CHAPTER 10

Governors

10.1 Governor system structure

A complete turbine governor system may be divided in three main components:

- *The controller.* This is the unit for execution of control processes. The unit may be of mechanical-hydraulic or electrohydraulic construction
- *Servo system.* The servo system is an amplifier that executes the admission changes determined by the controller.
- *The pressure oil supply system.* The principal duty for this system is at any time to supply sufficient quantities of pressure oil to the servo system.

A structure diagram of a representative turbine governor system is shown in Fig. 10.1.

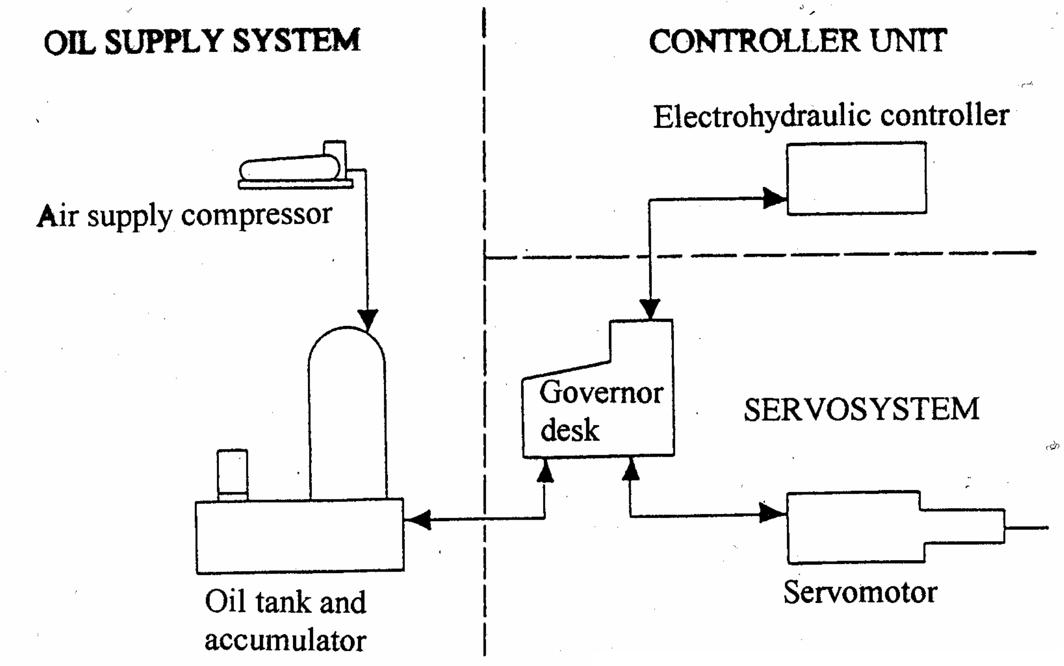

Fig. 10.1 Schematic structure of a turbine governor system /1/

Controller units and servo systems are considered in the following sections while the oil pressure supply system is dealt with in Chapter 12.

10.2 Electrohydraulic controllers

Standard Printed Circuit Boards (PCB) are normally used for electronics in the electrohydraulic controllers. The PCB's are housed in racks, which are mounted in a hinged frame. The power supply and auxiliary equipment are placed inside the governor desk.

10.2.1 Analogous controller

A typical system structure of an PCB-based controller /1/ is shown in the simplified block diagram on Fig. 10.2. The electric system of the controller consists of the following main components:

- power supply
- frequency measurement circuit for frequency control
- PID-control unit
- servo amplifier
- position measurement of the pilot control actuator
- input/output signal for remote and local control
- sensors for signal transducers (man - machine communication)

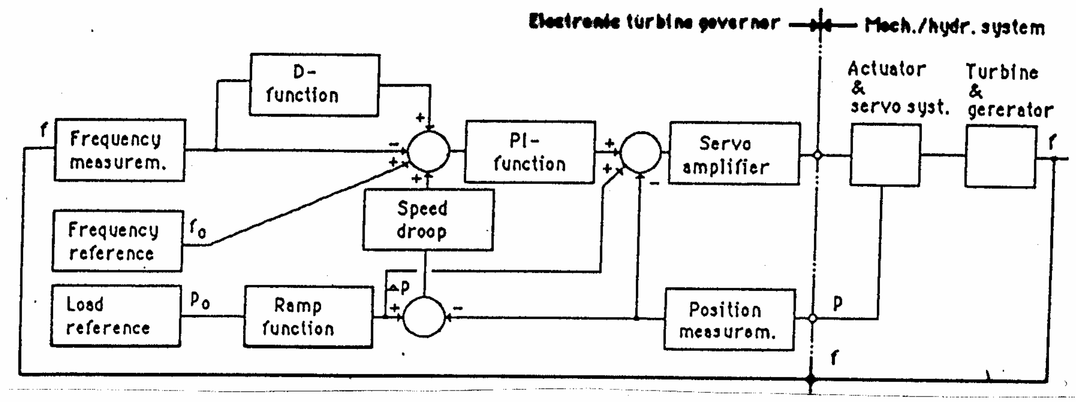

Fig. 10.2 Analogous electrohydraulic controller /1/

The controller has PID functions. Each parameter can be adjusted within a wide range. The adjustment of the amplification can be made without any influence on the time constants and vice versa.

Two inductive sensors close to each other measure the frequency. The sensors are activated by means of a segment disk attached to the turbine shaft. The pulses are received by a digital frequency measurement circuit and transformed to an analogue voltage. The analogue signal is input to the PID function block

The derivative function is influenced only by the frequency input and so giving a smooth changeover between reference changes and the frequency output.

The load reference signal is fed through a ramp function, which limits the rate of change in the reference value and thus the rate of change of the power output. The change will be linear and can be adjusted between 20 and 150 seconds per 100% load change.

The load reference signal also bypasses the PID control unit and is a direct input to the electro hydraulic actuator.

The feedback signal from the electrohydraulic actuator passes through the permanent speed droop circuit and corrects the output according to the actual frequency-load characteristics.

The output signal from the PID control unit is input to the amplifier. The amplifier also receives the feedback signal from the position transmitter on the electro hydraulic actuator.

The actuator will be regulated according to the output signal from the PID control unit. The actuator is connected to the main distributing valve which controls the main servomotor and the turbine admission.

In the “Manual” mode the mechanical-hydraulic load limiter controls the turbine power.

In “Manual” mode the supervision logic receives an alarm signal from the speed monitor at 100% speed, which results in an external stop command from the controller. This signal trips a shut-down function in the main control.

The governor parameters may be changed during operation with no system disturbances. It is also possible to switch between two pre-set parameter values depending on the operation conditions. This is done by means of a remote command.

The governor should be connected to a DC battery supply and 3-phase 50 or 60 Hz system. In addition a separate single-phase input is available for emergency power supply.

10.2.2 Digital computer based controller

A controller based on digital technique is for example a Programmable High-Speed Controller. It is designed to be used normally for all kinds and sizes of water turbines. It is completely autonomous, and is designed with a high inherent flexibility to enable individual requirements to the greatest possible extent.

A digital governor generally contains the following main parts:

- power supply
- frequency measurement
- controller, inclusive sequence control and monitoring
- servo interface
- automatic turbine admission control
- runner blade control
- options as water level control etc.

Two sensors reading a segment disc attached to the turbine shaft measure the frequency. The measurement signals are transformed to a digital code by the frequency measurement circuit. A linear relation exists between the measurement value and the cycle time of the unit frequency.

Alternatively the frequency measurement can be taken from a permanent magnet alternator. Except for the measurement signal there is no difference compared with the analogous controller.

The controller is based on a processor system. The controller hardware is generally built of standard components while the control functions are realised in a specific program.

The controller program includes the following functions:

- controller algorithm

- sequence control for start, stop, interlocking, etc.
- monitoring, process and self monitoring

Fig. 10.3 shows the block diagram[1] for a typical controller of a Francis turbine. The same block diagram will also be the basic part of a controller for a Pelton and Kaplan/bulb turbine.

The controller has a PID function. Each parameter can be set within a wide range. Adjustment of one parameter makes no influence on the others.

The servo interface is the joint between the electronic part and the hydraulic part of the governor.It is a part of the electrohydraulic position control of the actuator. The loop is closed in the processor.

One or several position control loops are provided depending on the version. Each loop contains a servo interface with a servo amplifier and a transducer for the actuator position measurement.

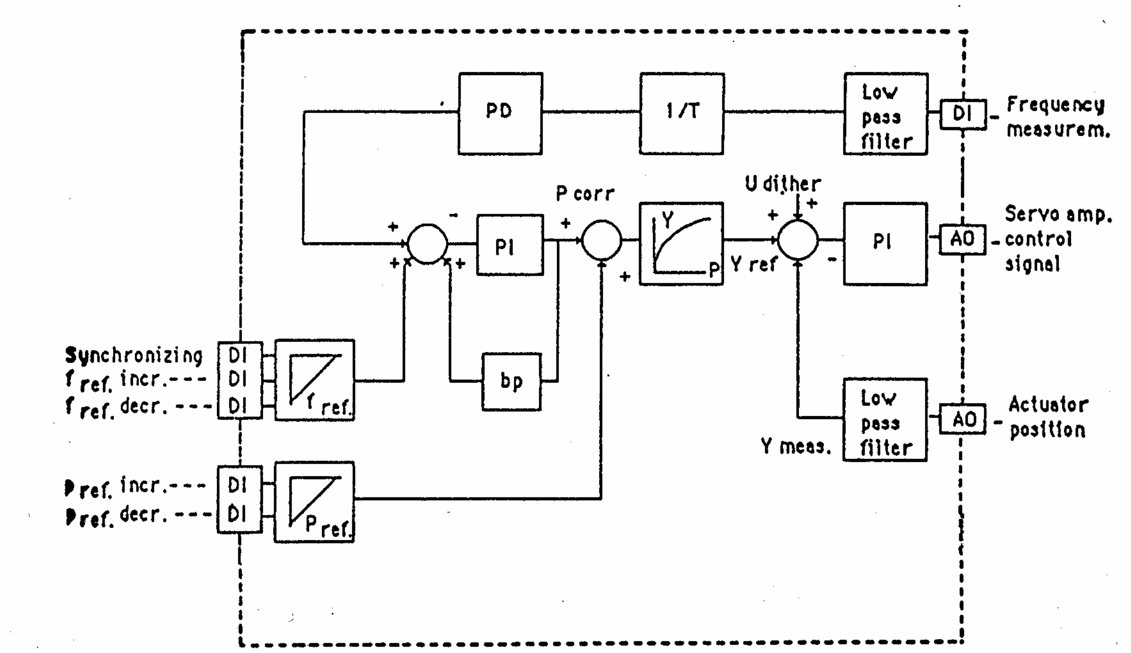

Fig.10.3 Turbine controller block diagram (Courtesy Kværner Brug as)

10.3 Servo system

10.3.1 Governor desk

The system structure in a turbine governor desk[1] is illustrated in Fig. 10.4.

The main components are:

- electrohydraulic actuator (servovalve and pilot control actuator)
- opening control valve
- rapid shut-down valve
- main control valve
- mechanical-hydraulic load limiter
- mechanical feedback
- control levers
- oil filters

- switches and sensors
- measuring device for the rotational speed

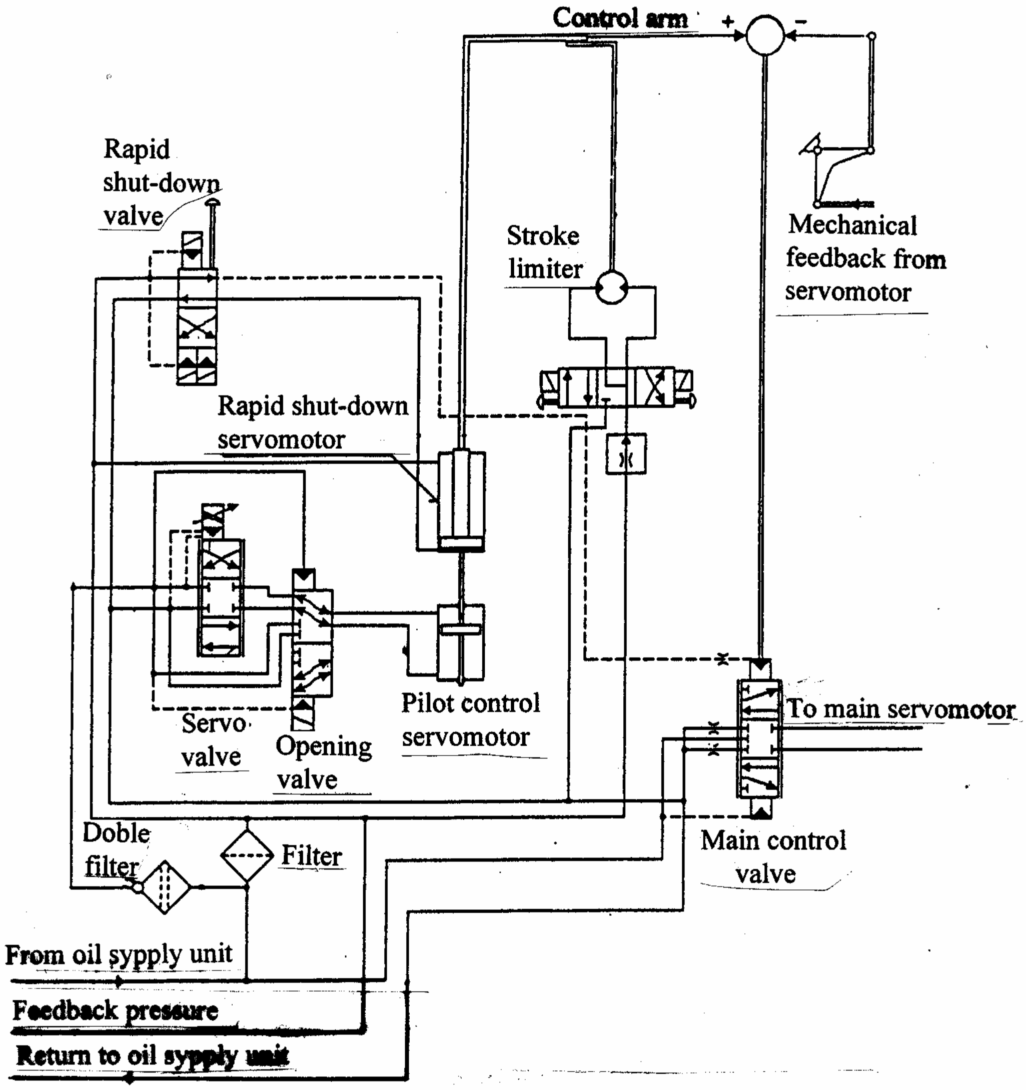

Fig. 10.4 Governor desk, hydraulic circuits /1/

The governor desk is an independent unit located near to the main servomotor. Thereby short pipe lengths between the desk and the servomotors as well as plain feedback mechanisms are obtained.

The hydraulic components in the governor desk are fed from the oil supply system. The output is pressure oil to the main servomotor which is mechanically connected with the feedback and the control lever on the main control valve.

In some new turbine governors it is an electronic feedback signal for the servomotor position. The load-limit function is carried out by the controller electronics and the servomotor is directly governed by the servovalve.

In this way the main governing hydraulics is compressed to a structure containing the servovalve, emergency shut down valves and the servomotor.

10.3.2 Main control servomotor

The main control servomotor consists of:

- cylinder
- piston and rod
- sealbox with bushing and sealbox ring

An ordinary design of the servomotor[/1/] is shown in Fig. 10.5

Cylinders are usually made of steel as casted or welded products.

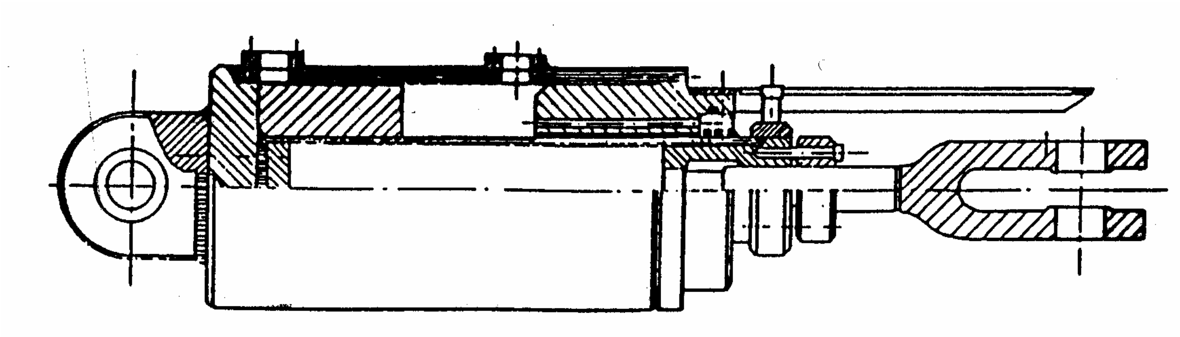

Fig. 10.5 Typical design of a servomotor /1/

10.4 Specific turbine governing equipment

10.4.1 Dual control of Pelton turbines

The governing of Pelton turbines is normally carried out with a dual control, e.g., needles in the nozzles and the deflectors. These components are described in Chapter 6.

By minor load changes the needle adjustment control is satisfying the control requirements alone.

By rapid load rejections however, the rotational speed rise is controlled and limited by activation of the deflector. The servomotor gives the deflector a rotary movement which bends the water jet away from the runner.

The sequence controlled nozzle follows the movement of the deflector servomotor by adjustment of the needle position until the discharge corresponds to the new power/load equilibrium. In this approach to equilibrium the deflector moves gradually out of the jet again to an idle position just outside the periphery of the jet.

The deflector function is controlled from the governor desk via the main control valve. The servomotor movement is transferred via bars, levers and links to the deflectors.

From the servomotor movement feedback signal is transferred to the control valve.

The sequence control of each needle is carried out via a cam disk which is driven by the deflector servomotor. The cam shape accomplishes an input function to the needle control valve which opens for adjusting the needle to correct position.

The feedback from the needle movement controls the valve openings until they reach neutral position and the needle has reached the correct position according to the reference.

The cabinet for the needle control is located as near to the nozzles as possible to obtain a plain feedback system from the needles and short oil pressure pipelines.

In some recent designs of Pelton governors electronics and separate electrohydraulic servosystems carry out the controller functions of the deflectors and the needles. Electronics is also utilised in the feedback systems. In this way the construction of the servomotors with mechanical levers and links have become more simplified.

10.4.2 By-pass control for Francis turbines

10.4.2.1 Function and general arrangement

The regulation following load rejections in high head Francis turbine plants makes it necessary to divert some parts of the instantaneous water flow to the turbine. In this way it is possible to obtain a rapid closure of the turbine admission and to retard the main flow in the penstock to minimise the pressure rise.

The diversion is normally branched off from the scroll casing[/1/] as shown schematically in Fig. 10.6. In this branched off system *the by-pass valve* is installed and its admission is controlled by the turbine governor. The guide vane movement controls the valve opening. This combined control of the guide vane movement and the by-pass through the valve makes it possible to control both the pressure rise and speed rise during load rejection.

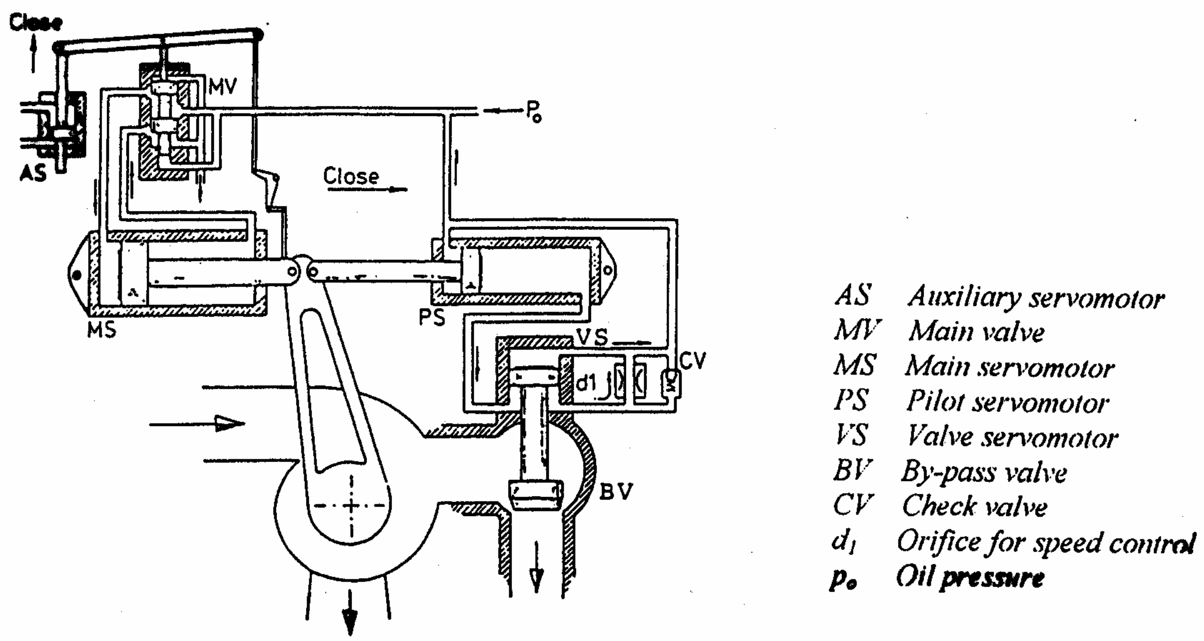

Fig. 10.6 By-pass valve with regulating system /1/

The water flow through the valve is led into an energy dissipater and then into the turbine draft tube as shown in Fig. 10.7.

A Norwegian turbine manufacturer has used this type of by-pass valve system for several years, and a long experience in the use of this equipment has proved a simple and reliable system.

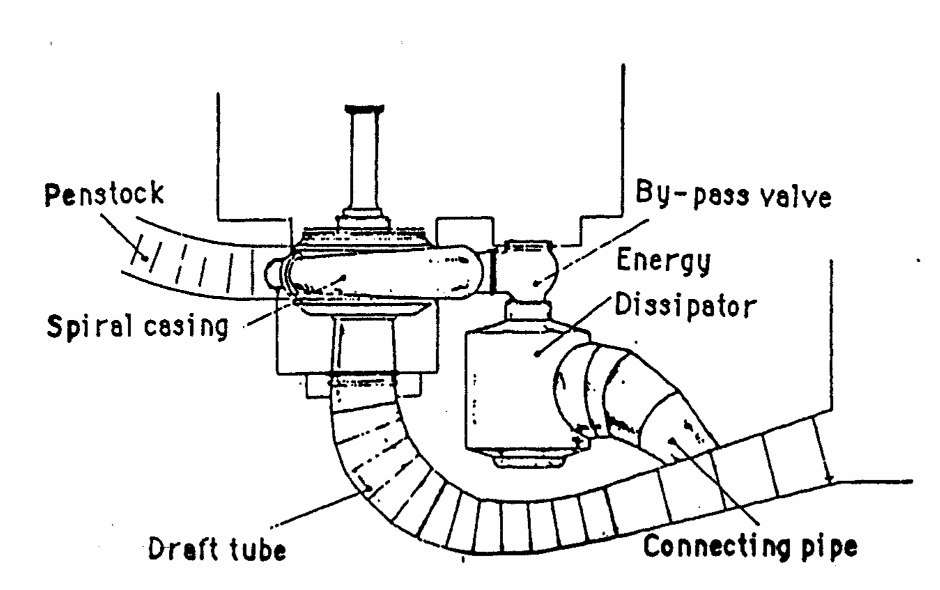

Fig. 10.7 Energy dissipater /1/

A vital point in the design of the control system has been to ensure full control of the pressure rise even if the valve should fail to operate. In this case the closing speed of the guide vanes will correspond to the speed given by the allowable pressure rise. The speed will then be higher than normal, but this is regarded as less serious because the generator is designed to withstand short lasting runaway speed of the unit.

10.4.2.2 The valve control system

A schematic diagram of the valve system and main servomotor control[/1/] is shown in Fig. 10.6. The auxiliary servomotor AS, via the main valve MV controls the guide vane servomotor MS. The double acting servomotor MS, moves the guide vane via the regulating ring. A pilot servomotor PS, is connected to this ring and copies the position according to the movement of MS.

The servomotor PS is pressurised via the orifice d_l from oil pressure supply p_o. The by-pass valve servomotor VS is hydraulically connected to PS. Under stationary conditions it moves to closed position because of the difference between the two sides of the piston areas.

During a closing movement of MS the oil from PS passes through d_l into the accumulator. If the closing speed exceeds a certain value, the pressure on the opening area on VS increases because of the orifice d_l, and VS then opens.

To avoid restriction of the guide vanes a check valve CV, is connected in parallel to d_l.

The size of the volume of VS relative to PS is given by the size of the opening of the by-pass valve at total flow capacity.

In the diagram Fig. 10.8 the relative movement between the guide vane servomotor MS and the by-pass valve BV are shown. Because of the close linearity between servomotor position and the water flow, this diagram also indicates the water flow in the system.

From this diagram it is seen that the guide vanes start closing at maximum speed $1/T_c$. The by-pass valve opens at a speed $1/T_o$ given by the relative servomotor volumes.

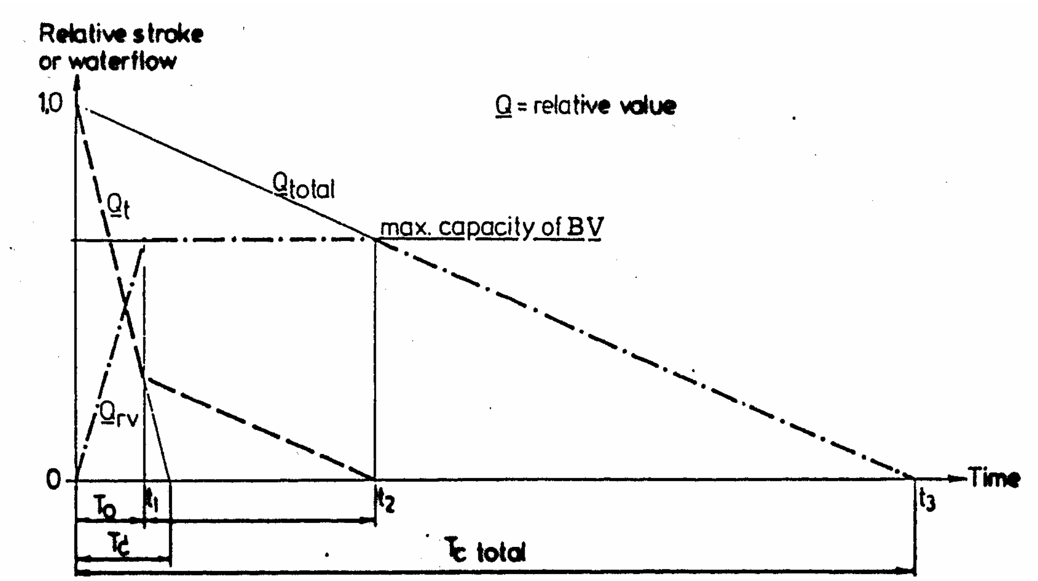

Fig. 10.8 Relative movements and water flow between guide vane cascade and by-pass valve /1/

When the by-pass valve is fully open at t_1, the closing speed of the guide vanes is reduced to a lower value. In closed guide vane position at the time t_2, the pilot servomotor PS stops and the pressure becomes equal p_o on both sides of the piston in valve servomotor VS. Then VS starts closing the by-pass valve because of the piston area difference.

The closing speed of VS shown as $1/T_{c\ total}$ in the diagram, is controlled by d_1. The oil volume from the opening side of VS is forced back to the accumulator.

The total water flow in the penstock is given by the sum of the flow through the guide vane cascade and the flow through the by-pass valve. This controls the pressure rise in the system.

10.4.3 Dual control of Kaplan/Bulb turbines

Optimal efficiencies of Kaplan and bulb turbines are obtained by optimal combination of the functions of the guide vane cascade control and the runner blade control. Examples of the construction of these control systems are described in Chapters 8 and 9.

The combination of the two control functions may be carried out either by mechanical-hydraulic or by electrohydraulic operation. The combination unit is usually located on the top or beside the top of the turbine-generator unit.

A mechanical-hydraulic combination unit is integrated in the runner blade control system and consists of:

- main valve
- feedback mechanism
- combination control function curve
- pipe connections to the oil supply unit

The combination control function is:

- distribute oil for operation of the runner blades via the main valve

- position the runner blades according to the control function curve disk which is governed by the guide vane control
- feedback of the spool position in the main valve.

An electrohydraulic combination unit has an electrical feedback from the position of the guide vane cascade and a combination control function in this case is produced electronically. The servomotor is then operated by an electrohydraulic servovalve.

References

1. Kværner Brug: COURSE III, Lecture compendium, Oslo, 1986

Bibliography

1. Brekke, H.: Governing of Hydropower Machines, Lectures at NTNU, Trondheim 1997 (in Norwegian).