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Intelligent module for monitoring proportional directional valves in hydraulic drive systems

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Abstract:

Increased performance of hydraulic drive components, as well as easier maintenance and diagnostics, can be achieved through the use of intelligent devices. Introducing sensors, electronic blocks and control algorithms into the equipment will enable easier repairs in the case of failure, or can increase the efficiency of the installation by providing selected operating parameters to the machine controller. In the case of a malfunction, the smart device can provide error codes. Smart devices can receive and send via various communication protocols (RS232, CAN, Fieldbus, Modbus) commands and feedback signals of monitored parameters. This paper presents the construction of such a monitoring and diagnostics module, the test application and the obtained charts.

Streszczenie:

Zwiększenie wydajności podzespołów hydraulicznych instalacji napędowych, jak również łatwiejsza konserwacja i diagnostyka mogą zostać osiągnięte poprzez zastosowanie inteligentnych urządzeń. Wprowadzenie czujników, bloków elektronicznych i algorytmów sterowania do urządzeń, umożliwi łatwiejsze naprawy w przypadku awarii lub może przyczynić się do zwiększenia wydajności instalacji dzięki dostarczeniu do sterownika maszyny wybranych parametrów roboczych. W przypadku nieprawidłowego działania, urządzenie inteligentne może dostarczyć kody błędów. Inteligentne urządzenia mogą odbierać i wysyłać przez różne protokoły komunikacyjne (RS232, CAN, Fieldbus, Modbus) polecenia i sygnały zwrotne monitorowanych parametrów. W artykule przedstawiono budowę takiego modułu monitoringu i diagnostyki, aplikację testową oraz uzyskane wykresy.

1. Introduction

Intelligent hydraulic components such as Hydraulic Valves with pressure sensors and built-in electronics with fast communication protocols lead to greater accuracy of machine control. These smart devices have diagnostic capabilities and compatibility with the Internet of Things (IoT) and can have built-in close control loops (pressure limitation, force control) without the need for a centralized processing structure (e.g. PLC), as in the case of centralized control systems [1]. The control responsibilities of the different subsystems of a machine can be taken individually by intelligent equipment, by distributed control [2]. The PLC can only ensure the overall management of the machine operation and the human – machine interface. The advantages of introducing intelligent hydraulic equipment on machines are the following: fewer cables, faster commissioning, remote diagnostics and alerting the maintenance team through IoT capabilities, customizable operation, cost reduction. The article presents an intelligent module with built-in sensors, which can be used for proportional directional valve monitoring and control. Such modules together with the related electronics can be embedded from the factory in new models of hydraulic equipment. With the information provided by the internal sensors, functional tests can be performed on specialized stands, without the need for external measuring equipment. The purpose of the paper is to present the structure of such an intelligent module that can be used to monitor the operating condition of the proportional directional valves by transmitting data remotely via the company's intranet (LAN) or for machinery automation. Also in the paper is presented a testing methodology for the intelligent module and results obtained after testing.

2. The structure of the intelligent module for proportional directional valves

The scheme of a module attachable to a proportional directional valve can be found in Fig. 1. Thus, in a hydraulic manifold in derivation with the routes to the ports P, T, A, B, miniature pressure sensors are installed and a temperature sensor on the return route T. Through the metal body, ducts are made for the route of the electrical wires towards the electronic board.

The microcontroller from the electronic board may contain algorithms for monitoring the pressure drop at the hydraulic motor, determining the pressure drop on the valve, limiting the pressure, controlling the force at the hydraulic motor and monitoring the hydraulic fluid temperature. For the connection to the process (PLC) the electronic scheme can have analog control input ± 10 V or ± 5 V, and for the transmission of all parameters it will have a RS232 serial port or a Modbus, CAN or fieldbus ports [3].

Direct driven proportional directional valves can use spool position feedback and embedded electronic module or not.

The valves without feedback act with the force of a proportional solenoid against a spring placed at the other end of the spool with role of restoring the spool to the null position. Two forces act on the spool, the flow force and the stiction forces [4].

Flow forces are a phenomenon found in all directional valves resulting from the momentum that occurs as a result of the strangulation effect of the flow section. This happens when the potential energy (pressure) is converted to kinetic energy (speed) in the strangulation region of the flow section. On spool valves, the flow force always acts to close the spool, regardless of the direction of flow. The consequence is that when using the valve, say at a low pressure drop, the spool is in a position where the force of the electromagnet is balanced by the return spring. As the valve pressure decreases, either due to a reduction in the motor load or an increase in the supply pressure, the flow force increases so as to close the valve spool.

Stiction forces also act on the spool and the solenoid armature, so that the spool position does not change slightly as the control current changes continuously and smoothly. Instead, the flow has a chain effect and the trail of the curve as the control current increases are not the same as the trail of the curve as the control current decreases, producing hysteresis induced by stiction phenomenon.

These inconveniences can be countered by generating an electronic dither signal to reduce stiction forces and by incorporating a closed loop for the spool position with LVDT position transducer, to minimize hysteresis.

By incorporating additional pressure and temperature sensors as well as an electronic board with microcontroller to allow remote parameter monitoring, diagnosis and internal control loops proportional valves become intelligent [5, 6, 7].

Other research on the integration of sensor modules in the structure of electro-hydraulic and electromechanical equipment has been performed by various authors [8, 9, 10]. Specific applications use different communication interfaces and data processing methods. In this paper, a module with pressure and temperature sensors with Modbus over TCP / IP transmission was studied. The module can perform and transmit the results of certain calculations performed, based on the measured parameters (pressure values of P, T, A, B ports) (e.g. pressure drop). Data analysis and processing can be done online with a monitoring application software.

A proposed constructive form of the intelligent module, looks like in Fig. 2, being in the form of a hydraulic manifold that has built-in pressure and temperature microsensors and has an electronic board box attached. The sensors are located in hollows that communicate with P, T, A, B lines and are connected through threaded holes.

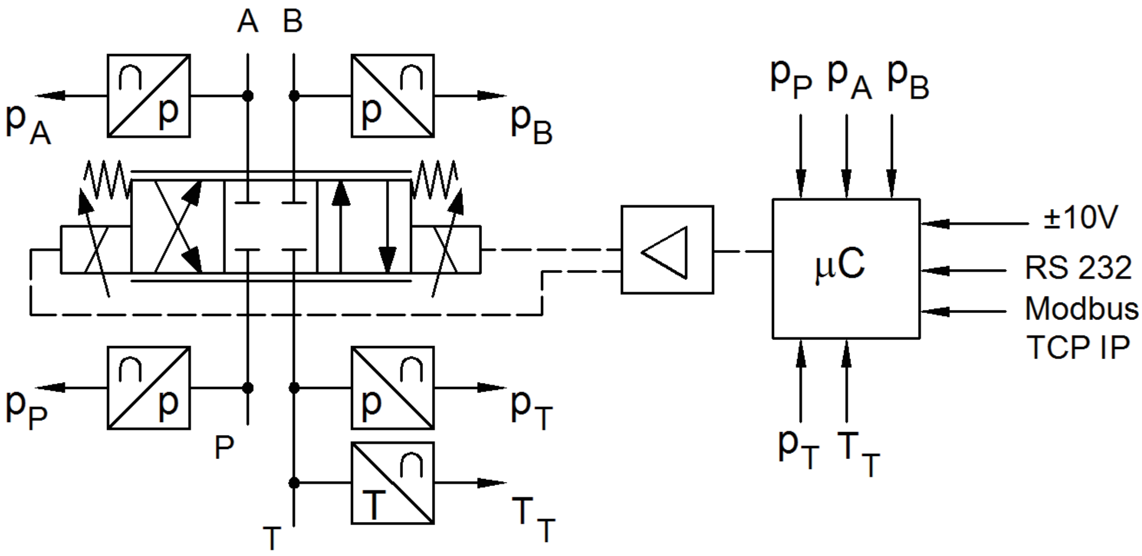

Fig. 1. Simplified scheme of proportional directional valve with intelligent module

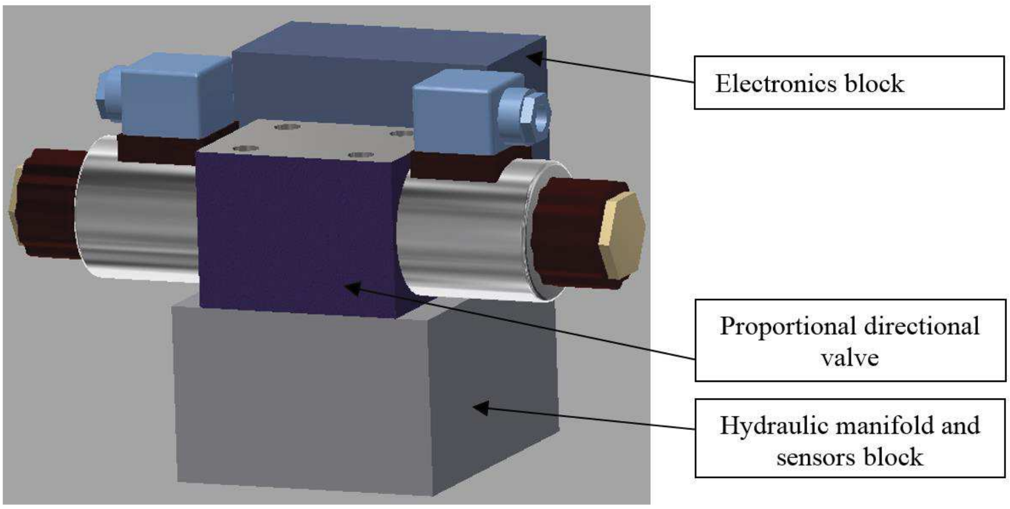

Fig. 2. Proposed constructive form of the intelligent module for proportional directional valve

The sensors can be like the ones in Fig. 3 with their own housing, but they can also be without the housing, placed directly in the metal block, well sealed and secured with threaded parts. In order to connect the sensors with the lines in the hydraulic manifold that communicate with the directional valve ports and for a compact arrangement, it is necessary to make technological holes that are subsequently plugged on the outside after processing.

Fig. 3. Micro pressure sensors type JC91 and NTC 10K temp sensor

The software architecture used for data communication is the client/server configuration. The microcontroller from electronic board, equipped with Ethernet controller, is configured as a server and communicate using the *MODBUS over TCP / IP* protocol. Client applications such as: monitoring and testing or for parameterization and control can be used. Other software applications may be some useful for experimental identification or simulations [11, 12] or application for data management, respectively the connection with a database via the LAN.

The testing of the intelligent module can be done by seeing that the data from the sensors are transmitted through the Modbus protocol and received correctly to a client application that monitors the values transmitted. If the module has implemented an algorithm for calculating the valve pressure drop, it can be used to obtain the graph of the static characteristic at Δp = ct [13].

3. Testing methodology

The intelligent module can be tested on a stand specialized in proportional equipment (Fig. 4). Fig. 5 shows the block diagram with the data acquisition system for testing the intelligent module and for plotting the static characteristic for a proportional directional valve. For testing, the P port of the module is connected by means of a hydraulic fitting and a hose to the flow source of the stand, another hose is connected between ports A and B, and the T port is connected to the tank by means of a flow meter. The flow meter is used to obtain the static characteristic of the proportional directional valve. If the proportional directional valve has a closed loop for the position of the spool, then the signal "actual value" provided at its connector can be used. To draw the diagram, a Virtual Instrument made in the LabView environment is used. The application generates a ramp signal that increases and decreases in the range 0 → +10 → 0→ - 10→ 0 volts by equal steps. At each step, the flow passing through the valve is measured and a point is recorded on the diagram. After completion, the diagram is saved.

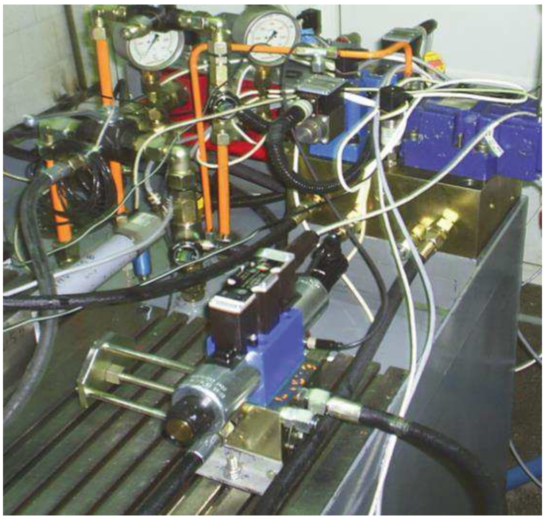

Fig. 4. Test bench and the proportional directional valve mounted on the manifold with sensors

Obtaining the static characteristic of the proportional directional valve requires that the value of the nominal pressure drop to remain constant during a test cycle between the minimum and maximum command signal [14, 15, 16]. This can be done by monitoring the directional valve pressure drop and correcting its value before each step of recording the points of the static characteristic. Correction of the pressure drop through the tested device, before acquiring the points for the diagram, can be done manually or through an algorithm in the virtual test instrument.

With the help of the sensors in the intelligent module it is possible to obtain the pressure drop on the device using the relation (1).

$$\Delta p = p_p - |p_A - p_B| - p_T \quad (1)$$

where:
Δp – pressure drop on directional valve
P_P - pressure at valve port P
p_A – pressure at valve port A
p_B– pressure at valve port B
p_T – pressure at valve port T.

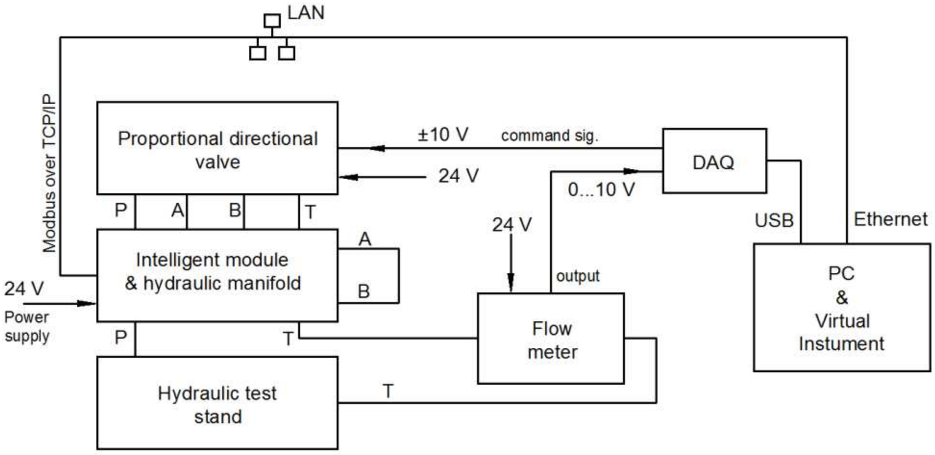

Fig. 5. Block diagram with data acquisition system

4. Intelligent module test results

The signals transmitted by the electronic board of intelligent module via LAN was acquired and also displayed with a virtual instrument made in LabView (Fig. 6). The block diagram of the VI for modbus data acquiring can be seen in Fig. 7.

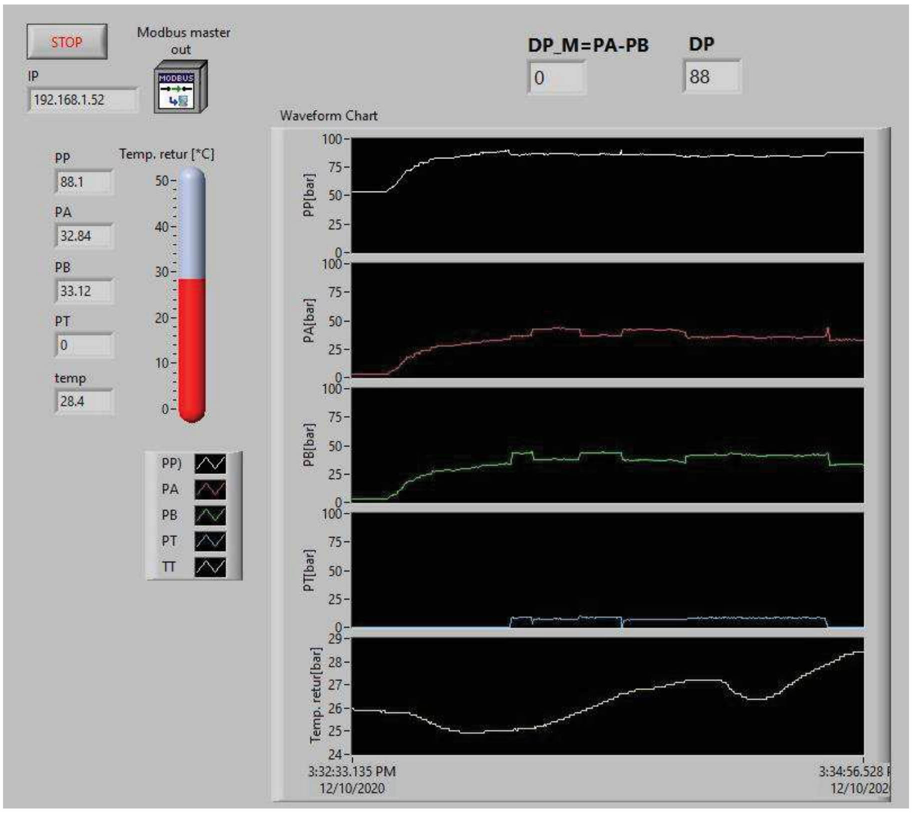

Fig. 6. LabView virtual instrument for monitoring the parameters transmitted by the intelligent module

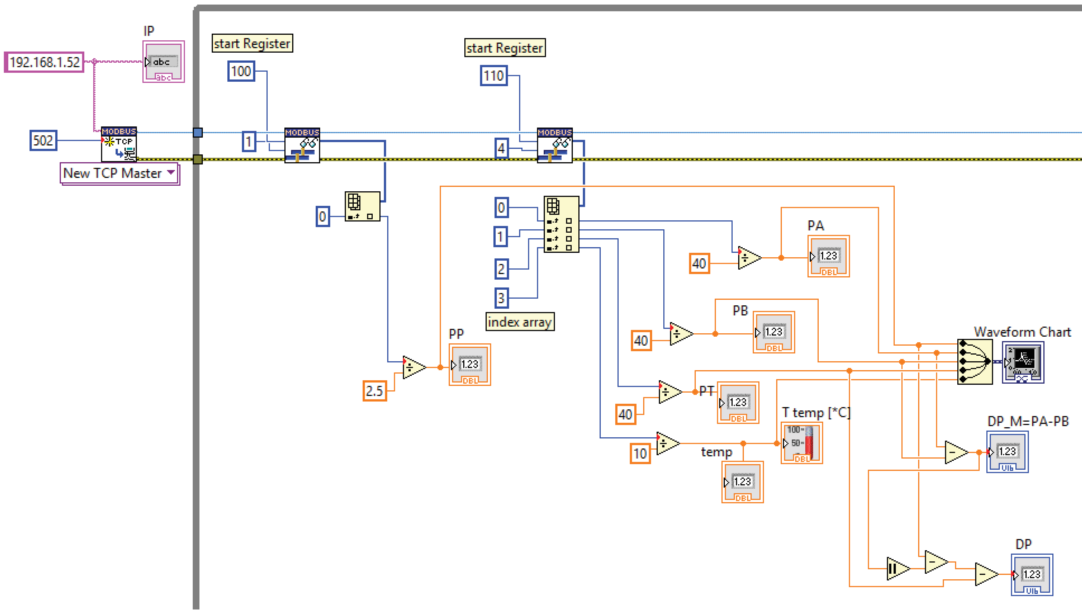

Fig. 7. The block diagram of the VI for modbus data acquiring

The static characteristic of the proportional directional valve obtained with an instrument made in the LabView environment is found in Fig. 8. The intelligent module was used to keep constant the pressure drop through the valve when drawing the diagram.

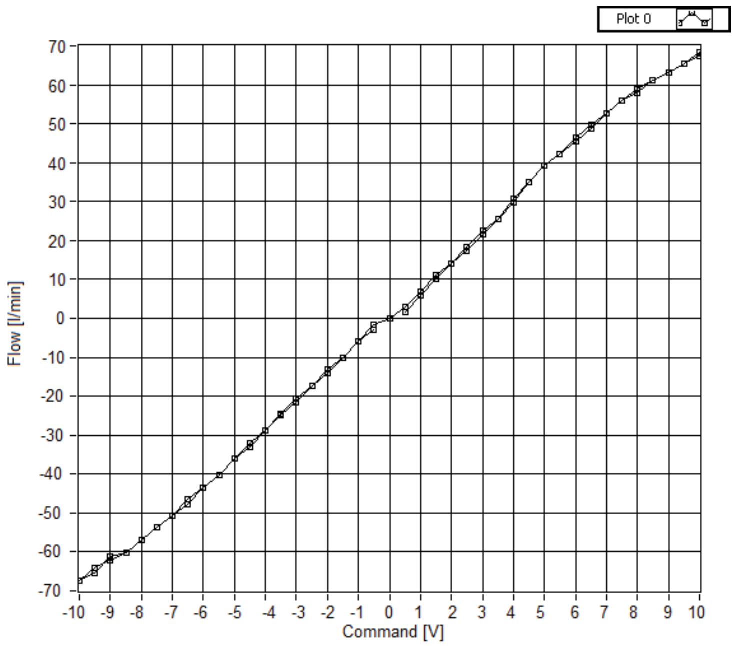

Fig. 8. Static characteristic for a proportional directional valve

The data transmitted by the electronic board of the module via TCP / IP modbus, in the LAN network, can be processed with the virtual instrument made in LabView. By means of a Modbus TCP master block, data and temperature registers can be read [17]. The data is processed to obtain the pressure drop and displayed on the screen for monitoring, thus being able to observe a malfunction of the equipment [18, 19, 20, 21].

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5. Summary

Miniature sensors and electronics can be incorporated into modern hydraulic equipment and together with communication modules and software algorithms lead to the realization of intelligent products.

Proportional directional valves with attached iintelligent module or with built-in sensors and electronics can be easily monitored and controlled.

Smart products connected in the network allow the provision of intelligent services. Thus, recording a history in a database or monitoring on mobile equipment leads to an increase in efficiency during servicing and maintenance.

Hydraulically driven machines that incorporate intelligent equipment can be diagnosed more easily, for repair, with the help of information or error codes transmitted to the operating console.

Automation subsystems of a hydraulically driven machine can be individually controlled by intelligent equipment.

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References

[1] Xu B., Shen J., Liu S., Su Q., Zhang J.: Research and Development of Electro-hydraulic Control Valves Oriented to Industry 4.0: A Review, Chinese Journal of Mechanical Engineering 33, 2020.

[2] Gannon M.: The new distributed control for smart hydraulic equipment https://www.fluidpowerworld.com/the-new-distributed-control-for-smart-hydraulic-equipment/ [accesed: 29.09. 2020].

[3] MODBUS Messaging on TCP/IP Implementation Guide: https://modbus.org/docs/Modbus_Messaging_Implementation_Guide_V1_0b.pdf [accesed: 28.09. 2020].

[4] Hubballi B.V., Sondur V.B.: Directional Control Spool Valve Performance Criteria and Analysis of Flow – Reaction Forces, International Journal for Research & Development in Technology, 2015.

[5] Scheidl R.: Actuators and Sensors for Smart Systems, 10th International Fluid Power Confernce, 2016.

[6] Schütze A., Helwig N., Schneider T.: Sensors 4.0 – smart sensors and measurement technology enable Industry 4.0, Journal of Sensors and Sensor Systems, 2018.

[7] Dutu I., Dumitrescu C., Matache G.: Smart Diagnosis of Proportional Electro-Hydraulic Equipment Using Specific Virtual Instruments, The Romanian Review Precision Mechanics, Optics & Mechatronics, No. 43, pp.98-101, 2013.

[8] Avram M., Bucsan C., Apostolescu T.C.: Specialised sensorial block, MATEC WEB of Conferences 121, 2017.

[9] Gang S., Haiping S., Lina C.: The research on integrated testing equipment of Electro-hydraulic Proportional Direction Valve, International Conference on Mechanic Automation and Control Engineering, 2010.

[10] Murphy B.J., Banks J., Reichard K.: Modeling of Hydraulic Systems Tailored to Diagnostic Fault Detection Systems, IEEE Aerospace Conference, 2006.

[11] Guta D.I., Dumitrescu C., Lepadatu I., Cristescu C.: Experimental identification of electrohydraulic servomechanisms with virtual instruments technique, HIDRAULICA no.3, pp.49-56, 2010.

[12] Dutu I. C., Maican E., Biris S., Dutu M. F.: Munteanu M. G., Simulation of an electro-hydraulic system for a PET waste baling press, Hidraulica no.4, pp. 6-11, 2018.

[13] Ledvoň M., Hružík L., Bureček A., Vašina M.: Static and dynamic characteristics of proportional directional valve, Volume 213, Experimental Fluid Mechanics 2018, EPJ Web Conferences, 2019.

[14] Zhao J., Jin J., Xing K.: Constant pressure control for steady – state pressure flow test of proportional valve, International Conference on Systems and Informatics (ICSAI), 2017.

[15] Castro R.M., Morona Y.M., Machado K., Cavaler L.C. et al.: Experimental Analysis of the Supply Pressure Variation of the Hydraulic System, International Journal of Recent Controbutions from Engineering, science & IT, No.4, 2014.

[16] Zhao T., Huang D.: Research and Implementation of Constant Pressure Control with Electro-pneumatic Proportional Valve, Journal of Physics: Conference Series, 4th International Conference on Electrical, Automation and Mechanical Engineering, 2020.

[17] Helwig, N., Merten, P., Schneider, T., Schütze A.: Integrated Sensor System for Condition Monitoring of Electromechanical Cylinders, MDPI Proceedings, 1, 626, 2017.

[18] Ferronatto D., Mendoza Y.E.A., Bastos P. P. C., Souza F. J. et al.: Proportional hydraulic valve condition monitoring method for on-line fault detection, 23rd ABCM International Congress of Mechanical Engineering, Rio de Janeiro, RJ, Brazil, 2015.

[19] Drumea P., Dumitrescu I. C., Hristea A., Chirita C.: Methods of Diagnosing Malfunctions in Hydraulic Actuations, Proceedings International Conference on Hydraulics and Pneumatics HERVEX, pp. 212-217, 2016.

[20] Raduenz H., Mendoza Y.E.A., Ferronatto D., Souza F.J., Bastos P.P.C. et al.: Online fault detection system for proportional hydraulic valves, Journal of the Brazilian Society of Mechanical Sciences and Engineering 40, 2018.

[21] Gupta S., Khosravy M., Gupta N. et al.: Hydraulic System Onboard Monitoring and Fault Diagnostic in Agricultural Machine, Agriculture Agribusiness and Biotechnology 62, 2019.