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Research Article

Designing of Hydraulic Forklift Circuit in Automation Studio^{tm} using Manufacturer's Catalogue

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Abstract

This project is based on the design of industrial hydraulic forklift circuit in Automation Studio™ simulation software which consists of three sections: 1) Hydrostatic power steering. 2) Tilt cylinders. 3) Mast cylinder. The details of each section is described as follows: 1) Hydrostatic power steering: The power steering unit is of Char-Lynn® steering control unit (SCU) of series 5 using metering unit for PID feedback control. 2) Tilt cylinders: These are each designed and tested for 4000 kg static and dynamic load, for an extension and retraction time of 3 sec. 3) Mast cylinder: It is tested for static and dynamic load of 4000 kg for extension and retraction time of 5 sec. The purpose of flow divider is also being studied here. Result shows that the new design is safe to use under working conditions.

***Keywords**: Hydraulic Forklift, Steering Control Unit, PVG Valve, Tilt Cylinder, Mast Cylinder, Manufacturer's catalogue, Flow divider, Automation Studio™ Software*

1. Introduction

In today's life, Forklifts have become one of the basic transportation tools. They are primarily used for lifting and transferring heavy loads to various stations or locations in warehouses, shops or construction sites. The industrial hydraulic circuit of forklift is built in Automation Studio™ Software which is a specialised simulation software for this domain. It has provided a computerised platform to construct virtual circuit model of forklift and test its various parameters saving enormous time and cost. The hydraulic forklift circuit is designed by using the manufacturer's catalogue of Parker and Eaton. The main feature of PVG valve over other valve is that it is load independent and load sensing. It saves the time and effort for loading and unloading and also reduces the fuel consumption to a great extend.

2. Literature Survey

1. Liai Pan, Qiulei Du, and Chunshan He. As a kind of industrial handling vehicles, forklift plays an indispensable role in people's life. Nowadays, in order to meet the needs of the people, the types of forklift are more and more. In this paper, based on already the basic parameters of the push forward forklift in the market, the working device of the forklift has been introduced. And according to the calculation and checking, the main structural parameters of the lifting oil cylinder have been determined. The hydraulic system has been designed and calculated. The results of the paper have important practical significance to design of work device of the forklift.

2.Aashishkumar L Sharnangat1, M. S. Tufail: We describe the development of robotic forklift intended to operate alongside human personnel, handling palletized materials within existing, busy, semi-structured outdoor storage facilities. The robot operates in minimally-prepared, semi structured environments, in which the forklift handles variable palletized cargo using only local sensing, and transports it while interacting with other moving vehicles.

3. Rahul B. Pandhare, Rajesh M.Metkar by Design Development and Automation of Hydraulic Broaching Machine This paper presents the design, modification and automation of hydraulic broaching machine by using simulation and automation tool as Automation Studio™. In automation, Accuracy and Precision are prime requirement for each machine tool. Controller, Solenoid valves, servo control valves are crucial components of any automation. Automation Studio™ can be used for design of automatic hydraulic machines. The Automation Studio™ tool helps to simulation, automation and design of hydraulic circuit. Automation Studio™ supports hydraulic, digital electrical and electronic technologies. The automation tool AS 5.7 helped to increase the productivity of

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broaching machine and to reduce the cycle time of broaching operation. The hydraulic broaching machine circuit has modified with solenoid operated valve and Automated by proximity sensor, proximity switch, electric JIC system. This electro-hydraulic automation results into the reduction of production cycle time and increase in production by 78 jobs/day. In this way, simulation of hydraulic broaching machine on Automation Studio™ approaches proved to be in good agreement. This study also helps for working of actual hydraulic system and gives results after simulation on Automation Studio™ of hydraulic system.

4. Narendra Rathore by Design of Hydraulic Circuit and Hydraulic Loss Calculation for Pre-Installation Check of Landing Gear Jack Accessories Universal test rig is the testing bay unit where we can test pressure and flow proof for line replacement units. This paper is about the design of test hydraulic circuit for the various pre-installation checks. Here the first challenge is to design hydraulic circuit for pre installation check of the different landing gear jack accessories. Here we have discussed about how the pre-installation check is work for landing gear accessories. Hydraulic circuit is the important part to test it. An effective design of hydraulic circuit is important to minimize the head losses. Based on different design parameter hydraulic circuit are designed and simulated over the Automation Studio™. During the pre-installation check there is significant head loss occurs. In this research there is calculation of head loss by analytical method as well as by AUTOMATION STUDIO™. Both results have been compared here and the variations in the pressure loss results are less than 8%.

5. Manar Abd Elhakim Eltantawie by Design, Manufacture and Simulate a Hydraulic Bending Press A small hydraulic press for V-bending operation is designed, manufactured and modelled. The hydraulic bending press consists of hydraulic circuit, punch, die and PLC control unit. Automation Studio™ and SimHydraulic in Matlab/Simulink library are used to model the hydraulic circuit. Using PLC program, the bending operation is controlled. The press had to be capable of withstanding 2 tons of force. The punch and dies are designed to be rigidly fixed and easily removable, changeable to any kind of forming operation with decreasing of spring back effect of the sheet metal.

6. Cheng Y.lin, Gary.R.Crossman This paper describes the development of the Automation Control Lab in the Mechanical Engineering Technology Program of the Engineering Technology Department at Old Dominin University. The reorganization goal of the development is to help students design, test and implement their automation designs effectively. Three processes are adopted to achieve this goal: (1) floor plan design and inventory control of the components (2) using Automation Studio™ to dynamically check each design and (3) using industrial Programmable Logic Controllers (PLC) controllers to download PLC programs.

3. Design Consideration for Hydraulic Circuit

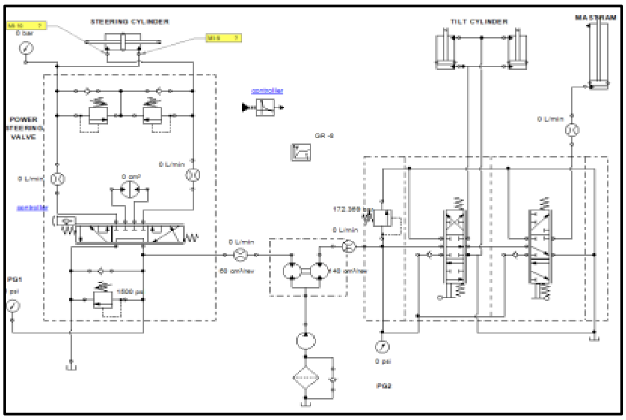


Fig.1 Hydraulic forklift circuit

For designing any component, the design considerations are very important. The following are the steps and design considerations for building the above hydraulic forklift circuit:

a) Power source: The main source of the hydraulic circuit is the hydraulic pump which converts the mechanical energy into hydraulic energy.

The main pump is of the Parker Series PV (Axial Piston Pump).

The specifications are considered for the pump:

Displacement = 200 cm^3/rev
Rated Speed = 1500 RPM
Rated flow = 300 L/min

a) The system has two distinct sections-steering section and operating section.

The pump would be directly being connected to the steering section and operating section. Due to the direct connection of the pump, it causes imbalance of high amount of pressure and flow to both the sections. Therefore, the flow divider is used to get the rid of this situation and to keep the two sections isolated. The total displacement of the pump is divided 60 cm^3/rev and 140 cm^3/rev to the steering unit and operating unit respectively.

The steering unit: The flow divider divides the flow 1/3rd to the power steering unit. Steering unit block is of the Char-Lynn® steering control unit of series 5 of the Eaton Company. This means there is no mechanical connection between the steering unit, the pump and the steering cylinders. The unit consists of a manually operated directional control servo valve and feedback meter element in a single body. It is used principally for fluid linked power steering systems but it can be used for some servo-type applications or any application where visual positioning is required. The steering control response from 0 to 100% for 1 sec.

For obtaining accurate control on the steering, the metering unit is used as a feedback to the system.

The steering unit of series 5 is selected such that the maximum pressure of this system is not more than 140 bar and the maximum flow is 19 L/min. The main feature of this valve is the load sensing, open centre, manual steering check valve and anti- cavitation valve.

b) Operating section: The operating section receives the flow rate of 210 L/min. It consists of the PVG block, flow divider, tilt cylinders and mast cylinder. The PVG block of VO40 Model of the Parker Company is selected. The VO40 is an open centre directional control valve with the flexibility of sectional construction. Consistent with this technology, it is simple in its application, reliable, easy to troubleshoot, and cost effective. It can handle for maximum system, the pressure is 300 bar and maximum flow rate is 40 L/min. The main features of the valve are load independent, load sensing and pressure compensated valve.

c) Tilt Cylinders: Assume that the tilt cylinders are at 60^0 inclinations, extension and retraction time = 3 sec, piston stroke = 200 mm and the external load = 4000 Kg including the self-weight = 100 Kg independent such that both the cylinders are synchronized in static and dynamic conditions. The logical solution behind the synchronization, the flow divider divides the flow at 50-50%. Both the piston extracts and retracts from 0 to 100%.

d)Mast Cylinder: Assume that the mast cylinder is at the inclination of 90^0, piston stroke = 1500 mm, extension and retraction time = 5sec, static load = 4100 Kg (including external load = 4000 Kg and self-weight = 100 Kg). For dynamic condition, consider 100 Kg constant load with resistive force curve.

4. Design of Main Pump and Flow Divider

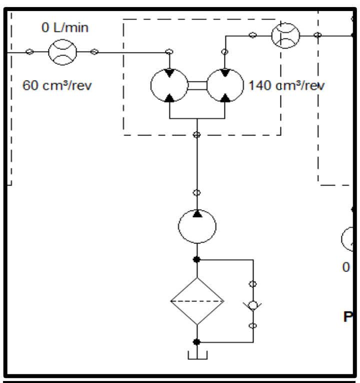


Fig.2 Main pump and flow divider

Figure-2 shows the basic parts of main pump, the rated flow of 300 L/min and connected to the flow divider. The flow divider is the device which divides the flow proportional equally or unequally to the steering unit or proportional unit. As the displacement of the pump increases, the pump rated flow also increases. The flow divider divides the flow in lesser amount to the steering unit and higher amount to the hydraulic actuation.

4.1 Pump

Hydraulic pumps are used in hydraulic drive systems and can be hydrostatic or hydrodynamic. A hydraulic pump is a mechanical source of the power, it converts mechanical energy into hydraulic energy (hydrostatic energy i.e. flows pressure). It generates the flow with enough power to overcome pressure induced by the load at the pump outlet. Design the pump as per the specifications of the parker series PV (Axial Piston Pump).

4.2 Flow Divider

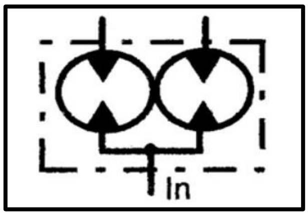


Fig.3 Flow Divider

In Rotary (motor type) flow divider consists of two or more hydraulic motors in the common housing. The biggest advantage of rotary type flow divider over spool type flow divider is energy transfer between the sections. Spool type flow divider can spilt the flow equally or unequally according to the orifice sizes. Therefore, the spool type flow divider is usually used at or near their rated flow. In most of the flow dividers, the fixed orifices are used. Due to this, the quality of the flow is poor, when it is used below their rated flow. If the flow exceeds the rating of the valve, it causes high pressure drop, poor performance and fluid heating.

The dividing accuracy of spool type flow divider can be close at 5 % depending on the pressure difference at the outlet ports.

Displacement on left side of the flow divider = 60 cm^3/rev

Output flow to Left side of the flow divider = 90 L/min

Displacement on right side of the flow divider = 140cm^3/rev

Output flow to right side of the flow divider = 210L/min

After setting the above values in hydraulic circuit, the steering section requires less flow and the actuating section requires more flow, as it is load carrying section of the circuit consisting of the tilt cylinders and mast cylinder.

5. Design Consideration of Steering Control Unit

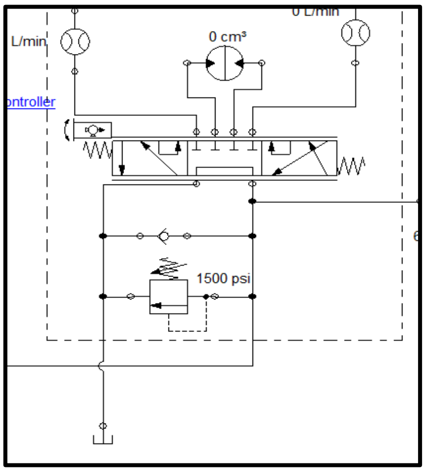


Fig.4 Steering control unit

The Char-Lynn® steering control unit (SCU) is fully fluid linked. This means there is no mechanical connection between the steering unit, pump and steering cylinders. The unit consists of a manually operated directional control servo valve and feedback meter element in a single body. It is used principally for fluid linked power steering systems but it can be used for some servo-type applications or any other applications where visual positioning is required.

The advantages of Char-Lynn power steering control unit are: It minimizes steering linkage, reduces cost, and provides flexibility in design. It provides complete isolation of load forces from the control station and provides operator comfort. It provides continuous, unlimited control action with very low input torque. It provides a wide selection of control circuits and meter sizes. It can work with many kinds of power steering pumps or fluid supply.

5.1 Series 5 Steering Control Unit

Fig.5 Series 5 Steering Unit

The Series 5 Steering Control Unit (SCU) provides best-in-class steering feel and better efficiency than competitive units.

Product Features

- The Load-sensing capabilities match performance to job requirements.
- Features of manual steering check valve, inlet relief valve, inlet check valve and integrated column for improved performance.
- Open-centre design and power beyond options deliver flexible application and operation.

Technical Information

- Max System Pressure 140 bar (2030 PSI)
- Max Back Pressure 10 bar (145 PSI)
- Max System Operating Temperature 93°C (200° F)
- Max Flow 19 L/min (5 GPM)
- Optional Relief Valve Settings
  - 40 bar (580 PSI)
  - 50 bar (725 PSI)
  - 70 bar (1015 PSI)
  - 90 bar (1305 PSI)
  - 125 bar (1812 PSI)

Features

1) Open Centre
2) Load Sensing
3) Manual steering check valve
4) Inlet relief valve
5) Load sense relief valve
6) Anti-cavitation valve

5.2 Pressure Relief valve

To set the pressure relief valve to 1500 psi as per design.

5.3 Proportional Servo Valve

In Automation Studio^{tm} design, first of all select the proportional valve from the library explorer.

Double click on the valve and select the number of spool and position as per requirement for building of valve.

Double click on the first position to select the desired spool. Repeat the procedure for remaining second and third position of the spool.

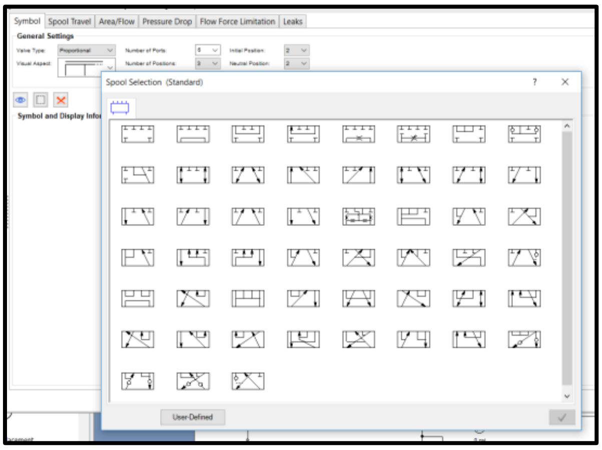


Fig 6. Different Types of the spool design

Add servo motor to the left by double clicking the question mark sign to the left-hand side.

5.4 Metering Unit

Select the metering unit from the library explorer.

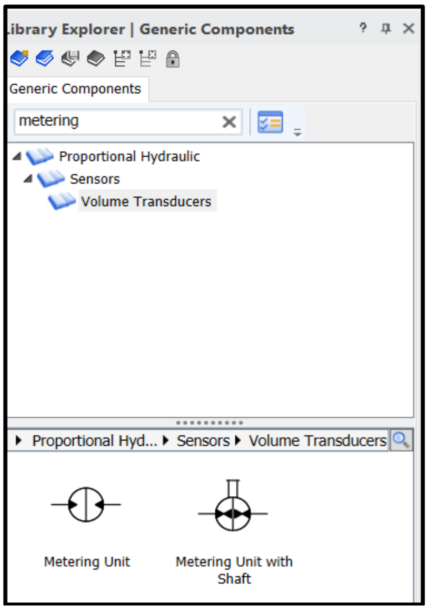


Fig 7.Metering unit in Automation Studio™

Double click on the metering unit and set the maximum displayed volume = 850 cm³ minimum displayed volume = -850cm³, maximum output signal = 10 and minimum output signal = -10.

5.5 Steering Cylinder

Select the double acting double rod cylinder from the library explorer.

Set the extension of cylinder to 50%.

In the builder option, click on the position sensor and set the maximum output signal position as 10 and minimum output signal position as -10 respectively.

In sizing sheet, design the steering cylinder. Calculate its stroke length for piston diameter of 80 mm and rod diameter of 30 mm.

Set the minimum output position range = -10 and maximum output position range= 10

6. PID Controller

In the designing of hydraulic system, PID tuning is done to increase the stability and to eliminate the steady state error. A proportional-integral-derivative (PID) controller is a control loop feedback mechanism. It is widely used in industrial control systems. A PID controller calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable.

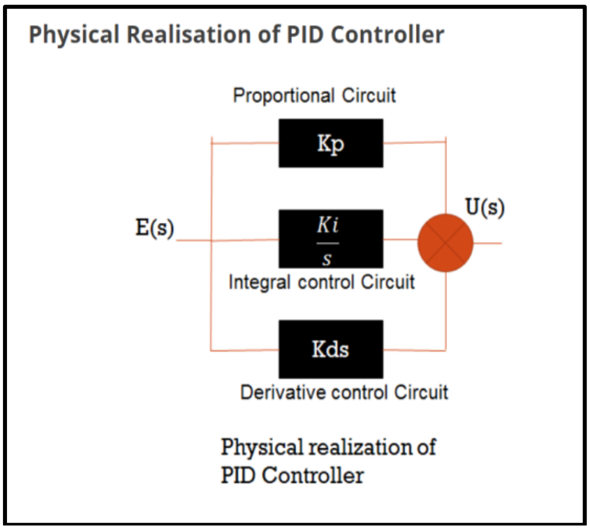


Fig.8 PID Controller

1. A proportional gain will have the effect of reducing the rise time and it will reduce but never eliminate the steady start error.
2. An integral gain will have an effect of eliminating the steady state error but it will make the transient response worst.
3. A derivative gain will have the effect of increasing the stability of the system, reducing the overshoot and improving the transient response but little response on rise time.

6.1 PID Tuning for Steering Unit

Select the control device from proportional hydraulic →sensors→ control device. Name it as controller

Select the y (t) graph from set point devices →y (t) Graph Variable generator.

Link the servo motor to the controller by double clicking the valve then servo motor to the left top corner and in variable assignment link it to the controller.

Then click on data and in operating condition set the parameter as:

Maximum Force = 120 N
Minimum Force = -120 N
Maximum signal = 10
Minimum signal = -10

Double click the controller. In output variable, write the equation as in the control device output. H82.OutputSignal -H59.OutputSignal.

Double click on the y (t) graph variable generator. Activate AUTO and LOOP mode.

In technical specification set the graph as shown.

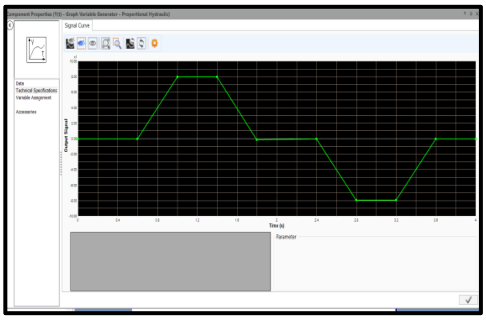


Fig.9 Setting the y(t) generator curve

Plot the graph of steering cylinder and y (t) graph verses time by selecting the first plot. Simulate it.

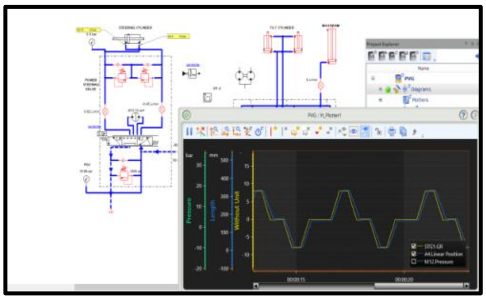


Fig10.PID tuning

Double click on the controller while simulation and set the proportional gain = 4, integral gain = 1 and derivative gain = 0.

7. PVG (Proportional Valve Group) Valve

Load independent proportional valve for the application of the hydraulic forklift with the flow up to 90L/min and pressure up to 2500 psi. Valve selected for the hydraulic forklift is the Parker VO40 Open Centre directional control valve.

Parker VO40 open centre PVG valve:

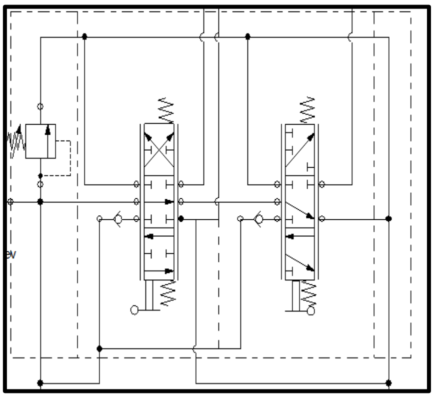


Fig.11 Parker VO40 open centre PVG valve circuit

7.1 VO40 Open Centre Valve Operation

In the open centre parallel circuit, oil flows through the open centre passage when all of the spools are in the neutral. When spools are shifted, the oil is diverted into the parallel path and available to each of the selected work sections. Simultaneous operation can be achieved, when two or more spools are selected

Specification:

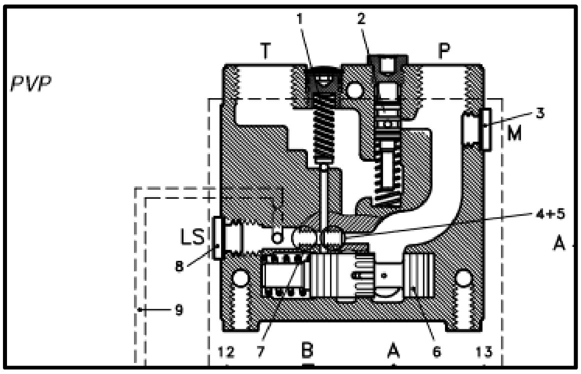
Pressures	Inlet port: 300 bar (4350PSI) Tank port:50 bar (725PSI) Work port: 300 bar (4350PSI)
Flow rate (maximum recommended)	40LPM (10.6 GPM)
Internal pilot pressure	Required for solenoid- contact parker
Spool leakage from work port to tank	Max. 6 ml/min@172 bar (2500 PSI) Oil temp. 50^{0}C (122^{0}F) and viscosity 40cSt

Fig.12 VO40 Open Valve

7.2 Achievement load independent and load sensing in the proportional valve

Consider the inlet module of the hydraulic PVG valve which consists of the pressure relief valve for relieving the excess pressure in the system, pressure reduction valve for pilot oil supply used for reducing the pressure and flow is through the pilot line, pressure gauge connection for measuring the pressure at the point and orifice for increase or decrease in the flow through the system.

When load is increases, the opening of the orifice is made to open and allow flow to increase. This increases the load carrying capacity. When the load decreases, the opening of orifice is decreased which reduce the flow.



1. Pressure relief valve
2. Pressure reduction valve for pilot oil supply
3. Pressure gauge connection
4. Plug, open centre
5. Orifice, closed centre
6. Pressure adjustment spool
7. Plug, closed centre
8. LS connection
9. LS signal
10. Shuttle valve

Fig.13 Load independent and load sensing

In this way, the load sensing and load independent is achieved by adjusting the opening of the orifice, thus the flow increases or decreases whenever it is used.

7.3 Performance Curve

It is concluded that the pressure is directly proportional to the flow rate.

Pressure drop and flow rate are dependent to each other. The higher the flow rate through the restriction, greater is the pressure drop. Conversely, the lower the flow rate, lower is the pressure drop.

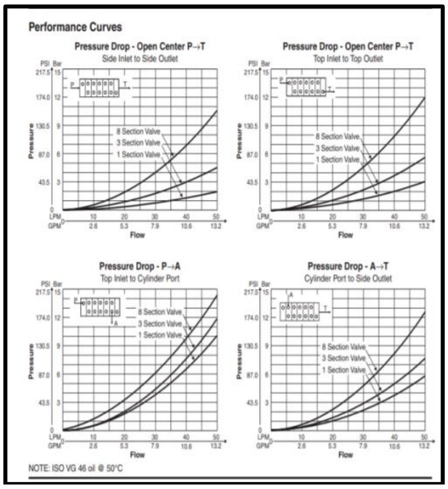


Fig.14 Performance curve of the pressure drop -Open Centre P→ T and pressure drop-P→A

8. Design of Tilt and Mast Cylinder

8.1 Tilt cylinder design procedure-

1) First of all we, assume that the stroke of the tilt cylinder is 200 mm, extension and retraction time = 3 sec.

2) In static design condition, the cylinder is designed for the stroke = 200 mm, extension and retraction time = 3sec, inclination = 60^0, static load = external load (4000 =Kg) + self-weight (100 Kg) = 4100 kg and Flow rate = 105 L/min independently.

Rod diameter and piston diameter is designed for such condition. We observed that the tilt cylinder extends one after the other without the flow divider. The same extension and retraction can be tested with flow divider.

3) In dynamic design, the resistive force curve of the both cylinder is set. Our main aim is:

a) To size the cylinder for resistive curve and assume that first strikes after the other.

b) To find the purpose of the flow divider.

a) To size the cylinder for resistive curve and assume that first strikes after other:

Prepare the new sizing sheet with

Outputs:

Piston diameter = 182.8183 mm

Inputs:

1) Extension time = 3 sec
2) External load = 4100 Kg
3) Gravity acceleration = 9.8 m/s^2
4) Inclination = 60^0
5) Piston side flow (extension) = 105 L/min
6) Piston side flow (retraction) = 105 L/min
7) Retraction time = 3 sec
8) Stroke = 200 mm

Transfer the parameter to the components. Now set the resistive force curve of both the cylinders as shown below:

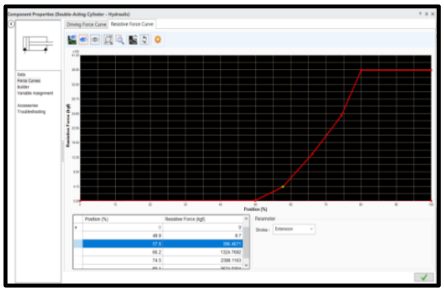


Fig.15 Resistive force curve of left tilt cylinder

Click on green tick mark to accept the change.

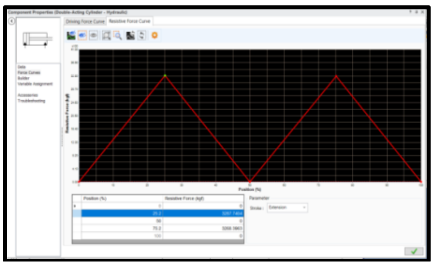


Fig.16 Resistive force curve of right tilt cylinder

Click on green tick mark to accept the change.

Plot the y (t) graph of piston side flow w.r.t time of both the tilt cylinder and simulate it.

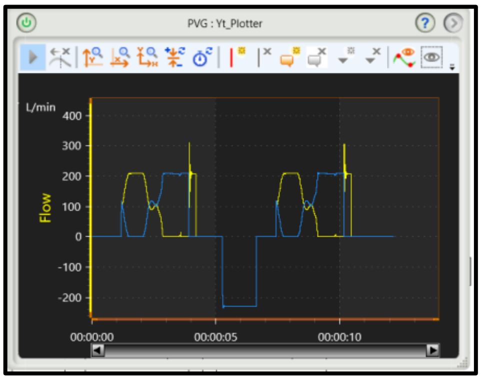


Fig.17 Piston side flow w.r.t time of both tilt cylinders without using flow divider

Plot the y (t) graph of the two cylinders for linear position verses time and simulate it.

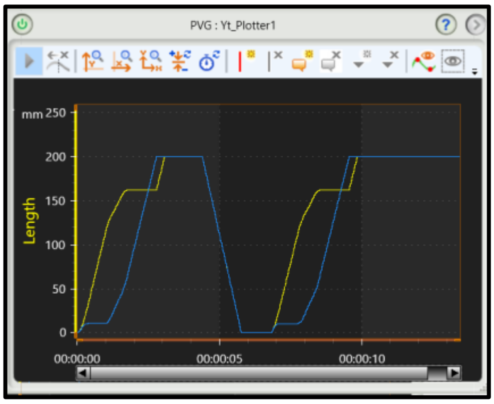


Fig.18 Linear position w.r.t time of both tilt cylinder without the flow divider

Now when we plot the graph of linear position verses time in y (t) of the tilt cylinder. We see that the linear position of the graph does not matches as the load on both the cylinder is different even though we take 50% of the flow on both the cylinder.

Also, when we plot the graph of the piston side flow verses time by y (t) of the tilt cylinder. The flow curve of both the cylinder is also different even though the flow is divided equally. In order to avoid the problem, so we use the flow divider.

a) To find the purpose of the flow divider:

Take the flow divider from the library explorer.
Set the displacement 1 = 70 cm^3/ rev
Displacement 2 = 70 cm^3/rev

Displacement is kept equal because the flow is equally distributed to both the cylinders for the extension and retraction.

Connect it to the tilt cylinders.

Now note down the changes in the plots of the piston side flow and linear position.

We see that the curves of the piston side flow and linear position overlaps each other that means the piston side flow in both the cylinder is equally distributed and also the linear position of both cylinder is same.

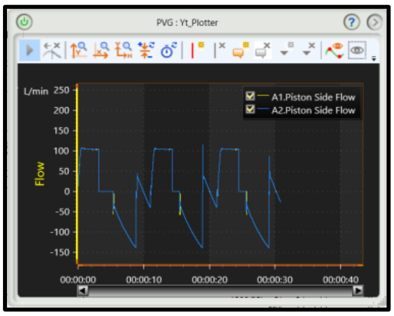


Fig.19 Piston side flow of both the tilt cylinders w.r.t time using flow divider

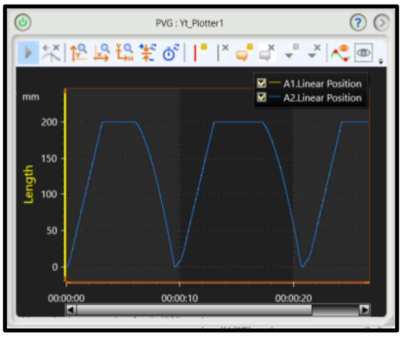


Fig.20 Linear position of both the tilt cylinders w.r.t time using flow divider

8.2 Design of the Mast cylinder of hydraulic forklift

Assume extension time = 5 sec
Retraction time = 5sec
Stroke = 1500 mm
Size the cylinder in the sizing sheet manager.
Output Variables:

Piston diameter = 121.8789 mm

Input Variables:
Extension time = 5 sec
External load = 100 Kg
Gravity acceleration = 9.8 m/s^2
Inclination = 90^0
Piston side flow (extension) = 210 L/min
Piston side flow (retraction) = 210 L/min
Retraction time = 5 sec
Stroke = 1500 mm
Transfer the parameter to the components.

Set the resistive force curve as shown in the figure. Take the ranges as:

Y maximum = 4100 Kgf
Y minimum = 0 Kgf
Click on tick mark sign.

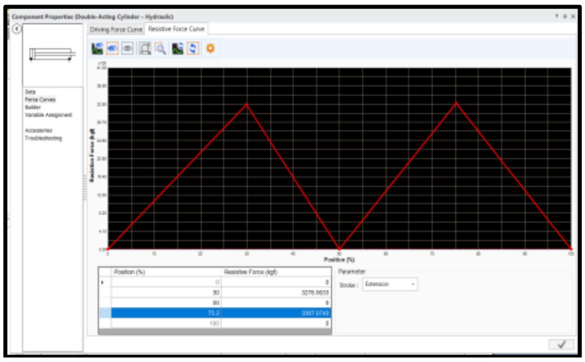


Fig.21 Resistive force curve of mast cylinder

After setting the resistive force curve, plot the y(t) graph of the mast cylinder of linear position w.r.t time and simulate it.

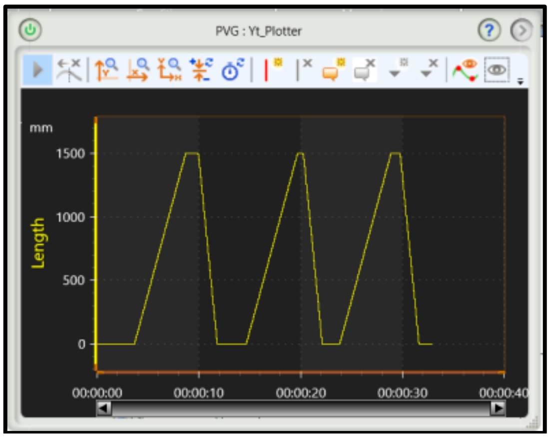


Fig.22 Linear position of mast cylinder w.r.t time during extension and retraction

Plot the y(t) graph of piston side pressure of mast cylinder and simulate it.

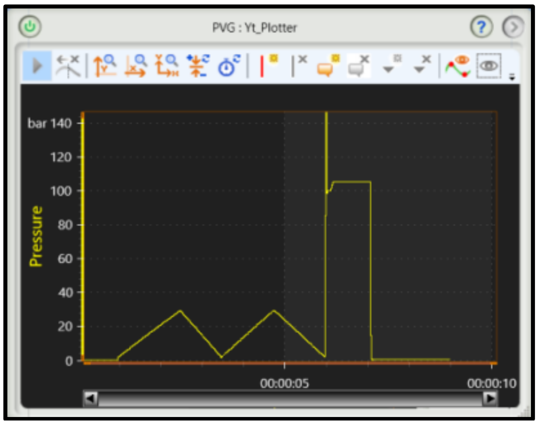


Fig.23 Piston side pressure w.r.t time of mast cylinder

Results and Discussion

For steering control unit

The results of steering control unit are tabled as below:

Sr.No.	Parameters being considered	Values
1.	Flow available to the steering unit	90 L/min (the flow is 1/3 rd of rated flow)
2.	System pressure	1500 psi
3.	PID signal range	-10 to 10
4.	Metering unit flow	850 L/min (for steering wheel and metering unit)
5.	Sizing of piston diameter(D) and rod diameter (d) to achieve the extraction and retraction timing in 1 sec	D = 80 mm d =30 mm L = 1000 mm
6.	PID Tunning is attend at	P = 4 I = 1 D = 0

For Operating unit -

The result of operating unit are tabled as below

Sr.No	Parameters being considered	Values
1.	Flow available at tilt cylinder	210 L/ min
2.	Operating or system pressure	2500 psi
3.	Sizing of tilt cylinder for static load for 0 to 100% in 3 sec	D=182.83 mm d= 30 mm α = 60 ^{0} L = 200 mm
4.	Piston synchronization flow divider is used for dynamic load	Flow divider valves = 210 L/min each Failure pressure = 60 bar
5.	Sizing of mast cylinder for static load for of 4000 Kgs. For piston extraction from 0 to 100 % in 5 sec	D = 121.88 mm d = 50 mm α = 90^0 L = 1500 mm

Conclusion

The design and simulation of industrial hydraulic forklift circuit was done under static and dynamic loading conditions using Automation Studio™ software. For designing purpose, the proper PVG Valve of Parker and Steering Control Unit of Eaton were selected from manufacturer's catalogue.

The important deductions are listed as below:

1.The PVG Valve of Parker VO40 was successfully designed under the operating parameters like rated flow, maximum operating pressure,etc to achieve the load sensing and load independent effect.

2. The PID Tuning was successfully done to increase the stability, eliminate the steady state error and achieve desired response.

3. The sizing of the tilt cylinders and mast cylinder was done successfully to meet the design requirements like external static and dynamic load, operating pressure, stroke, piston side flow, extension and retraction time,etc. In order to get the uniform extension and retraction, flow divider was used.

4.The Steering Control Unit (SCU) of Eaton of series 5 was selected and successfully designed with a metering unit as a feedback.

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