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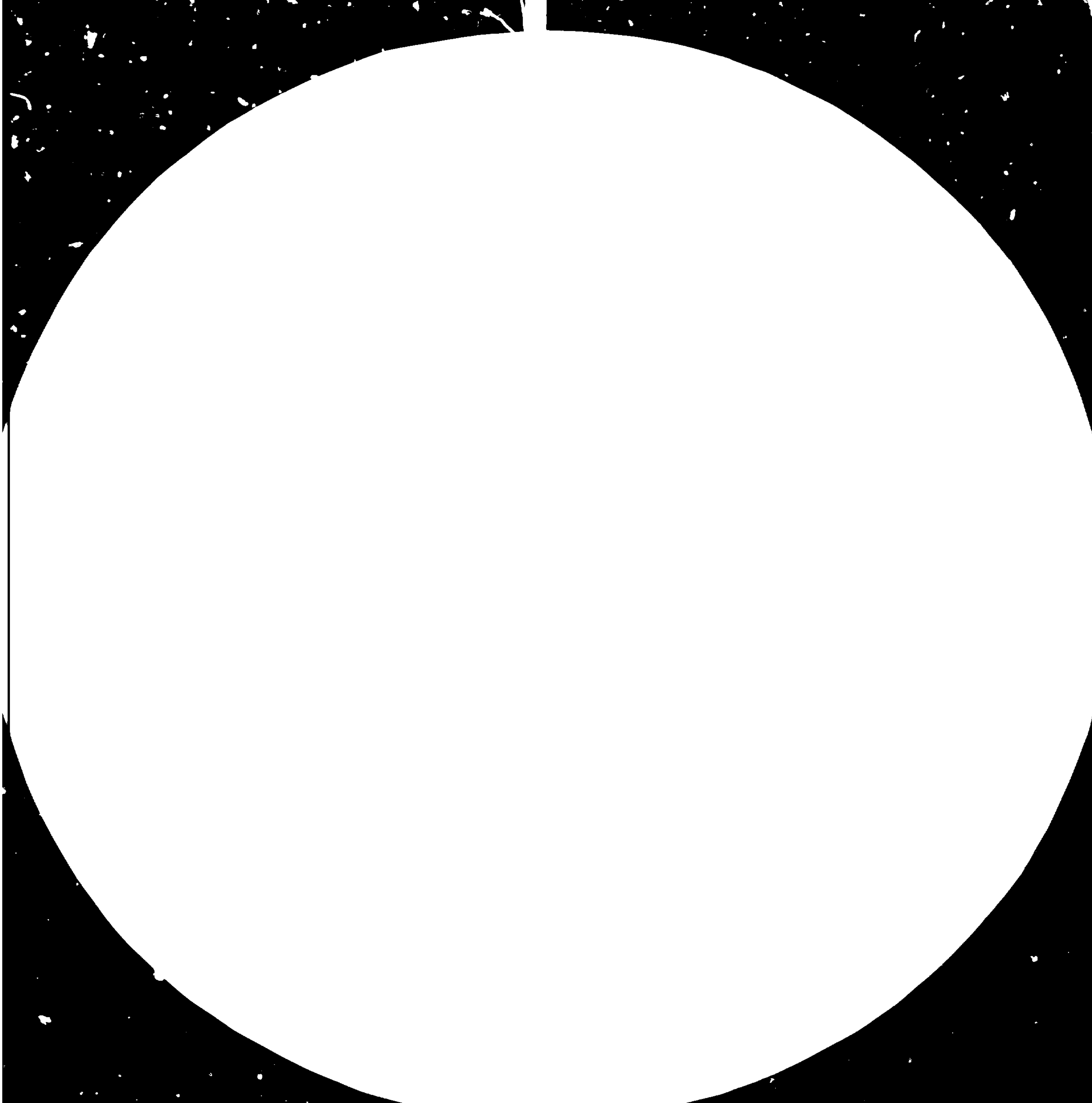

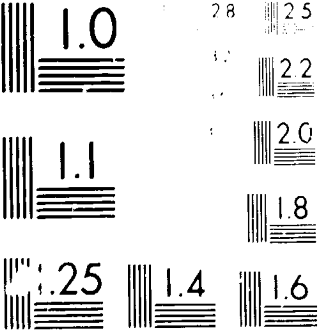
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DEVELOPMENT OF EQUIPMENT FOR HARNESSING HYDROPOWER ON A SMALL SCALE[*]

by

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CONTENTS

1. Introduction

2. Small propeller turbines

3. Development of a more appropriate turbine

    3.1 Criterias

    3.2 Design

    3.3 Performance

    3.4 Scope for application in rural areas

4. Cost of turbine and small projects

    4.1 Generation of mechanical power 10 to 15 KW

    4.2 Generation of mechanical power for lift irrigation 40 to 60 KW

    4.3 Generation of electricity in the range from 20 to 50 KW

5. Further development

    5.1 Power transmission (mechanical)

    5.2 Speed control and plant safety

        5.2.1 Automatic speed control with flow control governors
        5.2.2 Electronic load control
        5.2.3 Safety devices

6. Concluding remarks

1. Introduction.

In many of the hilly areas of Nepal, a wooden, vertical axis-type of water wheel has been in use for generations. Built with entirely local materials and a few iron parts, such wheels are exclusively used to drive millstones for grinding flour from maize, millet, and wheat.

Limitations imposed by materials and construction techniques in use result in a maximum power output of a few Horsepower in such devices. Skilled local individuals have in recent years built a number of horizontal-shaft, overshot and hybrid type of Water Wheels, with which upto ten horsepower poweroutput are possible. Such water wheels still have the severe disadvantage of being low speed, requiring costly step-up transmissions if any machine with fairly high speed should be operated.

The fact that there exists a lot of local expertise in diverting water from rivers and rivulets and in building earth canals for irrigation as well as the basic knowledge of how a simple water wheel works, make it possible to develop more sophisticated devices for harnessing water power with active participation of the rural population in its installation.

2. Small propeller turbines.

Balaju Yantra Shala Pvt. Ltd. a company set up by the Nepal Industrial Development Corporation (NIDC) and the Swiss Association for Technical Assistance (SATA) has done pioneering work in starting manufacture of small water turbines in the early sixties. A number of small (10-15 HP) propeller turbines have in the following years been fabricated and installed.

Most of these turbines are still in use, operating various milling machineries for upto 18 hours a day.

Although an important step had been made, it was realised that this turbine was still far from optimal. It could not easily be enlarged for higher power output, adaptability for an acceptably large head range was limited and it could not easily be speed regulated under vary ing load.

3. Development of a more appropriate turbine.

3.1 Criterias.

For further development, a set of criterias was established which would have to be fulfilled with a new turbine. These criterias were:

- to be fabricated from normally stocked materials e.g. steel sheet, profiles, pipe.
- to be fabricated with familiar general workshop techniques as in use already (no costing of steel or iron).
- a standard design consisting of a limited number of sizes for discharges from 50 l/sec. to 500 l/sec.
- to cover a head range from 4 to 40 metres.
- to cover an output range from 2 to 50 KW.
- to be decomposable for transportation by porters (head loads) without requiring highly skilled personnel for at site assembly.
- to cost considerably less than comparable imported turbines but to have a satisfactory efficiency.
- with a provision for manually controlling speed under changing load.

- little maintenance requirements.

A detailed study of existing turbine principles revealed that a <u>Banki</u> (or Mitchell) type of turbine could satisfy all the criterias set forth best. Consequently, the <u>BYS Cross Flow Turbine</u>, was developed based on the Banki principle. (see also Annex I).

3.2 Design.

The design chosen is a turbine of fully welded construction with a rotor diameter of 400mm. Rotor blades are cut from suitable steel pipe and welded between the side discs to form a cylindrical rotor with the blades at the outer circumference and the shaft going through its center and extending from both sides.

The whole turbine consists of six main components with bearing housings, regulator mechanism and cover sheets in addition. All parts are positioned with taper pins during assembly, permitting very quick and easy at-site assembly.

To get different sizes of turbines with different discharge, only the <u>width</u> is varied. In this way, the nozzle area determining the discharge under a given head can be chosen at will upto a rotor width/diameter ratio of 3.

A good number of parts are identical on all sizes of turbines which considerably simplifies stocking of ready-made parts.

The main bearings of selfaligning spherical double roller type reduce requirements of machining accuracy and give a long life without any other maintenance except occasional greasing.

3.3. Performance.

Even theoretically, a Banki Turbine cannot reach the very high efficiency of an optimally designed Francis Turbine or Pelton wheel. Ossberger, a commercial manufacturer of cross flow turbines claim an efficiency of over 80% at optimal gate opening with their turbines.

Tests with the BYS turbine have shown a more modest result with over 70% at the maximum. Much depends on the surface quality of the materials used and on workmanship, but rising efficiency by more than another 5% seems not very feasible except at considerable cost.

Durability of the turbine has so far been satisfactory. The prototype, installed four years ago, needs a replacement of the rotor-bearings this year, after approximately 15'000 working hours. The negative effect of silt suspended in the water has been surprisingly low on the runner blades and other parts and we estimate that a runner may well last 10 years or more.

3.4. Scope for application in rural areas.

Introducing a new technology in rural areas is a very time consuming job. Thanks to efforts of the Agricultural Development Bank, interest has been roused over the last few years on an individual basis in many districts so that continuous production of turbines is called for. Due to the absence of local know-how, any manufacturer of turbines in Nepal will have to set up an installation team capable of site identification, survey, design and finally installation of the equipment.

So far, more than 30 turbines have been installed mainly for driving milling machinery mechanically. In these activities, two other companies are involved, each of them building their own design of cross flow turbine. Interest from potential customers and capacity in producing turbines is such that at present 2o to 3o turbines are installed every year.

Electricity generation and rural electrification with these turbines are in the offing. In several mill installations a small dynamo has already been included, providing electric light for a number of houses. Full scale village electrification projects in the range of 20-50 KW are under progress in three places with many more planned in the near future.

Another important field of application of the cross flow turbines is in lift irrigation where turbines under a relatively low head are used to run water pumps mechanically, for lifting water to the generally much higher plateau (Tar) above the river. One such project is at present under construction where the power output from two turbines of 30 KW each shall be utilised to irrigate 50 hectares. Another three projects of this type are at the surve-ying stage.

4. Cost of turbine ans small projects.

The selling price of the entire range of turbines produced is in the range of U.S. $ 1200 to 1500, with a turbine for highest discharge and lower head at the upper end of the scale. To arrive at the capital cost of generating equipment a good number of other items need to be included. Much depends on the size of the unit, topographical site conditions and on the kind of power, either mechanical or electrical, made available. For an asessment of the total cost of a project, other variables such as transportation cost, availability of local construction materials and the extent of civil construction works required, have to be considered.

Some illustrative figures for different applications of turbines are given here:

4.1. Generation of mechanical power in the range from 10 to 15 KW.

a) Cost of generating equipment including transmission components for three machines.
$ 180.- to 280.- per KW capacity

b) Total project cost including head works, power house and milling machinery:
$ 400.- to 1'000.- per KW.

4.2. Generation of mechanical power in the range from 40 to 60 KW for irrigation.

a) Cost of generating equipment including water pumps:
$ 250.- to 400.- per KW capacity.

b) Total investment cost including all equipment, civil construction works and piping:
$ 600.- to 900.- per hectare of irrigated land.

4.3. Generation of electricity in the range from 20 to 50 KW

a) Cost of all electro-mechanical equipments, excluding penstock and its accessories:
$ 400.- to 600.- per KW capacity.

b) Total investment cost of all equipment and civil construction works but excluding transmission and distribution:
$ 1'000.- to 2'000.- per KW.

5. Further development.

As installations become bigger and more sophisticated (electrification) a number of problems crop up which had not previously to be coped with. For a power output of more than 10 KW at relatively low speed, the usual flat belt of a small milling installation is no longer satisfactory. In the case of electricity generation, overspeeding represents a serious problem which has to be tackled and once small projects are executed in growing numbers it seems quite essential to standardise as far as possible. All these factors provide a lot of scope for further work for anyone involved in the task.

5.1. Power transmission.

Depending on head, the cross flow turbine requires step up ratios of 2 to 5 to run a generator at standard 1500 RPM. In a few cases a multiple Vee-belt double stage transmission was used. Besides of quite high costs for pulleys (cast from aluminium) there are more bearings required and provision must be made for adjusting the belt tension. Another problem encountered was in finding a properly matched set of Vee-belts.

More promising is, in our experience, a chain drive arrangement. For several 20 KW units such systems have been designed with the sprocketwheel of a diameter of about 450 mm, machined from previously welded up circular steel plates and rims. The transmitting element is a standard triplex roller chain with a pitch of ½". Resulting dimensions of the components are much smaller than for a comparable Vee-belt drive. If the sprocket pinion is made from common mild steel, wear of the teeth will show fairly quickly. We have resorted to case hardening of these parts for the time being and are considering to apply metal-fusion spraying to improve hardness and wear-resistance.

A totally closed housing made out of sheet metal provides oil bath lubrication to the chain drive.

5.2. Speed control and plant safety.

Depending on the use of electricity, different requirements exist for the maximum permissible voltage and frequency fluctuations. Both voltage and frequency vary in direct proportion with the generator speed. Ideally therefore, speed should be kept constant. There are two basic possibilities to do this. Either the water flow through the turbine is regulated according to the power demand, known as flow control, or a constant load is provided, obviously requiring a constant flow, known as load control.

In a small installation say in the range of 5 to 10KW, where electricity is required only for lighting, it may be possible to solve the problem very simply by not providing any individual switches at light points.

Thus, whenever the plant is in operation all lights are on and the load is constant. A few bulbs (upto about 20% of the total) may go off without any serious problem arising. The voltage simply rises proportionally. In case of total failure of all consumers however, a safety device is required. Such a device as well as possibilities for flow control and load control are described in the following paragraphs:

5.2.1. Automatic speed control with flow control governors.

a) A commercially available speed governor of electro-oil hydraulic type with an electronic control unit was tested for its suitability under local conditions with the BYS Cross Flow Turbine. This governor consists chiefly of the following components:

-- electronic control unit with DC tachogenerator.

-- an assembly of solenoid operated hydraulic valves.

-- a hydraulic circuit with gear pump, filter, oil container and servo cylinder.

-- a pressure chamber with oil pressure switch.
-- a hand starting pump.

The operation of the system, described very briefly, is as follows: By operating the hand pump, oil is delivered to the side of the servo cylinder which causes the inlet regulator of the turbine to open. The turbine will now gain speed under no load and when an output voltage of 180 volts is reached, the electronic/electric circuit is switched on. The small tacho-generator mounted on the rear end of the generator to its shaft produces a speed proportional voltage. This voltage is fed into the electronic unit where it is compared with the adjustable rated voltage. Depending on the result of this comparison the electronic unit commands a 4-way solenoid valve to switch, causing the servo cylinder to open the turbine gate if speed is still too low or close the gate if speed is too high.

In case of disruption of electricity supply to the control unit, another solenoid valve drops, releasing pressure to the closing side of the servo cylinder, causing the turbine to be shut down. Reaction time, stability and accuracy of the system can be adjusted in the electronic control unit.

The governor described was installed in our testing facility and its performance evaluated. Although control accuracy is very good (± 4%) there were a number of reasons which convinced us that this governor could not be accepted as a satisfactory solution for remote installations. Some reasons are:

-- high cost (approx. $ 6'000.-)
-- highly sophisticated, requiring very skilled man-power for installation and maintenance.
-- practically none of the components are locally

available or could be repaired.

- fault finding is difficult if not impossible without costly equipment.

b) With the help of the Swiss Federal Institute of Technology in Zurich a simple mechanical water pressure governor is now under development. This governor must fulfill criterias such as the possibility of fabricating it in Nepal, a governing accuracy of ± 10%, costs not higher than turbine cost, and reliable operation. The governor that was consequently developed comprises three basic components, a flyweight pendulum mounted on the turbine shaft, a valve system, lever controlled by the flyweight, and a servo cylinder with compression spring, operating the turbine gate. The valve system is connected to the penstock on one side and to the servo cylinder (opening side only) at the other end. Without water pressure, the turbine gate remains closed due to the compression spring between gate and cylinder. With the system under pressure, the gate opens and the turbine gains speed. At rated speed, the flyweight pushrod reaches a pre-determined position which in turn moves the variable valve to a position where only the quantity of water leaking from the cylinder piston is admitted into the cylinder. The closing forces of the spring between cylinder and gate and the opening force on the piston due to water pressure are equal at this point, keeping the flow of the turbine, and thus speed, constant as long as no load variation occurs.

If load is switched on now, the speed of the turbine runner will decrease due to higher torque on the drive shaft. This results in a change of the position of the flyweight pushrod which in turn increases the flow of water into the servo cylinder by the action of the flow control valve. The pressure in the servo cylinder increases thus, causing the turbine gate to open up more.

Turbine speed now retruns to rated speed where the control cycle is completed. If load is switched off, the system corrects itself in the opposite way (for schematic of control loop and view of centrifugal pendulum refer to Annex II.

After extensive testing of a prototype in Zurich, the final configuration of the components used has now emerged and it has become clear that a relatively big flywheel will have to be included to give the system better stability. Maximum speed variations may then theoretically be reduced to any level desired but obviously this again is subject to economical and technological constraints.

5.2.2. Electronic load control.

As an alternative to flow control, this is considered a feasible proposition for an output range upto 100KW. Such a voltage sensing shunt regulator has been procured through ITDG, London, and was tested in our test plant. It monitors the line voltage of the alternator and adjusts a resistive shunt load (ballast circuit) to compensate for any changes in the load circuit caused either by the consumers switching appliances in or out, or by variations in the turbine output. The switching element is a semi conductor triac mounted on a heat sink. All other components are printed circuit board mounted. For a regular 3 Phase generator, the whole assembly comprises three identical units, one for each phase. The ballast circuit may consist of any resistive load. We propose to use ballast energy to heat water in a big tank.

In a village electrification scheme this water heater might be accessible to the public for free hot water. In this way, even if only a small percentage of energy produced is utilised in the consumer circuit at times, no energy is wasted. An important advantage of this system is the fact that the phase loads of the alternator remain perfectly balanced always no matter what single phase loads are switched in the consumer circuit. Its price is acceptably low with $ 1'000 to 2'000 depending on output capacity for a three phase unit including ballast circuit.

A distinct disadvantage is that such units will have to be imported in the first place. Local repair of a faulty printed circuit board assembly is not possible, but a plant electrician might be able to replace a fused triac or a complete circuit board. Spare parts to be kept on stock at all times therefore would cost probably 20 to 30% of total controller cost.

5.2.3. Safety devices.

Assuming that no system of speed control is entirely fail proof, it is clear that some sort of additional safety device must be integrated in a generating plant to protect mainly the alternator as the costliest single item. One method of doing this is to cause the plant to shut itself down when the maximum permissible overspeed of the generator has been reached due to failure of the governor or blowing of the main fuse in a constant load system.

For a 5 KW installation we have designed an electric-magnet controlled gate that cuts of the water flow if the magnet is de-energised either when the fuse blows or when actuated by an overvoltage relay. The gate is situated at the penstock inlet and this system therefore may only be applied when the penstock volume is not too large.

More versatile is a system that is based on the deflector principle by which the jet of a pelton wheel is diverted by a suitable deflector. In a cross flow turbine this cannot easily be integrated into the turbine but it may be done in the penstock, some suitable distance away from the turbine. The gadget then does not resemble a typical deflector but could be called an emergency flush gate. The penstock is provided with a short branch pipe, the end of which is closed by a hinged lid.

With levers and an lectric magnet this lid is kept tightly closed. Towards the turbine in the penstock itself a butterfly valve is mounted that is connected to the lid in such a way that it remains open whenever the lid keeps the branch pipe closed, but closes as the hinged lid opens. When the magnet is de-energised as described above, water pressure thrusts the lid open which causes the butterfly valve to close the passage to the turbine. All water discharges now through the orifice in the penstock branch and the power plant shuts down. For restarting the turbine, the penstock gate valve situated above the safety device is closed manually, the flush gate reset to its closed position and then the gate valve is opened again.

The prototype of this device has been completed some time ago and is at present being tested for its performance.

6. Concluding remarks.

Interest in small hydro power is steadily growing on all levels of society in Nepal as it is realised to be an instrument for rural development.

Balaju Yantra Shala, among others, will continue its effort in the field of harnessing hydro power in Nepal by further developing turbines and associated equipment for still better performance and economics of small installations and so make a humble contribution to rural development.

On a regional level, conferences such as the present one are welcomed and should help to disseminate know-how and experience gained in one particular country to the entire region and beyond.

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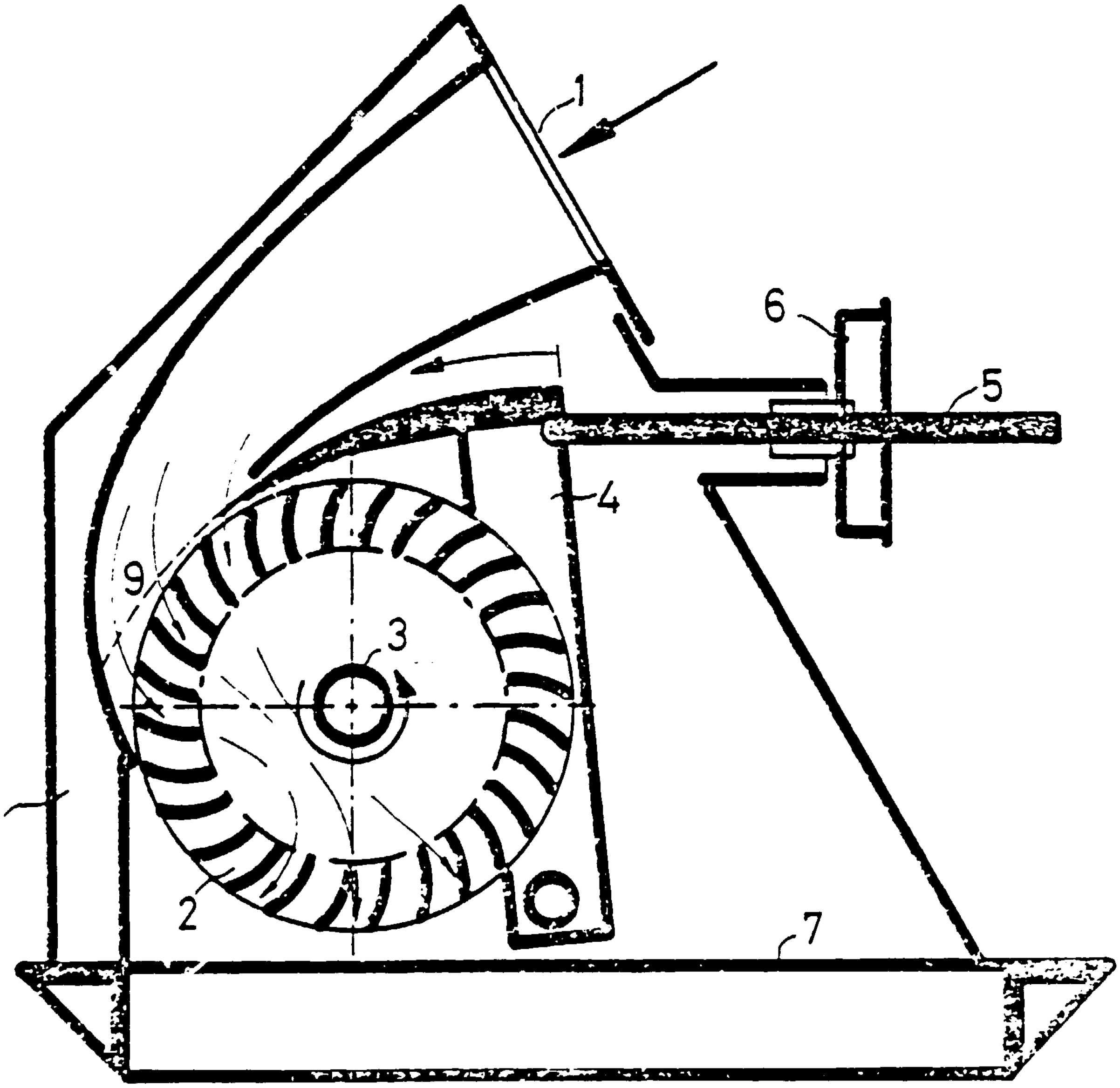
CROSS FLOW TURBINE FUNCTIONAL DIAGRAM

Water entering the turbine through the inlet(1) flows through the rectangular nozzle(9) radially into and again out of the rotor(2), thus setting the output-shaft(3) attached to the rotor into circular motion.

Rate of water flow and power output may be governed by the regulator wing (4) which is operated by a hand wheel (6) and push rod (5).



All parts are mounted onto the base frame (7) and in a body or housing (8).

Annex I

Simple centrifugal pendulum for water pressure governor.

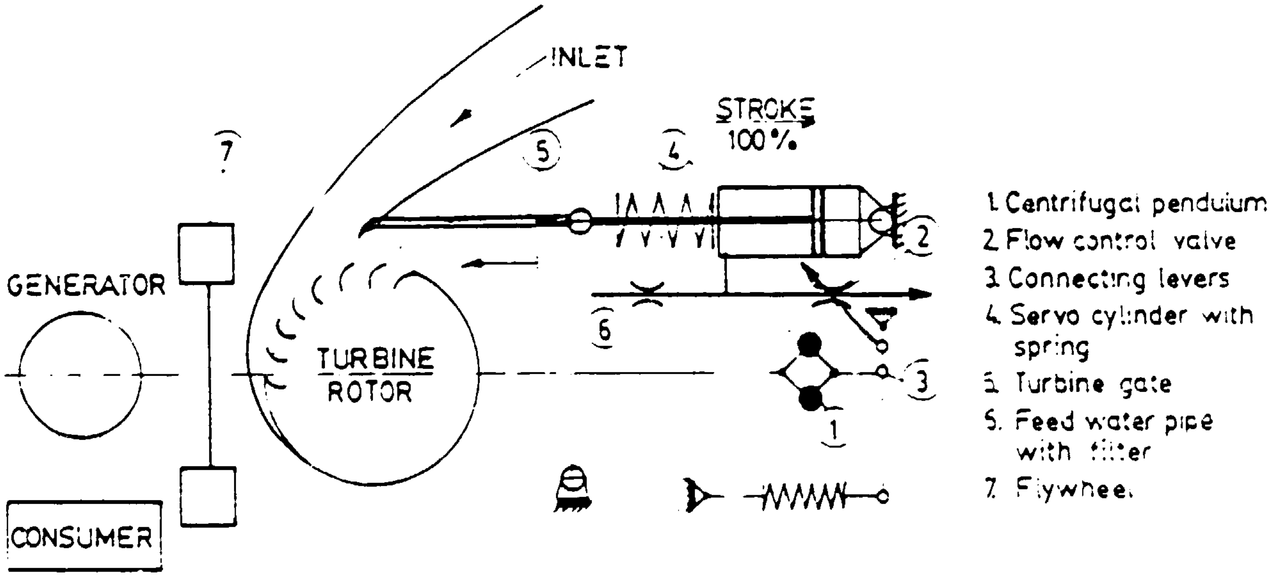


Fig.: 11

SCHEMATIC OF MECHANICAL WATER PRESSURE GOVERNOR

Annex II.