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DEMONSTRATIONAL PUMP SYSTEM

DEMONSTRACIONI PUMPNI SISTEM

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INTRODUCTION

In this paper is presented the educatioonal pump installation where students could demonstrate centrifugal pump testing after the international standard ISO 9906 and volumetric flow meter calibration. Fluid flow phenomenon, such as turbulent swirling flow and cavitation could be observed at the pump inlet and outlet due to the transparent piping. Students and engineers could observe and model various technical tasks, such as pump duty point regulation by use of the inverter, valve and by-pass. It is demonstrated how the pump head characteristic could be obtained for various pump speeds, as well as pump system hydraulic curves. LabVIEW applications are developed for all these tasks. In addition, is presented and discussed the concept of the installations in parallel and series modes.

KEYWORDS: centrifugal pump, test rig, demonstration, regulation.

1. TEST RIG

Pump system, designed and developed at the Hydraulic Machinery and Energy Systems Department (HMESD), University of Belgrade, is presented in Fig. 1(a). Elements of the installation are: 1 – pump with the transparent casing, 2 - T-joint, 3 - transparent pipe, 4 - transparent Venturi flow meter, 5 and 6 - valve for emptying the upper tank, 7 - scale on the calibration reservoir, V.10 - suction valve, 11 - suction pipe, 12 - lower reservoir with volume 250 l, 13 - T-joint, V.20 - valve, 21 - pipe for filling the upper reservoir, 22 - nozzle, 23 - upper reservoir with volume of 55 l, V.30 - valve, 31 – pipe to lower reservoir. In-built pump is Grundfos, model UPE 50-120 F, in-line type.

Connected differential pressure transmitters at positions 8 and 9 in Fig. 1(a), i.e. 1 and 2 in Fig. 1(b), are TPd-101, manufactured by Institute of Chemistry, Technology and Metallurgy, Department of Microelectronic Technologies, University of Belgrade, Belgrade, Serbia. They have measurement range 0-3 bar, power supply 14-26 VDC and output 4-20 mA. They are calibrated on the oil deadweight tester in HMESD and calibration curve is imported in the LabVIEW application. Acquisition system is the eight channel input module National Instruments NI-9203. USB CompactDAQ chassis cDAQ-9174 is connected to the laptop (positions 5 and 6, respectively, in Fig. 1(b)).

Pump speed could be controlled manually on the pump housing or by infrared remote controller, type R-100 (position 3, Fig. 1(b)). Pump original casing is replaced with the transparent one, with axial inlet and radial outlet (Fig. 2)

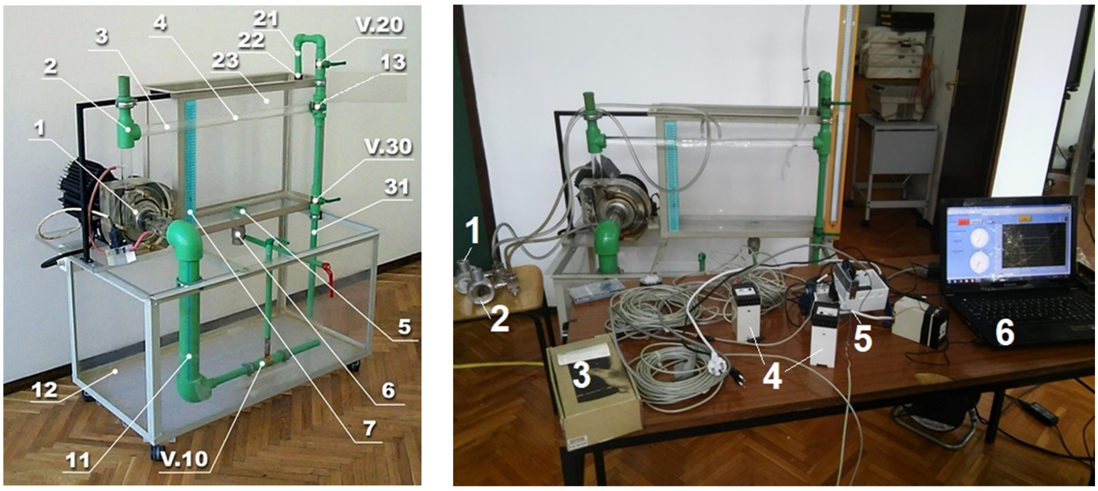

Fig. 1. a) Demonstrational test rig [1] and b) Test rig with pressure transmitters and acquisition system

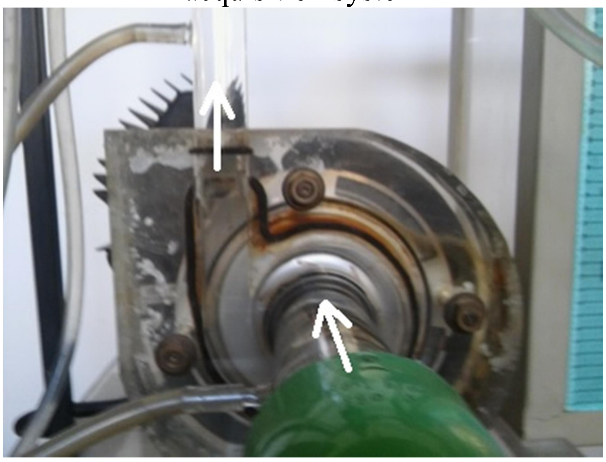

Fig. 2. Pump with transparent housing and denoted flow direction

Cavitation phenomena and turbulent swirl flow could be observed due to the transparent piping. Cavitation bubbles visualize turbulent swirling flow at the pump outlet. Positions of the pressure transmitter connections follow international standard ISO 9906. They are located two inner diameters up- and downstream the pump.

The main goals of this demonstrational test rig are the following:

1. centrifugal pump testing,
2. determination of the pipe hydraulic curves,
3. demonstration of the energy efficiency by using the inverter instead of the valve regulation,
4. investigation and visualization of the phenomena: turbulent swirl flow and cavitation,
5. calibration of the Venturi flow meter,
6. rotodynamic pump duty point determination (simple and complex piping systems) and etc.

2. TEST RIG OPERATION MODES

Test rig operation modes could be presented on the basis of the Fig. 3. Numbers of the test rig elements in Figure 2 correspond to those in Figure 1(a). The most complex case is when the pump pumps water from the lower reservoir (12) through suction pipe (11) with valve V.10, pipe (3) and Venturi flow meter (4) to the T-joint (2) to both reservoirs, if valves V.20 and V.30 are open. In this case, they learn how to determine the pump duty point for the complex hydraulic system.

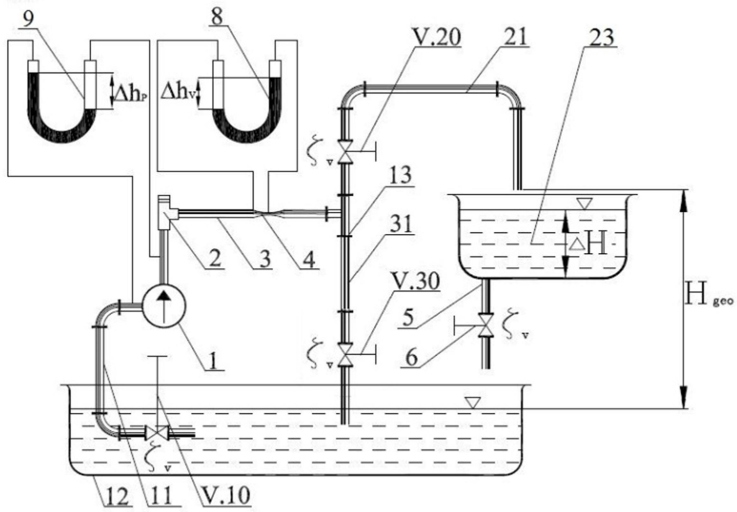

Fig. 3. Scheme of the test rig [2]

Following laboratory exercises could be demonstrated [2]:
"Venturi flow meter calibration (valve V.30 is closed);
Pump testing procedure after standard ISO 9906 [3];
Pump cavitation test;
Pump circulates water in the main, lower reservoir $H_{geo} = 0$ (valve V.20 is closed);
Pump transports water on the specific geodesic height $H_{geo} = const$ (valve V.30 is closed);
Pump regulation with by-pass. In this case pipes on the pump pressure side are in parallel and regulation is performed by valve V.30;
Energy efficiency issues: Comparison of pump regulation with throttling valve, pump speed and by-pass."

In addition, students learn how to start and stop the centrifugal pump which is dry. So, they must fill the pump with water. This is performed by opening the T-joint on the top (position 2, Fig. 1(a)) and with closed valves V.10, V.20 and V.30. When the pump is filled with water, it is started. This is followed by opening the inlet valve first, what is followed by opening the outlet valve afterwards. Closing procedure is vice versa, by closing the valves on the pump pressure side and afterwards on the pump inlet side. Pump is turned off.

Determination of the pump head is based on the following expression:

$$H = \frac{p_{II} - p_I}{\rho g} + \frac{c_{II}^2 - c_I^2}{2g} + \left(z_{II} - z_I\right), \qquad (1)$$

where p is an average pressure in the cross-section, c is an average velocity, z is a geodesic height of the cross-section center, ρ is a fluid density and g is an acceleration due to gravity. Pump inlet and outlet measuring cross-sections are denoted with indexes I and II, respectively. Measuring cross-sections are defined after ISO 9906 [3]. Pressure difference is measured by differential pressure transmitter, while average velocities are determined on the basis of the volume flow rate and cross-section surfaces. Volume flow rate (Q) is measured on the basis of the calibrated Venturi flow meter and differential pressure transmitter connected to it. Differential pressure transmitters are recorded by the LabVIEW application, first, for the fully open valves V.10 and V.30, while V.20 is always closed. For obtaining pump head characteristic, valve V.30 should be closed in steps and keeping pump rotation speed. Pump head characteristic could be obtained also for other pump rotation speeds, by repeating the whole procedure.

It is also interesting to demonstrate how the system characteristic could be obtained. First, the simple piping is observed by closing the valve V.20, so the mode $H_{geo} = 0$ is observed. In this case piping system characteristic would not have an additional term, a static component, so it is defined as follows:

$$Y_A = mQ^2, \text{ or } H_A = \frac{m}{g} Q^2 \tag{2}$$

where m [(J/kg)/(m^3/s)^2] is the pipe coefficient which involves all hydraulic losses described with Darcy and Weisbach formulas in the following way:

$$m_j = \frac{8}{d_j^4 \pi^2} \left(\sum_{i=1}^{N} \zeta_i + \lambda_j \frac{L_j}{d_j} \right), \tag{3}$$

where j denotes the j-th pipe section, N number of local hydraulic losses ζ, λ the dimensionless pipe friction loss coefficient, L pipe length and d is inner pipe diameter.

Afterwards, valve V.30 is completely open and the pump rotation speed could be varied. In this way is obtained the parabola which describe one system characteristic. This could be obtained, also, for other positions of the valve V.30.

The complex piping system could be, in addition, observed, when pipes are working in parallel mode, by opening valves V.20 and V.30. Flow direction in pipe 21 (Fig. 3.) could be varied by changing the pump rotation speed. These phenomena are interesting for determination of various pump duty points and flow rates in various pipes.

3. DEVELOPED LABVIEW APPLICATION

In the developed, LabVIEW application exist four screens [2, 4-6]. The first one is the input screen where the water density, acceleration due to gravity, calibration curve of the differential pressure transmitter, sampling frequency, calibration coefficient of the Venturi flow meter and specification of the export file are specified. The second screen is the photo and drawing of the installation with the specified positions. The third screen, “Measurements”, of the developed LabVIEW application is presented in Fig. 4, where: 1 - stop, 2 - start, 3 - pause, 4 - record, 5 - chart, 6 - pump efficiency, 7- pump head in [m], 8- pump current head in [kPa], 9 - pump current flow in [m^3/s] and 10- current pressure transmitter connected on Venturi flow meter in [kPa].

As it was specified above, two transmitters are connected, one for pump head measurements and the second for pump flow rate, so the pump head characteristic could be experimentally determined. So, it is possible to observe the real time pump duty points and to draw the head pump characteristic on the chart 5 (Fig. 4.).

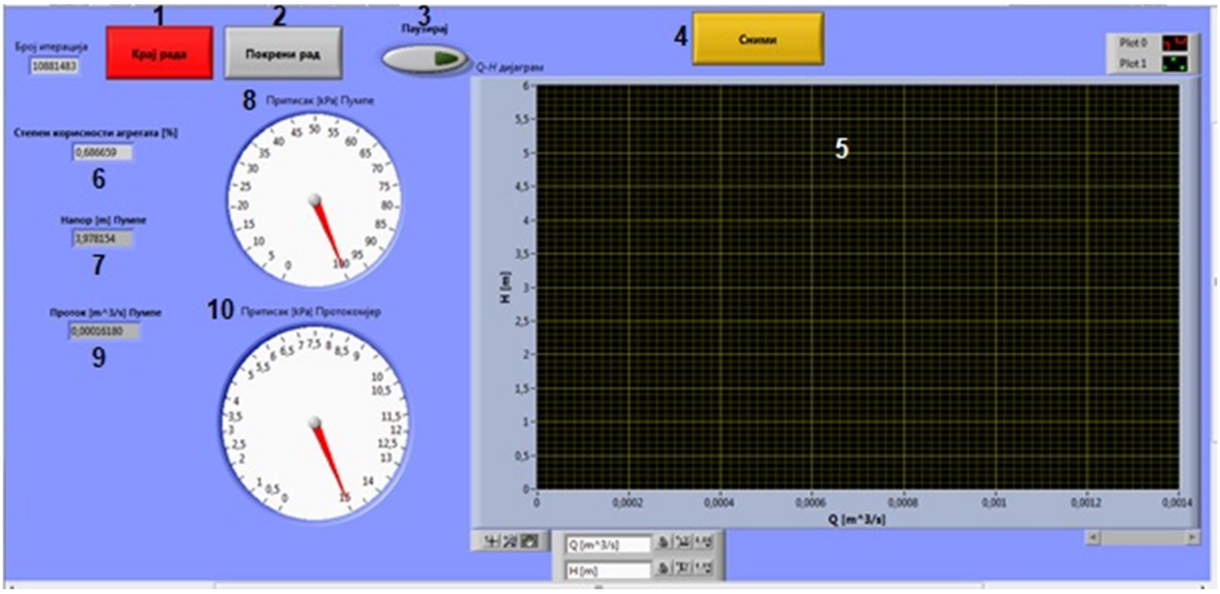

Fig. 4. Developed LabVIEW front panel [4]

The last screen, where the experimental results are shown, is presented in Fig. 5. Pump head characteristics for two various pump rotation speeds are presented in Fig. 5, where $n_1<n_2$. Obtained pump duty points are listed in Fig. 5. and could be exported in the specified file.

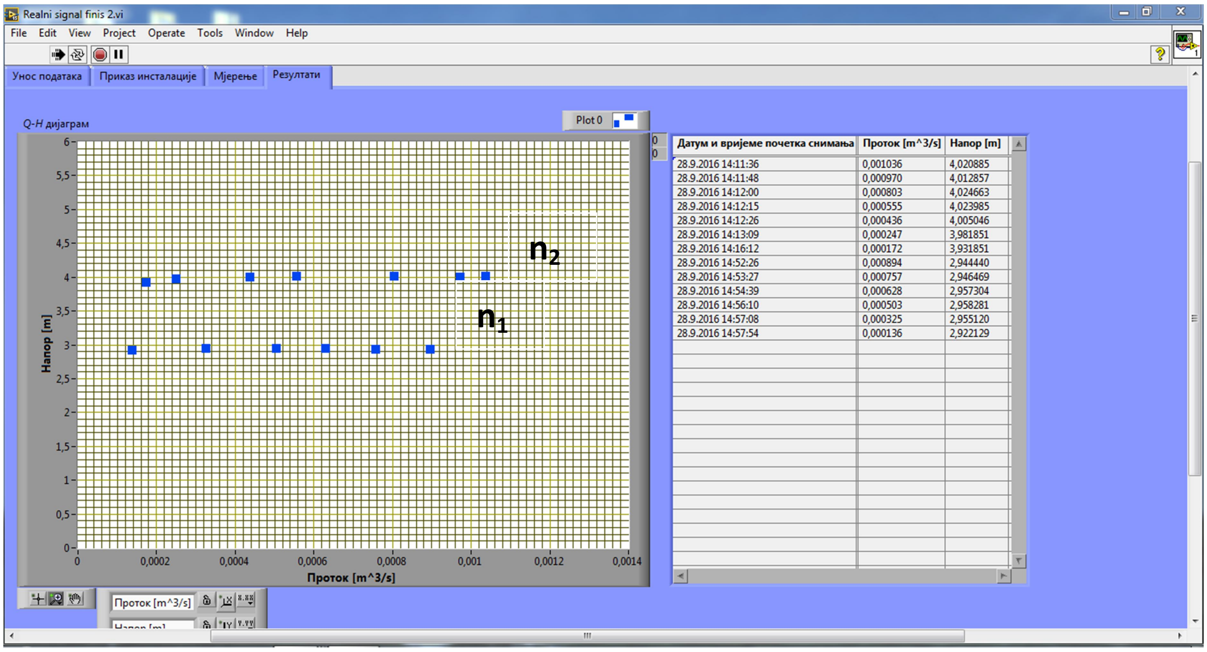

Fig. 5. Developed LabVIEW front panel [4]

It is possible to show the pump head characteristics for three rotation speeds, as well as for hydraulic pipes for the totally open and closed valves. Pump operating region could be also determined and presented in this way.

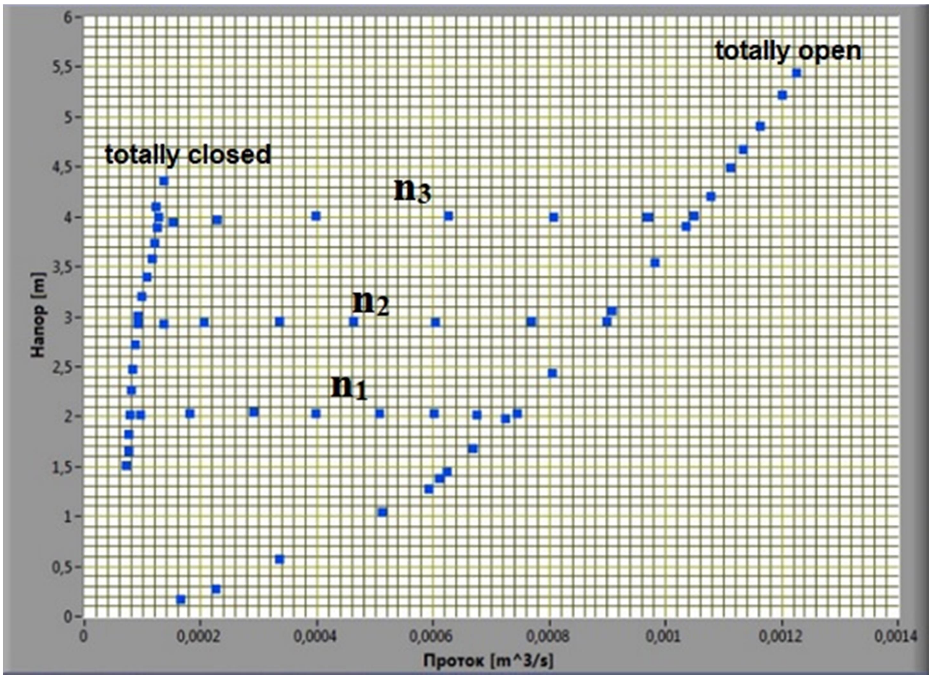

Fig. 6. Developed LabVIEW front panel

4. PARALLEL AND SERIES MODE OPERATION TEST RIGS

Demonstration of the parallel and series mode operation regimes for two pumps is important for students and engineers [7,8]. This is demonstrated in Fig. 7. Three various pumps (A, B and C) work in parallel mode and have system duty point P (Fig. 7.), while working in series mode, they generate system duty point S. Obtained pump duty points are also denoted. Flow rates for pump duty points working in the parallel mode, as well as heads for pumps working in the series mode are presented in Fig. 7.

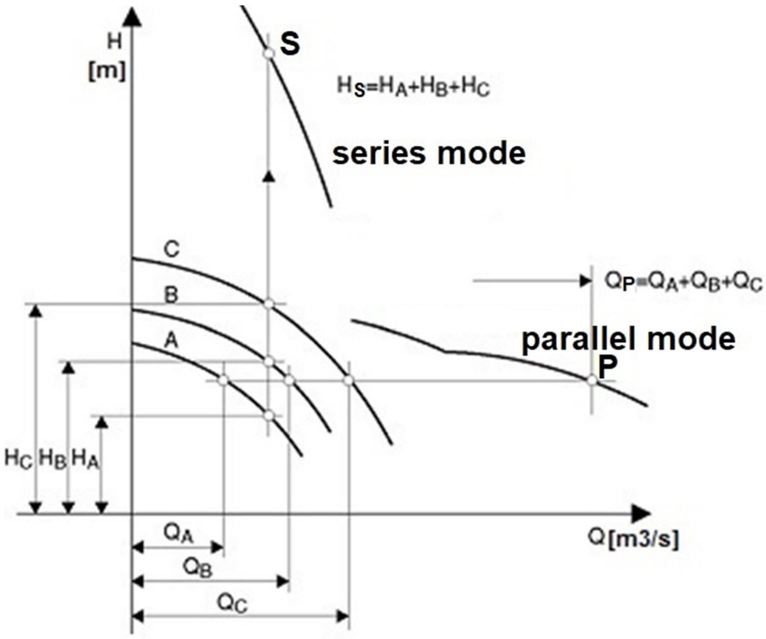

Fig. 7. Possible pump and system duty points [7,8]

Installation, which could support both modes, is designed and presented in Fig. 8., where: 1-suction tank, 2-pressure tank, 3 and 4-pumps, 5-return piping, 6-valve under testing, V1 to V7 are valves.

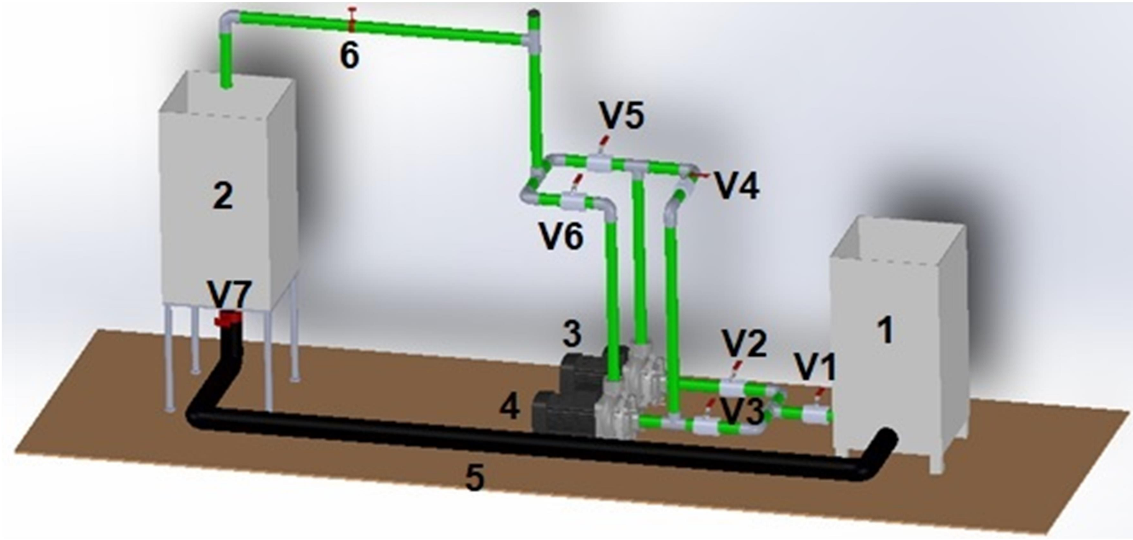

Fig. 8. Designed installation for the parallel and series mode operation regimes [4]

This test rig could serve as demonstrational, as well as for pump and valve characteristics determination. Pumps could work in series or parallel mode. If valve V4 is closed, pumps 3 and 4 pump water from tank 1 to tank 2 in parallel mode. If only valves V3 and V5 are closed pumps work in series mode. This is only one version of the installation, while some other variations are also developed.

5. **CONCLUSIONS**

In this paper is presented demonstrational test rig used for practical work in the laboratory for students and engineers. Various exercises could be demonstrated, such as: pump head characteristics determination, pump filling and starting process, different ways of pump regulation (bypass, valve and with inverter), calibration of the Venturi flow meter, as well as observation of the fluid flow phenomena such as cavitation and turbulent swirling flow. International standard ISO 9906 [3] is followed for this demonstrational test rig design.

LabVIEW application for data acquisition and presentation is developed. It could be modified and upgraded. Students could easily drive pump and determine its duty points by themselves, and export obtained data. Simple hydraulic system, as well as the complex one with three pipes in parallel and series operation mode could be demonstrated. Energy efficiency issues, like comparison of the pump regulation with valve and inverter could be also demonstrated. Students and engineers could perform experiments, collect data and export them for their e-reports, what enables easier learning process. Work on the upgraded version of the demonstrational pump installation for remote based learning is progress and some stages are presented in papers [2, 9-11].

In this paper is also presented and discussed the 3D model of the demonstrational test rig for pumps working in parallel or series modes.

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