Hydraulic Actuator Test Rig

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Declaration

I certify that this research work titled “Hydraulic Actuator Test Rig” is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

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Abstract

Hydraulic actuator is the main component in hydraulic power steering system of tractors and other hydraulic machinery. These actuators must be inspected to an acceptable level through an efficient inspection machine in order to prevent mechanical failure. Previous studies have shown that actuators with end of line quality testing perform well and enhance reliability and durability. Previous studies on analyzing industrial products through automated inspection machines make a significant contribution in the development of these products. In this research project , we have develop a fully automated hydraulic actuator test rig for hydraulic cylinder manufacturers for end of line quality testing. A series of advanced control valves combined with intelligent algorithm have been employed to measure the key performance parameters. Two external actuators have been connected with the central work piece actuator to enable the cylinder to cycle against an external load sufficient to maintain a constant operating pressure of 140 bar for 90,000 cycles. This will enable actuator to perform accordingly as per standard requirement in which total leakage shall not exceed 50ml/90,000 cycles. Hydraulic gear pump is used for fluid flow in the circuit. Hydraulic Pump is connected with eclectic 3-phase motor through couplings to transfer the hydraulic oil in hoses. Solenoid directional control valves, pressure distributor valve and pressure relief valves were used for maintaining the hydraulic oil pressure at 140 bar during endurance testing. Another test namely performance test has been performed on the hydraulic actuator in which piston keeps in between 25 mm and pressure on one side of the piston keeps at 240 bar for 1 minute and then pressure reduces to zero and than again pressure increases to 20 bar for 5 minutes. Same procedure was repeated on the other side of piston. Standard for this test requires no external leakage and internal leakage is set to be not exceeded than 5ml/minute during pressure test. Results of endurance test shows that leakage was not exceeded than 50ml/90,000 cycles. Results of performance test shows no external

leakage and internal leakage was not exceeded than 5ml/minute. The project research present an effective procedure to quality check hydraulic actuators with proof of the concept to actuators manufacturers. The new procedure is a significant improvement towards manufacturing more reliable actuators.
Key words: Hydraulic Actuator, Endurance testing, Performance testing

Contents

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Chapter 1

Introduction

Pakistan's agriculture sector plays a key role in its economy . Majority of the population directly or indirectly, dependent on this sector. It feeds whole rural and urban population. Hence , a significant progress in this sector correlates with the economic boost of Pakistan[1]. Importance of farm machines to enhance production is very significant in this industry. Tractors play a key role in agriculture. Among other parts , hydraulic actuator is very crucial part for working of tractor steering wheels. Recently Pakistani tractor industry has introduced the additional feature of hydraulic power steering on customers demand. This additional feature requires hydraulic actuator to be installed. Hydraulic actuators are being manufactured in Pakistani local industry. These hydraulic actuators have performed well in the steering control system of tractors. The hydraulic actuators are installed in the tractors without any prior testing so it is needed that quality assurance tests must be performed before installation. In Pakistan testing facility of these actuators are not available so it is need of the hour to develop the testing facility of the actuators. Hydraulic actuator test bench is developed so that actuators can be tested before installation. Hydraulic actuator test rig consists of oil pump, a.c motors ,external actuators and series of solenoid hydraulic control valves along with heat exchanger system. On this test bench actuator endurance and performance tests can be performed. In endurance testing , hydraulic cylinder shall be cycled against an external load sufficient to maintain a constant operating pressure of 140 bar for 90,000 cycles which ensures the actuator to work within leakage limit of 50ml/90,000 cycles and there should be no mechanical failure like wear and tear. In performance testing, Piston will be operated within 25mm of displacement. Pressure on one side of piston will be equal

to 240 bar for one minute and again pressure reduces to zero. Again pressure increases to 20 bar for five minutes. Same procedure repeated on other side of piston. There should be no leakage externally. Internal leakage rate shall not exceed 5ml/min during any pressure test.

Chapter 2

Literature Review

2.1 Hydraulic actuator

Hydraulic actuators use high pressurized hydraulic fluid to produce work in linear motion and force. Hydraulic actuators can be single or double acting according to the variety of power transfer applications. Single acting actuator are used to pressurized fluid in only one direction whereas double acting cylinders can be used to pressurized fluid according to required plane[2]. Important parameters for hydraulic actuators include maximum operating pressure, stroke length, bore diameter, rod diameter and actuator type. Hydraulic actuator is shown in fig 2.1. External actuator used for load on test piece is shown in fig 2.2.

Figure 2.1: Hydraulic actuator

Figure 2.2: External actuators for load on test piece

2.2 Hydraulic pump

Hydraulic gear pumps are such types of pump which convert mechanical energy into hydraulic energy of the fluid. Mechanical energy from rotation of gears is transferred into the fluid pressure at the outlet. Fluid flows around the teeth of the gears. Rotation of the gear causes suction at the inlet and fluid is transferred by gear pump [3]. Hydraulic pump used for cycling oil in hydraulic circuit is shown in fig 2.3 where hydraulic pump used for cycling oil in heat exchanger line is shown in fig 2.4

Figure 2.3: Hydraulic pump for cycling oil in complete circuit

Figure 2.4: Hydraulic pump for heat exchanger line

2.3 Electric motors

Electric motor converts electrical energy into mechanical energy. In industry three phase electric motors are widely used as these does not require any additional starting equipment. These are known as self starting induction motors [4] .These motors consist of two major parts. 1. A starter 2. A rotor

Three-phase Alternating Current (A.C) motors are widely used in industry for power conversion from electrical to mechanical energy. For small scale , single phase a.c motors are also used at industrial level. A.C (Alternating current) motor comes in two types namely Induction motor and Synchronous motor. 3-Phase Induction motors are used in this project. A.C motors used in this project are shown in fig 2.5 and fig 2.6

Figure 2.5: Three phase electric motor

Figure 2.6: Three phase electric motor for heat exchanger pump

2.4 Heat exchanger

Heat exchanger is a fluid powered device to remove heat from the system. It transfers thermal energy between two fluids without mixing them. Heat exchanger attached with system for maintaining hydraulic oil at required temperature. Heat exchanger used in the project is shown in fig 2.7

Figure 2.7: Heat exchanger attached with system for maintaining hydraulic oil at required temperature

2.5 Directional control valves

Directional control valves play a key role in hydraulic systems. It allows hydraulic oil into different paths from one or more sources. These valves are electrically operated that's why called as solenoid directional control valves. These valves consists of a spool inside a small cylinder which restricts or permits flow which controls fluid flow. Directional control valve is shown in fig 2.8

Figure 2.8: Directional control valve

2.6 Hydraulic distributor valve

Hydraulic distributor valve is used to connect pump and actuators. It lets the operator to observe flow of fluid through the system and also to control fluid flow with pressure relief valve. Hydraulic distributor valve used in the project is shown in fig 2.9

Figure 2.9: Hydraulic distributor valve

2.7 Pressure relief valve

Pressure relief valves are direct operated seat valves to limit pressure of a system. These valves act as a safety valve to control the pressure in the system. These valves are designed to open at a predetermined set pressure to protect hydraulic hoses from being subjected to pressures that exceeds their design limits. Pressure relief valve used in the project is shown in fig 2.10. Series of hydraulic solenoid control valves are shown in figures 2.11

Figure 2.10: Pressure relief valve

Figure 2.11: Series of solenoid control valve

2.8 Pneumatic solenoid valves

Pneumatic solenoid valves are used to control flow of air through pneumatic actuators. These pneumatic solenoid valves and actuators form auxiliary air circuits. Pnuematic solenoid valves are shown in fig 2.12

Figure 2.12: Pneumatic solenoid control valve

Pneumatic actuators are used to operate block gates of hydraulic cylinders during testing of actuators.

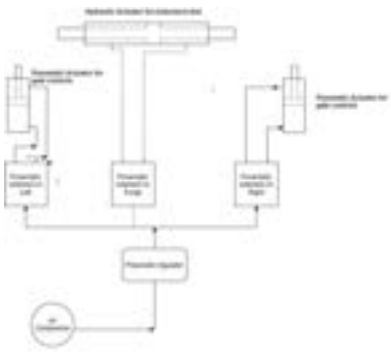

Figure 2.13: Pneumatic actuators block diagram

Figure 2.14: Pneumatic solenoid valve for purge

2.9 Couplings

Couplings are used to transmit rotating mechanical power of A.C motors to hydraulic pumps. One side of coupling is fitted with the input shaft of motor and other side is attached with the output shaft of hydraulic pump through which hydraulic fluid is directed [5]. Coupling used between A.C motor and hydraulic pump is shown in fig 2.15

Figure 2.15: Electric motor coupled with hydraulic pump through coupling

2.10 Oil flow metre

Oil flow meter is used to measure oil flow rate of fluid. The design of flow meter provides the operator with a direct visualisation of flow rate. This is a reliable method of measuring flow in high-pressure fluid systems. Oil flow meter is shown in figure 2.16

Figure 2.16: Oil flow meter

2.11 Oil level gauge

Oil level gauge sits inside the tank. It displays the level of oil remaining in the tank. Operator can manually visualise the level of oil in the tank and maintains a specific level. Specific gauge used in the project is shown in figure 2.17.

Figure 2.17: Oil level gauge

2.12 Float switch for oil signal

Float switch detects the level of oil in the tank. Switch floats on the top of the surface and act as a mechanical switch when oil level goes up and down [6]. This switch notifies the user about oil level and controls oil pump. Float switch is shown in figure 2.18

Figure 2.18: Float switch for oil signal

2.13 Thermocouple

Thermocouples are used to sense the temperature of oil in the tank. These are used in wide range of temperature measurement processes[7]. Thermocouple used in the project is shown in figure 2.19

Figure 2.19: Thermocouple

2.14 Hydraulic pressure sensor

Pressure sensor is an instrument consisting of a pressure sensitive element to determine the pressure applied to the sensor and convert into an output signal [8].Pressure sensor is used to measure pressure of oil in the running cycle. This pressure sensor acts as a transducer. Hydraulic pressure sensor is shown in figure 2.20

Figure 2.20: Hydraulic pressure sensor

2.15 Limit switches

Limit switches are used to detect the presence and absence of an object. These switches are electromechanical devices operated by a physical force applied to it by an object. Limit swtich is shown in fig 2.21

Figure 2.21: Limit switches

2.16 Oil filter

Oil filter protect hydraulic system from damage due to contamination. Hydraulic system contains contaminated particles which can cause damage to hydraulic system components. For the long life of hydraulic system, a good hydraulic filtration system is necessary. Specific oil filter used in the hydraulic line is shown in figure 2.22

Figure 2.22: Oil filter

2.17 Oil Tray

Oil tray is used to capture oil drips and spills from machinery. Oil tray is shown in figure 2.23

Figure 2.23: Oil Tray

2.18 Industrial computer/ DAQ

Data Acquisition is the process of measuring data from the system so that it can be analysed, displayed and stored in the computer. Data acquisition comprises a computer and a measuring system that can measure electrical and physical properties and save all that data for future use. Previously this concept of DAQ was mainly revolved around controlling and monitoring a physical quantity with the software[9]. DAQ computer is shown in figure 2.24

Figure 2.24: Industrial Computer

2.19 Proximity sensor

Proximity sensors are such sensors that detects the presence of an object without making physical contact with the object and converts that information captured into an electrical signal. As these sensors do not contact physically with the object thats why they do not damage the object [10]. Proximity sensors is shown in figure 2.25

Figure 2.25: Proximity sensor

Figure 2.26: Proximity sensor cover

2.20 Pneumatic Actuator

Pneumatic actuator converts energy in the form of compressed air into movement. There are two main types of actuators i.e linear and rotary. A linear actuator can move something in straight line. A rotary actuator can move something in a circular motion. Pnuematic actuators are shown in figure 2.27 and figure 2.28

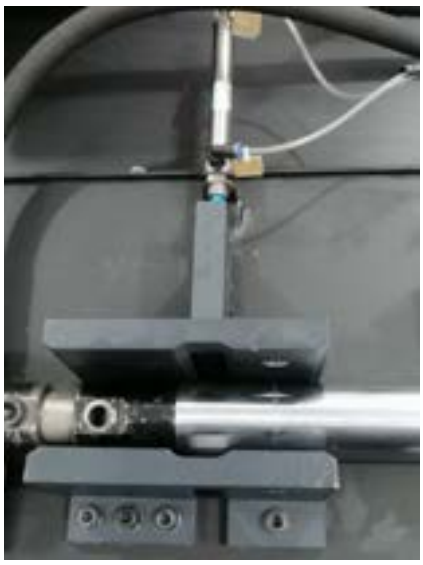

Figure 2.27: Pneumatic Actuator

Figure 2.28: Pneumatic Actuator

Chapter 3

Design and Methodology

Before the hydraulic actuator test rig design, the analysis of system dynamics and modeling is required. Test rig block diagram is shown in figure 3.1

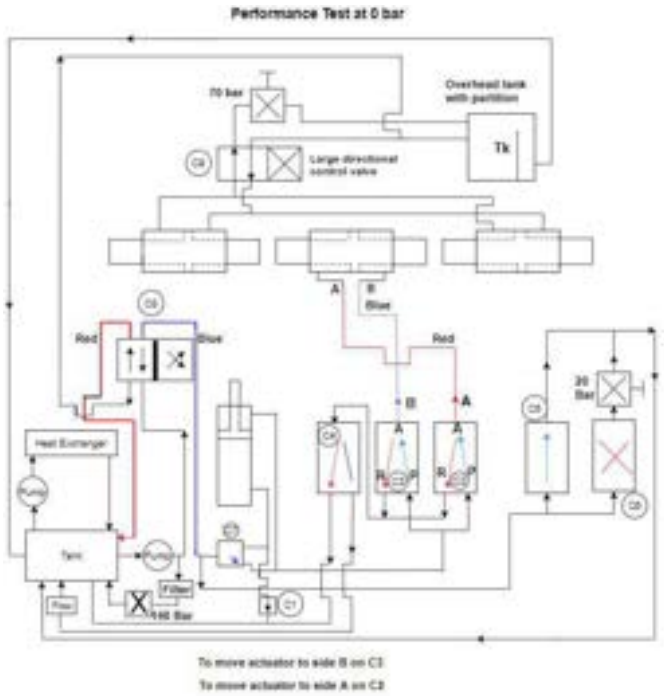

Figure 3.1: Test Rig Block Diagram

3.1 Hydraulic actuators test bench

In a hydraulic system as shown in figure 3.1, hydraulic cylinders were actuated with the hydraulic pressure through hydraulic fluid pump. This circuit is designed to manufacture a test rig for hydraulic cylinders which are being used in modern tractors. Hydraulic cylinders are used in hydraulic power steering's system of tractors. Steering technology plays a key role in tractors and all other vehicles. Previously mechanical steering's were used in tractors which were difficult to rotate the wheels. Tractor industries are using hydraulic power steering's. That's why we have made a test rig for these hydraulic actuators. Design , position of bars in assembly and final manufactured test bench is shown in figures 3.2 , 3.3 and 3.4 respectively.

Figure 3.2: Design of Hydraulic actuator test bench

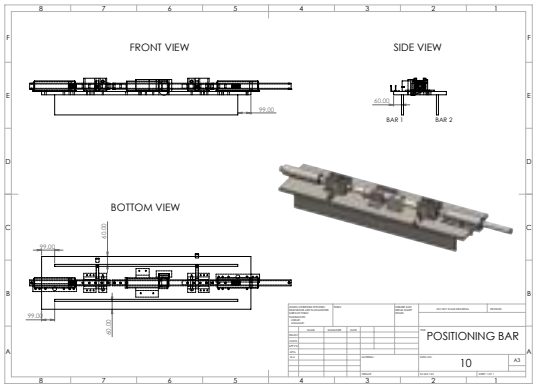

Figure 3.3: Position of bars in assembly

Figure 3.4: Final product of test bench

3.1.1 Base plate for actuators

A heavy duty mild steel base plate is designed for testing of hydraulic actuators as per testing parameters. Design of plate is shown in figure 3.5, a detailed deformation analysis of base plate is shown in figure 3.7 whereas Final product is shown in fig 3.8

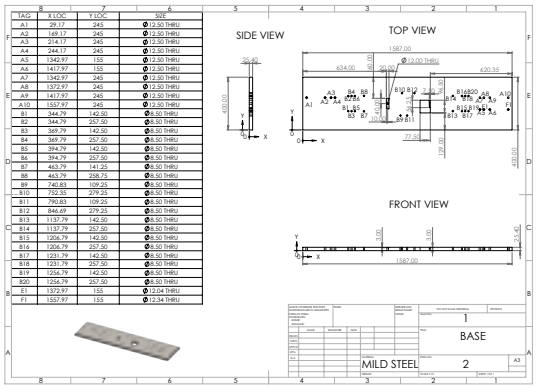

Figure 3.5: Base plate for hydraulic actuators

Figure 3.6: Deformation analysis for base plate

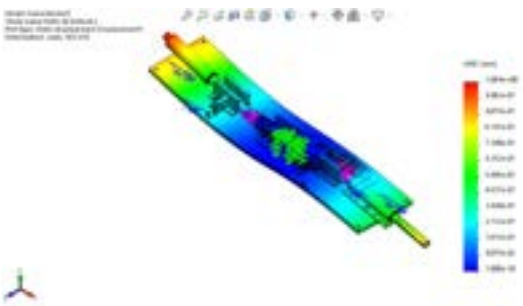

Figure 3.7: Deformation analysis for base plate

Figure 3.8: Base Plate Final Product

3.1.2 Fixtures for actuators

Fixtures like block stoppers, sliders , gates and stainless steel pins are used for support and blockage of actuators during performance and enduring tests. Their detail,design and final products are shown below.

Block stopper

Block stoppers are designed to support the actuators and align them as well as gates are slide and fixed in these stoppers on both side of test piece actuator for performing cylinder leakage test. Design of block stopper is shown in figure 3.9. Final product is shown in fig3.10

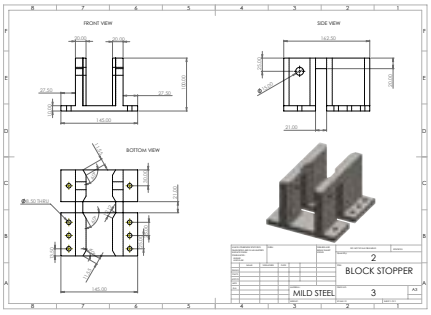

Figure 3.9: Design of block stopper

Figure 3.10: Final product of block stopper

Fixture for test piece

Test piece actuator is fixed and supported through a specially designed fixture which keeps the actuator fitted in cavity made in the base plate. Design and final product of fixture is shown in fig3.11 and fig3.12

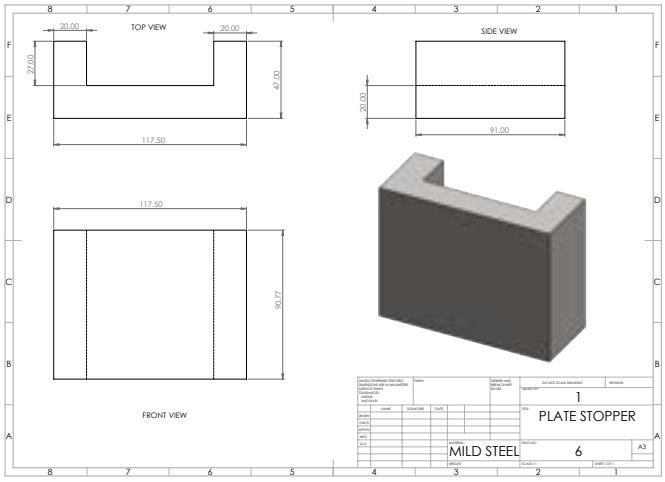

Figure 3.11: Fixture for test piece

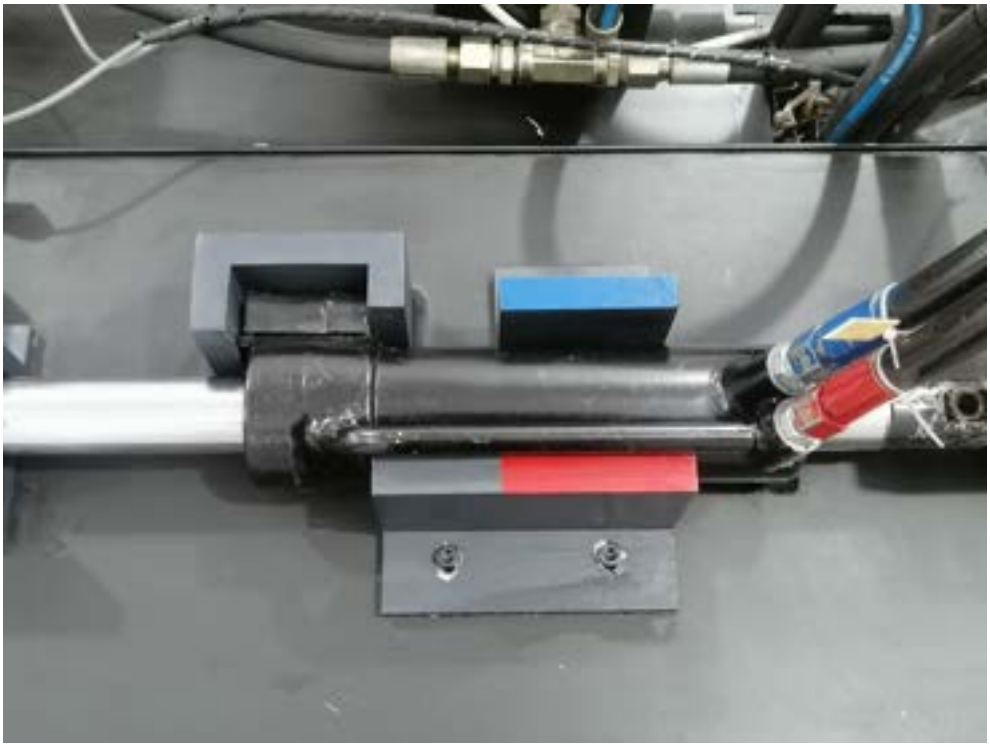

Figure 3.12: Fixture produced from final design

Supporting walls for central actuator assembly

Designs of supporting wall are shown in fig 3.13 and fig 3.14 and manufactured walls are shown in fig 3.15

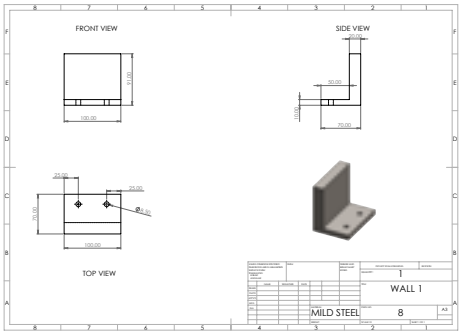

Figure 3.13: Design of supporting wall for actuator

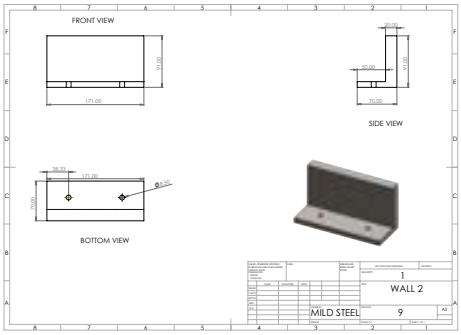

Figure 3.14: Design of supporting wall

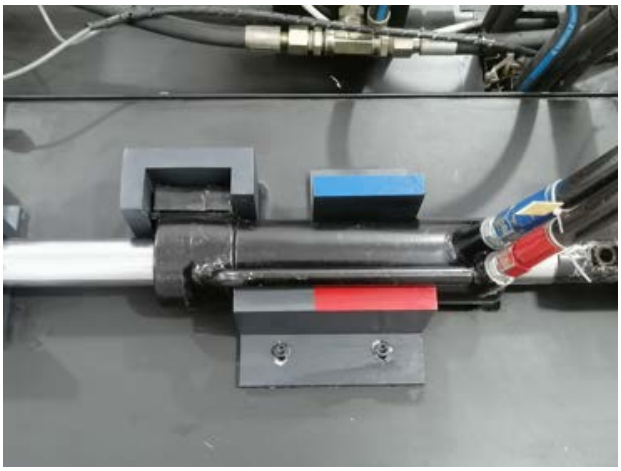

Figure 3.15: Manufactured supporting wall

Slider gate

Slider gate slides and fixed between block stopper through pneumatic actuators while performing cylinder leakage tests at 20 bar and 240 bar. Design of gate slider is shown in fig 3.16 and manufactured design is shown in fig 3.17 while gates operating with pnuematic actuators are shown in fig ??

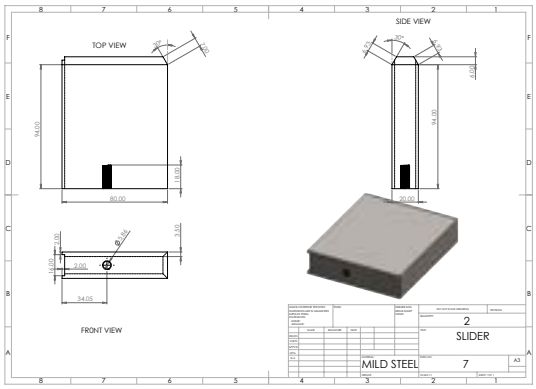

Figure 3.16: Design of slider gate

Figure 3.17: Manufactured gate slider

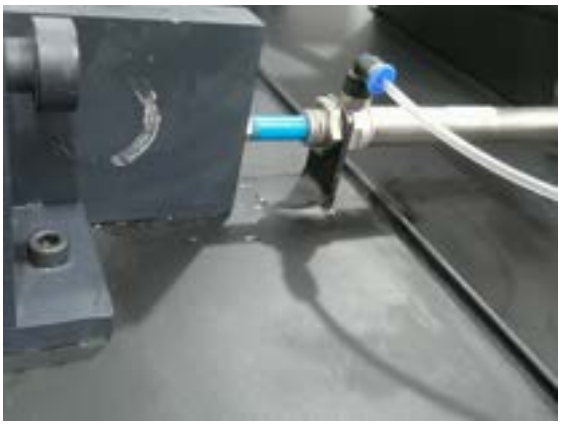

Figure 3.18: Gate operating with pneumatic actuator

Design of stainless steel pins

Design of stainless steel pin is shown in figure 3.19 and manufactured pin design , slider and gate are shown in figure 3.20

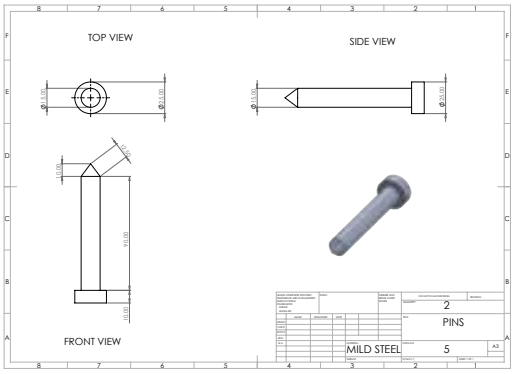

Figure 3.19: Design of stainless steel pin

Figure 3.20: Final product of block stopper,slider,pins

3.2 Actuators test bench

In these hydraulic actuators shown in figure 3.21, the central hydraulic cylinder is the test piece which has to be cycled against an external load sufficient to maintain a constant operating pressure of 140 bar for 90,000 cycles. Total leakage shall not exceed 50ml/90,000 cycles.

Figure 3.21: Test bench for hydraulic actuator

3.2.1 Connecting rod

In figure 3.21, external actuators are connected with central test piece hydraulic cylinder for load of 140 bar that is 70 bar from each external actuator through connecting rod shown in figure 3.22, seven holes are made on connecting rod for adjustment purpose.

Figure 3.22: Connecting Rod

Same connecting rod as shown in figure 3.22, is also used in tractors for connecting wheels with hydraulic power steering assembly as shown below in figure 3.23 while actuator fitted in tractor is shown in fig 3.24

Figure 3.23: Rod connecting steering wheel with hydraulic actuator

Figure 3.24: Hydraulic actuator fitted in tractor

Hydraulic actuator manufacturers need proof of concept to manufacture these actuators. This test rig will be able to give proof of the concept to manufacture hydraulic actuators for end of line quality testing.

3.3 Overhead tank

Overhead tank with partition was manufactured which serves as reservoir to provide the opportunity for air to escape from fluid before it is drawn into the pump inlet as well as it was also used to refill the system oil tank with a connected pipe. Manufactured oil tank is shown in fig 3.25. Hydraulic relief valve shown in fig 3.25 was attached in this circuit to maintain hydraulic pressure at 70 bar for each side actuators and a solenoid hydraulic distributor valve as shown in fig 3.25 was attached in the circuit for circulation of oil in both side actuators which was operated by the signals of proximity sensors as discussed earlier.

Figure 3.25: Overhead Tank with partition

3.4 Instruction manual for Operating test rig

Initialize system

1. Ensure the operator is fully trained and has taken all safety measures
2. Check oil level in the tank and pneumatic pressure
3. Turn ON DB box power supply
4. Power up the computer and start the software
5. Place the actuators on the test rig and connect the hydraulic hose pipes
6. Ensure hydraulic pressure control is at 0 bar

7. Run the oil pump

Testing actuators

1. Enter 20 bar on hydraulic pressure control
2. Prime the actuator by moving it end to end through the actuator side A/B controls
3. After priming , move the actuator to middle position and lock the gates using right / left lock controls
4. Start test by selecting Start/Cancel test cycle
5. At the end of the test results will be displayed on the pass/fail indicator
6. Drain the oil present in the actuator before removing
7. To drain the oil , select oil pressure 20 bar and move the actuator to one side. Disconnect the hydraulic pipe from the other side. Connect the air line and press actuator purge to move the actuator to the other side
8. Remove the actuators connections

Endurance test

1. Place the actuator in the designated location and keep the pipe connection in the performance test mode. Turn On the oil pump and select 20 bar pressure. Unload the external control valve. Remove the proximity sensor safety cover. Using the Left / Right buttons , move the actuators and insert the connecting links at both sides with threaded part directed towards the test actuators. Insert vertical pins
2. Turn Off the oil pump
3. Connect the hydraulic pipe in endurance test mode
4. Start the oil pump . Pressure will rise to 140 bar
5. Immediately click Endurance test button
6. Adjust the external load valve to 4 seconds cycle speed

Settings

1. The sensor gains can be adjusted from the Calibration settings
2. The test time can be changed from the Test Duration controls (time in seconds)
3. The leakage flow rate can be adjusted from the flow limit (ml/min)

Chapter 4

Results and Conclusion

The objective of this research was to develop a fully automated hydraulic actuator test bench for hydraulic cylinder manufacturer for end of line quality testing. A series of advanced control valves combined with intelligent algorithm measure the key performance parameters. Test rig was autonomous in performing the Endurance and Performance testing required by the industry to check the quality of hydraulic actuators by applying a constant operating pressure of 140 bar for 90,000 cycles. Test rig was fully automated. Desktop application was prepared to perform all the tests. A single operator can perform all the tests. Following tests were performed on test bench successfully.

1. Endurance Test
2. Performance test

4.1 Endurance test

In Endurance testing, hydraulic cylinder was cycled against an external load sufficient to maintain a constant operating pressure of 140 bar for 90000 cycles. Total leakage was not exceeded than 50ml/90000 cycles which was the requirement of test. Schematic diagram of Endurance test with endurance valve off and on is shown in figure 4.1 and 4.2 respectively.

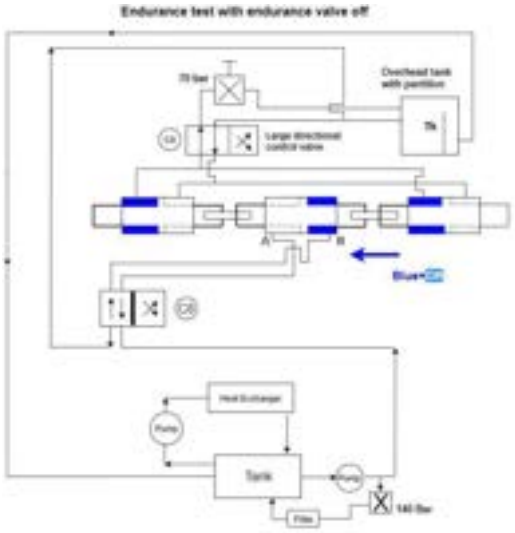

Figure 4.1: Endurance test block diagram with endurance valve OFF

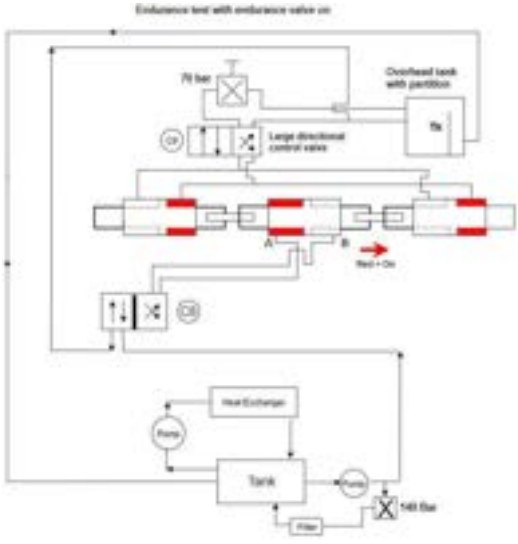

Figure 4.2: Endurance test block diagram with endurance valve ON

Failure definition

1. After completion of Endurance test, cylinder assembly have been compiled with the leakage requirements mentioned above.

2. Cylinder assembly exhibit no evidence of mechanical failure or excessive measure.

4.2 Performance test

In this test , piston of hydraulic cylinder was with in 25mm. Pressure on one side of piston was 240 bars for 60 seconds and then reduced pressure to zero bar and then again pressure was increased to 20 bars for 300 seconds that is 5 minutes. Procedure was repeated on the other side of the piston with same values of pressure and time. Leakage was not exceeded 5ml/min during any pressure test. Schematics of performance test with pressure at 0 bar, 20 bar and 240 bar are shown in figure 4.3, 4.4 and 4.2 respectively.

Failure definition

1. There was no leakage externally

2. Internal leakage rate was not exceeded 5ml/min during any pressure test

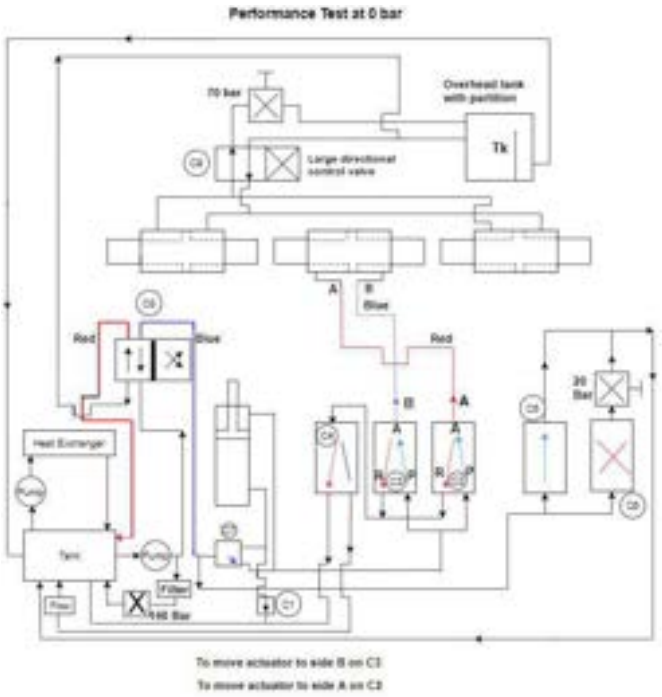

Figure 4.3: Performance test block diagram with pressure at 0 bar

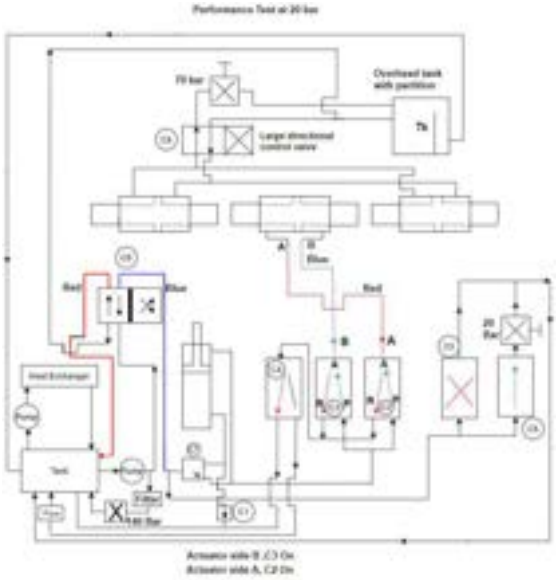

Figure 4.4: Performance test block diagram with pressure at 20 bar

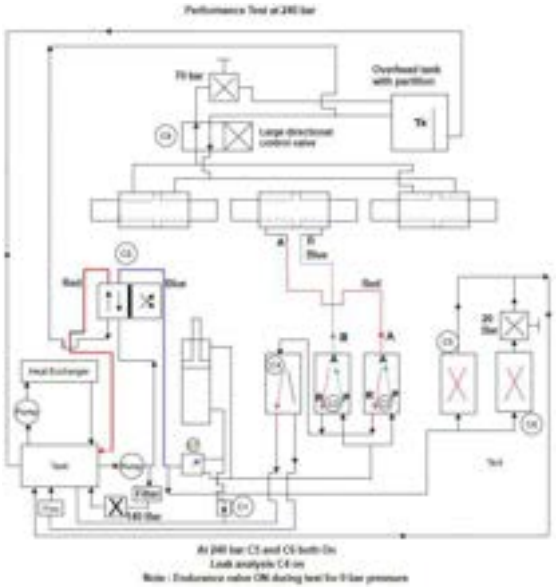

Figure 4.5: Performance test block diagram with pressure at 240bar

4.3 Conclusion

Following conclusions are drawn:

a) It is concluded that a fully automated hydraulic actuator test rig for hydraulic cylinder manufacturer for end of line quality testing is developed.

b) It is also concluded that a series of advanced control valves combined with intelligent algorithm measure the key performance parameters.

c) Desktop application was prepared for user interface.

d) Is is also concluded that the hydraulic cylinder cycled against an external load sufficient to maintain a constant operating pressure of 140 bars for 90,000 cycles.

e) It is concluded that no failure occurs during endurance and performance testing as per standard described in failure definition of both tests.

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