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Design and Implementation of PLC Based Hydraulic Test Unit Design for Diagnostics and Testing of Hydraulic Equipment

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ABSTRACT

In this research, a PLC-based test unit was designed to test the hydraulic block and hydraulic power supplies. The designed system can measure the maximum noise value, ambient temperature, oil temperature, relative humidity and oil pollution rate. Tests of a hydraulic power unit with a power of 11 kW and a working pressure of 250 bar, which was used in the experimental studies, were carried out. In the test report obtained as a result of the tests, the operating noise under pressure is 80 dB, the ambient temperature is 21.52 °C, the temperature of the oil filled into the tank is 21.26 °C, the relative humidity of the oil is 41.75% RH, and the pollution level of the oil (Nas 1638) is 4,000. The developed system succeeded in creating a test report by performing the test operations.

1. Introduction

Hydraulic systems are used in almost every sector of the industry today. With the introduction of hydraulics in electrical and electronic systems, especially in control systems, the use of pressurized fluid as an energy and transmission element has found a wide range of uses. In addition, the fact that hydraulics can be readily used in both mobile and stationary systems has increased the demand for hydraulics. Hydraulics have been particularly used in marine and aerospace industries, workbenches, lifting machines and power generation fields. For example; aircraft, machine tools, presses, injection molding machines, testing equipment, industrial robots, automotive industry, lifting and handling machines (forklifts, etc.), construction machinery (concrete pumps, graders, mobile cranes, excavators, etc.), agricultural machinery, dams, turbines, nuclear power plants, ship unloading and loading units, ship control systems are the areas where hydraulic systems are most commonly encountered. Hydraulic servo systems generally require constant pressure support and can also be used to control hydraulic actuators or hydraulic motors[1].

Manufacturers provide a large range of dimensions for pumps regarding hydraulic capacity. Hence, manufacturers provide complicated charts to verify the real flow given by a certain pump, while working at needed pressure [2]. One of the most important operational properties of products of machine-building production, including hydraulic machines, is its reliability. Reliability is laid in the design and construction of hydraulic machines, is ensured in the process of their production, and is confirmed during testing [3, 4]. The most important, as well as labor-consuming and energy-intensive type of testing of hydraulic machines, are life tests, during which the performance of hydraulic machines in the process of long-term use for their intended purpose, and their durability are revealed. At that, various braking devices (mechanical, electric, hydraulic, etc.) are used for strength loading of the hydraulic motor, as a result of which a significant amount of energy is lost [5]. In recent years, an active search has been conducted for a solution to this problem, as a result of which a method of life tests of hydraulic machines of rotational motion with energy recovery has been developed [6]. This method provides significant savings when testing hydraulic units and hydraulic manifolds, however, it cannot be directly used when testing hydraulic reciprocating machines - hydraulic cylinders [4].

Yenge et al. (2022) made a test machine for the valve industry and make it multipurpose which should be used for valve testing and pressure gauge testing. The machine was simple to maintain and easy to operate. Hence, they tried our hands on “Hydraulically operated valve cum pressure gauge testing.” Hydraulically operated valve cum pressure gauge testing device was a calibration and testing equipment especially meant for calibration of different types of pressure gauges for its truth ness and valve for its reliability [7].

Voloshina et al. (2020) developed an experimental test bench for testing high-torque hydraulic motors which allow

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testing a family of unified series of planetary hydraulic motors with a power of 6.5; 11; 22 and 33 kW, respectively [8].

Don Hai et al. (2011) developed a new type of hydraulic cylinder test bench is presented. Hydraulic technology, microelectronics technology, sensing detection technology, computer control and modern control theory are applied in the system [9].

Zehong Wang et al. (2016) A test and control system for hydraulic pulse test is designed according to the requirement of a high-temperature pulse endurance test of automotive air conditioning system. The system can control the temperature, pressure and switching frequency. It also has the function of timing detection and fault diagnosis [10].

Linbing Xu et al. (2021) developed a hydraulic vane pump test bench and builds a set of hydraulic automatic measurement and control systems based on the C/S framework, which can meet the requirements of single/double pump tests simultaneously. Among them, the client software is developed based on LabVIEW, the server is built based on FTP protocol and MYSQL database[11].

The present paper presents a developed PLS-based test stand that can be remotely controlled and has an advanced automation system for hydraulic power units and hydraulic blocks. Theoretically, with this test system; It has been ensured that the error is reduced to zero with maximum accuracy in the tests. The test stand provides a time and efficiency advantage, and the risk of work accidents is reduced thanks to extra work safety measures against high working pressure up to 350 bar and all electric motors up to 180 kW power are tested. This paper considers the intended application, structure, functionality, and specifics of the automated rig. The rig is used to test the following hydraulic equipment: On-off valve coils of 24 Vac/dc, 48 Vac/dc, 110 Vac/dc, and 220 Vac/dc types and ±0-10 V, ±0-20 mA, 4-20 mA different types of proportional valve coils on hydraulic power units and hydraulic blocks are provided. It is planned to supply energy to electric motors with 4 separate cable drum groups. To ensure the quality of the products delivered at the exit from the production lines there is used functionality testing stands are located at the exit of the line. The testability of the products is verified with the help of specialized stands. The testing stand can be controlled with dedicated electronic modules which ensure the logic of operation, or with PLCs. This paper will present an electronic module from a hydraulic motor testing stand, also provided with an operating console, which communicates serially with the control module.

2. Experimental

2.1. Materials and Methods

In this study, a PLC-controlled data acquisition and control and testing system of hydraulic blocks and units has been developed. The developed system is equipped with analog and digital input/output modules and is suitable for expansion fig. 1, the assembled state of the test unit is presented. The PLC was connected to the servo valves via dedicated control cards (valves amplifier). The simulation model was built by using the Solidworks tool. The hydraulic block and hydraulic unit were controlled by the hydraulic test unit. The test stand was built to compare the results of the simulation and the real objects.

In this developed system; temperature, oil pollution level, relative humidity and pressure can be measured. The measured values are displayed on the 10.1-inch TFT screen on the system and saved to the USB memory inserted into the USB port of the screen without a computer connection. It is expected that the developed system will be able to prepare the prepared test report depending on the measurements and operator markings.

Siemens S7-1200 series was used as the processor, Siemens PC panels and Siemens industrial tablet (Fig. 2) were used as the interface (HMI or Display). PLC is powered by 24 Vdc energy. The system is controlled by panel PCs and industrial tablets for remote control. A maximum of three communication modules can be installed on any SIEMENS SIMATIC S7-1200 CPU. RS485 and RS232 communication modules support point-to-point serial communication. Communication can be configured and programmed with advanced functions. In addition, it is possible to communicate with Siemens drives with the USS protocol in the STEP7 Basic project software's library and with third-party devices with the Modbus RTU master or slave protocol.

TIA Port V16 Ladder program is the new version of Simatic manager. S7-1200, S7-300 and S7-400 family PLCs from SIEMENS (Fig. 3). The new generation for programming and managing is the editor. Not only writing the program, but also the operator. It is also used in panel programming and creating SCADA.The developed test unit can supply 24 Vac/dc, 48 Vac/dc, 110 Vac/dc, 220 Vac/dc, 0-10 V voltage and 0-20mA, 4-20mA current inputs to energize the coils of conventional and proportional valves on the hydraulic blocks.

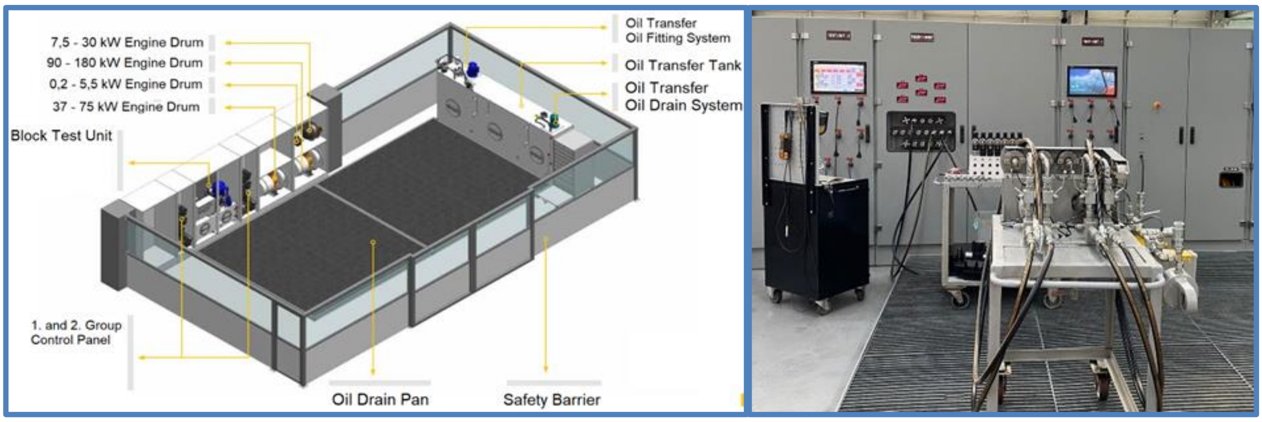

Fig. 1 Designed hydraulic test unit.

Fig. 2 Tablet and panel PC used in the system.

The test unit can also test hydraulic power units. The developed test unit is equipped with a hydraulic oil filling and unloading unit used to fill the tank of the hydraulic power unit to be tested. Inrush currents are prevented by using micro relays to drive the valves controlled by PLC and soft-starters to start the motors.

The circuit diagram of the developed hydraulic system is presented in Fig. 4.

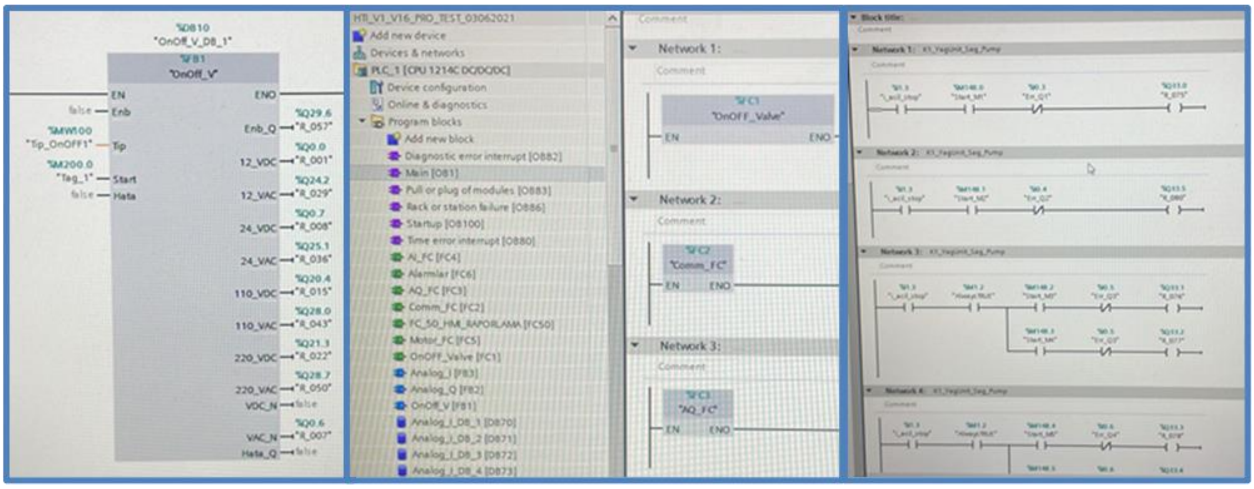

Fig. 3 The ladder diagram section view of TIA Portal V16.

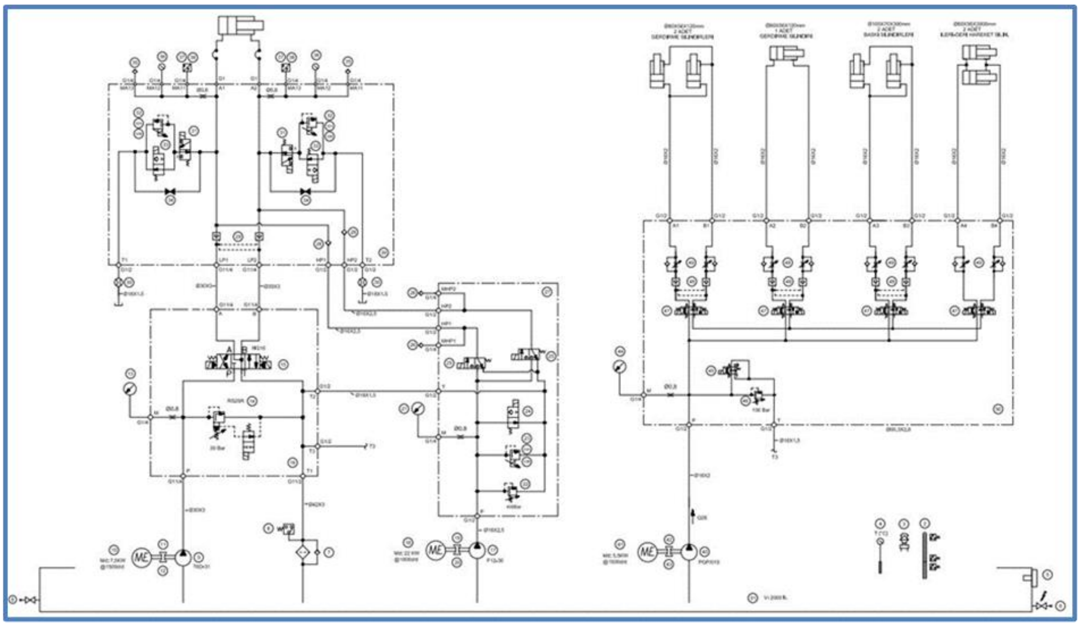

Fig. 4 Designed Hydraulic Test Unit Circuit Diagram

The designed system will be able to test motors from 0.25kW to 185kW. The flow rate of the transfer pump is 100 liters/min. The maximum working pressure level in industrial hydraulics is 350 bar and applies to all products. Thus, the maximum test pressure that can be applied to the designed system was determined as 350 bar. In the designed system, the temperature and contamination level of the test oil can be measured online and continuously. If the oil temperature and cleaning level are not suitable, the test can be stopped by PLC control.

Pollution particle measurements in hydraulic systems are measured by adhering to ISO 4406, NAS 1638 and SAE AS 4059 standards. In this study, the test oil temperature was determined as 45 - 50 C and the oil cleanliness level was NAS 5 - 6 in line with these standards.

The base of the developed test unit is equipped with an oil pan. With the oil pan, oil deposits that are lost, that cause environmental pollution and that can cause personnel to fall due to the slippery floor are prevented. In this way, environmental cleanliness and occupational safety are ensured. Leaky oils can be accumulated in the ceiling and then be filtered and used.Thus, recycling is provided. Oil pans, safety barriers and doors were designed for the occupational safety measures of the system.

The electrical system of the designed test unit (Fig. 4) is 380 V AC 50 Hz. The electrical system is 24 V DC. Valve systems that can be tested; 12V DC, 24 Vdc, 110 Vdc, 220 Vdc, and 12 Vac, 24 Vac, 110 Vac, 220 Vac. Engines that can be tested; are asynchronous motors between 0.25 kW and 200 kW.

Hose drums with electric cable (Fig. 5); are used in cranes, mobile cranes, mobile rescue and telescopic vehicle platforms; They are systems that can provide current and signal transmission through the cable on the same reel with hydraulic hoses.

These systems, which allow us to use all of the hoses and cables wound on them, are designed to work smoothly with special grounded springs. If desired, the rollers can be driven by 12/24/48 Vdc, 220 Vac or 380 Vac electric motors, pneumatic motors or hydro motors.

As the length of the hose and cable length of the drum, problems may occur in rewinding, and a row winding system can be added to the drum to prevent this. In addition, rotating guide systems can be added to the outlet part of the drum to prevent corrosion of the hose and cable.

Table 1 presents the general list of system components. The measurement algorithm with the developed test unit is presented in Fig. 6. The success of the developed test unit was tested with a hydraulic block and a hydraulic power source. In the experiments 1000 t metal baler main press block was used (Fig. 7) . This hydraulic control block belongs to a metal scrap

Fig. 5 Electric drums and their control unit.

Table 1. List of materials used in the test unit

System Components					
1	Hydraulic Tank	9	Hydraulic Pump	17	Locking valve
2	Level Indicator	10	Electric motor	18	Flow indicator
3	Tank Cap	11	Manometer	19	Proportional pressure valve board
4	Thermometer	12	Pressure relief valve	20	Pressure gauge fitting
5	Temperature sensor	13	Directional control valve	21	Pressure sensor
6	Spherical valve	14	Block	22	Gear pump
7	Filter	15	Proportional pressure valve	23	Coupling
8	Pollution switch	16	Check valve	24	Speed regulating valve

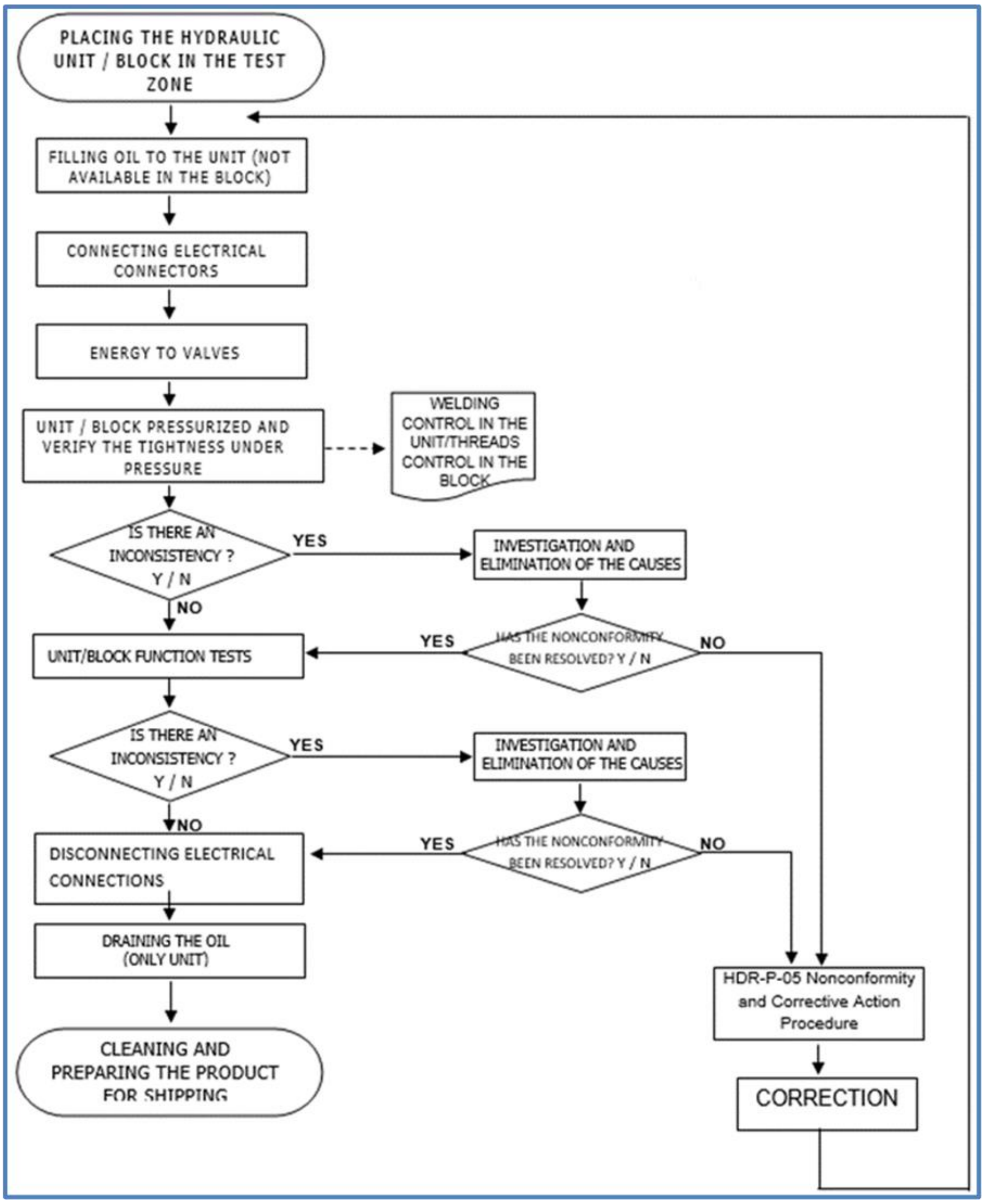

Fig. 6 Test unit's block test diagram

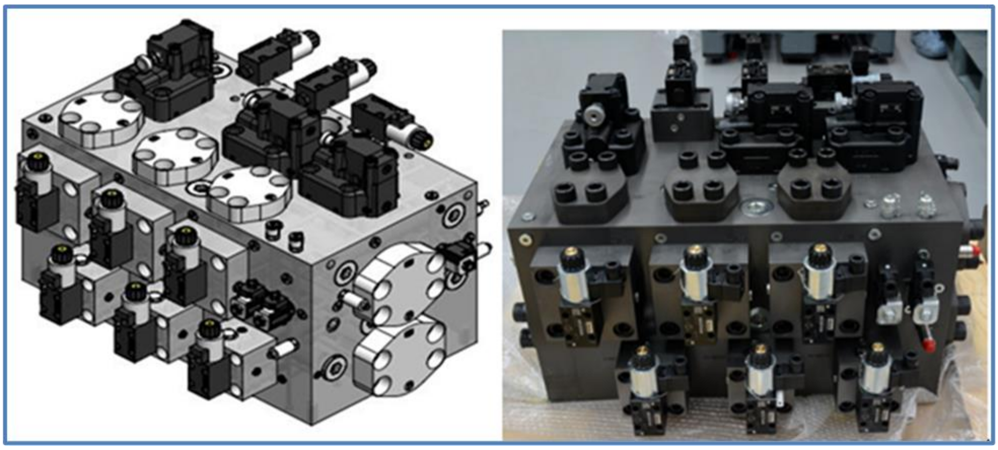

Fig. 7 3D model of the test block.

press machine with 1000 t printing capacity. It can work at high speeds. The designed hydraulic circuit belongs to the main pressure block. The main pressure block has been designed considering the speed value of the machine in the total cycle. This speed determines the pump flow rate to be used in the hydraulic system. The pump flow rate also determines the size of the valves to be used in the block. By complying with these criteria, first, the circuit diagram is created and the valve and other instruments to be used are selected. The block design is made according to international standards, the block material is spheroidal graphite cast iron GGG40. It is manufactured in a very sensitive horizontal machining center and functional tests are performed in the versatile test system. In this study, the tests of the block given in Fig. 6 were carried out.

In this study, the tests of the hydraulic power unit given in Fig. 8 were carried out. The designed system belongs to a styrofoam injection machine hydraulic system. Automotive and decoration manufacturing companies use this machine. Among the prominent features of the system is energy efficiency. Load sensing controlled variable displacement pump is used in the designed hydraulic system. In this way, the oil will transmit as much oil as the system needs, and the oil it transmits will spend energy according to the pressure value. Projecting and design criteria are progressing as I mentioned above. The size of the hydraulic cylinders is determined according to the molding area of the machine. In this way, the pressing force increases. Poppet valves are preferred in valve groups because 0 leakages are preferred under pressure.

3. Results and Discussion

The performance of the PLC-based test unit developed in this research was tested using the prepared sample hydraulic block and hydraulic power unit. In a literature review of PLC, implementations Can et al. (2022), Tselischev et al. (2019), Dalmis et al. (2018), Bayindir et al. (2011) designed or tested PLC-based systems [12-15].

Tselishchev et. al. (2019) performed validation studies of a similar hydraulic test setup and determined that the system was operating with a 1.5% error. In this study, the accuracy of the measurement results is ensured by the certified and calibration certificated sensors used. The maximum error rate for the sensors used is determined as 1-2% from the product certificates.

In the experiments, the temperature, relative humidity and oil pollution level of the oil were measured. The process of recording the data continued until the end of the testing period. The obtained data are stored as .xls files that can be processed in MS Excel program.

The designed interface of the developed measurement system it is presented in Fig.9. The operator was able to successfully initiate the tests through the designed interface and created the test reports.

The test report was obtained as a result of the test performed by using the hydraulic block connected to the designed measuring system Presented in Fig.10.

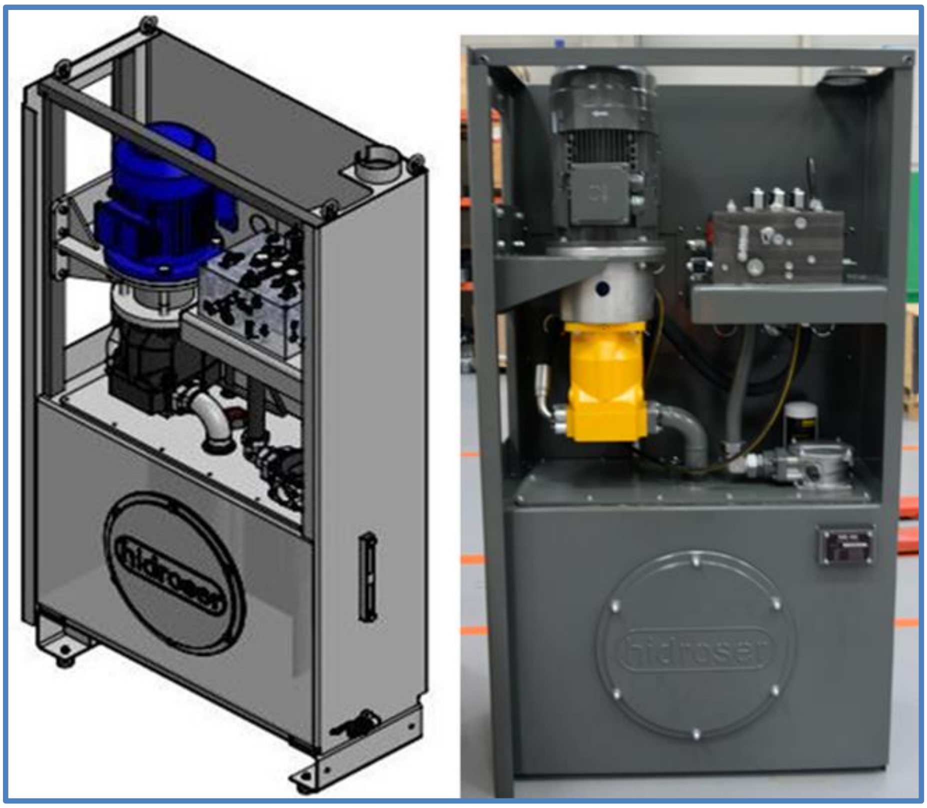

Fig. 8 3D model of the test hydraulic power unit.

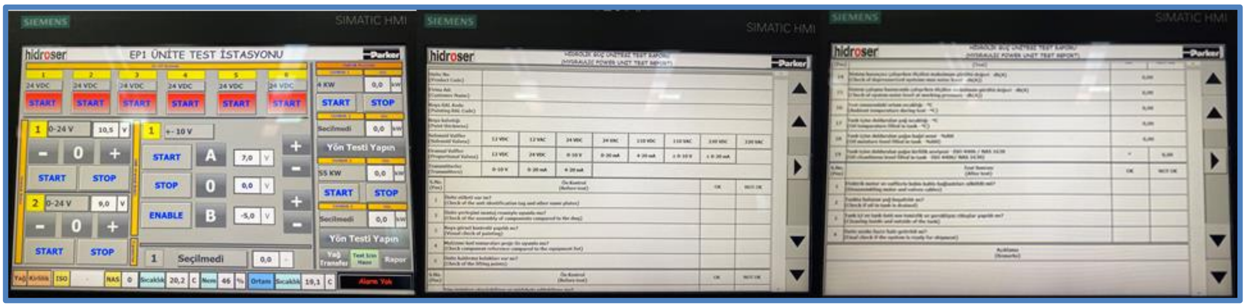

Fig. 9 Screens of the developed control system.

S.No. (Pos.)	Ön Kontrol (Before Test)	OK	NOT OK
1	**Blok etiketi var mı?** (Check manifolds label and tag number)	✓	
2	**Blok yerleşimi montaj resmiyle uyumlu mu?** (Check of manifold assembly compared to the assembly dwg)	✓	
3	**Boya görsel kontrolü yapıldı mı?** (Visual paint check)	✓	
4	**Malzeme kod numaraları proje ile uyumlu mu?** (Check component reference compared to the equipment list)	✓	
5	**Tüm ürünlere ulaşılabiliyor ve müdahale edilebiliyor mu?** (Check of the accessibility of equipments)	✓	
6	**Bağlantı elemanları,civataları ve ölçüleri proje ile uyumlu mu?** (Check of the size of hyd connections and bolts)	✓	
7	**Blok içi görsel temizlik kontrolü yapıldı mı?** (Visual check of manifold cleanliness)	✓	
S.No. (Pos.)	**Test** (Test)	**OK**	**NOT OK**
1	**Testte kullanılan yağın sıcaklığı,bağıl nemi ve ve yağ kirlilik seviyesi test raporuna işlendi mi?** (Oil temperature,moisture level and cleanliness level recorded in test reports)	✓	
2	**Test yapılan ortam sıcaklığı test raporuna işlendi mi?** (Ambient temperature recorded in test reports)	✓	
3	**Test esnasında yağ kaçakları oluştu mu? Oluştuysa giderildi mi?** (Check and stop oil leakage during test)	✓	
4	**Blok çalışma fonksiyon testleri yapıldı mı?** (Check of system functionality)	✓	
5	**Test basıncı - bar** (Test pressure - bar)	252.70	
6	**Test esnasındaki ortam sıcaklığı - °C** (Ambient temperature during test - °C)	21.87	
7	**Testte kullanılan yağ sıcaklığı - °C** (Test oil temperature - °C)	43.05	
8	**Testte kullanılan yağın bağıl nemi - %RH** (Test oil moisture level filled in tank - %RH)	35.66	
9	**Testte kullanılan yağın kirlilik seviyesi - ISO 4406 / NAS 1638** (Test oil cleanliness level - ISO 4406 / NAS 1638)	16/14/11	5.00

Fig.10 Hydraulic block test report

The hydraulic test block tests were carried out in two stages pre-control and test. The operator was able to successfully mark the options on the tablet in the pre-control area presented in the form of a questionnaire.

In the measurements made during the test phase, the test pressure was 252.70 bar, the ambient temperature was 21.87 °C, the oil temperature used in the test was 43 °C, the relative humidity of the test oil was 30.66% RH, and the oil contamination level was Class 5.00 according to the NAS 1638 standard.

Tests of the hydraulic power unit were also carried out. In the tests, solenoid valve coil voltages, test pressure, ambient temperature during the test, oil temperature used in the test, relative humidity of the oil used in the test and the contamination level of the oil used in the test were successfully measured. (Fig. 11).

S.No. (Pos.)	Pompalar (Pumps)	E-motor gücü - kW (E-motor power - kW)	Çalışma basıncı - bar (Operating pressure - bar)	Test basıncı - bar (Test pressure - bar)	Boşta çekilen güç - kW (Power kW at 0 bar)	Yükte çekilen güç - kW (Power kW at WP)
P1	PV063R1K1T1NMFC	11.00	250.00	250.00	6.10	8.00
P2		0.00	0.00	0.00	0.00	0.00
P3		0.00	0.00	0.00	0.00	0.00
P4		0.00	0.00	0.00	0.00	0.00
P5		0.00	0.00	0.00	0.00	0.00
P6		0.00	0.00	0.00	0.00	0.00
P7		0.00	0.00	0.00	0.00	0.00
P8		0.00	0.00	0.00	0.00	0.00
5	Test esnasında yağ kaçakları oluştu mu? Oluştuysa giderildi mi? (Check and stop oil leakage during test)				✓	
6	Ünite çalışma fonksiyon testleri yapıldı mı? (Check of system functionality)				✓	
7	Sistem basınçsız çalışırken ölçülen maksimum gürültü değeri - db(A) (Check of depressurized systems max noise level - db(A))				75.00	
8	Sistem çalışma basıncında çalışırken ölçülen maksimum gürültü değeri - db(A) (Check of system noise level at working pressure - db(A))				80.00	
9	Test esnasındaki ortam sıcaklığı - °C (Ambient temperature during test - °C)				21.52	
10	Tank içine doldurulan yağ sıcaklığı - °C (Oil temparature filled in tank - °C)				21.26	
11	Tank içine doldurulan yağın bağıl nemi - %RH (Oil moisture level filled in tank - %RH)				41.75	
12	Tank içine doldurulan yağın kirlilik seviyesi - ISO 4406 / NAS 1638 (Oil cleanliness level filled in tank - ISO 4406/ NAS 1638)				15/13/10	4.00

Fig. 11 Hydraulic power unit test report.

The hydraulic power unit was successfully connected to the developed measuring set, which will be tested. While the electrical connections of the valves are provided with suitable 24 Vdc sockets, the hydraulic connections are provided via quick coupling couplings. During the test, the operator was able to successfully fill the test pre-checklist. In the tests performed, the maximum noise value measured when the system is operating without pressure is 75 dB according to the IEC 61672:2003 standard, the maximum noise value measured while operating at the operating pressure is 80 dB, the ambient temperature during the test is 21.52 °C, the oil temperature is 21.26 °C, the relative humidity of the oil is 41.75. % and the pollution level of the oil used was measured as Class 4.00 according to the NAS 1638 standard.

4. Conclusion

This work carried out was mounted on the hydraulic block and a PLC-controlled data acquisition and control system was realized to perform the function test. The system is structurally equipped with analog and digital input/output modules suitable for expansion. This expandable structure allows the system to perform functional tests. The hydraulic power unit was successfully connected to the developed measuring set, which will be tested. In the measurements made during the test phase, the test pressure was 250.00 bar, the system noise level at working pressure was 80 dB (A), the ambient temperature was 21.52 °C, the oil temperature used in the test was 21,26 °C, the relative humidity of the test oil was 41,75% RH, and the oil contamination level was Class 4.00 according to the NAS 1638 standard. In this test, solenoid valve coil voltages, test pressure, ambient temperature during the test, oil temperature used in the test, relative humidity of the oil used in the test, and the contamination level of the oil used in the test were successfully measured. It was observed that the hydraulic block and unit test setup designed in the research successfully performed the tests expected from it. As a suggestion, a flow measurement parameter can be added to the test setup in future work. Further research aims to improve the models of hydraulic test units.

Declaration

Author Contribution: Conceive- S.Y., S.U.; Design- S.Y., S.U.; Supervision- I.S.D.; Experimental Performance, Data Collection and/or Processing S.Y., S.U.; Analysis and/or Interpretation S.Y., S.U. İ.S.D.; Literature Review- S.Y., İ.S.D.; Writer- S.Y.; Critical Reviews - I.S.D.

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