RECENT DEVELOPMENTS IN MACHINERY

FOR

SMALL HYDRO-ELECTRIC SCHEMES

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1 INTRODUCTION

Small hydro could be said to have started with water wheels, reaching a peak in the 1930's. It was then ousted by grid power from large schemes and cheap diesel power. The oil crisis, which emphasized the need to supplant fossil fuel generation and to provide an economic and reliable supply to isolated communities has brought about a renewed interest in small schemes.

Now that a number of small hydro schemes have been built, it is appropriate to review developments in mechanical and electrical plant, indicate the problems encountered and consider how the technology can be advanced.

2 TURBINES

The selection of the most suitable type of turbine is critical to the success of any scheme. The designer needs to make many judgements and decisions: the type of turbine, whether it should be horizontal or vertical, the need for speed governing, and so on.

Low-head developments are inherently expensive because the high flows need large machines. Hence, most of the research and development effort has concentrated on the design of low head machines that minimize both civil and equipment costs. While some of these new machines show promise, most have yet to demonstrate that they are as cost effective and reliable as modern versions of traditional machines.

Fre2.1Flow

Several turbines designed to be placed in free flowing water have been proposed and some have been built. They all have two big disadvantages: because the head is very small, they have to be very large to produce much power and they are prone to damage during floods[1] Some, such as the Schneider lift engine, are mechanically complex [2]. (See Figs. 1 and 2).

2.2 Right Angle Drive

In an effort to reduce cost, a standard range of small right angle-drive bulb turbines with fixed guidevanes and blades have been adapted from marine bow thrusters. As they can only operate at full output, several machines must be installed to match varying flows. Because the output is fixed, operation on an isolated system is possible only in conjunction with a load diversion governing system which, when the load is low, dissipates the surplus output in an eddy-current brake[3]. With this system their overall efficiency varies from about 85 per cent at rated load to a very low figure at low loads. Only in special circumstances do they appear to have any advantages over a conventional open-flume Francis turbine[4].

2.3 Straflo

The Straflo turbine, in concept, is a model of simplicity. As originally conceived, it consisted of a fixed-blade propeller runner with the generator rotor on its periphery. The whole assembly was carried on special hydrostatic bearings adjacent to the generator rotor. Special seals kept the water out of the rotor and bearings[5].

In the event, the peripheral bearings were dispensed with and conventional bearings in the hub were used. Problems with blade deflection due to hydraulic thrust have effectively ruled out the use of adjustable runner blades, so that the turbine has a high efficiency only over a small range of flows and heads[6].

Although several Straflo turbines have been installed, the machine does not appear to offer substantial advantages over a Kaplan or geared bulb turbine except for tidal power applications. The mini Straflo, in which a high speed generator is driven by a belt passing around the periphery of the runner, is also an attractive and simple concept, but so far has not been commercially successful.

2.4 Inverted Kaplan

This novel low-head turbine has been developed in France[7]. It is a vertical open-flume Kaplan machine with fixed guidevanes, but with an inverted draft tube acting as a syphon. This minimizes excavation and eliminates the need for a headgate because a vacuum pump and syphon breaker valve control the flow of water. The machine is suitable for heads between 2 and 4 m, and the largest unit in service has a 3.5 m diameter runner; it generates 1 MW (Fig. 3). Within this rather narrow range of application it has advantages over the machines discussed above.

2.5 Semi Kaplan

This turbine uses a Kaplan type runner with adjustable blades and fixed guide vanes. It can be mounted in an open flume or be fed by a pipe which incorporates a right angle bend using turning vanes. In the latter case there must be fairly large head losses in the bend and in the inlet valve; these would reduce the overall efficiency. (Fig 4)

2.6 Bulb

Of bulb turbines one engineer said: "You are building a submarine", and that is a fair description. The Kaplan runner is the propeller and the generator is the hull. As with a submarine, there are problems with keeping the water out and fitting the equipment in. The machine is expensive, but this can be offset by savings in civil works. The gain in efficiency arising from the relatively unconvoluted waterways is often negated by high velocity losses at the draft tube exit. This is because of space limitations; if the draft tube were the same size as that of a Kaplan turbine, much of the advantage in civil works would be lost.

Bulb turbines are attractive where the site is constricted, the flows are in excess of 50 m^3/s and the head is below 15 m. As the small diameter, low speed generator has little inertia, bulb turbines are often incapable of controlling the frequency on an isolated system. A recent development is the use of an epicyclic gearbox to drive a high speed generator. This eliminates the cost and problems of a direct driven generator and allows the use of a flywheel to increase the inertia[8]. However such a large gearbox is inherently less reliable than a direct drive and this must be set against the savings in overall cost.

2.7 Tubular

Tubular turbines are an alternative to bulb or Kaplan turbines at outputs below 3 to 4 MW. To reduce cost, most tubular turbines have fixed guidevanes and adjustable runner blades. This gives a reasonable efficiency down to about 40 per cent load, but it does require an inlet valve for starting and shutting down. Where efficiency is important, a double regulated tubular turbine (which does not need an inlet valve) is worth the extra expense.

Double-regulated tubular turbines are less efficient and more difficult to maintain than conventional Kaplan turbines. Because the whole machine must be set low (to avoid cavitation problems) the civil costs can be high. Many tubular turbines have been unreliable[9]. There have been problems with efficiency, cavitation, the underwater bearing, deflections in the long shafts, draft tube vibration and the like. Before a decision to use tubular turbines is made, Kaplan and open flume Francis turbines should be evaluated.

Tubular turbines with fixed runner blades and adjustable guidevanes have peaky efficiency curves, poor cavitation characteristics and little merit.

The tubular turbine was an early candidate for complete standardization; for reasons given later in this article, this was not entirely successful. Since then, a number of manufacturers have rationalized their designs to give a small range of runners that can be tailored to fit a range of outputs and heads[10, 11].

2.8 Open-flume Francis

Although often considered to be obsolete, a vertical open flume Francis turbine driving a generator through a speed-increasing gearbox is economic from 15 m down to about 5 m head. It is a simple, reliable and cheap machine with reasonable part-load performance. It is easy to erect and easy to maintain. (Fig. 5)

Where efficiency is relatively unimportant and the output is below 2 MW, it is likely to be the most suitable machine.

2.9 Vertical Kaplan

This is the classic solution where there are low heads and large flows. The adjustable guidevanes and runner blades enable it to operate efficiently over a wide range of both flow and head. It is easy to maintain and most turbines of this type have been very reliable. It is an option that should not be lightly discarded.

2.10 Francis

Many significant improvements have been made in the design and manufacture of conventional Francis turbines.

The cost of design, draughting and manufacture has been dramatically reduced by the use of computers, numerically controlled machines and standardizing minor items.

Forty years ago, most horizontal Francis turbines had four or five bearings and a flywheel between the turbine and generator. The draft tube was often convoluted and inefficient. It was difficult to dismantle the turbine without removing shafts and bearings (Fig. 6). Although turbines of this type are still available, most modern turbines have two bearings; a guide bearing between the turbine and generator; and a thrust bearing at the other end. If a flywheel is needed, it is overhung from the rear bearing. Draft tubes are simple cones formed in concrete. The runner is fixed to the shaft by high pressure oil or by Ringfeder couplings, and both the runner and the covers can be removed from the downstream side without disturbing the shaft (Fig. 7).

As a result of those improvements, the cost of a modern Francis turbine is perhaps 60 per cent of the cost of the earlier machine. (The "price", on the other hand, is, as ever, what the market can stand!)

Where there is a need for efficient operation at low loads, twin turbines overhung from each end of a single generator are simpler and less expensive than two turbine and generator sets[12].

If it is acceptable to operate at only full or half load, then 20 to 30 per cent of the turbine costs can be saved by using twin turbines without guidevanes. This gives a simple, compact unit operating at maximum efficiency at either load.

There is a widely held misconception that Francis turbines cannot be operated for long periods below 40 per cent load; this has often led to the selection of two or more machines when only one is needed. While it is true that some larger Francis turbines have a band of unsteady operation at about 40 per cent, below this band they usually run smoothly. Most small machines operate smoothly at any load. Admitting air to the centre of the draft tube often cures unsteady operation.

2.11 Impulse (Pelton and Turgo)

As with Francis turbines, a rationalization programme has been carried out by some manufacturers. It has resulted in a small range of casings and runners that can be tailored to fit a wide range of outputs and heads[13].

Because Pelton runners must be machined from a high quality casting, Pelton turbines for moderate heads are very expensive, and high-head Francis turbines should also be considered.

2.12 Pumps as Turbines

Many pump manufacturers have suggested that standard pumps be used as water turbines[14]. The idea is attractive but, when pumps are used as turbines, they operate at higher heads and flows and hence deliver more power. As a result, each application must be reviewed, since special casings, shafts and bearings may be needed[15].

The turbine developed by Flygt from their range of submersible axial flow pumps appears to provide an economic solution for low heads and constant flows. A simple, compact unit which can be removed in one piece for servicing has been developed from the pump by changing the runner blades and adding a draft tube. However, the efficiency is low, and some gearbox problems have been reported.

2.13 Standard Turbines

The concept of standard machines (that is, the production of a range of machines of identical design as is done with diesel generators) was discussed by G McHamish of Boving at the First European Conference on Small Hydro, organized by *Water Power and Dam Construction* in 1982[16]; he said:

> *"Another question is the question of standard ranges of turbines - or standard designs. To cover the market you are talking about 50, 100, 200 standard designs and, with the market as it is at the moment (and it is not going to change very much) one manufacturer can receive in one year an order for maybe 10 or 20 designs. As time goes on, he will change his ideas about how to design those machines. So, if he has already made 50 or 100 designs, many will already be obsolete before he has a chance to use them. So I don't think it will be much benefit to the customer to write a specification which is intended to take some advantages from standardization from a particular manufacturer."*

Although many papers have been written expounding the advantages of having a range of standard machines available "off the shelf", it is now generally recognized that standard turbines are applicable only to micro and mini turbines, where cost is important and efficiency is not.

3 ELECTRICAL EQUIPMENT

Electrical equipment can easily be standardized without compromising efficiency or excessive cost. Therefore, wherever a programme of small hydro development is being embarked upon, electrical systems should be standardized to ease the load of maintenance staff, to minimize spares holdings and to encourage local manufacture.

Because even a large mismatch in the ratings of electrical equipment will not lead to excessive costs or an efficiency penalty, it is not difficult to design a limited range of standard control and protection systems, switchgear and transformers which are suitable for outputs from a few hundred kilowatts to several megawatts[17].

4 MECHANCIAL EQUIPMENT

Although gates and penstocks have been somewhat neglected, there have been improvements in this field; in particular, costs have been reduced by careful design and by minimizing the amount of work to be carried out on site.

4.1 Intake Gates

Traditionally, gates sliding on machined bronze inserts have been used for small (less than 2 x 2 m) penstock intakes. Considerable economies have been achieved by the use of low friction polythene runners backed by rubber which deforms up to 2 mm to minimize leakage and to ensure that the load is evenly distributed.

For larger intakes and higher heads radial intake gates are finding favour. They are inherently cheaper than wheeled gates, partly because of their simple structure, but mostly because of the much simpler fixed parts. Although radial gates normally have two arms, a single arm has been used for gates up to 3 m square, leading to savings in civil works, simpler erection and lower costs[18].

10 *Haas, P. "The 'S' turbine; A successful solution for low head small hydro." First European Conference on Small Hydro, Monte Carlo; November 1982.*

11 *Bagliani, G and Borcilani, G A. "The standardization of the hydraulic machine." First European Conference on Small Hydro, Monte Carlo; November 1982.*

12 *Leyland, B W, "Machine Selection and Powerhouse Design for Small Hydropower Schemes", Water Power '83 Conference, Tennessee, USA; 1983.*

13 *Eisrfeldt, G. "Standardized turbines for mini hydro plants" First European Conference on Small Hydro, Monte Carlo; November 1982.*

14 *Gordon, A G and Bain, J M. "Pump turbine - The economic answer" First International Conference on Small Hydro, Singapore; February 1984.*

15 *Schafer, L L. "Practical applications for pumps as hydraulic turbines for small scale hydro power." Water Power '83 Conference, Tennessee, USA; 1983.*

16 *McHamish, G, Specifications for small water turbines" First European Conference on Small Hydro, Monte Carlo; November 1982.*

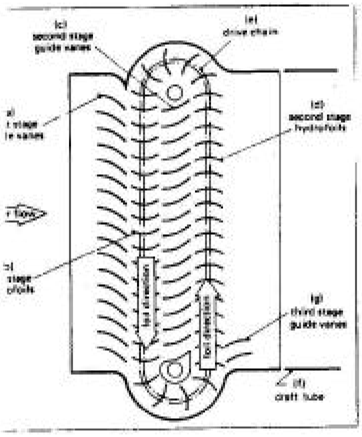
17 *Leyland, B W, "Standardisation, rationalisation and specification of mechanical and electrical equipment for small schemes" First International Conference on Small Hydro, Singapore; February 1984.*

18 *Leyland, B W, Jessup, G R, Berry, S R,"Designing gates for Small Hydro Schemes" Water Power and Dam Construction, April 1985*

19 *Leyland, B W, Jessup, G R, Berry, S R,"Automatic Controls for Spillway Gates and Outlets" Water Power and Dam Construction, January 1986*

20 *"Small Hydro Needs its Own Experts" Water Power and Dam Construction, December 1982*

21 *Gilbert-Green, J, Murray, D G, Gordon J L "Small hydro - a challenge for consultants" First International Conference on Small Hydro, Singapore; February 1984.*



;. 1. Schneider Engine

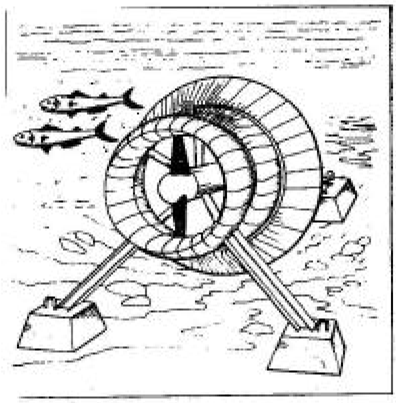
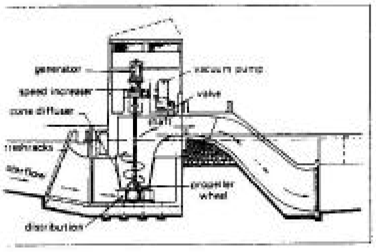


Fig. 2. Run of river ducted turbine



g. 3. Inverted Flow Kaplan

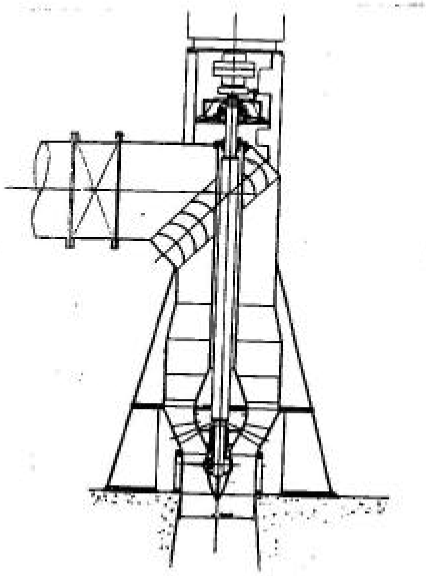
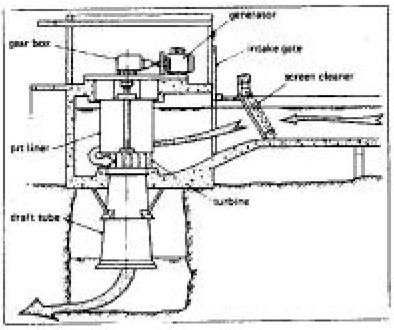


Fig. 4. Semi Kaplan



g. 5. Open flume Francis

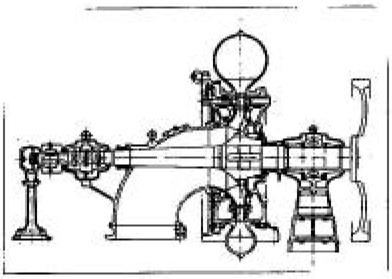


Fig. 6. Old style Francis turbine

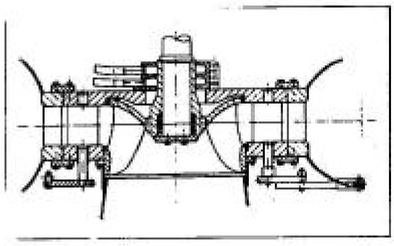


Fig. 7. Modern Francis turbine (Boving)

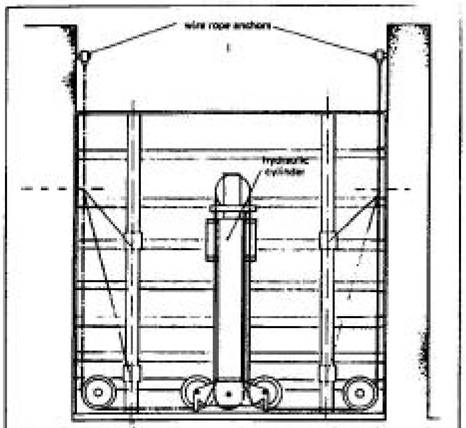


Fig. 8. A spillway radial gate with self-contained lifting gear, viewed from downstream.

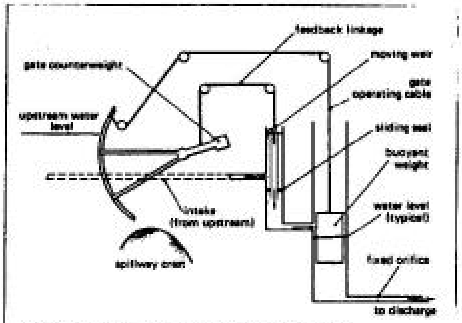


Fig. 9 The buoyant-weight-controlled spilling gate.

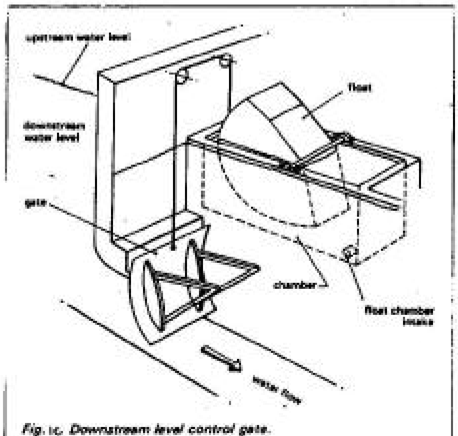


Fig. 10 Downstream level control gate.