MICRO-HYDROELECTRIC PLANT SYSTEMS AND EQUIPMENT DESIGNED, BUILT, AND TESTED AT THE “ŞTEFAN CEL MARE” UNIVERSITY OF SUCEAVA

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Abstract. *This paper presents hydroelectric systems and equipment conceived, designed, and built at the University of Suceava between 1981-1990. These installations have been set to work in micro-hydro plants such those of Ariniş and Mălini in the district of Suceava. Collaborating with the specialists of the Electric Network Enterprise of Suceava, a series of physical parameters have been monitored, such as torque, speed, vibration level, bearing temperature, hydraulic and electric parameters.*

Keywords: *hydraulic turbines, testing bed, micro-hydro plant, measuring installation*

Introduction

In order to accommodate low flow rate hydroelectric plants, a standard machine building programme has been implemented in Romania, comprising low-power hydroelectric machinery (between 100 and 1,200 (2,500) kW) and micro-hydro machinery (for powers under 100 kW).

Low-power hydroelectric installations are equipped as follows:

- horizontal shaft Francis turbines for heads between 15 m and 130 m;
- horizontal shaft propeller, semi-Kaplan, Kaplan, S-turbines (EOS type) for heads between 3 m and 15 m;
- Pelton turbines for heads between 100 m and 700 m;
- automatic speed regulators or positioner systems;
- synchronous or asynchronous generators.

Micro-hydro power installations fall into two categories:

- for heads between 4.5 and 14.5 m and flows between 0.11 and 0.33 m^3/s;
- for heads between 16 and 35 m and flows between 0.145 and 0.37 m^3/s.

At the University of Suceava, a micro-hydro power installation and a propeller turbine rotor testing bed were built. At the same time, equipment and installations were conceived, designed, and built, for the EOS-type hydropower machinery employed in a series of micro-hydro power plants in the district of Suceava.

1. Micro-Hydro Power Installation and Propeller Rotor Testing Bed

a. 5 kW Hydro Installation

Within the attempt to harness all hydroelectric resources, the specialists at the University of Suceava have built 5 kW hydropower installation. Efficient tapping of water power for flows of 0.1 – 1.0 m^3/s and 2-3 m head requires the use of horizontal or slanted shaft propeller turbines, axial flow offering a number of advantages – high efficiency, diminished size and specific mass, increased per-unit power.

A bulb-type turbine was chosen, the rotor being placed inside the water passageway. The bulb was placed upstream due to resulting advantages: it is shorter, lighter, hence less expensive, and it yields increased efficiency. Variable geometry of the wicket gate and rotor blades allows these turbines to function under optimised conditions yielding high efficiency in a wide range of flows and powers. For economic reasons and due to reduced size, adjustable wicket gates were chosen. The way in which the rotor blades are mounted in the hub allows them to move when the turbine does not function, thus allowing for adjusting rotor blades at the optimum position according to head, thus yielding high efficiency for various functioning conditions.

The outline of the turbine is presented in Figure 1. The rotor, formed of hub 2 with the blades 5 fixed onto it and hood 1, is mounted on shaft 4. This outputs torque to electric generator rotor 12 through the medium of bolt elastic coupler 7. The driveshaft is supported by 3 bearings: 2 O-mounted radial-axial taper roller bearings and one radial ball bearing. The electric generator is placed inside bulb 9, the upstream end of which is elongate ogive 10, the hydrodynamic form of which reduce hydraulic loss. The bulb is fixed on the housing by means of three legs 11, the cross section of which is hydrodynamic. A waterproof pipe in the upper leg houses the electric conductors.

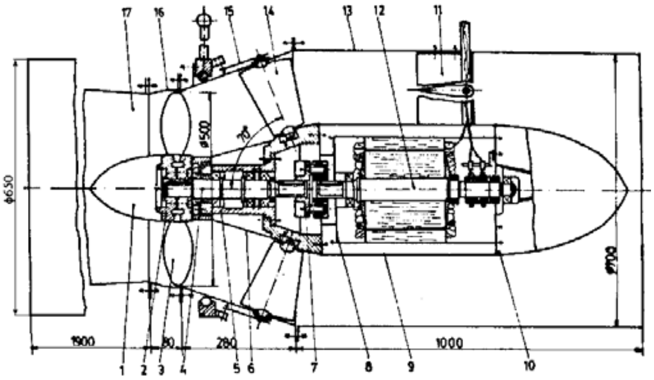

Figure 1. 5 kW hydroelectric installation

The flow and, consequently, the torque are adjusted with wicket gates 14. Simultaneous rotation of wicket gates is ensured by mechanism 15. The gates were attached to the outer cone in such a way that a small radial movement should be allowed, so that the rotor should be centred with respect to stator 16. Taper draft tube 17 is located downstream from rotor and is fixed with respect to stator 16.

The electric equipment of the hydroelectric installation is formed of self-excited synchronous generator and an electronic regulator maintaining constant output (Figure 2). The classic hydrogenerator variant, three-phase, synchronous generator has a rated power of 5 kW for a 580 V output and 50 Hz frequency, the specific speed being 500 rpm.

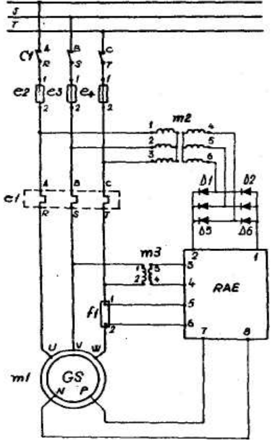

Figure 2. Electronic regulator

The stator of the synchronous generator was built by reusing the magnetic circuit of an asynchronous motor and providing it with an appropriately calibrated three-phase star winding. The rotor of the generator was designed and built accordingly; the magnetic circuit was provided by plates having six pairs of apparent poles on the circumference and a concentrated winding connected to two slip-rings, brushes and brush holders. The electronic excitation regulator is powered by the generator output terminal through a three-phase transformer and provides the direct current power for the excitation winding so that the alternative output of the generator should be fixed at the rated value.

b. Propeller Turbine Rotor Testing Bed

The model tests aim at determining rotor efficiency in various conditions in order to find the optimum variant, on the bases of which an optimum turbine should be designed using similitude theory. A testing bed was built in the Hydraulics Laboratory at the Faculty of Mechanical Engineering in order to perform power tests on propeller rotors.

The main parts of the testing bed, cf. Figure 3, are as follows: pumping groups 1, fluid tanks 2 and 11, connecting pipe 3 with valve 13, controls which controls flow variation through pipe 14, which houses test rotor 9, adjustment valves 4, flowmeter 7, electrodynamic braking system 10, and control and metering table 12.

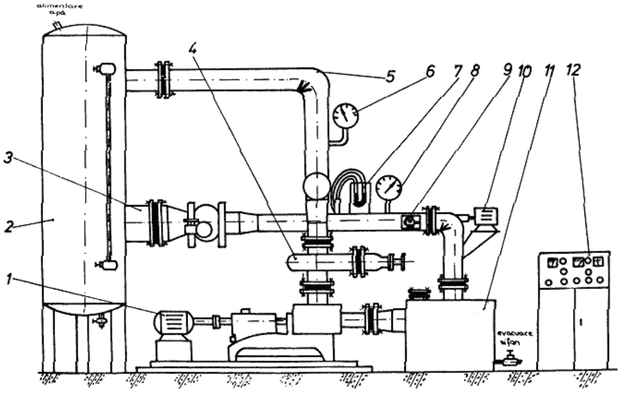

Figure 3. Turbine rotor testing bed

The flow is measured using a Pitot-Prandtl tube. The speed is measured using dc tachogenerator *f2* (Figure 4) connected to voltmeter g_4 graduated into angular velocity units. The torque on the shaft is measured using tensiometer g_3, the input of which is connected to tensiometric transducer f_1 attached to an elastic plate embedded in a stand which is rigidly attached to the bed frame. The elastic plate is acted on by one end of a metallic rod which is rigidly attached to the generator stator. The braking electromagnetic torque is adjusted either by adjusting the excitation current supplied by the stabilised power source ST or by shifting rheostat position.

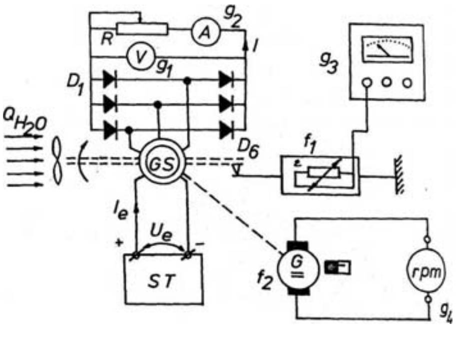

Figure 4. Testing bed measuring system outline

2. Micro-Hydropower Plant Optimisation Systems and Equipment

Since the physical parameters of hydroelectric facilities where EOS-type installations are located differ from input data in turbine design, turbine performance after setup does not always reach expectations. In order to achieve optimal functioning parameters, it was necessary to measure a series of specific quantities and build a series of systems to improve results and reduce exploitation costs. Thus, a number of devices were conceived, designed, and built, which are presented in the following.

a. Small Hydraulic Turbine Torque and Speed Measuring Systems

The torsion meter conceived and built to measure torque employs pulse transducers, the output quantity of which is signal phase, generating two pulse sequences, the lag between which is in direct proportion to applied torque. The electronic measuring block of the torquemeter is an analogue or digital output phase meter.

The signals output by the pulse transducers contain information not only on the torque (lag), but also on speed (pulse frequency). This information is displayed in analogue and upon relatively simple processing the mechanical power at the shaft can be determined, which is important in torque measuring.

The pulse induction transducers that were used are two steel disks with a fixed number of holes (toothed wheel) placed in two different sections of the shaft. Facing each wheel, there are a permanent magnet and a coil, the magnetic circuit of which being open and positioned so as the teeth of the wheels should cause reluctance variation.

In order to measure phase, the pulse transducer, analogue output torquemeters employ a bistable circuit or gate phase meter. Figure 5 presents the block diagram of the torquemeter.

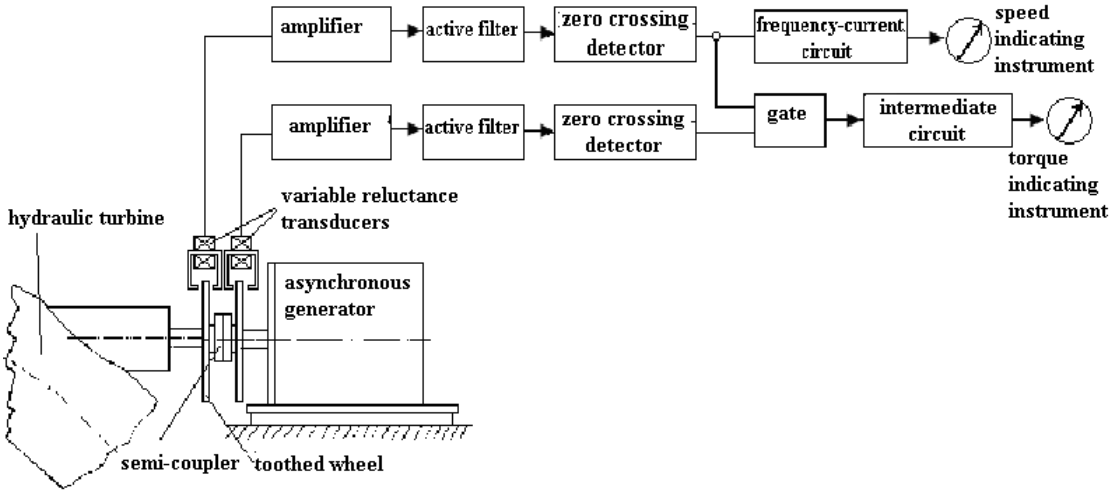

Figure 5. Torque and speed measure diagram

The measuring circuit outputs current in direct proportion to the input pulse frequency, which is indicated by a magneto-electric instrument. This function is fulfilled by a frequency-current converter, built around a CDB4121 monostable circuit.

The measuring system comprises: elastic coupler, variable reluctance transducer, and electronic torquemeter. The latter is a device that, apart from measuring torque, can also be used to measure angular speed. The component parts of this device are shown in Figure 5.

b. Temperature and Vibration Level Measuring System

The vibration level measuring system consists of vibration captor and electronic vibrometer. The vibration captor that was used is a seismic-type magneto-electric transducer. Using a set of two CTV 201 vibration transducers, measuring could be performed along two directions at a right angle. The electronic vibrometer used to process the signal output by the transducers is an a.c. millivoltmeter with a special amplitude characteristic, which is necessary for proper functioning at low frequency.

Temperature recording is useful in detecting abnormal bearing functioning.

The vibration amplitude and temperature measuring chain block diagrams are presented in Figure 6 and 7, respectively. The captors and displaying devices that were used are adequate to the specific purposes.

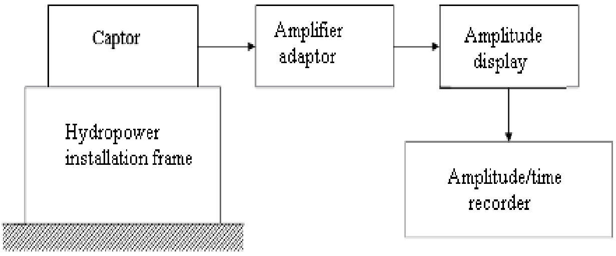

Figure 6. Vibration measuring block diagram

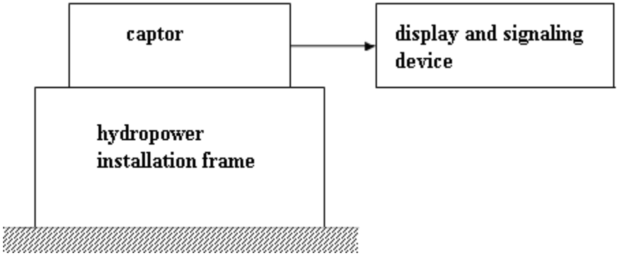

Figure 7. Temperature measuring block diagram

c. Hydraulic and Electric Parameter Measuring System

c.1. Hydraulic Equipment

Rational functioning of any installation containing fluid requires rigorous determination of transferred quantities per time unit. In the case of a hydraulic turbine, it is absolutely necessary to know the water flow, considering the fact that the turbine power is in direct proportion to it.

The flow measuring installation used in the micro-hydropower plant of Ariniş is mainly formed of two Pitot-Prandtl tubes (differential pressure gauges) mounted in the same cross section of the pipe and two U-tube differential manometers attached to a simple stand. The pressure gauges and manometers are connected using elastic tubes.

The Pitot-Prandtl tube used for flow measuring during exploitation allows for direct dynamic pressure reading in the point where it is necessary to measure water velocity. The device is formed of a cylindrical front part ending in a axially perforated spherical head mounted on a spherical chamber of the same diameter having peripheral holes designed for static pressure measurement. The axial channel and static pressure holes are each connected to a tube, as they represent the connection points towards the secondary element.

The U-tube differential manometer is a device that enables measurement of pressures that are higher or lower than air pressure, as well as differential pressures. The device consists of two glass tubes of the same diameter connected at the lower ends, placed vertically in a windowed box. Ruler placed between the two tubes allows for direct reading of pressure difference. The upper ends of the tubes are fixed in a five-tap metallic block.

c.2. Asynchronous Generator Related Equipment

Since the rated technical data of the EOS700 installation generator are provided for motor mode and the data concerning the generator of the EOS1100 installation are calculated and not experimentally determined, measurements were required in order to establish the electric generator functioning characteristics.

The equipment that was used for experimental measuring consists of: T 51 electro-dynamic ammeter, electro-dynamic wattmeter, HL 55 current transformer, Thompson bridge, digital frequency meter, electronic torquemeter, electronic tachogenerator. The control electric diagram has been improved by equipping the asynchronous generator with a tachogenerator, which interlocks with the main switch, connecting it when the generator rotor reaches synchronous speed.

d. Micro-Hydropower Station Reservoir Water Level Remote Measuring

Upon analysis of pressure measuring variants, for functional, economic, and technologic reasons, a measure and control system inside the plant was conceived, to measure water level in reservoir and to turn on and off the hydraulic installations in micro-hydropower plants. The system comprises two distinct pieces of equipment: turbine-working condition measuring installation, mainly composed of the Pitot-Prandtl tube, the differential pressure electronic transducer, and the control regulator, and turbine-paused condition measuring installation, comprising U-tube manometers and proximity transducer.

According to the diagram presented in Figure 8, the electronic transducer is hydraulically connected to the total and static pressure outputs of the Pitot-Prandtl tube and the manometer to the total pressure output of the gauge. The control regulator, the electronic transducer, and the proximity inductive transducer are electrically connected to the power plant control table.

The installation constantly indicates water level in the reservoir, by means of mercury level in the differential manometer tubes on the right, signalling the maximum, intermediary, and minimum levels by means of LED’s. Using the signals provided by the level measuring hydraulic system, automatic control electric equipment was built in order to open and close the valves on the supply pipe.

Conclusions

At the University of Suceava, devices and equipment have been conceived, designed, and built for use in local micro-hydropower plants housing EOS hydroelectric installations. A

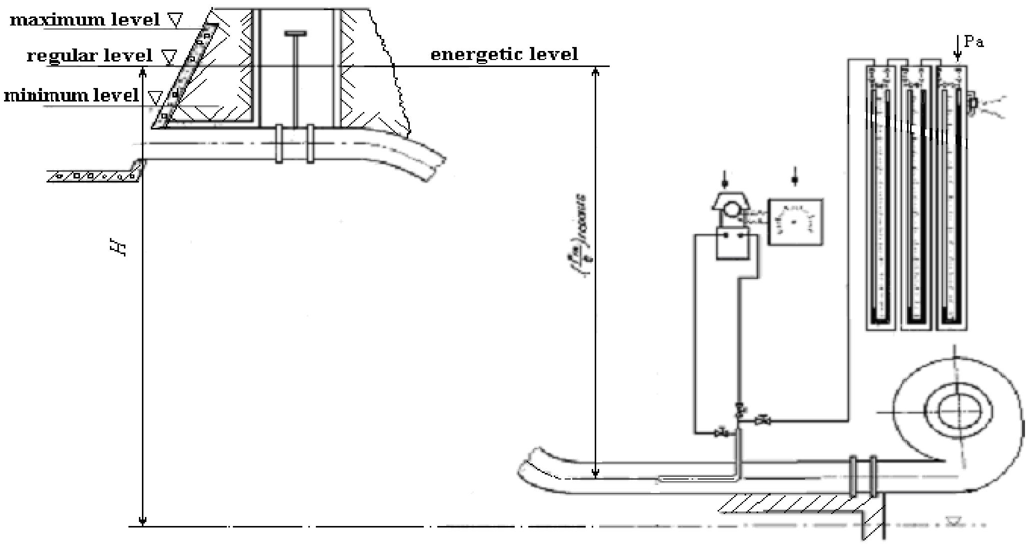

Figure 8. Water level remote measuring installation

series of elements have been tested in the laboratory on original testing beds in order to ensure appropriate functioning in the field and a 5 kW hydroelectric installation was built.

In order to achieve the optimum values of functional parameters, it was necessary to measure a number of specific – mechanical, hydraulic, electric – quantities, which resulted in equipment that ensured optimisation of hydroelectric installations and reduced exploitation costs.

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