12:	M_{11} at 60% opening = 0.0009

$$M = 0.0009 \cdot 324 \cdot \sqrt{30.89} = 1.62 \quad [\mathrm{Nm}]$$

This value represents the hydraulic torque only. To dimension the working capacity of the valve positioning device, add approx. 100Nm as an offset to overcome friction.

This publication is not simply an additional book on cross flow turbines. It represents the feasible reply to the need of a satisfactory turbine which can be manufactured without the use of a foundry: **the T12 turbine,** which is a tested cross flow turbine model. The content of the hard-box is Volume 3 in the MHPG series "Harnessing Water Power on a Small Scale":

Cross Flow Turbine Design and Equipment Engineering

and consists of a complete set of workshop drawings, including all detailled drawings and partlists. The box also contains all information required for size selection within the specific application range.

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