U.P.B. Sci. Bull., Series D, Vol. 75, Iss. 1, 2013 ISSN 1454-2358

EXPERIMENTAL ANALYSIS OF THE BY-PASS VALVES CHARACTERISTICS OF FRANCIS TURBINES

Georgiana DUNCA[1], Diana Maria BUCUR [2], Iulian BĂLĂUNȚESCU[3], Constantin CĂLINOIU[4]

În lucrare sunt prezentate sintetic rezultatele cercetărilor experimentale, sistematice pentru determinarea caracteristicilor ventilelor sincron care echipeaza turbinele de tip Francis. Încercările au fost efectuate pentru diferite valori ale deschiderii aparatului director al turbinei şi vana de admisie a apei în turbină închisă. Măsurările au fost efectuate pentru cinci ventile sincron, iar rezultatele sunt prezentate în corelație cu deplasarea şi viteza de închidere a aparatelor directoare aferente turbinelor.

The paper summarizes the experimental and systematic research results, for obtaining the by-pass valves characteristics of the Francis turbines. The tests have been made for different values of the turbine guide vane opening and for the turbine inlet valve closed. The measurements were performed for five by-pass valves and results are presented related to the stroke and the closing speed of the turbines guide vanes.

Keywords: turbine, valve, by-pass, transient, hydraulic

1. Introduction

The by-pass valve is a hydro-mechanical device, which equips the high head Francis type turbines. Essentially, the by-pass valve is installed at the entrance of the turbine and it is designed to use some of the penstock water flow and to take it downstream the turbine.

The by-pass valve opening speed is conditioned by the closing speed of the turbine guide vane for limiting penstock water pressure during transient regimes. When the hydroelectric power supplied to the consumer must be decreased or in case of sudden load rejection, which requires rapid closure of the turbine inlet, there are discharge flow variations in the penstock and the so-called "hydraulic shock" phenomenon appears. In literature [1, 2] this phenomenon is

[1]Lecturer, Hydraulics, Hydraulic Machinery and Environment Engineering Department, University POLITEHNICA of Bucharest, Romania
[2]Lecturer, Hydraulics, Hydraulic Machinery and Environment Engineering Department, University POLITEHNICA of Bucharest, Romania, e-mail: dmbucur@yahoo.com
[3] Eng., SH Bistrița, SC HIDROELECTRICA SA, Romania
[4] Associate professor, Hydraulics, Hydraulic Machinery and Environment Engineering Department, University POLITEHNICA of Bucharest, Romania

well studied and it can be demonstrated that the water pressure variations in the penstock during this transient phenomenon, are proportional to the variation speed of the flow through the pipes. Therefore, for restricting the pipe pressure and hence the mechanical stresses, the discharge flow variations must be limited. Because the turbine must be closed quickly, to avoid over-speed phenomenon, taking a part of the water flow passing the penstock through the by-pass valve appears as an objective necessity.

The continuity equation applied on the discharges during the transient regime is given by (1):

$$Q_c = Q_t + Q_v \tag{1}$$

where

- Q_c- the penstock discharge;
- Q_t – the turbined discharge;
- Q_v- the by-pass valve discharge.

The turbines analyzed in this paper have different power outputs: three units with an output power of 27,5 MW each and two units with an output power 50 MW each. They have a common surge tank and the penstock has a length of 165 m. Every turbine has its own by-pass valve located at the turbine inlet.

2. By-pass valve structure and operation

In the literature, there are presented several types of by-pass valves [3]. The by-pass valves, which equip these units, have the characteristics and dimensions corresponding to the two values of the turbines output power. The rated strokes of the guide vanes and by-pass valves corresponding to the units are presented in Table 1.

In Figure 1 is presented the by-pass valve scheme, which includes the closing device, the closing device actuator, the mechanical hydraulic main-valve and action and reaction elements [4, 5].

Table 1

Rated strokes of the guide vane and by-pass valve of the units

Hydro unit	1	2	3	5	6
Guide vane rated stroke (mm)	370	370	370	370	370
By-pass valve rated stroke (mm)	238-240	238-240	238-240	350	350

When a closing command is sent to the guide vanes, their actuators begin to move towards closing.

If the closing speed of the guide vane exceeds a predetermined value, a command is transmitted to the by hydraulic main valve of the by-pass valve so that it is opened. When the guide vane is closed, the main valve receives an opposite command and the by-pass valve closes. During the entire period when the by-pass valve is opened, a part of the penstock discharge is taken directly downstream through the valve.

A by-pass valve has a proper operation if the opening is realized with a high speed and the closing with a relatively low speed, in order to obtain a limited water pressure in the penstock. As a part of the adjustment of the by-pass valve parameters there should be realized a balance between the value of pressure increase in the pipeline and the value of the water volume passed through the by-pass valve, which represents an energy loss.

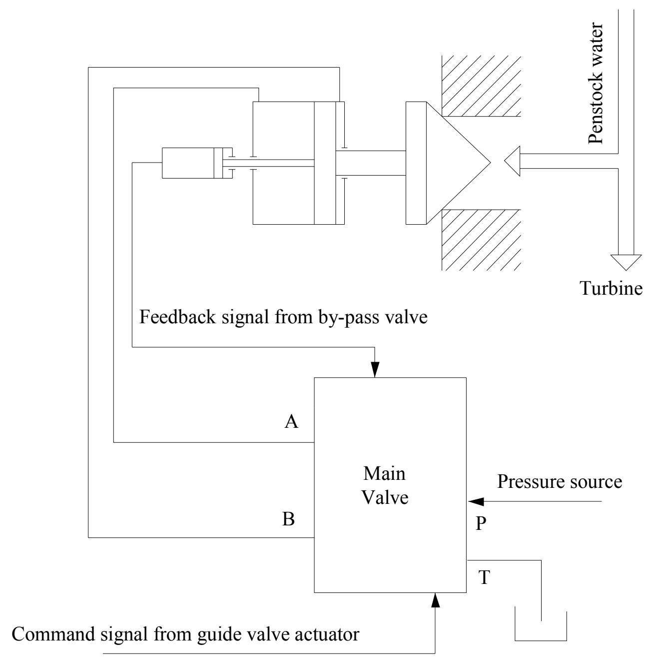

Fig.1. The by-pass valve scheme.

3. Test measurements

In order to obtain the by-pass valve characteristics measurements of the actuator rods for operating the guide vane and for the by-pass valve closing device numerous tests where carried out. In Figure 2 is presented the data acquisition and processing system scheme [6].

The measurements were performed with the turbine inlet valve in the “closed” position to avoid simulation of damages with load rejection. The measurements were performed for by-pass valves which equip the five hydro units and for guide vane opening values of 40%, 60%, 80% and 100% of the nominal opening.

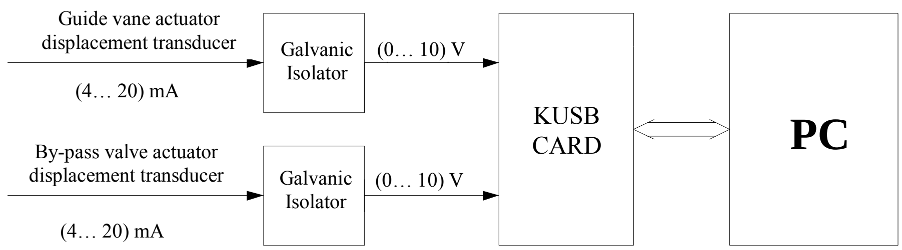

Fig.2. The data acquisition and processing system scheme.

In Figs. 3 to 6 the time variations of the rods stroke of the guide vanes actuator and of the by-pass valves actuator are presented for a small hydro unit of 27,5 MW (SHU) and for a big hydro unit of 50 MW (BHU).

In Figs. 7 and 8 the variation of the actuator rod stroke of the by-pass valve as a function of the guide vane closing speed is presented for the two hydro units (SHU and BHU).

In Tables 2 and 3 are summarized the time values for the guide vanes closing and for the by-pass valves opening and closing and in Tables 4 and 5 the differences between the start of the guide vanes closure and the start of by-pass valve opening for the studied hydro units.

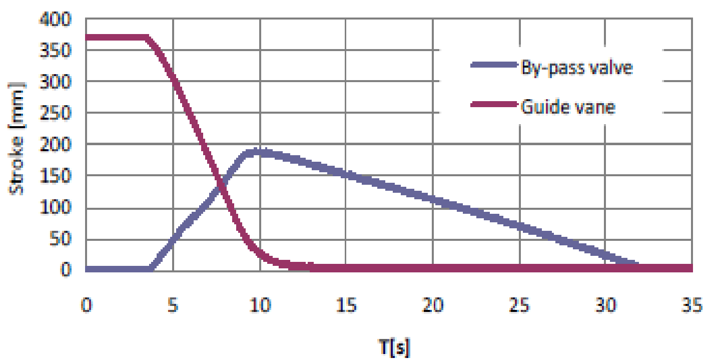

Fig.3. Time variation of the actuator rod stroke for the guide vane and for the by-pass valve. of the SHU. Guide vane opening = 100%.

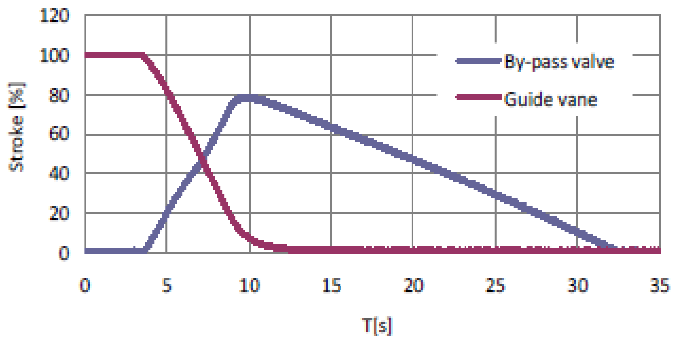

Fig.4. Time variation of the actuator rod (in percents) stroke for the guide vane and for the by-pass valve of the SHU. Guide vane opening = 100%.

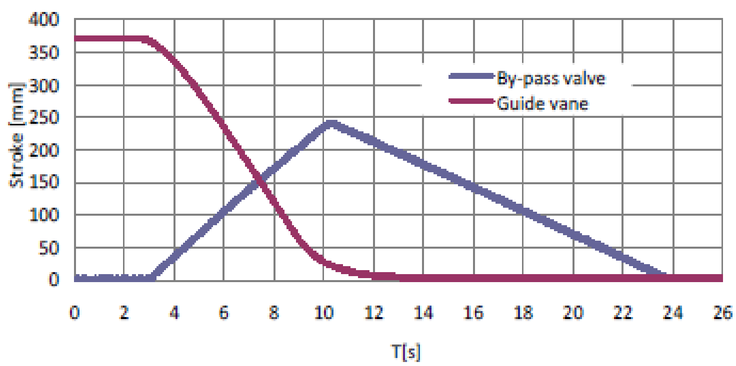

Fig.5. Time variation of the actuator rod stroke for the guide vane and for the by-pass valve of the BHU. Guide vane opening = 100%.

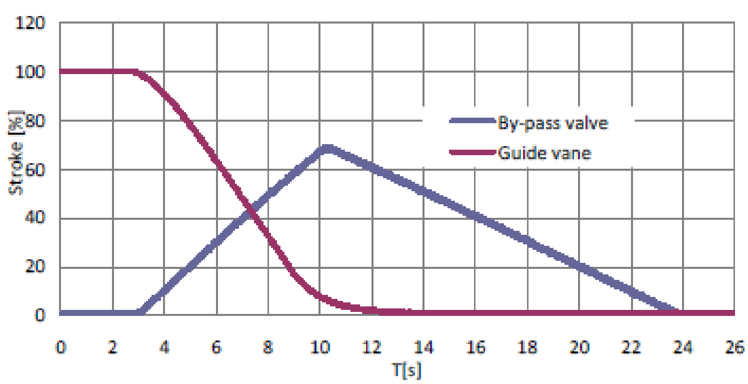

Fig.6. Time variation of the actuator rod (in percents) stroke for the guide vane and for the by-pass valve of the BHU. Guide vane opening = 100%.

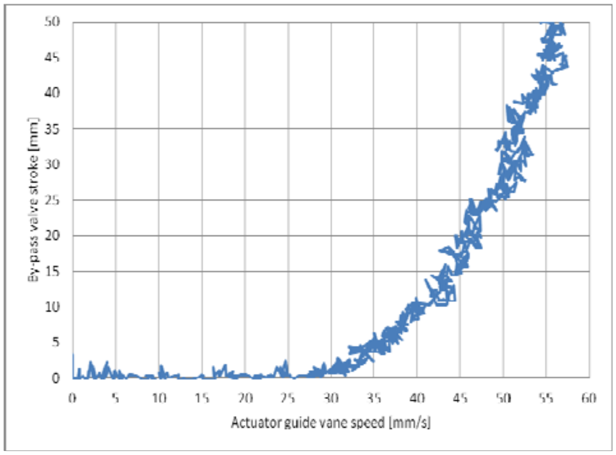

Fig.7. By-pass valve rod stroke as a function of the guide vane closing speed for SHU.
Guide vane opening AD = 100%.

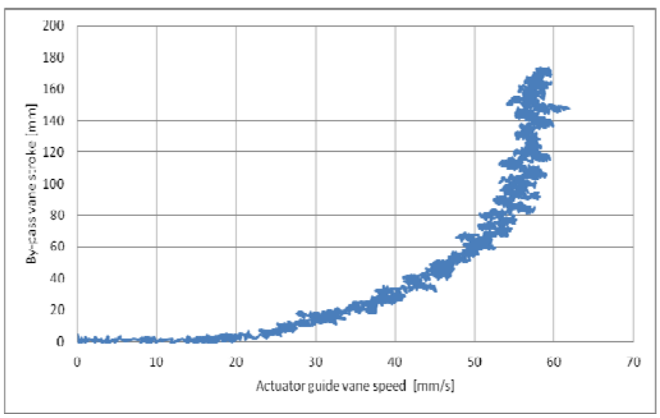

Fig.8. By-pass valve rod stroke as a function of the guide vane closing speed for BHU.
Guide vane opening AD = 100%.

Table 2

Guide vane closing time values and by-pass valve opening/closing time values for SHU

Guide vane opening	Guide vane opening	Guide vane closing time	By-pass valve opening time	By-pass valve closing time	Guide vane maximum speed
[%]	[mm]	[s]	[s]	[s]	[mm/s]
40	148	6	2.4	8	50
60	222	5	3	10	55.5
80	296	6	4.3	15	59
100	370	7.5	5.4	22	61

Table 3

Guide vane closing time values and by-pass valve opening/closing time values for BHU

Guide vane opening	Guide vane opening	Guide vane closing time	By-pass valve opening time	By-pass valve closing time	Guide vane maximum speed
[%]	[mm]	[s]	[s]	[s]	[mm/s]
40	148	5	3.9	7.3	50
60	222	6	4	7.6	55.5
80	296	6.5	4.3	8	59
100	370	7.5	7.2	13.5	61

Table 4

The time intervals between the start of the guide vane closing and the time of the by-pass valve opening for SHU

Guide vane opening	40%	60%	80%	100%
t_1 [s]	4,3	3.6	3.5	3.5
t_2 [s]	4.8	4.3	4.0	3.7
$\Delta t = t_2 - t_1$ [s]	0.5	0.7	0.4	0.2

t_1 – the start moment of the guide vane closing, t_2 – the start moment of the by-pass valve opening.

Table 5

The time intervals between the start of the guide vane closing and the time of the by-pass valve opening for BHU

Guide vane opening	40%	60%	80%	100%
t_1 [s]	2.9	3.8	6.8	2.9
t_2 [s]	4.3	6.6	10.2	3.1
$\Delta t = t_2 - t_1$ [s]	0.4	2.8	3.4	0.2

t_1 – the start moment of the guide vane closing, t_2 – the start moment of the by-pass valve opening.

6. Conclusions

The paper presents the experimental manner for obtaining the operation characteristics of the hydro units by-pass valves. The experimental research led to the following conclusions:

1. The maximum values of the guide vane closing times, from the 100% opened position, are between 6 and 8 seconds, regardless the hydro unit size.
2. The maximum values of the by-pass valves opening times, for the maximum guide vanes opening, are between 5.4 and 7.2 seconds. Therefore, it can be stated that the by-pass valves have a good behavior from this point of view.
3. The by-pass valves closing time values (7…22 seconds) are higher then their opening time values (2...7 seconds), which is a favorable thing in terms of

amplitudes of pressure waves produced by the occurrence of water hammer phenomenon.

4. General characteristic of all analysed by-pass valves is that the moment when they start to close corresponds to the moment in which the guide vanes are very close to the closed position. This feature is favorable both in terms of amplitude of the water hammer phenomenon and in terms of water volume transited through the valve.

5. The start moment of the by-pass valve opening is correlated with the guide vane opening speed.

6. Obtaining the guide vane closing speed by deriving the displacement signal is not a solution for the analyzed situation. The use of digital filters for processing experimental data leads inherently to delays of the filtered signal relative to the original signal. The values of these "delays" that are in tens of milliseconds, affect the accuracy of determining the difference between the start of the guide vane closing and the start of the by-pass valve opening. This difference is in hundreds of milliseconds.

R E F E R E N C E S

[1] *E.C. Isbăşoiu*, *D.M. Bucur*, Tratat de Mecanica Fluidelor (Fluid Mechanics Treatise), Editura AGIR, Bucureşti, 2011. (in Romanian)
[2] *Wylie, E., Streeter, V.* Fluid Transients. Mc Graw Hill Book Company, New York, 1983.
[3] *Arne Kjolle*. Hydropower in Norway. Mecanical Equipment. Trondheim. 2001.
[4] *** Technical Documentation ISPH-Bucureşti.
[5]. *** Research contract, entitled "Determination of real operation parameters of Francis turbines with power output higher than 20 MW", 2011
[6] *** Technical Documentation National Instruments.