DESIGN AND EXPERIMENTATION OF TEST RIG TO CHARACTERIZE HYDROSTATIC DRIVEFOR LINEAR ACTUATOR

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Abstract

The main goal of this work is to develop and run a complete test rig to measure all the needed parameters to characterize the performance of a displacement controlled linear actuator (hydraulic cylinder) in a closed hydraulic circuit. The proposed hydraulic circuit is equipped with all the necessary measuring devices such as pressure transducers, load cells, shaft encoder, thermocouple, and data acquisition system to monitor and save measuring results. A PC with a software developed by LabView measuring kit was used to draw and demonstrate the time relationships graphs. These results demonstrate that accurate measuring results is achieved to do identification of the displacement controlled hydraulic system. Moreover, depending on these results a complete control method can be found to be applied on the proposed closed hydraulic circuit. In this work the test rig and measuring instruments, method, and results are presented.

Keywords: *Displacement Controlled Linear Actuator, Hydraulic System, Data Acquisition.*

Abbreviations:*DC: Displacement Controlled, DAQ: Data Acquisition*

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1. INTRODUCTION

Hydraulic systems are considered one of a major type of power transmitting due to many advantages such as robustness, great power to weight ratio, etc. All vehicle, planes, mechanical equipment, and agricultural equipment have at least one or two hydraulic systems. Most of hydraulic systems use the same type of components like control valves, pumps, etc. However, they suffer from low efficiency because of the usage of control valves, which lead to fluid throttling. Thus, there is an urgent need to improve the efficiency in hydraulic systems in terms of eliminating the metering loses associated with hydraulic valves and allowing energy recovery. Moreover, improving the efficiency of hydraulic systems will lead to reduce the pollution, fuel consumption, and running cost, which considered the current world challenge. One of the main idea to improve the efficiency of hydraulic system is to use Displacement Controlled (DC) actuator and valve-less hydraulic circuit. The common usage of displacement-controlled actuators was on hydrostatic transmission, which use symmetrical actuators (hydraulic motors). Recently, the researchers investigate the usage of displacement controlled linear actuator in closed hydraulic circuit without the usage of direction control valves. It is worth mentioning that the new trend of integrating electronic and mechanical systems (mechatronics) open the hope to solve the problem of flow compensation between the two terminals of a linear actuator in an efficient manner. In addition, the reasonable prices of the current variable displacement pumps encourage the investigator to include them in developing any new hydraulic system. Moreover, modern measurements techniques, affordable software, PCs, microcontrollers and precise transducers made testing, identification of any developed system is fast, and accurate compared to the traditional analytical identification techniques. Based on aforementioned advantages of the DC linear actuator, this paper will mainly focus on developing a practical DC hydraulic circuit and measure all the necessary data to characterize the performance and calculate the efficiency of the proposed hydraulic circuit.

2. TEST RIG DESCRIPTION

2.1 Hydraulic Circuit

The experimental work was done on a proportional controlled variable axial piston pump driven by a three phase electrical conduction motor, the pump is linked to a double acting, single rod hydraulic cylinder by means of hoses which is lifting an arm. A bladder type, four liters, hydraulic accumulator is fitted to link to the rod side of the hydraulic cylinder to compensate the fluid flow difference between the cylinder two sides. A solenoid controlled 2X2 hydraulic on-off valve to hold the cylinder at any position, two reliefvalves manually adjusted are used improve the system safety and durability.

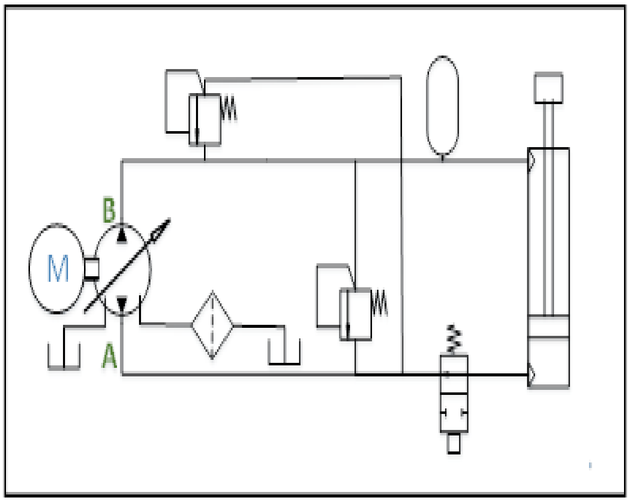

Fig-1: Hydraulic circuit schematic drawing

Fig-2: Test rig photo

2.2 Instrumentations

All the pre discussed hydraulic components are equipped with a group of transducers and devices were used to measure, operate, and monitoring the system.

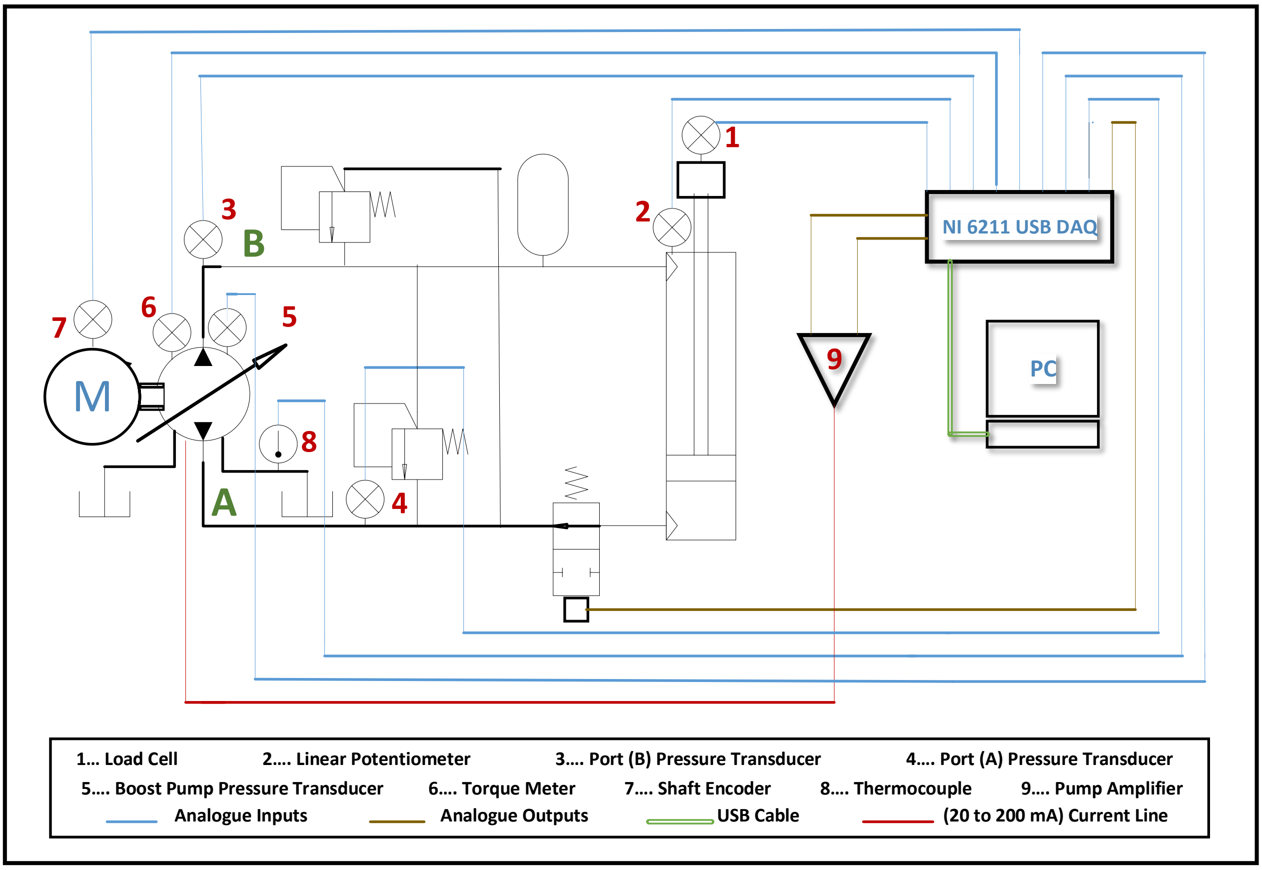

Fig-3: Setup schematic drawing

Data acquisition system (DAQ) with eight differential analogue input channels, two analogue output channels was used to convert the sensors analogue signals to digital ones to send them to the PC to conduct measurements and doing calculations, and plotting results. DAQ controls the hydraulic pump via an analogue output channel by producing (-8) to (+8) volts to the pump amplifier card which convert these voltages to current (200 to 600 mA)(4.B)to operate and control the pump proportional solenoids. The second analogue channel is used to control the on off valve to hold the hydraulic cylinder to a desired position. DAQ counter is wired to shaft encoder to calculate motor/pump angular speed, a digital output channel is to operate the electrical motor via a relay and soft starter. The hydraulic cylinder is fitted to a loading mechanism consists of an H beam arm and a base, which ascends different weights to apply variable forces to the hydraulic cylinder.The instruments and devices used to operate the setup are:

1. Displacement transducer to measure the displacement of the hydraulic cylinder.
2. Pressure transducer (A) to measure the pressure of pump port (A).
3. Pressure transducer (B) to measure the pressure of pump port (B).
4. Pressure transducer (c) to measure the pressure of the scavenging pump.
5. Incremental shaft encoder to measure the pump angular velocity.
6. J-type thermo-couple to measure the fluid temperature.
7. A two tons amplified load cell to measure the acting load on the cylinder.
8. A ten kilo grams load cell equipped with an external amplifier to measure the pump torque via a balancing mechanism.
9. Amplifier to drive the pump's proportional solenoids.
10. DC power supplies to bias all the instrumentations.
11. A 9211 NI USB data acquisition board.
12. PC.
13. Shielded cables (200 meters).
14. AC power source.
15. A pivoted boom mechanism (loading).

Fig-4: Loading mechanism photo

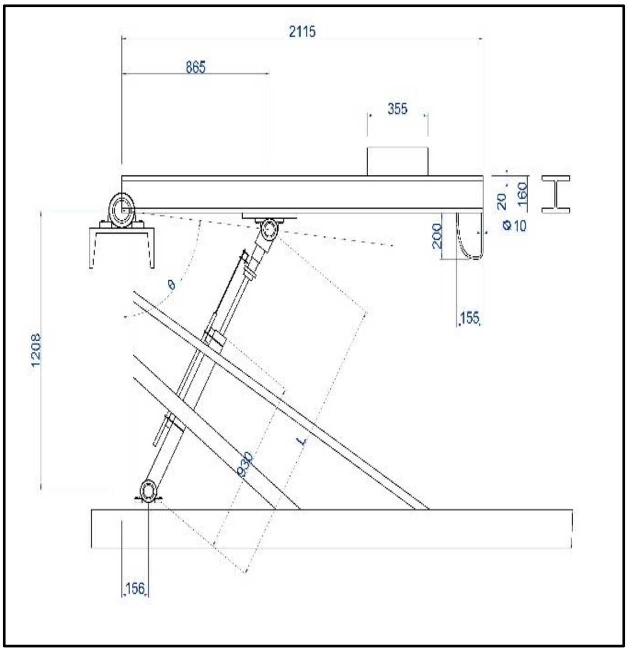

Fig-5: CAD drawing of the loading mechanism

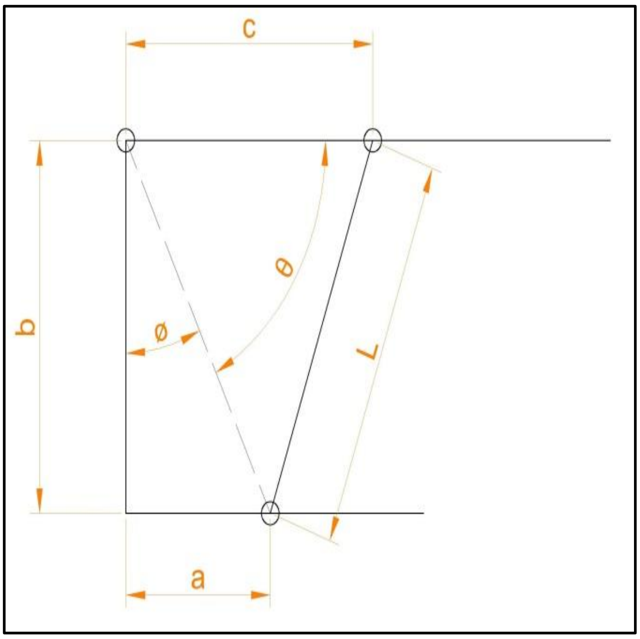

Fig-6: Loading mechanism kinematics

Hence:

The dashed line=$\sqrt{a^2+b^2}$

$$L^2 = a^2 + b^2 + c^2 - 2c\sqrt{a^2+b^2}\cos(\theta)$$

$$L = \sqrt{a^2 + b^2 + c^2 - 2c\sqrt{a^2+b^2}\cos(\theta)} \quad (2.1)$$

Where a, b, c, and ø are constants, the length of the linear actuator can be obtained by knowing (θ).
Where: α = ø + θ

3. HYDRAULIC COMPONENTS

3.1 Pump

Rexroth pump type (A10VG) is used which is an axial piston variable pump with integrated boost pump and swash plate designed for hydrostatic drives in closed circuits. Flow is proportional to drive speed and displacement. This pump generates controls and regulates a hydraulic fluid so, flow can be steplessly changed by controlling the swash plate angle via two proportional solenoids (A, and B), with the following main specifications.

Table-1: Pump main Specifications

Size (V_{gmax})	18	cc/rev
Control Method	Proportional Solenoid	24 Volts
Max pressure	250	Bar
Min/Max Rotation Speed	500/4000	RPM
Boost Pump Pressure/size	18 to 25/ 5.5	Bar/cc

The swash plate is mounted for easy motion in swivel bearings and the neutral position is spring centered. Pump output flow increases with the swivel angle of the swash plate from 0 to its maximum value, flow direction changes smoothly when the swash plate is moved through the neutral position. If the swash plate is not swiveled out, the displacement is equal to zero. Depending on the preselected current I at the two proportional solenoids (A, and B), the stroke cylinder of the pump is supplied with control pressure via the electro-proportional (EP) control unit. Thus, the swash plate angle and, the displacement are infinitely adjustable. One direction of the flow is assigned to each proportional solenoid. The pump internal relief valves are preset to 250 bar as maximum pressure.

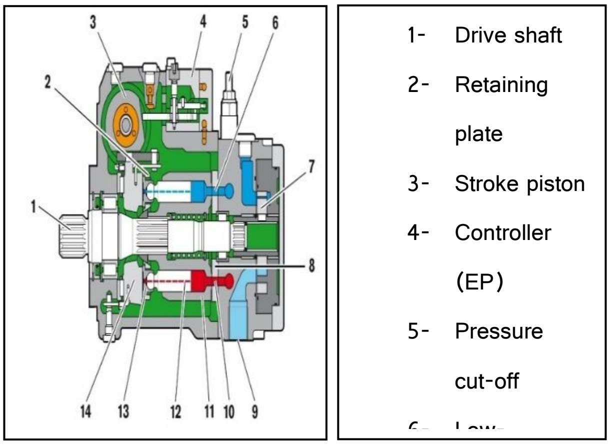

Fig-7: Pump components

3.1.1 Boost (Scavenging) Pump

The boost pump is an internal gear pump which is driven directly via the drive shaft of the main pump. It continuously supplies a sufficient volume of fluid from a tank to the low pressure side of the closed circuit via a check valve to replenish the internal leakage of the variable pump and consumer. This pump also, acts as a feed and control fluid pump, the maximum boost pressure is limited by a built in boost pressure relief valve with 25 bar as maximum pressure.

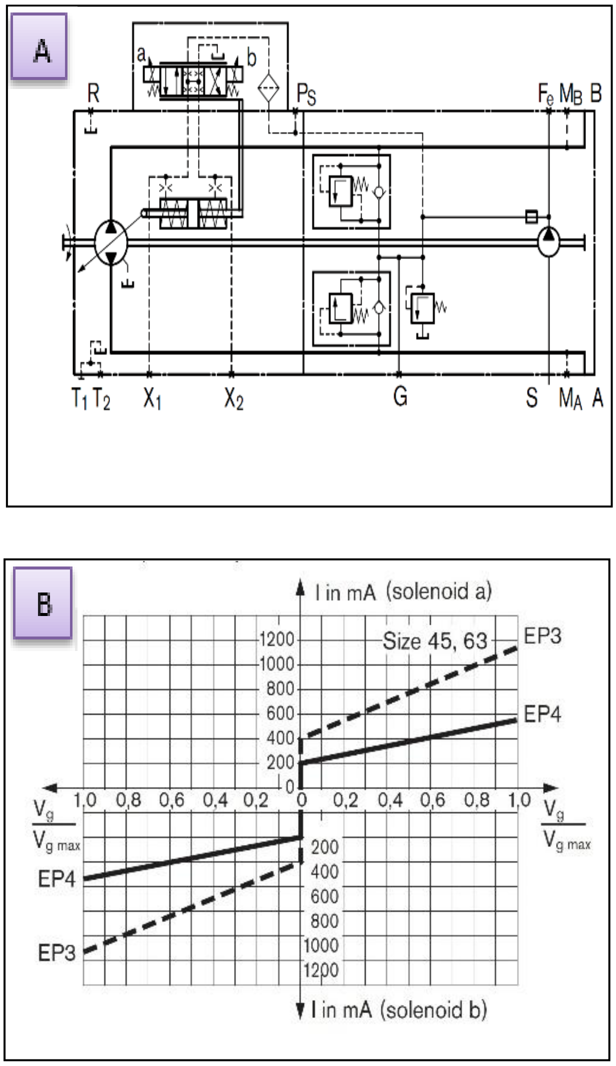

Fig-8: A: Pump internal circuit B: (EP) Controlling current

3.2 Hydraulic Cylinder

A double acting hydraulic cylinder is used with the following specifications:

Table-2: Hydraulic cylinder specifications

Cylinder Diameter	55	mm
Rod Diameter	25	mm
Stroke	900	mm
Ends Assembly	Hinged	Both Sides
Ports Diameters	10	mm

3.3 Accumulator

Hydac bladder type accumulator, its pressure vessel is four liters volume, the flexible bladder with gas valve and the hydraulic connection with check valve.

3.4 On-Off Valve

Solenoid controlled 2x2 on/ off valve with 12 volts, 250 mA supply.

3.5 Relief Valves

Two identical relief valves size 8 mm manually adjusted with 350 bar maximum pressures.

4. MEASUREMENTS

In this section the measured criteria and instrumentations will be discussed

4.1 Hydraulic Cylinder Displacement Measurement

Displacement of the hydraulic cylinder is considered to be the output of the whole system by measuring it its velocity and acceleration can be calculated and plotted by differentiate displacement readings with respect to time. A linear potentiometer with 8500 mm stroke, resistance 5k ohm and 5 volt power supply is used for that. The linear potentiometer is fitted to the cylinder in parallel position with fixed end and ball and socket in the other one.

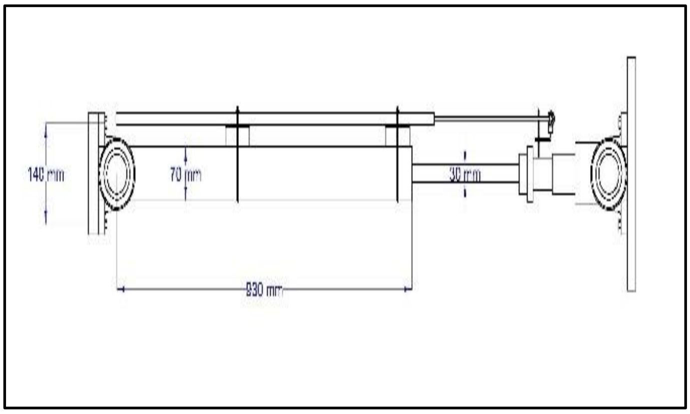

Fig-9: Linear potentiometer mounting

4.2 Pump Port (A) Pressure

For measuring the pressure of pump port (A) which is the delivery side in the case of hydraulic cylinder ascending. A Rexroth strain gauge pressure transducer with 12 volt supply, 0 to 5 volts output, and 150 bar maximum permissible pressure is used.

4.3 Pump Port (A) Pressure

Pump port (B) is the delivery side while hydraulic cylinder descending process. An American Sensor with 12 volts supply, 0 to 5 volts output and 60 bar maximum pressure is used for measurement.

4.4 Pressure Transducer (c)

In order to monitor the pump condition during operating processes a BD sensor with40 bar maximum pressure and 5 volts supply was used for measuring the boost pump pressure.

4.5 Pump Angular Speed

For measuring the electrical motor angular speed an incremental shaft encoder is used which has a 12 volts power supply and a resolution of 360 pulse per revolution, and is fitted to the motor shaft by means of flexible coupling.

4.6 Hydraulic Fluid Temperature

Measuring fluid temperature is important to conduct measurements in the pump operating temperatures range and to not exceed the minimum or maximum temperature limits. A thermocouple type (J) is used with power supply, and transmitter to perform the temperature reading into voltage and send it to the DAQ as an analogue.

4.7 Acting Load

Honeywell load cell model 41 was used with 2000 N full scale range, 26 volts supply, and +/- 5 volts output. The load cell is fitted to the load mechanism to measure the normal loading only and keeping it away from pending and side loads.

4.8 Pump Torque

Pump torque is measured as the motor output torque by measuring the reaction torque on the motor case. A mechanism is designed to fit the motor supports on two ball bearings as shown in fig. a 10 N load cell is used to measure the reaction force on motor case to calculate motor torque.

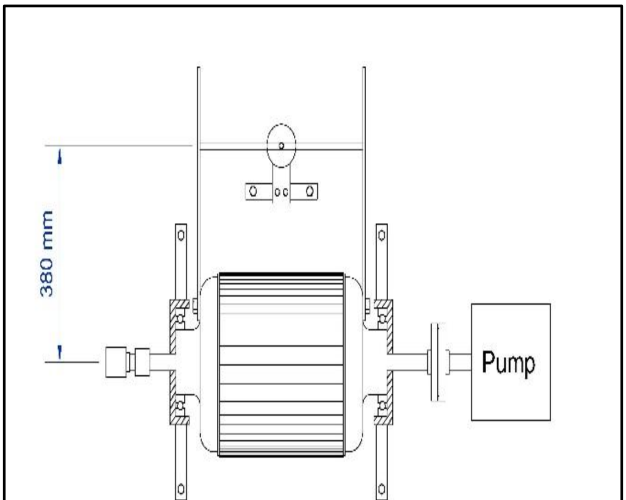

Fig-10: Motor torque measurement

5. TYPICAL TEST MEASUREMENTS AND RESULT GRAPHS

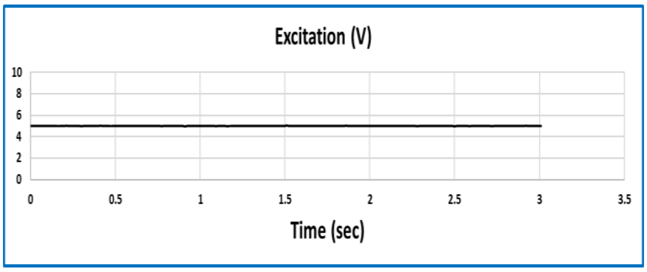

Chart-1: Excitation (pump input voltage)

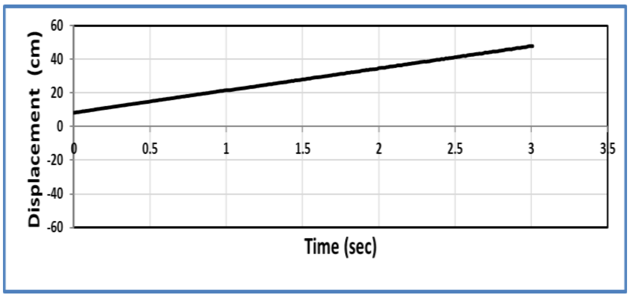

Chart-2: Hydraulic cylinderDisplacement

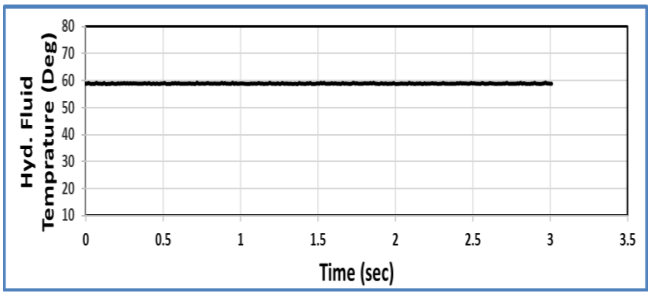

Chart-3: Fluid Temperature

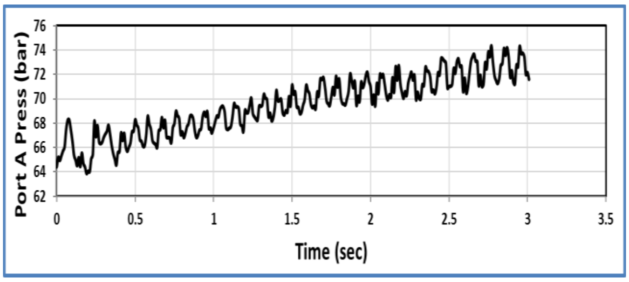

Chart-4: Port (A) Pressure

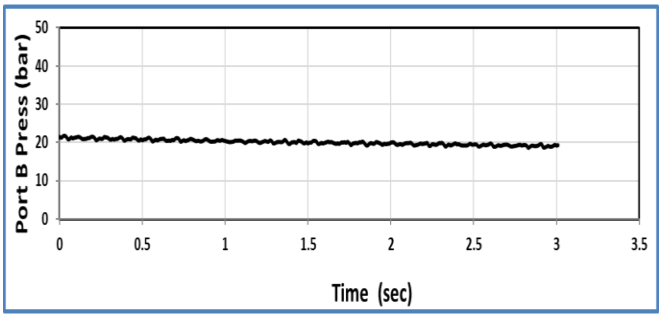

Chart-5: Port (B) Pressure

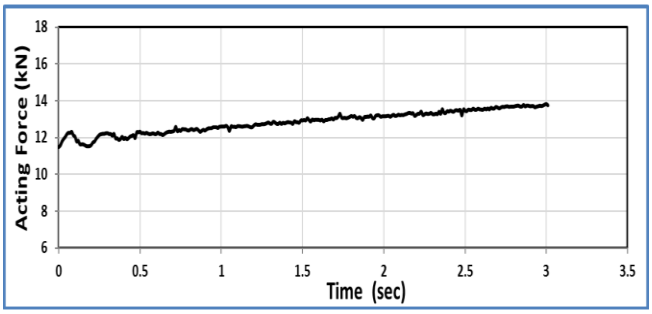

Chart-6: Acting Force

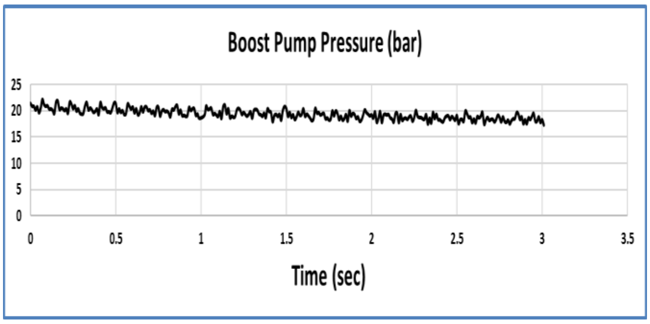

Chart-7: Boost Pump Pressure

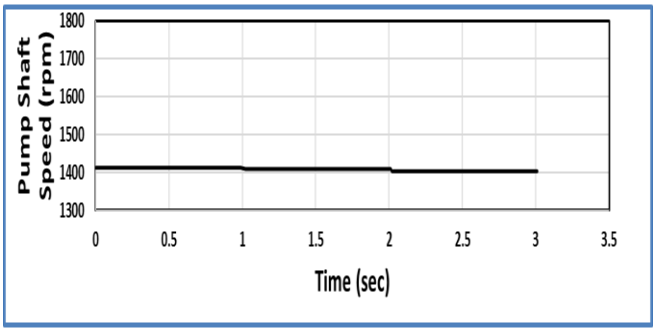

Chart-8: Pump Shaft Speed

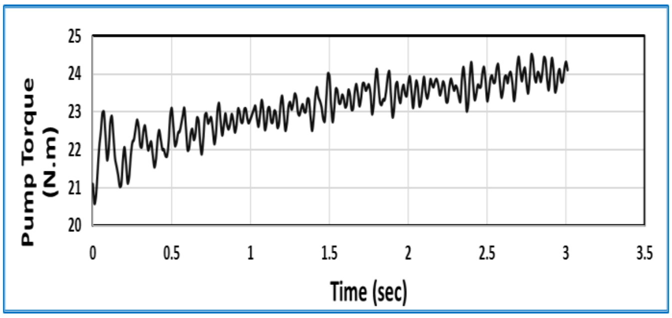

Chart-9: Pump input torque

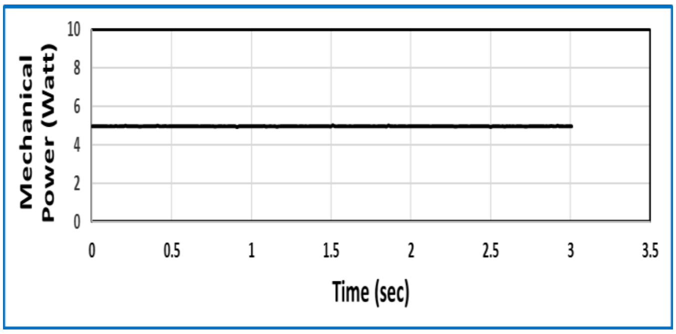

Chart-10: MeasuredMechanicalpower

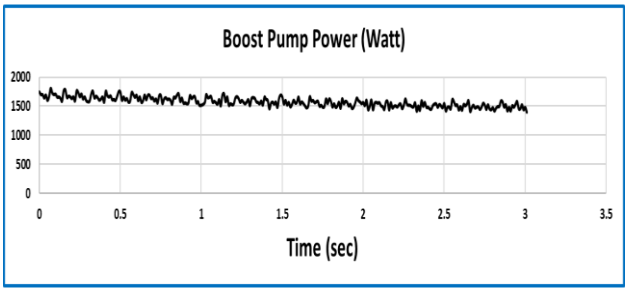

Chart-11: Boost pump power

Hence,
Hydraulic cylinder inner diameter D= 55mm
L… hydraulic cylinder displacement
V… hydraulic cylinder velocity.
P_A... Pump Port A pressure (hydraulic cylinder input pressure).
P_B… Pump port B pressure (hydraulic cylinder output pressure).
P_{out}… Pump output power.
P_{in}… Pump input power.
n… Pump rotational speed.
η … system efficiency.

$$P_{diff}=P_A - P_B$$

$$V=\frac{dL}{dt}$$

$$Q=\frac{\pi}{4} * D^2 * V$$

$$P_{out}=P_{diff} * Q$$

$$P_{in} = T * n * 2 * \frac{\pi}{60}$$

$$\eta = \frac{P_{out}}{P_{in}}$$

By measuring the aforementioned parameters from the test rig, and using of previous equations; the system efficiency can be estimated as follows:

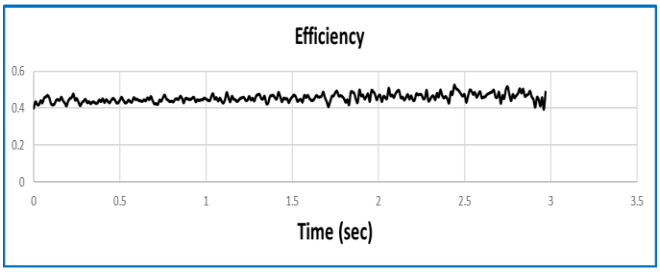

Chart-12: System efficiency

6. DISCUSSIONS

The hydraulic system and measuring instruments that has been demonstrated in this work showed that accurate measurements and precise calibrated transducers can characterize the performance of hydraulic circuit. System input and output power is calculated from measurements, so efficiency is easily estimated.

Depending on these results the system transfer function can be obtained and a system controller can be designed.

7. CONCLUSION

In this paper the output power is from 1300 to 1700 Watt and the boost pump power is from 1400 to 1750 Watt so, the system efficiency is relatively low (0.43 to 0.5) because of using small loads which need relatively small power.

The maximum power achieved by this type of pump is 75 KW so using of high power applications will lead to increasing the system efficiency up to 0.9.

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