DEVELOPMENT OF A COMPUTER PROGRAM FOR STEADY STATE DESIGN AND SIMULATION OF OPEN LOOP HYDRAULIC POWER CIRCUITS

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Approval of the Graduate School of Natural and Applied Sciences.

Prof. Dr. İsmail TOSUN
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Rüknettin OSKAY
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Prof. Dr. Y. Samim ÜNLÜSOY
Supervisor

Examining Committee Members

Prof. Dr. Ömer ANLAĞAN

Prof. Dr. Y. Samim ÜNLÜSOY

Prof. Dr. O. Cahit ERALP

Prof. Dr. Demir BAYKA

Y. Müh. Fatih ÖCAL

ABSTRACT

DEVELOPMENT OF A COMPUTER PROGRAM FOR STEADY STATE DESIGN AND SIMULATION OF OPEN LOOP HYDRAULIC POWER CIRCUITS

Gül, Fırat
M.S., Department of Mechanical Engineering
Supervisor: Prof. Dr. Y. Samim ÜNLÜSOY

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A computer program has been prepared to interactively draw, design and, simulate the steady state operation of open-loop hydraulic power circuits. Basic concepts for open-loop hydraulic power circuits are compiled, and rules for drawing, design and simulation have been developed for the computer program.

A hydraulic power symbol library has been prepared and used in the program. For design operation, a databank containing specifications of commercially available components is included in the program. A facility for the user data entrance to the databank and data annulment from databank has been provided. Examples of drawing, design, and simulation using the program are illustrated.

Keywords: Computer aided Design, Open-Loop Hydraulic Power Circuits, Drawing, Design, Simulation.

ÖZ

AÇIK ÇEVRİM HİDROLİK GÜÇ DEVRELERİNİN SÜREKLİ ŞARTLARDA ÇALIŞMASININ TASARLANMASI VE SİMULASYONU İÇİN BİR BİLGİSAYAR PROGRAMININ GELİŞTİRİLMESİ

Gül, Fırat
Yüksek Lisans, Makina Mühendisliği Bölümü
Tez Yöneticisi: Prof. Dr. Y. Samim ÜNLÜSOY

Eylül, 1995, 116 sayfa

Açık çevrim hidrolik güç devrelerinin etkileşimli çiziminde, tasarımında ve sürekli rejimde simülasyonunda kullanılmak üzere bir bilgisayar programı geliştirildi. Açık çevrim hidrolik güç devreleri hakkında temel bilgiler derlendi ve bilgisayar programı için çizim, simülasyon ve tasarım kuralları geliştirildi.

Bilgisayar programında kullanılmak üzere bir sembol kütüphanesi hazırlandı. Tasarım operasyonu için çeşitli devre elemanlarının özelliklerini içeren bir bilgi bankası hazırlandı. Bilgi bankasına bilgi girişi sağlandı. Program kullanarak hazırlanan çizim, tasarım ve simülasyon örnekleri sunuldu.

Anahtar Kelimeler: Bilgisayar Destekli Tasarım, Açık Çevrim Hidrolik Güç Devreleri, Çizim, Tasarım, Simülasyon.

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LIST OF SYMBOLS

Q, q Flow rate

Δp Pressure difference between two point

F Force

T Torque

A Area

S Cylinder stroke

d Diameter

t Time

V Velocity

n Rotational velocity

v Displacement

C Orifice coefficient

f Friction coefficients

Re Reynolds Number

γ Specific weight

ν Kinematics viscosity

g Acceleration due to gravity

η_v Volumetric efficiency

η_m Mechanical efficiency

CHAPTER I

INTRODUCTION

1.1 Introduction

The thesis study aims to develop a computer program to be used for training students and helping engineers working with the Hydraulic Power Systems. The thesis is based on the preparation and development of a computer program, called "**Hydra D&S**", to draw, design, and simulate the steady state operation of open-loop circuits. This section covers basic rules about hydraulic power systems and components, program structure, design and simulation algorithms, constraints, and some example sessions prepared using the program.

The program "**Hydra D&S**" contains the basic elements to form workable hydraulic power systems. These elements do not have specific sizes or working conditions at the beginning. The user can draw circuits by using these components, and then can design and simulate the operation of the system. It is possible to save a complete system, modify it and eventually take a hardcopy of the system.

Hydraulic power systems consist of two basic groups, open-loop and closed-loop. In closed-loop systems output is controlled by a feedback mechanism in which a signal proportional to output is compared to an input or command signal and no feedback mechanism. The performance characteristics of the circuits are determined entirely by the characteristics of the individual components and their interaction in the circuit as well as with the environment.

In this thesis only open-loop circuits are considered. Design and simulation are based entirely on steady-state conditions, so transient behavior of the circuit is completely neglected.

Hydra D&S has a modular structure in drawing, simulating, and designing a circuit. It is written in the programming language "Visual Basic". In this language there are forms, modules, and custom controls like picture boxes, dialog boxes that are ready tools to directly use in any program. Each of these controls has its action type like click, mouse down, or some other; code input areas under these action names. When control is made active, the code under this control becomes active. Moreover to control procedures, which respond to a specific action, independent subroutines and functions can be written in a form or module. Although a procedure inside a module is available to other forms and modules, a procedure inside a form is not. Some features includes "if then else" blocks, loops, seven data types, numerous mathematical and string functions.

This study is hoped to provide a tool for drawing, simulation and design of open loop hydraulic power circuits for the practicing engineers. A second goal is the use of the program as a teaching tool in the particular area.

1.2 Literature Survey

Computer-aided design has given design engineers the most productive tool. Work on creating improved software for fluid power technology is continuing in the world and there are a number of programs available for different purposes. In particular, software for drawing hydraulic power circuits are quite popular. Most drafting packages also include a module for drawing hydraulic or pneumatic circuits with the associated electrical circuit. However, software including simulation are quite rare and usually very expensive. Design software on the other hand are practically nonexistent.

Commercially available software releated to fluid power circuits are compiled and described below [1].

Cylinder drawings for CAD, by Miller Fluid Power, includes 2-D, orthographic dimensional drawings of cylinders. Moreover, it covers heavy, medium duty hydraulic, pneumatic cylinders, rodless cylinders, rod end accessories.

Accumulator sizing software, by Greer Hydraulics, includes selecting and sizing accumulators to serve particular application. Program addresses variety of accumulator applications, from energy storage and shock absorption to suction stabilization.

CalCad has developed family of software. Software includes both schematic drawing with industrial and mobile hydraulic, pneumatic, and electric components and bill of materials.

Tabul Accumulator Inc. has created a program that performs 14 different calculations and sizing operations for accumulators in hydraulic systems for supplementing pump flow, providing emergency power, leak compensation, damping line shock or pump pulsation.

Parker Hannifin Corporation has developed two program, one is for valve drawing, the other is for cylinder selection.

HYDROWORKS software, by Tech Team Inc., is for hydraulic and pneumatic power schematics, library includes 600 symbols and bill of materials.

Salesmate software, by Aeroquip Corp., has developed for hose assembly selection. Software includes pricing data, specifications, full color product and application graphics, customer references on hose, adapters, and quick acting couplings.

Version 5.0 of CADSYM contains over 1350 electrical and 850 hydraulic and pneumatic symbols for circuit drawing purposes.

HydrauSim and PneuSim software, by Famic Automation Inc., contain extensive libraries of fluid power symbols for constructing schematics in metric or inch dimension. Once a system is drawn, software simulates operation by animating functions of components.

PneuCAD software, by Festo Corp., helps user design pneumatic circuit drawings. Library consists of standard DIN/ISO 1219 symbols for cylinders, drivers, directional, flow control and check valves, FRLs, vacuum components, sensors, and electrical components. Software also allows drawing custom symbols and combining frequently used components into macro assemblies.

In addition to these information about the software, Hydraulic & Pneumatic Magazine has compiled and tabled almost all software related to fluid power, see Appendix B [2].

CHAPTER II

BASIC CONCEPTS FOR THE DESIGN OF HYDRAULIC POWER CIRCUITS

In this chapter, basic information about hydraulic power systems is given. Since the program's design part classifies and designs circuits depending on the circuit type, classification of hydraulic power circuits and basic rules to design a hydraulic power circuit are explained. Furthermore, load classification and analysis are discussed.

2.1 Definitions

2.1.1 Energy Transfer Systems

There are basically three types of energy transfer systems, these are electrical systems, mechanical systems and hydraulic power systems. These are used as interface, to make the energy useful, between an input and an output device.

A hydraulic power system, as an energy transfer system, has three functional sections. These are;

1. Energy input device, i.e., a pump or a compressor, receives the energy from energy source, i.e., an electric motor, as input speed, n_i , and input torque, T_i, and converts these variables to hydraulic power variables as output pressure, p_1, and flow rate, Q_1.

2. Energy control devices, i.e., directional or flow control valves, receive the energy from the energy input device, as p_2 and Q_2 variables, and deliver controlled energy to energy output devices when required.

3. Energy output devices, i.e., a hydraulic motor or a cylinder, receive the energy from the energy control devices as p_4 and Q_4 variables and transmit these variables to a load or a mechanism as output variables, V_0 and F_0 or n_0 and T_0.

A typical hydraulic power energy transfer system can be seen in Figure 2.1. On the other hand, due to interactions between devices and friction , some energy losses take place causing a reduction of useful energy output. Entry, exit loses, and friction loses are typical loss sources. Also some losses are caused by control methods used in control devices.

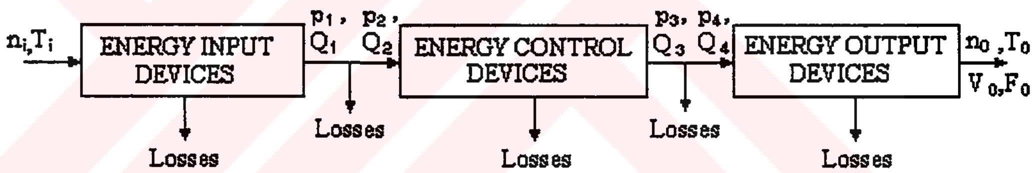


Figure 2.1 Functional segments of a hydraulic power energy transfer system.

2.1.2 Classification of Hydraulic Power Circuits

Hydraulic power systems can be divided into two main groups, Open-Loop and Closed-Loop. In a closed-loop system, a feedback mechanism continually monitors system output, generating a signal proportional to this output and comparing it to an input or command signal. If the two match, there is no adjustment and system continues to operate as programmed. If there is a difference between the input command signal and the feedback signal, the output is adjusted automatically to match command requirements [3]. A closed-loop circuit is illustrated in Figure 2.2.

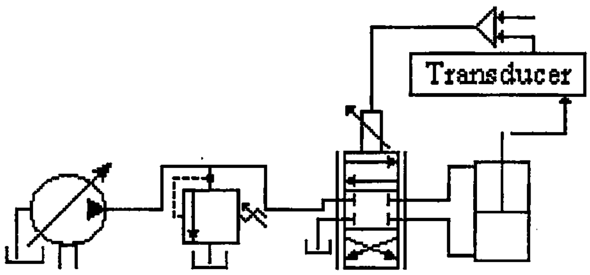


Figure 2.2 A typical closed-loop hydraulic power circuit.

On the other hand, in an open-loop system there is no feedback mechanism. The performance characteristics of the system determined entirely by the characteristic of individual components and their interaction in the circuit as well as with the environment. An open-loop circuit can be seen in Figure 2.3.

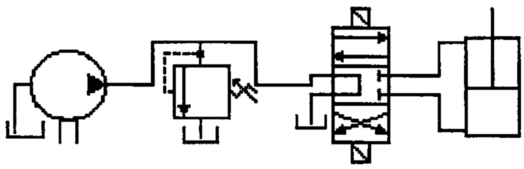


Figure 2.3 A typical open-loop hydraulic power circuit.

Open-loop hydraulic power circuits can also be classified as constant flow and demand flow circuits. In constant flow circuits, directional control valve bypasses oil to tank when the valve is in center position, thus unloading the pump. The circuit includes a fixed displacement pump and a relief valve. The circuit in Figure 2.3 is a constant flow circuit.

A demand flow system is composed of either a fixed displacement pump, an accumulator and an unloading valve, or a variable displacement pump. The directional control valve is closed in its neutral position. Two types of demand flow circuits are shown in Figure 2.4. Energy transfer starts from zero in constant flow circuits, however it starts from the maximum pressure setting of the circuit in demand flow system. [3]

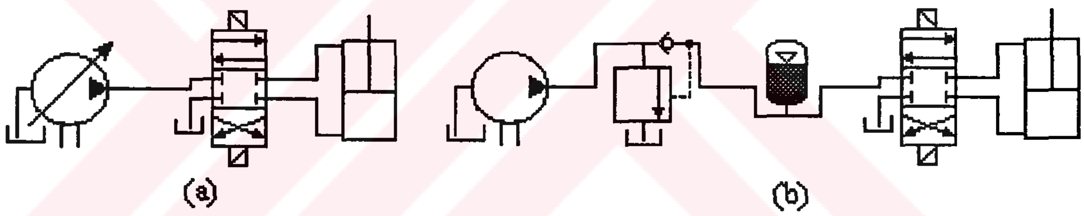


Figure 2.4 Demand flow circuits, in (a) with variable displacement pump, in (b) with a fixed displacement pump, an unloading valve and an accumulator

In addition to these classifications, hydraulic power circuits can be grouped as open or closed circuit (commonly called Hydrostatic Transmission). Note the difference between open-loop and open-circuit terms, the former denotes control type, the latter explains whether the fluid returns the reservoir or not. In the closed circuit the operation is continuous, the fluid flows to the pump after actuator.

However, in open circuit, the operation is not continuos, the flow turns to reservoir after actuator. The circuits in Figure 2.3 and 2.4 are of open-circuit type. A closed-circuit is shown in Figure 2.5

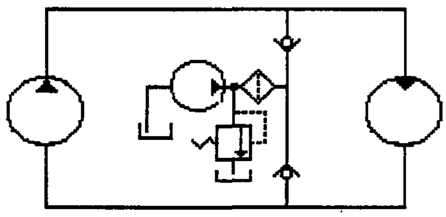


Figure 2.5 A typical closed-circuit type hydraulic power system.

2.1.3 Control Methods of Hydraulic Power

There are three basic control methods, directional control, flow control, pressure control used in hydraulic power systems.

Directional control regulates the distribution of energy within the circuit. In directional control, many types of directional control valves are available for use. Pump control is limited to reversal of direction of flow from a variable displacement reversible pump. Hydraulic motor control is similar to pump control, this technique uses reversible motors.

Flow control regulates the rate at which energy transferred by adjusting flow rate in a circuit or branch of circuit. Valve controls use one of several types of flow control valves. The position of the flow control valve determines the appropriate type to use. When the valve is between the pump and the actuator, this is meter-in control. When flow control valve controls energy transfer by limiting the rate of flow out of the actuator then this is meter-out control. In bleed-off control, flow control valve is placed parallel to the actuator, it limits the rate of energy transfer to the actuator by controlling the amount bypassed through the parallel circuit. These circuits can be seen in Figure 2.6. In addition to valve control, there are pump and hydraulic motor control of flow.

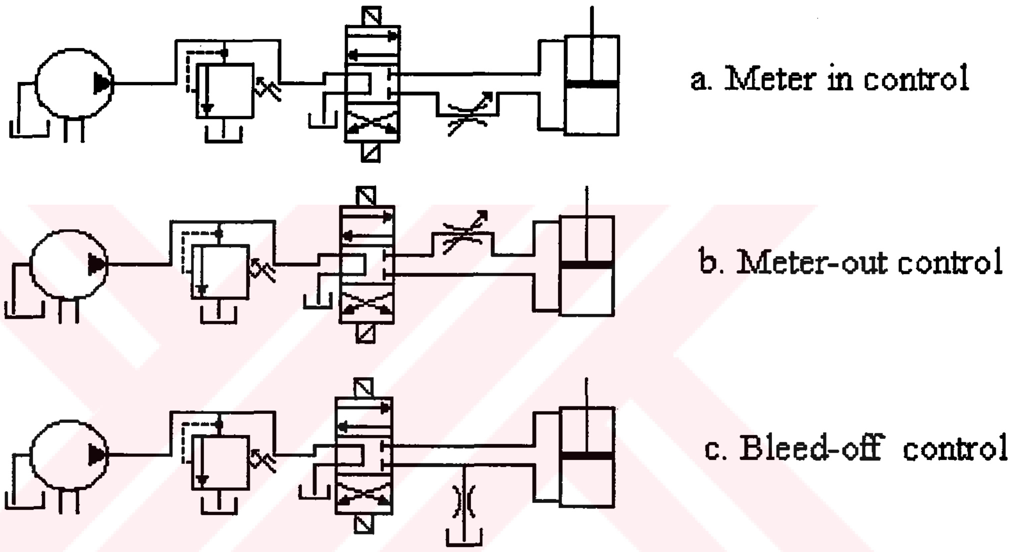


Figure 2.6 Types of flow control in open-loop circuits

Pump control, as flow control, involves the use of one of two methods, depending on the type of pump used. Multiple fixed displacement pumps (Hi-Lo circuit) provide a step variation in flow Figure 2.7. Variable displacement pumps deliver infinitely variable flows between zero and maximum flow.

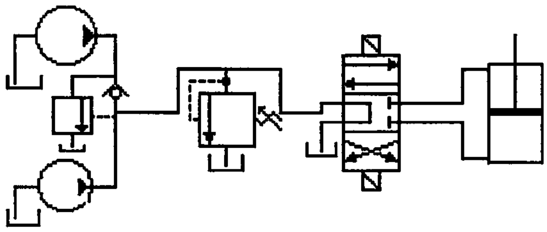


Figure 2.7 Pump controls of flow for an open-loop circuit

Pressure controls regulate energy transfer by adjusting pressure level or by using a specific pressure level as a signal to initiate a secondary action. Valve controls use one or more of several types of pressure control valves. Relief valves limit the maximum energy level of the system, by limiting maximum operating pressure. Unloading valves regulate pressure level by bypassing hydraulic to tank at a low energy level, unloading valves open when the pressure reaches a preset level Figure 2.4 b. Sequence valves react to a pressure signal to divert energy from a primary circuit to a secondary circuit Figure 2.8. Pressure reducing valves react to a pressure signal to throttle flow to a secondary branch, thus delivering energy at a lower level to the secondary than to the primary branch Figure 2.8. Counterbalance valves control the potential energy differential across an actuator by maintaining a preset back pressure in the return line. Their purpose is to prevent a load from drifting, see again Figure 2.8.

Pump control of pressure in an open-loop circuit is generally achieved with a pressure compensated variable displacement pumps. Energy transfer is controlled by varying flow from the pump in response to a pressure-level signal across the compensator.[3]

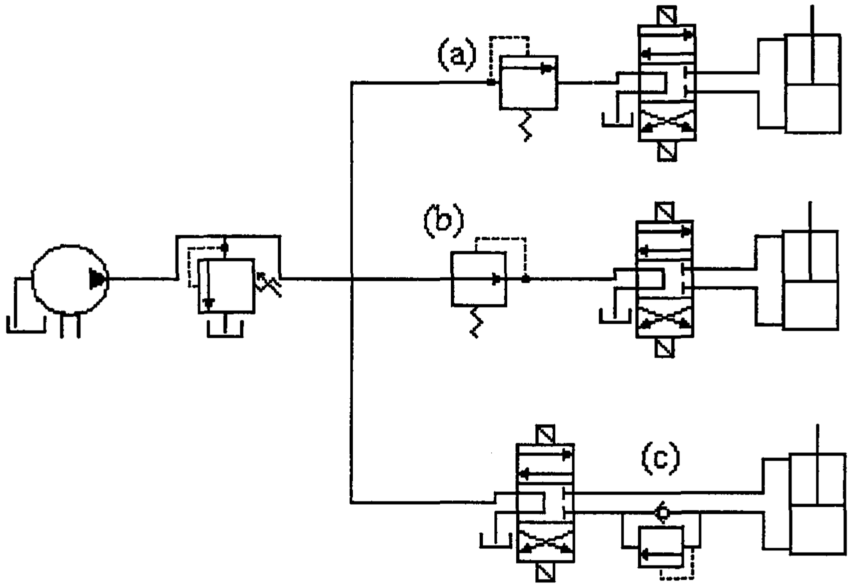


Figure 2.8 Valve controls of pressure, (a) sequence, (b) pressure reducing and (c) counterbalance valves.

2.2 Basic Design Procedure

The basic design procedure for a hydraulic circuit starts with a complete analysis of the function expected from the system to be designed. This analysis includes the determination of the loads, environmental conditions, and the requirements imposed upon the design to be produced. In the second stage the designer draws a hydraulic power circuit bringing available components together and examines the conceptual operation of the system. The circuit is continuously modified to conform to requirements on the function that is expected and the availability and basic cost of the components to be used. This process is continued till a satisfactory circuit obtained. The following stage is the selection of commercial components for the elements in the final circuit. For this a through analysis of the flow rates, pressure drops in the system and the complete specification of the components should be obtained. In the final stage, a simulation of the operation of the system must be performed so that whether the designed circuit is satisfactory or not. Once the simulation results are found satisfactory, the actual assembly and final commissioning of the system will be possible.

The software Hydra D&S is ment for the steps following the determination of the loads and before the actual assembly.

2.3 Load Analysis

There are basically three types of loads, these are resistive load, overrunning load, and inertial load. In a load analysis one can commonly have two or three types of load together. The designer should find the biggest load value from load analysis before starting the design part of the program.

2.3.1 Resistive Load

A resistive load is one in which the load reaction on the output device opposes the motion of the actuator. It is caused by friction between two surfaces that have a relative motion between each other. Thus, to calculate a resistive load, friction coefficient between those surfaces should be known. A resistive load can be either constant or variable and can be calculated from

$$F_f = \mu W \qquad 2.1$$

where, F_f is the resistive load, μ is the friction coefficient and W is the force normal to the direction of motion.

2.3.2 Overrunning Load

An overrunning load can be characterized by the load reaction acting in the same direction as powered motion of the circuit output device. The amount of the load depends on the situation. Overrunning loads may be either constant or variable.

2.3.3 Inertial Load

An inertial load is one in which the condition of the output from the system tends to remain in a given state unless some external force acts to change that state. The relation between applied force and linear acceleration is,

$$F = m a \qquad 2.2$$

where, F is the force applied, or inertial load, m is the mass of the load accelerated and a is the acceleration due to force. Similarly, the relation between applied torque and angular acceleration is,

$$T = J_m \alpha \qquad 2.3$$

where, T is the torque applied, or inertial load, J_m is the moment of inertia of the load, and α is the angular acceleration.

Since acceleration forces depends on the velocity change, before beginning to calculate inertial loads, the motion cycle of the circuit must be determined.

2.4 Design Criteria for Open-Loop Circuits

Design of any circuit must begin with through understanding and analysis of the functions, the circuit is to perform. Here are the some basic rules a designer should follow.

The first design step is an analysis of the load cycle. This will help find the maximum load a circuit must carry or move. Also load cycle may determine the control method, for example, an overrunning load requires a meter out control.

Time per work cycle must be determined inside the load analysis because inertial load depends on the velocity change during acceleration and deceleration part of the cycle. Furthermore, time per work cycle sets the flow requirements relative to the cycle displacement pattern and horsepower requirements of the circuit.

An actuator should be selected after determining cycle time, because combination of actuator displacement and cycle time will determine fluid flow rates in the circuit. However, at this point a working pressure should be selected before actuator selection, since working pressure is an important parameter to determine actuator geometry.

When actuator geometry and cycle time are resolved, flow pattern can be defined. This is important because it shows how flow rate varies in different segments of the circuit. The sum of the flow rate, for multibranch circuits should be found out to select a pump.

The next step is determining other components of the circuit. The two parameters are important that influence selection of other components. The first one is flow requirements of the circuit, this causes a circuit to be constant flow or demand flow. The second is the control type of the circuit depending on the load and velocity requirements of the output device, for example, flow control and pressure control.

After determining components and drawing the circuit, one can size all the components. The procedure for this is selecting all components according to the flow rate and working pressure range. Pressure drops across the components are calculated after selection, and finally a pump supplying the required flow rate at the specified pressure is chosen.

After this explanations, design of a hydraulic power system can be listed as below.[4]

1. Sizing actuators from output objectives

2. Establishing work cycles using time, flow, pressure and horsepower plots

3. Designing the circuit

4. Sizing and selecting components

2.5 Circuit Design According to Circuit Type

As discussed before open loop hydraulic power circuits can be classified as constant flow circuits and demand flow circuits. Due to component characteristics sometimes those are named as open center and closed center respectively. Here, properties of those circuit types and components used are examined.

The program examine circuits before starting to design and classifies as constant flow or demand flow and designs circuits according to the releated rules.

flow circuits Figure 2.9

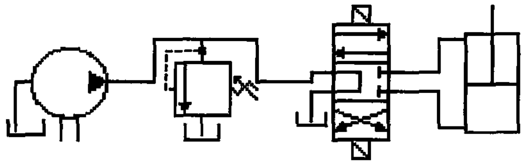


Figure 2.9 A typical open-center circuit.

In constant flow circuits, the pressure at which the pump discharges fluid is a function of the load resistance encountered by and reflected across the actuator. The system operating pressure required by the load is a function of the actuator geometry. If the pump can not satisfy power demand relief valve will open to bypass oil to tank, however, this wastes energy.

In open-center circuits, pump output is not determined by the actuator's instantaneous speed requirements, because a constant flow design technique generally calls for a fixed displacement pump. Discharge rate of a pump is a function of pump displacement and its speed of rotation. Pump output and actuator displacement jointly determine a steady state speed according to the equation,

$$V_a = Q_p / v_a \qquad 2.4$$

where V_a is the speed of the actuator, v_a is actuator displacement, and Q_p is pump output. If there are more than one actuator in the circuit then Q_p is the flow rate passing over the actuator and for such a case pump must be sized according to peak flow requirement of the circuit .

In a constant flow circuit, designers try to size actuators to meet speed requirements as a function of pump output. A cylinder may be selected according to the following equation,

$$Q_p = A\,S / t \qquad 2.5$$

where, A is the piston area, S is the cylinder stroke, t is the time to complete work, and Q_p is the flow rate. For a hydraulic motor equation becomes,

$$Q_p = v_a\,n \qquad 2.6$$

where, v_a is the displacement of the motor, n is the operating speed.

The directional control valve, in a constant flow circuit, unloads the pump when the valve is in its neutral position. By unloading the pump, the designer reduces unnecessary energy dissipation during passive intervals in the cycle, thus minimizing generation of heat. The directional control valve must have enough capacity to bypass full pump output without causing excessive pressure drop.

Actuator speed control may be succeeded by restricting flow with a metering or flow control device. Another approach takes advantage of the throttling characteristics of the directional control valve, Figure 2.6.

Characteristics of the constant flow circuit may be listed as follows;

1. Pump discharge pressure is a function of load resistance and must build from zero pressure.

2. Pump output is not determined by actuator speed requirement, because pump is fixed displacement.

3. Actuators are sized to meet speed requirements as a function of pump output for a selected pump. [3]

2.5.2 Demand Flow Circuits

Closed center circuits are equipped with a fixed displacement pump and an accumulator, Figure 2.4 b, or a variable displacement pressure compensated pump, Figure 2.4 a. Closed center circuits are more accurately characterized as demand flow circuits.

In demand flow circuits that use a fixed displacement pump and an accumulator, oil pressure from the pump is not directly determined by actuator's force requirement. The pump charges the accumulator to design pressure, when the directional valve is centered. Design pressure in the circuit is controlled by the spring setting of an unloading valve. When this setting is reached, the valve opens and bypasses fluid to tank, at low pressure. Note that the pilot signal to the relief valve is taken downstream of a check valve placed between the pump and accumulator, Figure 2.4 b. The check valve prevents the unloading of the accumulator as well as the pump.

When the directional valve is shifted so that it ports fluid to the actuator, the full design pressure, as stored in accumulator, is immediately available to the system. As the actuator moves, fluid is forced from the accumulator by the compressed gas charge behind the fluid. After a time, system pressure drops because of the expansion of the gas charge in the accumulator. At some pressure level for which it has been designed, the unloading valve closes and causes output from the pump to reenter the system. At this time pump will either add its output to that from the accumulator at the lower pressure level or recharge the accumulator to a higher pressure.

Some accumulator circuits are designed so that the accumulator supplies all the fluid used during active part of the cycle. The pressure in the system is not constant, because the pressure of the gas charge drops as the gas expands when fluid flows out of the accumulator. The load cycle must be designed so the system can still function at the lowest pressure level delivered by the accumulator. This design feature is used where the active or work segment of the cycle is rather short and is followed by a relatively long passive or dwell segment during which the pump recharges the accumulator Figure 2.10.

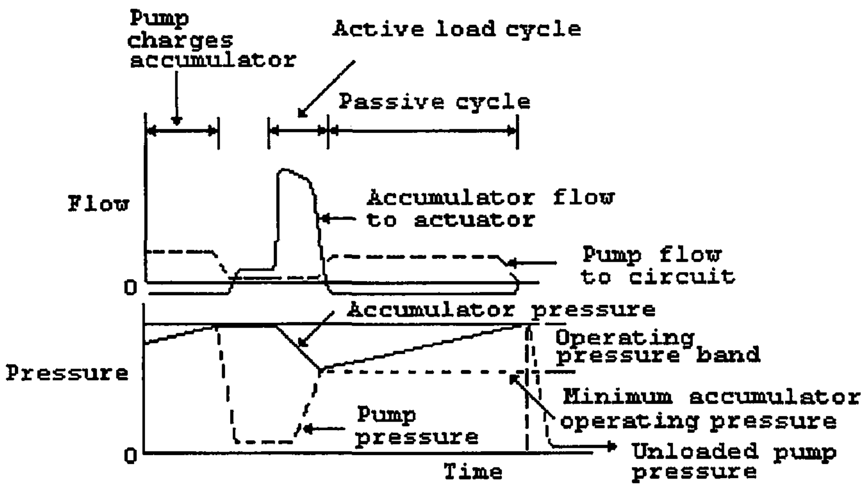


Figure 2.10 Typical pressure and flow curves for an accumulator circuit that has short work segment and long dwell segment.

If the demand flow circuit uses a variable displacement pressure compensated pump, then the compensator setting determines maximum circuit pressure Figure 2.11. Pump output is constant until the system reaches a given pressure, called cutoff pressure. At this point the force acting on the compensator begins to exceed the force of the control spring that holds the pump on stroke. As pressure increases, pump starts to move off stroke to reduce displacement. The slope of the curve of this decreasing displacement is controlled to some extent by the spring rate of the compensator spring. When the pressure in the system reaches the level known as deadhead pressure, pump output flow is zero. The only power consumed by the pump at deadhead is the relatively small amount required to overcome mechanical loses and compensate internal leakage.

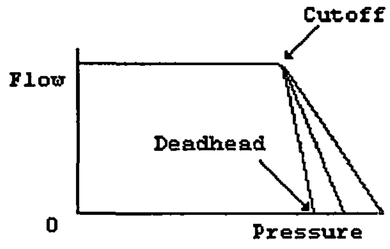


Figure 2.11 Flow versus pressure variations of a pressure compensated variable displacement pump.

As indicated the compensator setting determines upper limit of system pressure. With a pressure compensated pump, full force can act on the actuator and load, but there will be no flow until the load starts to accelerate. Thus, a system that uses a pressure compensated pump is a demand system. A pressure compensated pump functions as its own relief valve, shifting the deadhead conditions when an excessive load is applied.

In a demand flow circuit equipped with pressure compensated pump, pump delivery is related to actuator speed requirement as shown in Figure 2.12. From time zero to time t_0 the control valve is in neutral position and the pump is deadheading. At time t_0 the control valve shifts porting pressurized oil to the actuator. Thus full deadhead pressure acts on the actuator. Because the actuator cannot accelerate instantaneously, pump output remains at zero for a short time interval $t_0 < t < t_1$, Figure 2.12. During this interval the actuator begins to move. The pressure drops to some level required to accelerate the load and below the deadhead level. Simultaneously, the pump moves on stroke.

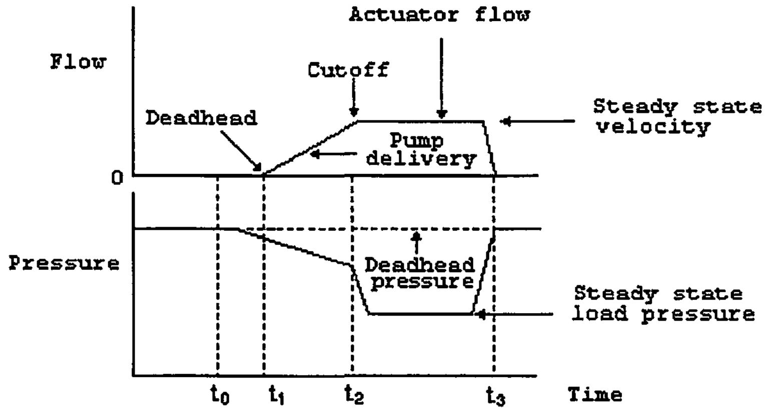


Figure 2.12 Pump output and actuator speed requirement relation, in a demand flow circuit with pressure compensated pump.

If the acceleration force requires a pressure greater than the cutoff pressure, the pump will compensate by reducing its output flow rate. this new output flow rate will be lower than that corresponding to the cutoff flow rate but higher than corresponding to deadhead pressure. Between times t_1 and t_2 the load accelerates to steady state speed. By time t_2 the pump has been stroked to full displacement, the load stops accelerating, and system pressure drops to some value corresponding to steady state resistive load. At time t_3 the actuator hits a mechanical stop, or the end of its stroke, and fluid pressure rises immediately. The pump is destroked and its output drops to zero. It deadheads until the directional control valve shifts to retract the cylinder. In this circuit no pressurized fluid flows over a relief valve [3].

2.5.3 Pressure Control Circuits

Before starting to examine pressure control methods and circuits, pressure drop consideration should be examined. Pressure drop is a reduction in pressure between two consecutive points in a hydraulic power system. Pressure drop happens because some energy in the system is required to do work to maintain oil flow against a resistance. This resistance can be internal fluid friction orifice-like restrictions in the flow path, or external load resistance. A pressure drop between a pump and actuator represents a loss in energy which manifests itself as heat. The pressure drop across the actuator reflects the energy being transferred to the external load. Actuator efficiency is an indication of internal losses which reduce the actual energy of the actuator and the energy available for transfer.

The pressure drop across a given valve varies as the ratio of the specific gravity of the fluid, the relation

$$\Delta p_2 = \Delta p_1 \, (S_{g2} / S_{g1}) \qquad 2.7$$

and, similarly pressure drop varies with flowrates as,

$$\Delta p_2 = \Delta p_1 \, (Q_2 / Q_1)^2 \qquad 2.8$$

Pressure control affects the potential energy level of the fluid in the system. Two pressure control modes are used in hydraulic power circuits. These are direct control of the pressure level, such as; relief valves to control maximum pressure, pressure reducing valves to control pressure at some level below maximum system pressure and, pressure compensated variable displacement pumps. The second mode is the secondary control exercised when a given pressure level is reached such as; sequence valves to switch flow to a secondary circuit when fluid pressure in the primary circuit has reached a preset level and unloading valves to bypass pump flow to reservoir after system pressure has reached a preset level.

A relief valve is the most commonly used means to control maximum pressure in a circuit see Figure 2.9. When system pressure reaches a preset level, the relief valve allows oil to bypass to tank. The pressure drop across the valve is equal to primary system pressure. Flow, Q, through an orifice is expressed by the equation 2.9 [5].

$$Q = C\,A\,((2g\,\Delta p)\,/\,\gamma\,)^{1/2} \qquad 2.9$$

where C is a coefficient characteristics of the orifice, A is the orifice area, Δp is the pressure drop across the orifice and γ is specific weight of the fluid and g is the acceleration due to gravity. As Δp approaches the preset pressure, the valve will open partially allowing a part of pump output to bypass to tank.

Maximum system pressure can be controlled with an accumulator and an unloading valve, Figure 2.13. In this configuration, system pressure is a function of

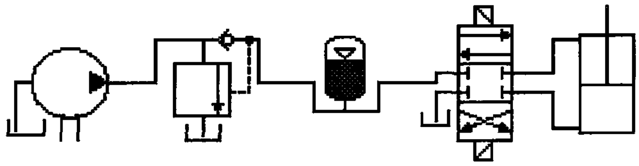


Figure 2.13 Control of maximum system pressure with an accumulator and an unloading valve.

gas precharge and the volume of oil in the accumulator. Maximum pressure is depends on the setting of the unloading valve. When a preset pressure is reached, the unloading valve opens and bypasses pump output to tank. A check valve in the line prevents the accumulator from being unloaded at the same time.

Pump control of maximum pressure involves the use of a pressure compensated variable displacement pump, Figure 2.14. The function of such an application has explained in 2.4.2.

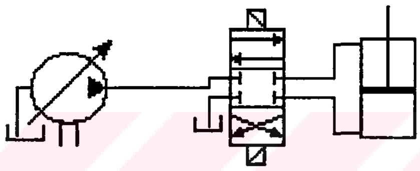


Figure 2.14 Control of maximum pressure with pressure compensated variable displacement pump.

A hydraulic fuse consists of a rupture disc which blows out at a preset pressure level, releasing system oil to tank. It is used where the rate of pressure rise is very high. The respond of a hydraulic fuse is faster than a relief valve. Like an electric fuse it must be replaced when it blowed out.

Pressure reducing valves, normally open two way valves, senses system pressure downstream from the valve inlet. There are two basic types, one maintains fixed reduced pressure in a circuit branch regardless of the pressure in the balance of the system. The other maintains a fixed pressure differential to provide varying reduced pressure with change in system pressure Figure 2.15 a. Like relief valves, pressure reducing valves can be either direct acting or pilot operated.

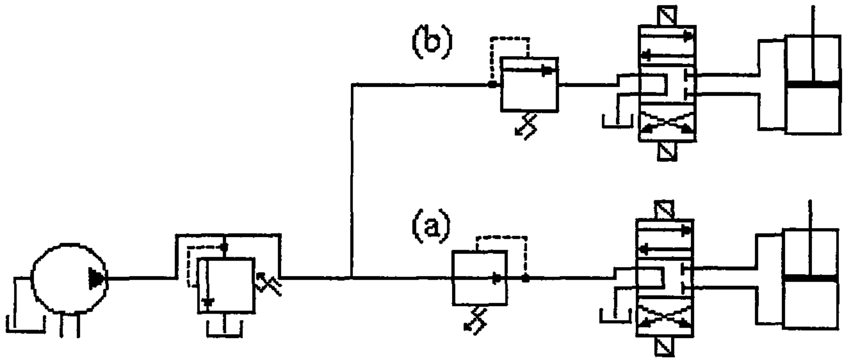


Figure 2.15 Pressure reducing valve (a), and sequence valve (b).

Sequence valves are normally closed, internally piloted valves which remain closed until pressure in the primary circuit reaches the preset pressure level of the valve Figure 2.15 b. When this occurs sequence valve opens to provide output flow into the secondary circuit. This type of control is frequently used to switch to a secondary circuit after the actuator in the primary circuit has reached the end of its stroke and pressure starts to rise. This design eliminates the need for a directional valve to sequence flows.

A counterbalance valve is a normally closed two way valve with internal pilot, internal drain and usually a built in, free flow check valve for reverse flow Figure 2.16. It is used to prevent free fall of a load held up by a cylinder or hydraulic motor or to provide controlled resistance in a line.

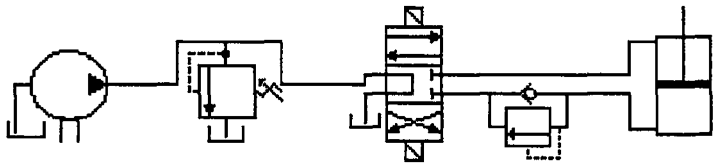


Figure 2.16 A counterbalance valve application.

There are many ways to unload a pump, one of them is to use an unloading valve as shown in Figure 2.13. An other method to unload a pump is employing a open center directional control valve Figure 2.16. We can also unload a pump by using bypass ports built into the cylinder Figure 2.17. When piston passes over bypass port, the port opens to the cap end, permitting incoming oil to bypass to tank

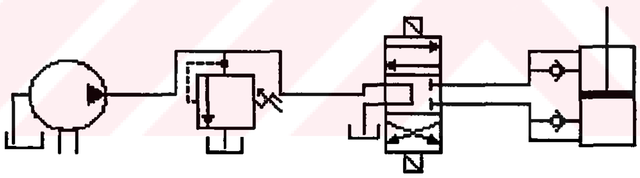


Figure 2.17. Using bypass ports to unload a pump.

Hi-Lo circuits provide two output forces at two operating pressures, Figure 2.18. Usually such a system delivers low force (or torque) and high actuator speed, and then on signal, shifts to high force and slow actuator speed by unloading the high-flow, low pressure pump. The unloading valve unloads the high-flow, low pressure pump when system reaches a preset pressure. Until this point, both pumps supply oil to the circuit. After the low pressure pump, pump A, is unloaded, only the high pressure pump, pump B, supplies oil to the circuit. The check valve separates the primary and the secondary pumps and do not allow the primary pump to be unloaded.

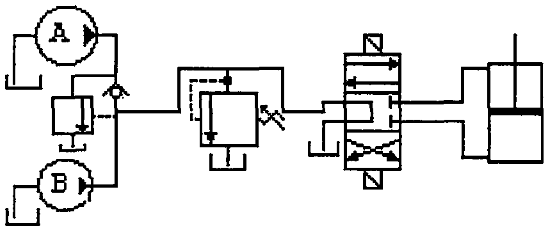


Figure 2.18. A Hi-Lo circuit.

All the circuits described in this section provide pressure control under specific conditions. Figure 2.19 illustrates a technique for obtaining two different controlled pressure in a cylinder, one in the cap end, another in the head end. Relief valve A, connected to the line connected from the directional control valve to the cylinder's cap end is set to open at one pressure and relief valve B, to the cylinder head end is set to open at another.

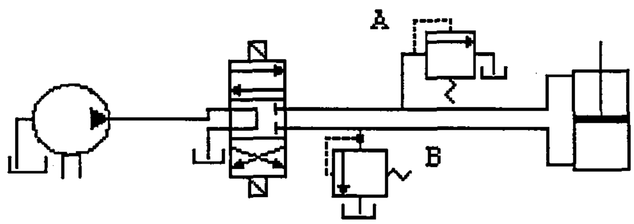


Figure 2.19. Relief valve usage to provide different pressures in each end of the cylinder.

Flow control deals with the rate of energy transfer which is related to the rate of fluid flow. There are many types of controlling flow rate and speed of the actuator.

The simplest way to control flow in a branch of a circuit is using orifice type flow control valves. Some of the valves used in hydraulic power circuits are flow regulators with or without bypass port, pressure compensated, variable flow control valves, pressure compensated, temperature compensated, variable flow control valves and demand compensated flow control valves.

When a flow control valve is placed in the line connecting the controlled output port of a directional control valve to the cap end of the cylinder, Figure 2.20, the flow control valve controls the rate of flow to into the cylinder and thus the output velocity of the piston rod. This technique is best used with resistive loads and the circuit is called Meter-In Circuit. The control of speed is lost when the load reverses from resistive to overrunning.

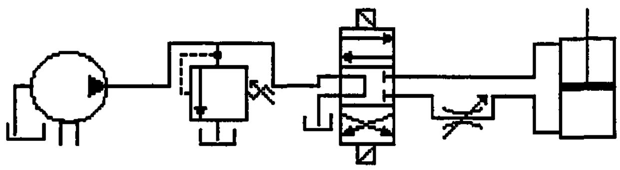


Figure 2.20. A meter-in circuit.

When the flow control valve is placed in the line connected to the return flow port of the actuator, such as the cylinder head end, Figure 2.21, a Meter-Out Circuit is formed. The output velocity of the piston rod is controlled by limiting the rate at which oil leaves the cylinder. This control technique is used with overrunning loads. The pump operates against a relatively constant pressure which consists of the sum of the load reaction and the flow control backpressure. This type of circuit is rather inefficient, because at low load levels or with overrunning load cycles valve backpressure may exceed pump pressure because of the area differential across the piston.

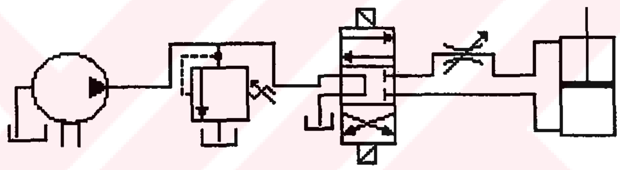


Figure 2.21. A meter-out circuit.

In Bleed-Off Circuits, part of pump output is bypassed to tank at system pressure, Figure 2.22. This arrangement provides speed adjustment around some average value. However, it does not allow speed control over the entire range. An other disadvantage is that it does not provide positive load control like meter-in and meter-out circuits.

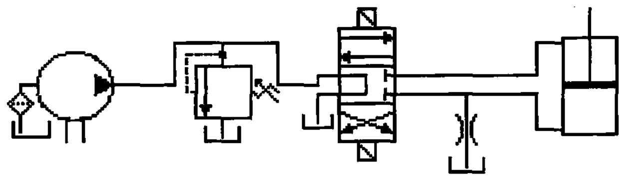


Figure 2.22. A bleed-off circuit.

In a regenerative circuit, Figure 2.23, a directional valve connects both cylinder ports in parallel to the supply port. Pressure is applied equally to the cap and head end of the cylinder. The oil in the head end of the cylinder is added to the pump output and a new velocity arrangement can be succeeded at the actuator output according to the ratio of the area between cylinder's cap end and head end.

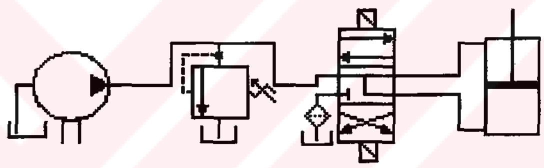


Figure 2.23. Regenerative circuit.

A flow divider valve is a form of pressure compensated flow control valve which receives one input flow and splits it into two output flows, the valve can deliver equal flow rates in each stream or a predetermined ratio of flow rates, Figure 2.25. Flow dividers, like all pressure and flow control devices, operate over a narrow bandwidth rather than at one set point. Thus, there will be a variation of flow rates in the secondary branches, and precise synchronization cannot be achieved with a flow divider alone [3].

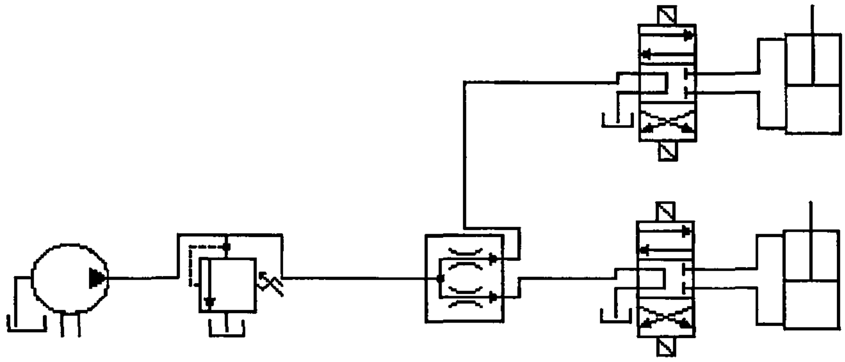


Figure 2.24 A flow divider application.

CHAPTER III

THE COMPUTER PROGRAM

The computer program basically consists of three interdependent functional modules. These are circuit drawing module, simulation module and design module. Each of them has its own execution rules which are explained in detail in this chapter.

3.1 Capabilities and Limitations of the Program

The capabilities of the program are listed below.

1. The user can draw a variety of hydraulic power circuits with hydraulic power schematic components. All the components included in the drawing library prepared according to TSE[6] and ISO[3] fluid power graphic symbols. Program includes as many components as a designer may need for most application.

2. Simulation of the steady state behavior of the circuit is provided. Simulation is a visual representation of flow motion and component responses depending on logical rules.

3. The program includes a design tool used for the selection of components from commercially available components. All the required specifications of these components are stored in the databank files and new component data can be

added to databank by the user. In addition, designer can visualize and take print out of design results, change system parameter after design.

4. A complete circuit can be saved together with design results for future use. When a drawing is saved, design results saving operation is optional.

5. Print is a tool employed to take a hardcopy of circuits and design results for documentation.

6. In the program there are other file and edit tools like " New ", "Save", " Save as", " Delete Last ", "Delete Selected ", " Insert ", " Copy ", " Paste " and " Reset " to make the program easy to use. Moreover to these properties, with horizontal and vertical scroll bars, the screen can be extended two times of normal maximized form in every direction. Details can be found in 3.3.1.

7. Help includes a guide about the program for new users. Necessary information about the program and tools are given in the help.

The limitations of the program are below ;

1. Flexible pilot line drawing is not possible. Inter unit pilot lines cannot be implemented, but there are pilot lines included within units and some pilot line operations can be simulated manually.

2. Drawing is limited by the component library. The designer cannot add any components to the library of the program, all the components in the library have special drawing, simulation and design rules.

3. The number of operational accumulators in design and simulation is limited to a maximum of two.

4. The program does not allow the usage of more than three operational sequence valves in simulation and design.

5. Outlets of rams and motors except for single direction motors can only be connected to a directional control valve or a component that has proper line connection. You cannot take a line in front of such actuators to extend the circuit or to use somewhere else.

6. Since sequence of operation of the circuit is not known by the program, selection of the components from connection of branches to the pump is made by using full flow requirement of the circuit except branches in which sequence valves are employed. Flow rate of sequenced branches are not added to total flow requirement as will be expressed in 3.5.1.

7. Retract velocity and load cancot be specified. Therefore, the program does not calculate retract pressure and velocity.

8. Overrunning loads can not be specified. Circuits with such loads cannot be designed.

9. Simulations of reversible pumps in closed circuits are made only for one direction.

10. Because the program is not able to evaluate pressure rise, sequence and relief valves open when all the ports closed in the circuit.

11. In closed circuit, a maximum of one hydraulic motor can be used.

The compiler used in the preparation of the program is Visual Basic. It is a powerful programming tool in creating applications that require visual presentation, ease of data entry, and presentation of results. Visual Basic supplies a number of visual elements as well as forms and modules. All the visual elements have their own event types and codes written under those elements work when the specified events are activated.

3.2 Algorithms of the Program

Algorithms are developed for the three main functional groups of the program, drawing, simulation and design. These three functional groups consist of different subroutines and functions explained below. Interrelation among the main parts is shown schematically in Figure 3.1. Program manager is a collection of code under the main form, or display, that manipulates and manages user interaction and employs proper forms or modules.

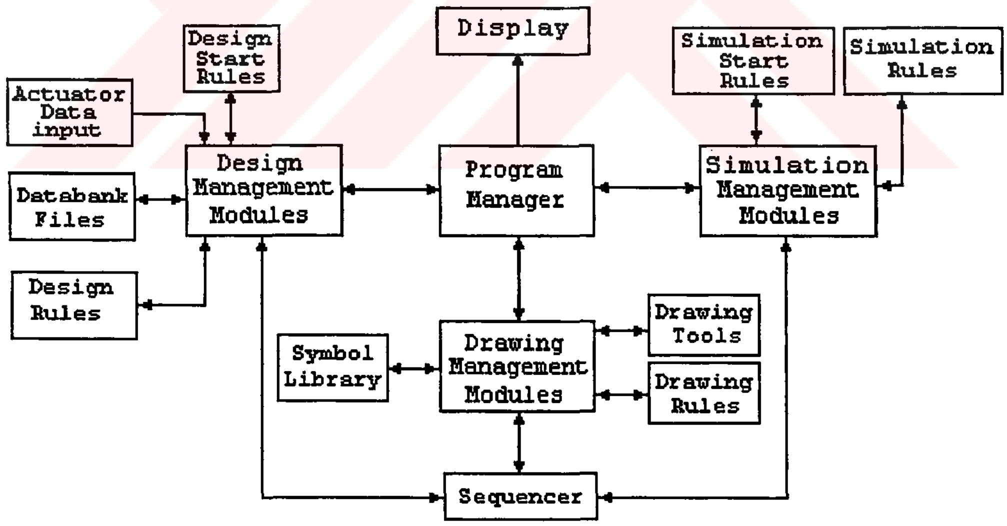


Figure 3.1. General algorithms of the program.

3.3 Drawing a Circuit and Drawing Algorithms

The program has a drawing area which has the dimension of Visual Basic maximized form. This area can be extended in any direction, except left, almost two times of maximized form by using vertical and horizontal scroll bars. The drawing form includes a matrix of picture boxes that has a dimension of 52 by 99 pixels, Figure 3.2. These dimensions are valid for open-loop open circuit drawing. When the designer start to draw an open-loop closed circuit, dimension of the picture box changes to 75 by 99 pixels. Loading of picture boxes onto the drawing table is automatically done by the program. The program checks the line connections and branch end points and then places picture boxes to proper places. The user cannot pass to another point before completing a branch.

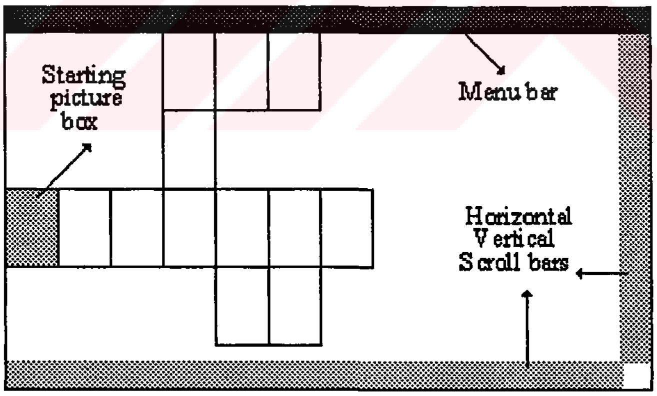


Figure 3.2 Appearance of the drawing table.

The program contains a number of hydraulic power components prepared in the bitmap drawing program Paintbrush and stored with *.Bmp extension in the

BMP directory. Some of these components are pumps, hydraulic motors, rams, directional, flow, pressure control valves, accumulators, and so on, a full list is given in Appendix A. Since hydraulic power components included here are general, there is one representative component for all types of a component. For example, a fixed displacement pump represents both gear and vane type fixed displacement pumps. Similarly, a directional control valve represents all directional control valves that have the same way and positions, but control method is left to the designer. Flow and pressure ranges determine type of component commercially available and selection of a specific component will be explained in the design part.

On the other hand, in the component library, the user has a pump with reservoir or without reservoir or with filter and reservoir. This makes the circuit drawing more practical. In addition, there are some components composed of two different functional components like a cylinder with dual bypass ports to unload the pump.

As discussed above closed circuit symbols are not identical in dimension and in terms of line connection with open circuit symbols. Since actuator output is connected to pump inlet, line connection of a closed circuit differs from open circuit drawings. Therefore, open circuit and closed circuit drawings are made on different forms and with different rules.

When a drawing is completed, it can be stored in *.Hyd extension.

3.3.1 Circuit Drawing

As mentioned previously, closed and open circuit drawing are different. Thus the elements available are collected in two different libraries. Once the user decides to draw an open or closed circuit drawings, then the components in the other library are not available till a new session is started.

When the first component is chosen, by means of a pointing device, from library, it is directly copied to the first, i.e. default, empty picture box on the display. Then according to the line connections, the user clicks right, upper or bottom side of the previous picture box to place a new picture box and selects a new component from library. Program warns the user, when any improper point of the form is clicked.

If the user wants to remove any component from the drawing, that component should be selected by mouse click event, then from edit menu bar delete command is to be selected. If the user wants to replace any component, again it should be selected first, and then the required component from component library can be copied onto the old one.

In addition to these, insertion of a component within the circuit can be made. To do this, the component in front of which a new component is to be inserted is selected. Then the user must select insert command from edit menu bar. When the empty picture box is placed in front of selected component, then required component is chosen from library. Copy and paste menu commands also work similarly. First the component that will be copied is selected, then copy command is selected. The picture box to paste the component in memory is selected, finally from edit menu paste command is used.

The drawing rules, arranged and organized according to fluid power logical rules, are as follows;

1. A fixed displacement pump requires a relief valve after the pump. The program places a relief valve after a fixed displacement pump automatically.

2. When a picture box is empty, any attempt to load a new picture box, before placing a proper component on the empty picture box, causes a warning message that forces the user to place a component on the empty picture box first. Each time drawing manager controls picture boxes before loading a new one.

3. If the designer uses a line with one input and two or three outputs, there must be at least two or three branches in the circuit. Without completing a branch with an actuator or with a reservoir, the user can not start to draw other branches. Such an attempt causes a warning message and program forces the user to complete the incomplete branch before passing another branch.

4. The designer cannot delete lines that have one input and two or three output, if there are components connected to output sides of the lines. However, if components connected to upper or lower output sides of the lines are deleted first, then those lines can also be deleted.

5. When the designer tries to use a component without proper line connections and place, program displays a warning message against incompatibility.

6. Program warns the user during drawing against wrong click events, because all click events assumed a command to place a new picture box.

In addition to these main rules, there are a number of auxiliary drawing rules releated to connection of the components and placement of picture boxes. For example, after a 4/3 directional control valve, a filter cannot be placed. After an actuator, the designer cannot place a picture box. In front of a pump a picture box cannot be placed.

3.3.2 Drawing Algorithms

Each component in the library has been defined by using Visual Basic's "Tag" property. The names of the components and places are stored in the sequencer of the program. During edit, simulation, and design operations, sequencer uses those names and employs proper function and subroutine.

All the sections required to draw a circuit and interactions among them can be seen schematically in Figure 3.3. Drawing manager manipulates library, loads picture boxes according to user action and lets the designer use delete, insert, copy and paste tools. It keeps under control all the picture boxes. Drawing operation is made by means of "Loadpicture()" property of Visual Basic.

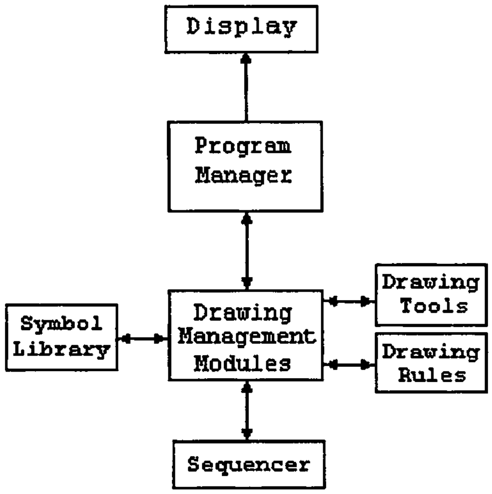


Figure 3.3 Drawing algorithms.

3.4 Simulation of the Operation of a Circuit and Simulation Algorithms

In the simulation part the designer can visually follow the flow of working fluid along the lines and other components. Some of the components give visual reaction in accord of fluid power rules, such as accumulators and relief valves. In the simulation, there are three types of components in terms of action type. The first group consists of passive ones, these type of components only let the flow pass on themselves causing energy increase, like pumps, or energy drop, like hydraulic motors and lines. The second group includes active components, these are sensitive to system pressure logically. When pressure in the system rises these components react to pressure increase, like accumulators, relief valves and sequence valves. The last group involves user-activated components. These are directional and flow control valves. Control types of the valves are left to designer and activation in the program is made by mouse click event.

Pumps: Pumps have an inlet port, low pressure side, and an outlet port, high pressure side. Flow is always from inlet port to outlet port.

Hydraulic Motors: Hydraulic motors have two ports, inlet and outlet. Direction of flow is always from high pressure side to low pressure side. According to the type of motor, they may rotate in two direction. In closed circuit simulation, load increment by a scroll bar is possible. To use this property, after simulation of a closed circuit click on the motor. A scroll bar will be displayed. Load on the motor can be changed logically and the respond of the components can be visualized.

Cylinders: There are two types of cylinders, one single acting the other double acting. Single acting cylinder has one input port and no output port when on load stroke, during retraction input port becomes output port. Double acting cylinders have one input and one output. Inlet and outlet change place depending on the position of directional control valve.

Lines: Lines transmit flow from high pressure side to low pressure side. They have one input and one or more outputs.

Directional Control Valves: Directional control valves are user-driven, or activated, components, they may have different positions and flow paths. Depending on their types, they may have two input, one from pump to actuator and one from actuator to reservoir, and two output or one input and one output. The number of ports and direction of flow changes according to the type of valve. When a directional control valve is blocked for any reason, for example due to an other valve, it does not respond user action.

Flow Control Valves: Flow control valves mostly have one input and one output. Flow direction is from high pressure side to low pressure side. As a flow control valve, flow dividers have one input and two outputs. The designer can change the setting of a flow control valve logically and visualize responds of other components in the circuit. To use this property circuit must be one branched. After simulation is started, the designer should click on the flow control valve. Then a horizontal scroll bar will be displayed. Setting of flow control valve can be changed by using this bar.

Pressure Control Valves: These valves have generally one input and one output. Flow direction is from high pressure side to low pressure side.

Sequence Valves: These are a type of pressure control valves. In simulation, those components are action type components. When conditions cause pressure to increase logically for example, blocking all ports in other branches, then sequence valves open and let the flow pass to the sequenced branch. Because the program is not able to evaluate pressure rise, these components, like relief valves open when all the ports closed in the circuit. They have one input and one output when they are open, otherwise there is no input and output port.

Counterbalance Valves: These are similar to sequence valves in terms of action type, but placement and function of a counterbalance valve is different. A sequence valve blocks the inlet of a branch or component, however a counterbalance valve blocks the outlet of a component. Counterbalance valves open when pressure at outlet of the actuator reaches set pressure of the valve.

Relief Valves: Relief valves are a type of pressure control valves. They have normally no output to reservoir, and all the oil passes to the circuit. When the system reaches a pressure level, succeeded by only blocking all ports, relief valves let the flow pass to the reservoir.

Unloading Valves: These are types of pressure control valves and work like relief valves. Unloading valves are used in accord with accumulators in demand flow circuits to unload pump when accumulator charged. When pressure in the pilot line, taken from accumulator line, reaches the setting of the valve, unloading valve opens and ports pump output to the tank. Ports and actions are the same as relief valves

Accumulators: Accumulators have two action types, these are charged when all ports in the circuit are blocked and discharged when one of ports open. They are used in closed center circuits.

Check Valves: Check valves have one input and one output only in one direction. Flow direction is always from open side to constrained side.

Pilot Operated Check Valves: These valves have free inlet, and constrained return. As soon as the setting of the valve is reached reverse flow is possible. In closed circuit, simulation of the valve is click driven.

Reservoirs: A reservoir has one input or one output depending on the component connected. Input comes from last component, like an actuator or directional control valve, and pump suction line is output of the reservoir.

Filters: Filters have one input and one output in one direction always.

All the information expressed above are used as a rule in simulation and successively applied according to sequence of the components.

3.4.1 Simulation

When the circuit drawing is completed, the designer can pass to the simulation of the operation of the circuit. In the simulation the circuit is checked by rules called simulation starting rules, expressed below.

1. There must be a pump in the system.

2. The circuit must be completed properly. As a rule, if there is an actuator there should be a directional control valve to control it, but for some actuators, for example, a hydraulic motor with one direction of rotation this rule is not valid. Any condition, incompatible with this rule, causes a warning message.

3. No branch can be left uncompleted. Any attempt to pass simulation without completing the circuit drawing causes a warning message and simulation is stopped.

4. If the designer has used a fixed displacement pump without a relief valve, the program asks the designer to use a relief valve after pump, but does not force the designer so that simulation can be completed.

5. If an accumulator is used in the circuit with open center directional valves, the program warns the user against unnecessary usage, but does not force the designer to remove that component , because accumulator may be used against pressure surge or pulsation.

6. In an accumulator circuit, designer should use an unloading valve with a check valve before the accumulator to prevent the accumulator from being unloaded and to bypass pump output flow to tank at low pressure. If an unloading valve not used, then the program warns the designer, but does not stop the simulation.

7. If the designer uses an relief valve or an accumulator with a variable displacement pump this causes a warning message indicating redundancy use of those components with a variable displacement pump. The user can continue simulation after the warning message.

8. A sequence valve cannot be placed on the main supply line to block pump output. It can only be placed at the inlet of a branch, otherwise the program warns the user and stops simulation.

9. If all the branches of the circuit are blocked by sequence valves program warns the user to remove one of them. There is no point in sequencing all branches with a valve.

In addition to these main rules, there are auxiliary simulation rules applied in the program. For example, if a pressurized line is blocked from both sides, it does not change color. If a previously charged accumulator is blocked from both sides, the components connected to this accumulator does not change color, and the potential energy stored in the accumulator is available to those components.

After these rules applied to circuit, simulation starts by activating pump line and other components in sequence. When a directional control valve is reached, the valve is controlled to obtain information about its center condition, i.e. open center or closed center valve. If the valve is open center, simulation activates the component in sequence. When the last component in this branch is reached, then simulation manager passes to other branches, if there is any. After this operation is completed then the program waits the user to activate a directional valve. A directional control valve can be activated by clicking on the position boxes of valve. When a position box is clicked by a mouse, it shifts to the center position allowing flow from inlet port to actuator. During this operation simulation algorithms control all the circuit, if there is any component affected by valve shifting operation this component is activated. For example, if all the ports are blocked after the last valve shifting operation, then relief valve opens and ports the oil to the tank.

3.4.2 Simulation Algorithms

When the user passes to simulation, simulation start rules and component action rules are applied to circuit. The sequencer controls type, place and sequence of the component and uses these information in the simulation. When a component activated, for example, which component is to be activated after this component is decided by the sequencer.

Each component has a simulation subroutine in simulation module. When a component activated, simulation manager employs the subroutine of that component. Flow is simulated by Visual Basic Pset ( ) method. Reload operation of components after shifting of a directional control valve or reset operation, is made by Loadpicture( ) method.

Simulation of a closed circuit is not much different than open circuit. In the closed circuits flow turns to pump inlet after actuator, but in the open circuit flow passes over the reservoir always. Maximum one hydraulic motor can be used in the closed circuit.

Simulation algorithm can be seen schematically in Figure 3.4

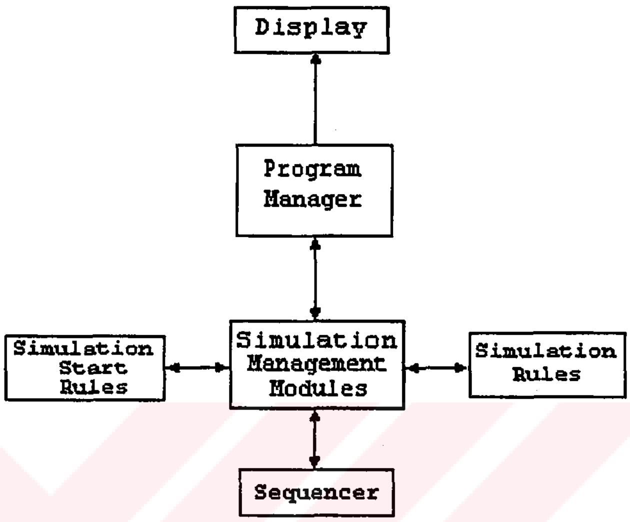


Figure 3.4 Simulation algorithms.

3.5 Designing a Circuit, and Design Algorithms

In the design part of the program the circuit is designed according to steady state hydraulic power rules. Design is a tool for sizing and selection of hydraulic power components depending on force (or torque) and linear (or rotational) velocity requirements of the output devices. Selection of a component is made among commercially available components from the databank.

When the designer passes the design part after completing drawing, the circuit is controlled by design start rules, similar to simulation start rules. These are as follows.

1. The program checks whether the circuit is completed, or not. If the circuit is not completed the user is forced to complete the circuit as soon as the design operation is started.

2. If an accumulator is used with open center directional control valves and a fixed displacement pump, the program can not classify the circuit as demand flow circuit or constant flow circuit, and warns the user indicating valve's being open center. However, the program does not force the designer to delete the accumulator, because accumulators may be used against pressure surge or pulsation. On the other hand, if the user wants to continue, the circuit is assumed as constant flow circuit.

3. If the designer uses open center and closed center directional control valves together in the same drawing, program warns the user by a message for the same reason expressed above and again, if the user wants to continue, the circuit is assumed as constant flow type.

4. If a fixed displacement pump is used without a relief valve, program warns the designer to use a relief valve and stops the design operation.

5. An accumulator circuit should use an unloading valve with a check valve, involved in unloading valve unit, to unload the pump and prevent the accumulator from being unloaded. If an unloading valve is not used before the accumulator, then the program warns the user and stops the design operation.

6. If the designer uses a relief valve or an accumulator with variable displacement pump, this causes a warning message indicating redundant use of these components with variable displacement pump. The user can continue design or stops the design operation to remove those components.

7. A sequence valve cannot be placed on the main supply line to block pump output. It can only be placed inlet of a branch, otherwise the program warns the user and stops simulation.

8. If all the branches of the circuit are blocked by a sequence valve program warns the user to delete one of them, because it is not reasonable to sequence all the branches with a sequence valve. At least one branch, generally one with lowest pressure requirement, is left without sequence valve.

After these rules are applied to the circuit drawn, design operation can be started. First, the program asks the designer to enter required output parameters of each actuator. Before looking at data entry for actuators, it is better to examine working pressure, pressure drop and displacement relations.

Working pressure is related to the actuator displacement and load as,

$$\Delta p = F / A \qquad \text{for a cylinder or ,} \qquad 3.1\ a$$

$$\Delta p = 2\pi\, T / v_m \qquad \text{for a hydraulic motor,} \qquad 3.1\ b$$

where, Δp is pressure drop across the actuator, F and T are force and torque applied on the actuator, A is cylinder piston area and v_m is the displacement of hydraulic motor. As shown from equations above, when we select a low working pressure for a high load, then displacement or area of the actuator rises to supply predetermined actuator velocity causing high flow rates and causing high pressure drop at other components of the system according to the Equation 2.8.

On the other hand, if we select a high working pressure for a comparably low load then displacement will drop according to the Equation 3.1, but volumetric efficiency will also drop due to slip and leakage caused by high pressure.

The tendency is to use a working pressure high enough to reduce flow rate which causes high pressure drop across control components and lines. In addition to Equation 2.8, if we examine flow rate versus pressure drop graphics of components, we can see the dramatic result of rise of flow rate. Therefore, the designer should try to use a working pressure that does not cause either high volumetric efficiency drop or high flow rate increase.

In the light of this important fact we can pass examination of required data entry to design a circuit. According to the circuit and actuator type, the following information is required in the design part of the program.

If the circuit is constant flow type, i.e. fixed displacement pump with open center directional control valves, then the user should enter the following data about the system.

1. Depending on the actuator type, maximum force or torque that will be applied on actuator in N or in Nm.

2. Maximum linear or rotational velocity of the actuator in m/s or rpm.

3. Maximum working pressure point of actuator in bar. This pressure point may decrease a bit after selection of output device due to displacement of the selected actuator.

If the circuit is demand flow with a fixed displacement pump, an accumulator and closed center directional control valves, then required data is as follows.

1. The three data required for constant flow circuit.

2. Idle portion of cycle in s (second).

3. Work portion of cycle in s.

If the circuit is demand flow with variable displacement pump and closed center directional control valves, then required data is the same as constant flow circuit.

If the circuit is a Hi-Lo type, that consists of a high pressure low capacity pump and a low pressure high capacity pump, then required data is as follows.

1. Maximum force or torque that may be applied on actuator in N or in Nm.

2. Maximum linear or rotational velocity of the actuator in m/s or rpm.

3. Linear or rotational velocity of the actuator when only high pressure pump is working, in m/s or rpm.

4. Working pressure point of actuator in bar.

In addition to the data related to the circuit types, the designer should enter the following information for all types of circuits.

1. Total equivalent line length including fittings, entry, and exit loses.

2. Line type that will be used in the circuit, hose, tube, or pipe. Databank includes information for both types of lines.

3. Heat transfer coefficient of the reservoir.

4. Mesh width of filtering elements for filters.

5. Required settings for related components, such as relief valve, sequence valve, pressure regulator.

3.5.1 Designing a Circuit

After entering all required actuator output data and other information, the program starts to size and select the components of the circuit. Sizing and selection of the components are made always from actuator to the pump, so the program starts to examine the last element first. Design process is as follows.

1. The program divides the circuit to branches by using line connections, then finds the actuator of the first branch.

2. The first actuator is sized depending on the output requirements and then a proper actuator is selected from the actuator databank file. The flow rate of this branch is calculated after selection by using displacement of the selected actuator and velocity output requirement of this actuator.

3. The next step is selection of other components at the same branch by using flow rate and working pressure calculated for the actuator. Again from databank files proper components are chosen. These selections are made by comparing pressure range and working flow rate ranges of the components in databank. Since all components have pressure drops at a given flow rate, all the pressure drops are added to main pressure drop value calculated for the actuator. This total pressure drop is the pressure required of a branch to successfully supply output requirements.

4. Step 2 and 3 are successively applied to all branches in the circuit

5. After sizing and selection operations are completed for branches, the program starts to compare pressure requirements of branches at line connections. If pressure requirements differ for two or three branches that are fed from the same line connection, then the largest pressure requirement is accepted as required pressure at that connection. Also flow rates of all branches connected at that line are added to find total flow rate. Since output requirements of actuators may not be the same, there may be pressure differences between calculated pressures at one or two of branches and accepted pressure at line connection. Therefore the designer should use some flow or pressure regulation devices at branches that require lower pressure.

6. The components after any connection, toward pump side, are sized according to the pressure and flow rate found in step 5.

7. Step 6 is repeated until a new connection is found or the pump is reached.

8. When the pump is reached, pressure and flow rate required is obtained from the component after the pump. A pump can be selected by using these pressure and flow rate values, except accumulator circuits. In an accumulator circuit, accumulator is sized to supply the total circuit requirements during work cycle, and pump is selected by using dwell time and accumulator capacity.

9. All the components that requires any setting, like a relief valve and a flow control valve, is set in proper sequence during design operation.

The program selects the components in the following manner. First it searches proper databank files; for example, for a hydraulic motor the program finds the motor file, then selects all the components appropriate for the pressure and flow rate conditions. After the program stores these components in an array. The next step is the selection of the smallest component, as size, among them. All the databank files include Rexroth's catalog information[7]. If the designer wants to use another company's component, the compatibility between components should be provided, or the designer can enter other company's catalog information to the databank.

All the properties of a component, like pressure drop, flow rate, total pressure drop to the position of the component itsef, type of selected component, are stored in the variables. Some of the variables can be seen in the following formulations.

Each component in the library has its own characteristic design methods in the design module. These are expressed below and all the formulas have been taken from the program.

Pumps: A pump can be selected by using total system requirements, flow rate and pressure required. At the beginning of the pump selection, the program searches the databank file to find a pump that supplies required flow rate at 1500 rpm and at the specified pressure. If the program could not find such a pump, then it searches for the pumps proper for the specified conditions, among proper ones the smallest pump is chosen. Since we know the displacement of the pump from catalog information and flow rate, rotational velocity can be calculated, with the terms used in the program, as,

$$avel(seri) = 1000 * qglob(seri) / cap(seri) \qquad 3.2$$

where avel(seri) is the array in that the rotational velocity of the pump, or any velocity of the other components are stored, in rpm for a pump, qglob(seri) is the array in that flow rates of all components are stored, in lt/min, and cap(seri) is the array in that displacements of pumps and hydraulic motors and the settings of components, like relief valve pressure setting, are stored and seri is the variable used by sequencer to define the place and the sequence of components. Volumetric and hydramechanical efficiencies are used before obtaining flow rate and pressure level.

Hydraulic Motors: A hydraulic motor can be sized and selected by using output parameters, torque required and steady state rotational velocity, and working pressure defined by user. First, displacement of the motor is calculated,

vm = 20 * 3.1416 * aforce(seri) / (ehm * apres(seri)) 3.3

where, wm is the displacement in cm^3/rev, aforce(seri) is the array in that force or torque outputs of the actuators are stored in N or Nm, apres(seri) is the working pressure in bar and ehm is the hydramechanical efficiency. Then, flow rate can be calculated, again whit terms used in the program, as,

cap(seri)= vm

qglob(seri) = cap(seri) * avel(seri) / (ev * 1000) 3.4

where, ev is the volumetric efficiency. Finally, by using vm, qglob(seri) and avel(seri) a motor is selected and new pressure drop across motor is calculated as,

pdrop(seri) = 2 * 10 * 3.1416 * aforce(seri) / (ehm * cap(seri)) 3.5

where pdrop(seri) is the pressure drop across hydraulic motor in bar. During selection of the motors, proper components for specified condition is elected and stored to an array, then among them the smallest one is chosen.

Cylinders: A cylinder can be sized and selected by using output parameters, force required and steady state linear velocity, and working pressure in this way; first, diameter of the piston is calculated as,

ar = aforce(seri) * 10 / apres(seri) 3.6

dr = ((4 / 3.1416) * ar) ^ .5 3.7

where, ar is the area of the piston in mm^2 and dr is the diameter of the piston in mm. Then by using dr and apres(seri), a ram can be selected as expressed for hydraulic motors. Depending on the selected ram new, piston area is specified and lastly by assistance of new piston area we can calculate flow rate, in lt/min, required and real pressure drop, in bar, as,

cap(seri) = dr

pdrop(seri) = aforce(seri) * 10 / ((3.1416 / 4) * ev * cap(seri) ^ 2) 3.8

qglob(seri) = (6 / 100) * (3.1416 / 4) * (cap(seri) ^ 2) * (avel(seri)) 3.9

where ev is the volumetric efficiency.

Directional Control Valves: A directional control valve can be selected by using the flow rate passing through it and maximum working pressure of the valve. Pressure drop can be found after a valve has been selected by using catalog information. In databank, there are pressure drop coefficients for all directional control valves modeled in the form of $a\ q^2$, where a is the pressure drop coefficient and q is flow rate, so pressure drop, in bar, is

pdrop(seri) = a * q ^ 2 3.10

If the valve is a 4 way valve then, the program asks the designer, if he/she wants the return line filter, between the valve and reservoir, to be sized and selected. If the designer wants to use a return line filter, program selects a proper return line filter, otherwise the program skips this stage.

Flow Control Valves: A flow control valve can be selected by using the flow rate passing on it and maximum working pressure of the valve. Pressure drop can be found after a valve has been chosen by using catalog information, but setting of the flow control valve is determined before pressure drop calculation. Therefore the program sets the flow control valve according to the catalog information and uses the wide open position, but not fully open, not to cause high pressure drop at the beginning. Later the user can change the settings. In databank, there are pressure drop coefficients for all flow control valves and for all settings modeled in the form of $a\ q$, where a is the pressure drop coefficient, so pressure drop;

pdrop(seri) = a * q 3.11

Pressure Control, Sequence, Relief and Unloading Valves: These components can be selected by using flow rate and working pressure. For pressure control and sequence valves, pressure drops are entered by the user according to the flow rate and component type that are presented to the user. Pressure drop due to throttling can be found by comparing inlet pressure and pressure setting of each component. When the program finds a sequence valve, flow rate of the branch including sequence valve is compared to total flow requirements of the other branch, or branches, that do not include a sequence valve then the largest flow rate value is taken as flow rate of the circuit.

Counterbalance Valves: These are similar to sequence valves as construction, but placement and function of a counterbalance valve is different. A sequence valve blocks the inlet of a branch or component until a pressure value, however a counterbalance valve blocks the outlet of a component. Both types of valves open when a preset inlet pressure are reached.

Reservoirs: Reservoirs are sized to have a volume to accommodate three times the pump flow output for one minute. In terms of heat generation and dissipation, the program calculates minimum reservoir area to dissipate the heat generated by the system. To do this the program asks the designer to enter heat transfer coefficient of the reservoir and approximate temperature difference between reservoir and surrounding. Then the program calculates the differance between energy output and energy input to the system, this differance is the heat generated by the system. Designer uses either minimum reservoir volume or minimum reservoir area, depending on which one is critical. Both results are given as design outputs.

Accumulators: Accumulators are sized to meet the requirement of maximum flow rate and pressure level during work cycle. However, those, used in constant flow circuits to decrease the effect of pressure surge and pulsation, are not sized by the program. To size an accumulator we have to know idle and work time of the cycle, Moreover, setting of unloading valve is used as maximum charge pressure.

Assuming that the charge event of the accumulator is isothermal, we can use equation 3.11.

$$p_1 V_1 = p_2 V_2 = p_3 V_3 \qquad 3.11$$

Assuming the discharge event of the accumulator is adiabatic, we can use equation 3.12.

$$p_1 V_1^n = p_2 V_2^n = p_3 V_3^n \qquad 3.12$$

In the light of these assumptions, one can find out minimum accumulator capacity, after some manipulations as,

v1 = dv * (p2 / p1) ^ (1 / n1) / ((p2 / p3) ^ (1 / n) - 1) 3.13

where dv is total accumulator discharge amount during work cycle and can be found,

dv = t * q / 60 3.14

where t is the time of work portion of the cycle in second, q is the total flow rate requirement of the circuit. In equation 3.13, p1 is the accumulator precharge pressure and is taken as,

$$p1 = 0.9 * p3 \qquad 3.15$$

p2 is the unloading valve setting, p3 is lowest working pressure. p2 and p3 are user inputs. In the equation n and n1 are determined depending on, respectively, charge and discharge conditions of the accumulator. Those have values between 1 and 1.4. n and n1 are also user input.

Lines: Lines are sized to carry required flow rate without excessive pressure drop and without excessive flow velocity. Flow velocities are to be kept below limits to make the flow laminar. The tendency is to keep the flow velocity around 5 m/s in supply lines, 2 m/s in return lines and 1 m/s in suction lines[3]. The pressure drop in a line is calculated by,

$$\Delta p = \gamma f (L / d) (V^2/2g) \qquad 3.16$$

$$f = 16 / Re \text{ , for laminar flow} \qquad 3.17$$

where γ is specific weight of the oil, f is the friction factor, L is the equivalent length of the line predicted and entered by the user, including fittings, entry and exit losses, in m, d is the diameter of the line in m, V is the velocity of the flow in m/s, and g is acceleration due to gravity in m/s^2.

Proper line diameter can be calculated in this way,

$$di = 1000 * (4 * qglob(seri) / (60 * 3141.6 * V)) \wedge .5 \qquad 3.18$$

where, di is line diameter in mm, qglob(seri) is the flow rate and V is the velocity of the flow. After that a higher standard line diameter is selected. Then, new velocity value is calculated and Reynolds number is controlled by using equation 3.19 and 3.20.

$$V = 4 * qglob(seri) / (60 * 3141.6 * di \wedge 2) \qquad 3.19$$

$$Re = di * V / \nu \qquad 3.20$$

where ν is kinematic viscosity and approximately is 0.000041 m^2/s. If Reynolds number is smaller than 2000, then the flow is laminar and the program passes to the calculation of pressure drops. If Reynolds number is higher than 2000 then line diameter is recalculated by accepting Reynolds number as 1500 and using equation 3.20. Then new flow velocity is calculated for this dimension by using equation 3.19.

Commercially available hose diameters as follows[8] ;

Table 3.1 Diameter of commarically available hoses.

Nominal diameter	Inner diameter (mm)
5	4.8
6	6.4
8	7.9
10	10.3
12	12.7
16	15.9
20	22.2
25	25.8
32	34.9
40	38.1
40	46.0
50	50.8
60	60.3

In the program, during calculations, inner line diameters are used.

After sizing and selecting all the components in the circuit, the user can take printout of design results such as ordering code of selected component, pressure drop, flow rate, and other required information. Then the user can save all design result in a file by the same file name with drawing, but in *.Des extension. On the other hand, when the user opens an old drawing file with design results and makes modification on drawing and then saves it again without redesigning the circuit, this will cause old design file to be deleted.

3.5.2 Design Algorithms

General sections of the design tool and interactions among those sections can be seen schematically in Figure 3.5.

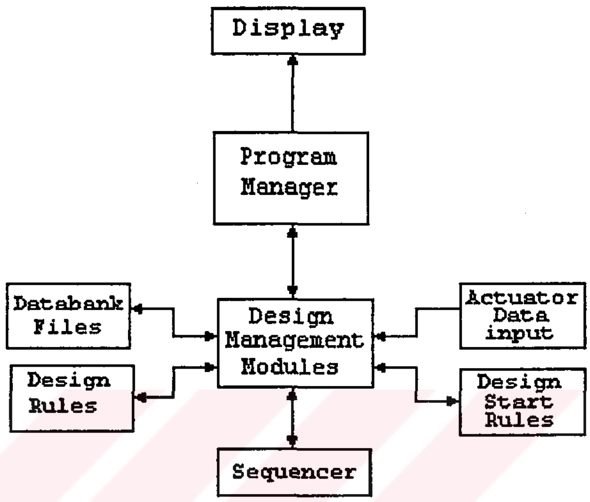


Figure 3.5 General algorithm of the design process.

3.5.3 Component Data Entry

The design part of the program uses databank files prepared according to the commercially available components. All the components, except for reservoirs and accumulators, have their own databank files[7]. The extension of these files is *.Dat .

The user can enter data of new components in the data entry part and the program uses them in design when necessary. During the entry of new data, data entry format helps the user to enter data in a proper way. Moreover, the user can visualize and delete any component data from databank files.

The sequence of the sizes of components is not important in databank files, because during the design process the program first elects all the proper components from databank files then stores them in an array. Finally the program selects the smallest size among them, by comparing size of elected components.

3.6 Examination of Operating Condition of Circuits

The program has the ability to find out the steady state operating conditions of the circuits. On the design menu bar there are "CSP (Change System Parameter) and Show Operating Condition", and "Show Operating Condition" commands. The former is used when the designer wants to change a system parameter, or setting, and then visualize operating condition. The latter is used to see operating condition according to the current settings.

Since multibranched hydraulic power circuits are so flexible in terms of control of sequence and there are many possible operating conditions, examination of such circuits is difficult. Therefore the designer can examine the operating conditions for circuits with a maximum of three branchs. As expressed in limitation part, the sequence diagram cannot be used by the program, examination is done assuming all actuators work together.

The components whose settings can be changed are flow control valve, sequence valve, counterbalance valve, relief valve and unloading valve, and pilot operated check valve.

3.6.1 Examination of Operating Condition of One Branched Circuit

A one branch circuit can be examined by adding all pressure drops across components. Normally, pressure at pump output is lower than relief valve setting, because in the design relief valve setting should be set higher than required pressure at the pump output when system on load. On the other hand, if there is a flow control valve in the system, and if the designer throttles the valve by changing the setting, then all the pressure drops of components are recalculated with full flow and required pressure at the pump output is found. At this point, if required pressure at the output of the pump is higher than relief valve setting then, this means that some of flow passes to tank over the relief valve. The amount of this flow can be found by decreasing flow rate in the system incrementally until total pressure drop is equal to the relief valve setting. Then related data is presented to user.

3.6.2 Examination of Operating Condition of Two Branched Circuit

When a two branch circuit is designed by the program, it is seen that total pressure drops of the branches at the line connections are different. These pressure drops shows total pressure requirements of the branches at the connection point, assuming both branches work separately.

However, in actual practice, there are two possibilities; either both work together, or one completes its stroke before the other due to unbalance. In the first case, if the difference between pressure requirements of the branches at the line connection is not high, a balance point, or balance pressure, may. Since pressure drops of components except actuators depend on basically flow rate, we can find balance point by decreasing flow rate at the circuit with high total pressure drop and increasing flow rate at the circuit with low total pressure drop until total pressure drops of both branches are equal at the line connection. The flow rates and actuator velocities will be different at the balance than required due to changed flow rates. To preserve velocity output of actuators a flow control valve can be placed to the low pressure branch.

In the second case, if there is no balance point, the circuit with low pressure requirement completes its stroke first with full flow. Then the other branch operates again with full flow. When the branches are on load cycle pressure drops are recalculated with full flow separately and compared with relief valve setting against the possibility of exceeding relief valve setting. If this happens, then the amount of flow passing to reservoir over relief valve should be calculated. At this point, total pressure drop of the circuit is equal to the relief valve setting.

Flow rate passing to tank can be found by decreasing flow rate in the circuit incrementally and recalculating total pressure drops until total pressure drop equal to the relief valve setting.

When there is a sequence valve in a branch, the setting of component is compared with the total pressure drop of the other branch. If pressure drop of the unsequenced branch exceeds the setting of sequence valve then both branches operate at the same time at a balance point that can be found as expressed above. If the other case occurs, then unsequenced branch completes its stroke with full pump output, after that pressure rises until setting of the valve and the other branch operates. The pressure in the system, again may exceeds the relief setting when the second case takes place. Similarly a balance point can be found as expressed above.

After visualizing operating condition of the circuit, the designer can rechange the setting of the proper components and reanalyze the circuit. Related information is given on the two form one by one for each branch.

3.6.3 Examination of Operating Condition of Three Branched Circuit

Examination of three branched circuits is similar to two branched circuit. There are three possible conditions. The first one is the case where all actuator works together at a balance point, the second is the case where two of them operates together and then third actuator works. The last one is the operation of each actuator one by one. The procedure to find balance point, controlling relief and sequence valve settings and determining operating sequence of the actuator when there is no balance point are the same as expressed in 3.6.2.

CHAPTER IV

CASE STUDIES

Case Study 1: A machine for hollow grinding blades consists of a sliding table having a 500-mm movement on which the blades are mechanically clamped. The table is hydraulically driven past a fixed position grinding wheel, the blades being positioned so that the forward pass rough grinds the blade and the return pass finish grinding.

Design a hydraulic circuit so that the table moves at the same speed in both direction, the speed to be adjustable between 2 and 4 m/min. The cycle is to be electrically controlled, with a push-button to start. A limit switch signals cylinder to reverse at the end of the extend stroke and a second limit switch at the end of the retract stroke is used to stop to stop the cylinder and unload the pump. The maximum system pressure is to be 50 bar, and the cylinder is to exert a maximum force of 2 kN in both directions. Assume that dynamic trust of the cylinder is 0.9 times the static trust. Select a standard metric cylinder and determine the relief valve setting for the maximum trust of 2 kN. Calculate theoretical pump delivery and pump input power [9].

Solution: Since speed is to be the same in both directions, a double rod cylinder is preferable. Also a flow control valve is to be used to adjust speed between required range. A fixed displacement pump and a 4/3 tandem center directional control valve are proper for the circuit. The proposed circuit can be seen in Figure 4.1.

Data entrance to the program is listed below,

$V = 4$ m/min $\cong 0.0667$ m/s , ram velocity input.

Because maximum system pressure is to be 50 bar, a 35 bar pressure differential on the ram seems to be enough, therefore,

$\Delta p = 35$ bar, ram pressure drop input.

$F = 2000$ N, force input.

$L = 5$ m , equvalent line lenght.

Line type is entered as hose.

The design results as program output are listed below. Input power can be calculated manually by using pump output parameters.

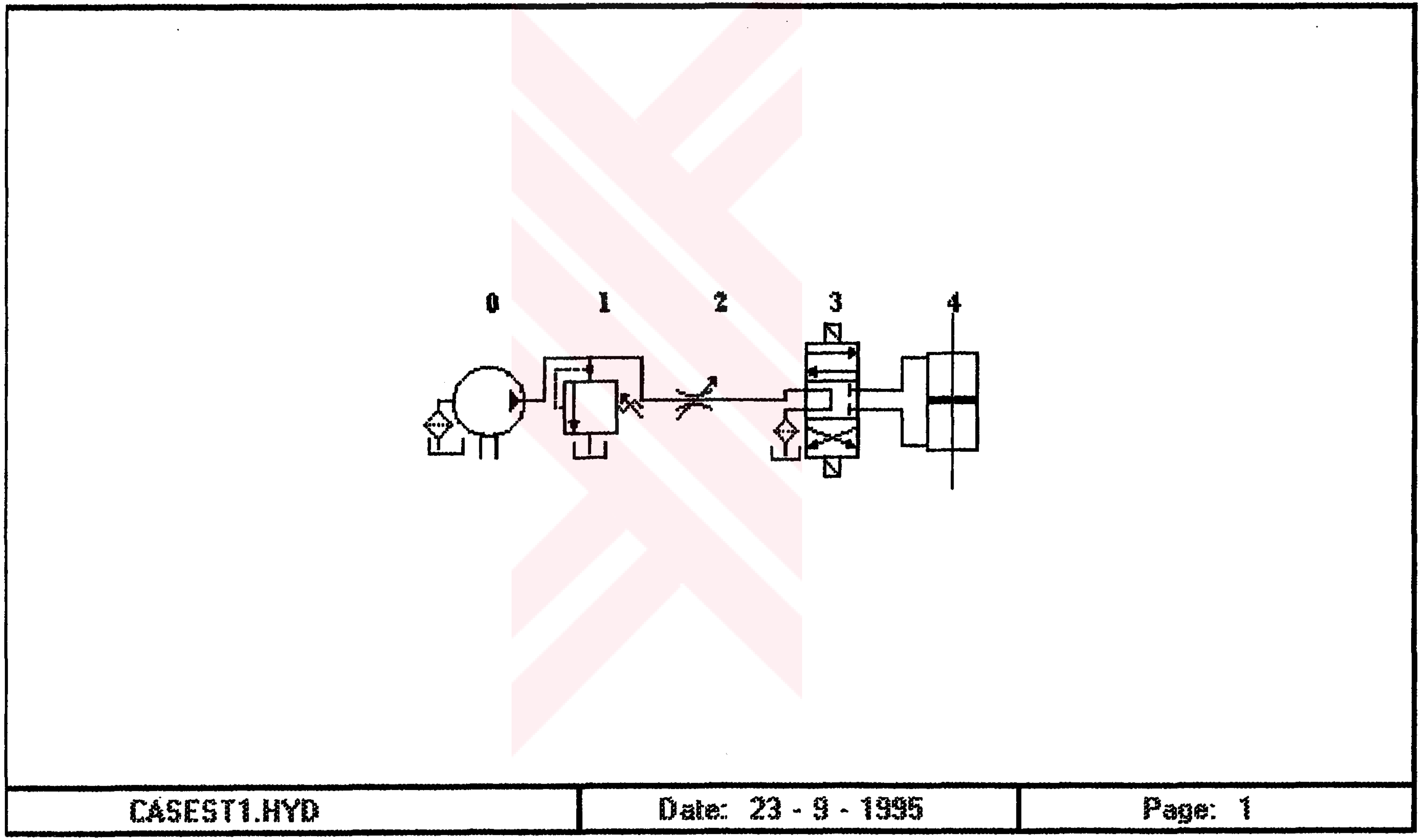


Figure 4.1 Circuit output for Case Study 1

Hydra D&S
Design Results
CASEST1.HYD
Date: 24 - 9 -1995, Page 1

0 Constant Displacement Pump:

```
Type                         = PFPR4-10/2
Outlet Pressure              = 46.5 bar
Flow Rate                    = 2.26 lt/min
Rotational Velocity          = 1059 RPM
Displacement                 = 2.14 cm^3/rev
Line Diameter at Outlet      = 6.4 mm
Line Diameter at Suction     = 7.9 mm
Outlet Flow Velocity         = 1.17 m/s
Suction Flow Velocity        = .771 m/s

Overall Line Pressure drop = 3.4 bar

Type of suction filter       = R-RF30/25
Mesh width of the filter     = 2.14 micron
Pressure drop                = .002 bar
```

1 Relief Valve:

```
Type             = DBD6 10
Flow Rate        = 2.26 lt/min
Pressure Setting = 50 bar
```

2 Flow Control Valve:

```
Type                     = DV8
Total Pressure Drop      = 46.5 bar
Reflected Pressure Drop at full flow = 2.59 bar
Real Pressure Drop at full flow      = 2.59 bar
Flow Rate                = 2.26 lt/min
Throttle Setting         = 5 revolusion
```

3 4/3 Directional Control Valve:

```
Type                       = 4WMM10G
Flow Rate                  = 2.26 lt/min
Total Pressure Drop        = 43.90 bar
Pressure Drop at inlet     = .022 bar
Pressure Drop at outlet    = .020 bar

Type of Return Line Filter = R-RF30/25
Filtration Capacity        = 25
```

4 Clinder:

```
Type                               = CG70 32/18
Pressure Drop                      = 40.4 bar
Pressure Drop with line losses     = 43.8 bar
Flow Rate                          = 2.26 lt/min
Linear Velocity                    = .066 m/s
Load                               = 2000 N
Piston Diameter                    = 32 mm
Supply Line Diameter               = 6.4 mm
Return Line Diameter               = 6.4 mm
Inlet Flow Velocity                = 1.17 m/s
Return Flow Velocity               = 1.17 m/s
```

Case Study 2: A hydraulically-operated tilting mechanism is to use a rear trunnion mounted cylinder with a rod mounted clevis. The cylinder is to have a stroke of 2.3 m and exert a minimum force of 140 kN in each direction. It is to have a speed of 4.5 m/min on extend and retract and must be capable of being locked in any position against a reversible load [9].

(a) Draw a suitable circuit and select a standard metric cylinder assuming a maximum system pressure of 200 bar. What will be the actual operating pressure of the system?

(b) Calculate required pump delivery and input power.

Solution: The force the cylinder must exert is the same in both direction, therefore, a double rod cylinder is useful. Moreover, pilot operated double check valve is used to lock the cylinder against a reversible load, but when the system locked the directional valve should be in the center position. A fixed displacement pump and a 4/3 tandem center directional control valve are proper for the circuit. The proposed circuit can be seen in Figure 4.2.

Data entrance to the program is listed below,

V = 4.5 m/min = 0.075 m/s , ram velocity input.

Because maximum system pressure is to be 200 bar, a 175 bar pressure differential on the ram seems to be enough, so,

Δp = 175 bar, ram pressure drop input.

F = 140000 N, force input.

L = 5 m , equvalent line lenght.

Line type is entered as hose.

The design results as program output are listed below. Input power can be calculated manually by using pump output parameters.

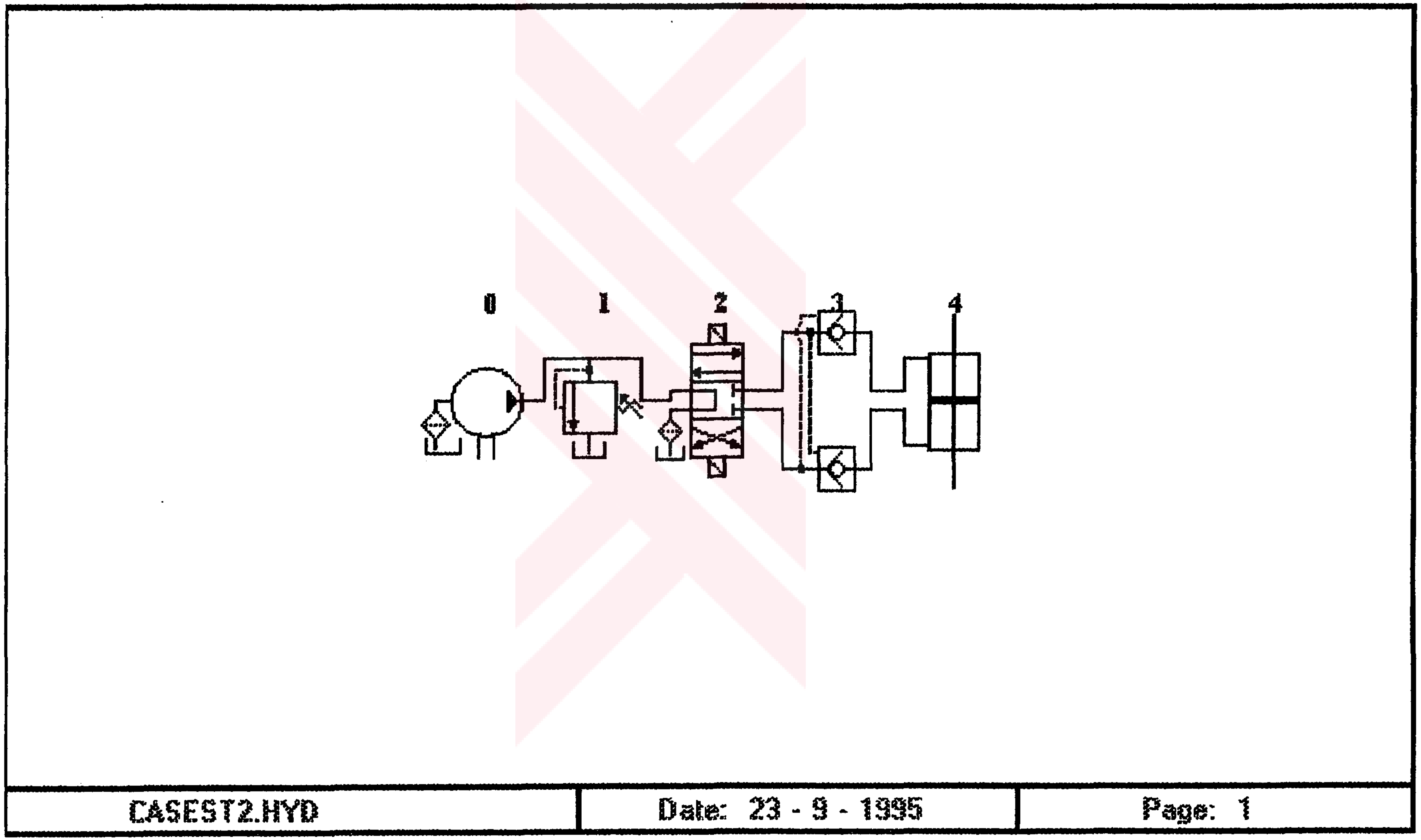


Figure 4.2 Circuit output for Case Study 2

Hydra D&S
Design Results
CASEST2.HYD
Date: 24 - 9 -1995, Page 1

0 Constant Displacement Pump:

Type	=	PFP A2FO/32
Outlet Pressure	=	177. bar
Flow Rate	=	45.5 lt/min
Rotational Velocity	=	1422 RPM
Displacement	=	32 cm^3/rev
Line Diameter at Outlet	=	15.9 mm
Line Diameter at Suction	=	34.9 mm
Outlet Flow Velocity	=	3.81 m/s
Suction Flow Velocity	=	.792 m/s

Overall Line Pressure drop = 1.1 bar

Type of suction filter	=	R-RF60/25
Mesh width of the filter	=	32 micron
Pressure drop	=	.205 bar

1 Relief Valve:

Type	=	DBD6 10
Flow Rate	=	45.5 lt/min
Pressure Setting	=	200 bar

2 4/3 Directional Control Valve:

Type	=	4WMM10G
Flow Rate	=	45.5 lt/min
Total Pressure Drop	=	177.9 bar
Pressure Drop at inlet	=	9.06 bar
Pressure Drop at outlet	=	7.65 bar

Type of Return Line Filter	=	R-RF60/25
Filtration Capacity	=	25

3 Pilot Operated Check Valve:

Type = S15
Flow Rate = 45.5 lt/min
Pressure setting of the valve = 150 bar
Total Pressure Drop = 161. bar
Pressure Drop = 1.5 bar

4 Clinder:

Type	=	CG210 125/56
Pressure Drop	=	158. bar
Pressure Drop with line losses	=	159. bar
Flow Rate	=	45.5 lt/min
Linear Velocity	=	.075 m/s
Load	=	1400 N
Piston Diameter	=	125 mm
Supply Line Diameter	=	15.9 mm
Return Line Diameter	=	22.2 mm
Inlet Flow Velocity	=	3.81 m/s
Return Flow Velocity	=	1.95 m/s

Case Study 3: A gravity track feeds components to a conveyor transfer point (Figure 4.3) which has to lift a load of 3.5 tonnes a height of 3 m to an upper track. When a component is on the lower track it runs under gravity on to the platform on cylinder A. If there is space available on the top track, cylinder A lifts the component level with the top track and cylinder B extends with a maximum trust of 1000 kg, moving the component 0.4 m onto the upper gravity track. As cylinder A lifts, a mechanical stop prevents further components being fed along the bottom track.

The cylinders are both front flange mounted, the piston rod of the cylinder A being rigidly guided while cylinder B piston rod is unguided. The maximum system pressure is to be 140 bar. If the upper track is clear, the time for one complete cycle is to be 60 second. Neglecting all losses in the system determine suitable standard metric cylinder sizes and pump delivery rate required. Design a suitable circuit using solenoid operated directional control valves [9].

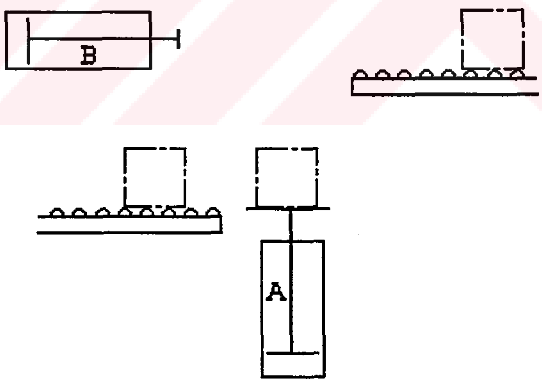


Figure 4.3 Presentation of the cylinders and trucks for Case Study 3.

Solution: Because the program assumes all actuators working at the same time and cylinder A is to extend first, a sequence valve with free return check valve should be used before cylinder B. A fixed displacement pump and 4/3 tandem and 4/3 closed center directional control valves are proper for the circuit. The proposed circuit can be seen in Figure 4.4. Since calculation is performed by the program losses cannot be neglected.

A complete cycle is to be 60 second, so we may have 5 s for both loading and unloading of the load, 30 s for extend, 20 s for retract stroke of the cylinder A. Cylinder B has 5 s for extend 55 s for retract strokes.

Data entrance to the program is listed below.

For cylinder A;

$V = 3\ m/30\ s = 0.1\ m/s$, velocity input

Because maximum system pressure is to be 140 bar, a 120 bar pressure differential on the ram seems to be enough, so,

$\Delta p = 120$ bar , pressure drop input.

$F = 3.5$ tonnes $\cong 35000$ N , force input.

For cylinder B;

$V = 0.4\ m/5\ s = 0.08\ m/s$, velocity input

$\Delta p = 120$ bar , pressure drop input.

$F = 1000$ kg $\cong 10000$ N , force input.

$L = 10$ m , equivalent line length.

Line type is entered as hose.

The design results as program output are listed below. Input power can be calculated manually by using pump output parameters.

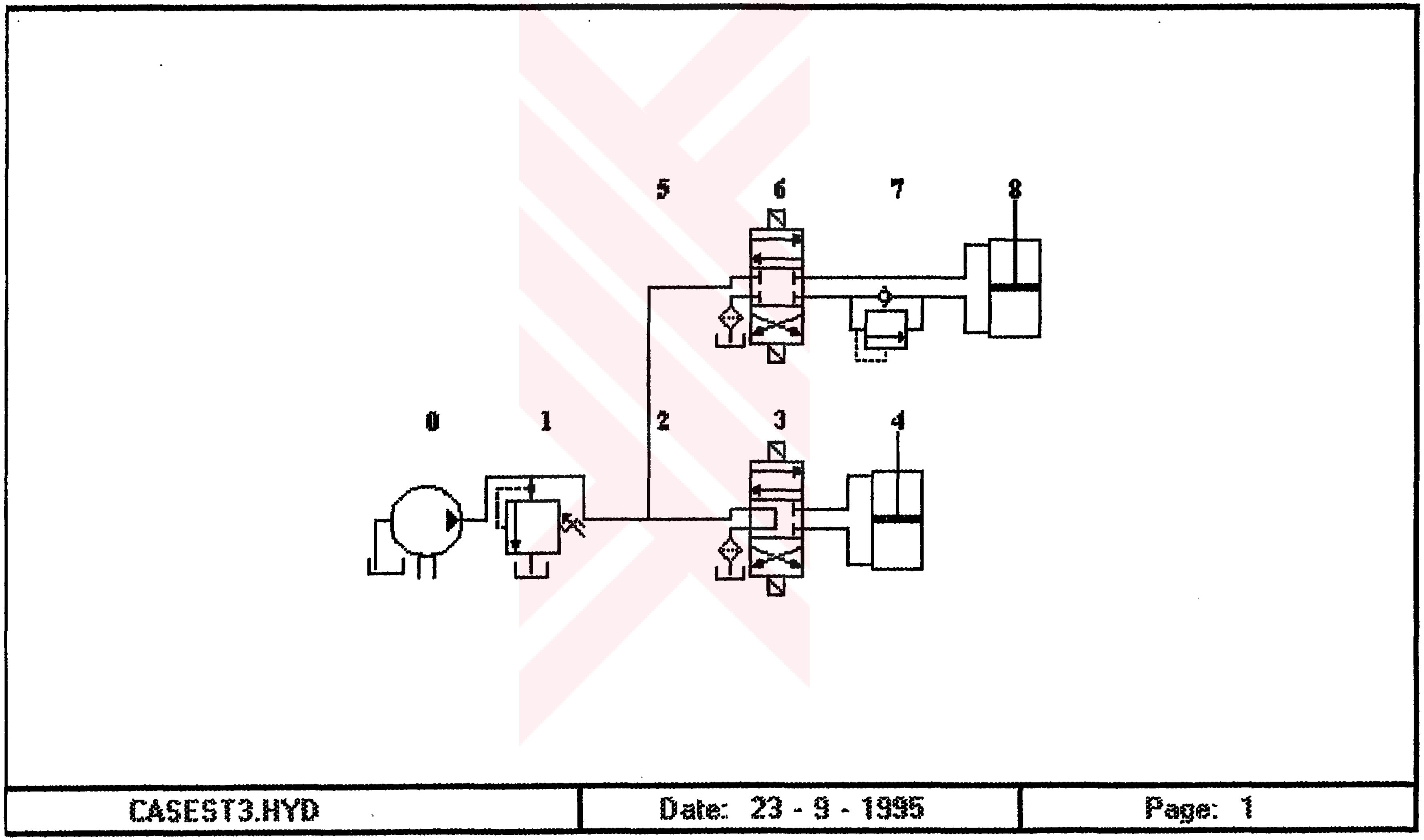


Figure 4.4 Circuit output for Case Study 3

Hydra D&S
Design Results
CASEST3.HYD
Date: 24 - 9 -1995, Page 1

0 Constant Displacement Pump:

```
Type                        = PFPR4-10/16
Outlet Pressure             = 137. bar
Flow Rate                   = 19.2 lt/min
Rotational Velocity         = 1199 RPM
Displacement                = 16.0 cm^3/rev
Line Diameter at Outlet     = 10.3 mm
Line Diameter at Suction    = 22.2 mm
Outlet Flow Velocity        = 3.85 m/s
Suction Flow Velocity       = .830 m/s

Overall Line Pressure drop = 5.5 bar
```

1 Relief Valve:

```
Type             = DBD6 10
Flow Rate        = 19.2 lt/min
Pressure Setting = 140 bar
```

2 Line :

```
Total Pressure Prop        = 137. bar
Flow Rate at Inlet         = 19.2  l/min
Inlet Line Diameter        = 10.3 mm
Inlet Flow Velocity        = 3.85 m/s
Outlet Line Diameter at 1 = 10.3 mm
Outlet Line Diameter at 2 = 7.9 mm
```

3 4/3 Directional Control Valve:

```
Type                      = 4WMM10G
Flow Rate                 = 19.2 lt/min
Total Pressure Drop       = 129.8 bar
Pressure Drop at inlet    = 1.62 bar
Pressure Drop at outlet   = .769 bar

Type of Return Line Filter = R-RF30/25
Filtration Capacity        = 25
```

4 Clinder:

```
Type                              = CD210 63/28
Pressure Drop                     = 124. bar
Pressure Drop with line losses    = 127. bar
Flow Rate                         = 19.2 lt/min
Linear Velocity                   = .1 m/s
Load                              = 3500 N
Piston Diameter                   = 63 mm
Supply Line Diameter              = 10.3 mm
Return Line Diameter              = 15.9 mm
Inlet Flow Velocity               = 3.85 m/s
Return Flow Velocity              = 2.02 m/s
Area Ratio (Piston Side/ Rod Side)  = 1.25
```

Hydra D&S
Design Results
CASEST3.HYD
Date: 24 - 9 -1995, Page 2

5 Line:

```
Flow Rate         = 6.21 lt/min
Pressure at inlet = 137. bar
Line Diameter     = 7.9 mm
```

6 4/3 Directional Control Valve:

```
Type                       = 4WMM10E
Flow Rate                  = 6.21 lt/min
Total Pressure Drop        = 137.0 bar
Pressure Drop at inlet     = .061 bar
Pressure Drop at outlet    = .030 bar

Type of Return Line Filter = R-RF30/25
Filtration Capacity          = 25
```

7 Sequence Valve:

```
Type                 = DZ10 30
Total Pressure Drop  = 137 bar
Pressure Drop        = 2 bar
Flow Rate            = 6.21 lt/min
Pressure Setting     = 135 bar
```

8 Clinder:

```
Type                              = CD70 40/18
Pressure Drop                     = 88.4 bar
Pressure Drop with line losses    = 91.3 bar
Flow Rate                         = 6.21 lt/min
Linear Velocity                   = .08 m/s
Load                              = 1000 N
Piston Diameter                   = 40 mm
Supply Line Diameter              = 7.9 mm
Return Line Diameter              = 10.3 mm
Inlet Flow Velocity               = 2.11 m/s
Return Flow Velocity              = 1.55 m/s
Area Ratio (Piston Side/ Rod Side)   = 1.25
```

Reservoir:

```
Minimum Reservoir Volume = 57.8 lt
Minimum Reservoir area   = .023 m2
```

Case Study 4: A hydraulic press design is required. The velocities during rapid approach and pressing are 0.25 and 0.002 m/s respectively. The maximum pressing force is 200,000 N and maximum system pressure is to be 200 bar.

Solution: Since two different velocities are required, a Hi-Lo circuit may be proper for this application. Inside the circuit two fixed displacement pumps, a 4/3 tandem center directional control valve and a double acting cylinder are used. The proposed circuit can be seen in Figure 4.5.

Data entrance to the program is listed below,

Vmax. = 0.25 m/s , ram high velocity input.

Vmin. = 0.002 m/s , ram low velocity input.

Because maximum system pressure is to be 200 bar, a 180 bar pressure differential on the ram seems to be enough, so,

Δp = 180 bar, ram pressure drop input.

F = 200000 N, force input.

L = 10 m , equvalent line lenght.

Line type is entered as tube.

The design results as program output are listed below.

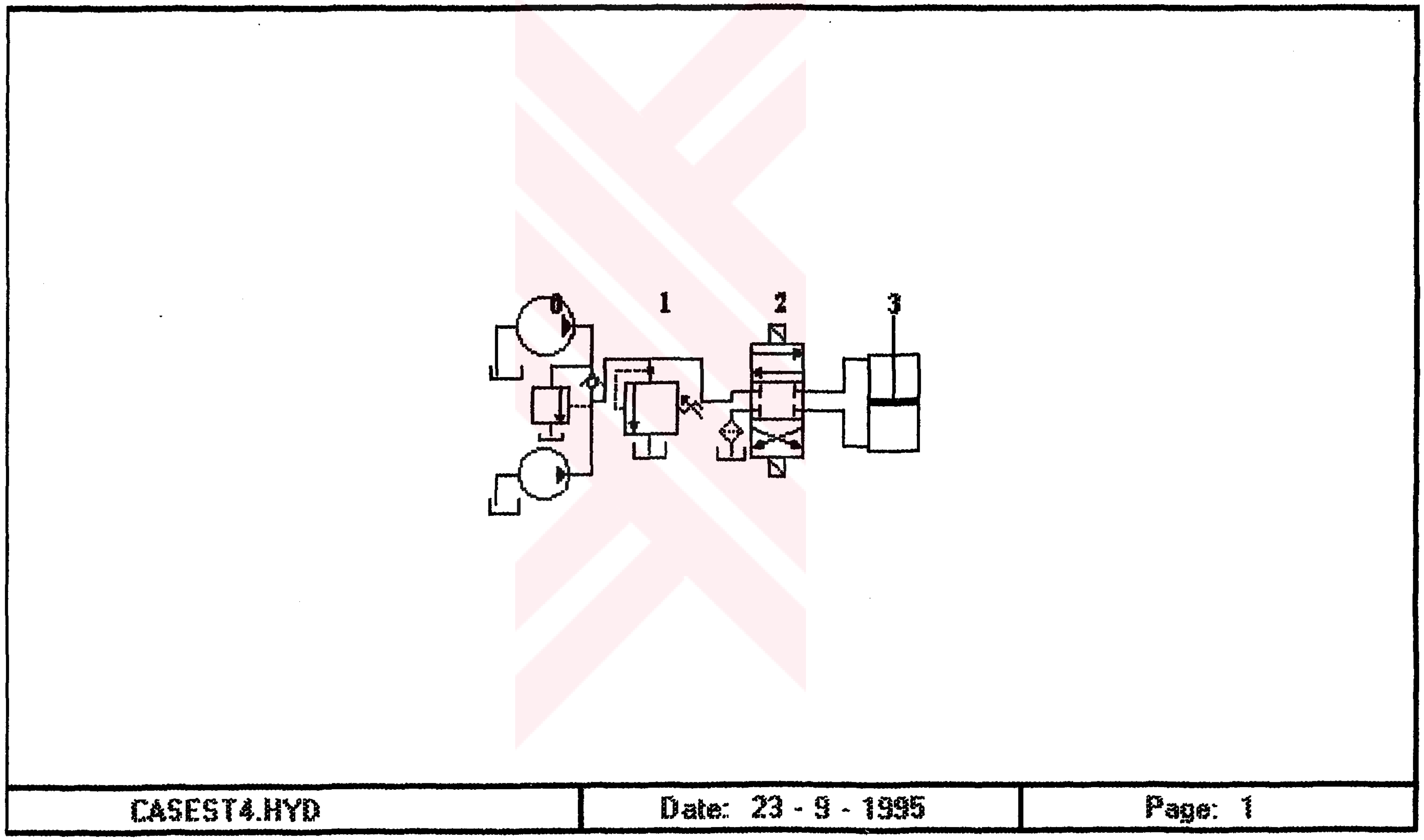


Figure 4.5 Circuit output for Case Study 4

Hydra D&S
Design Results
CASEST4.HYD
Date: 24 - 9 -1995, Page 1

0 Pump Group:

Low Pressure Constant Displacement Pump

Type	= PFP A2FO/125
Displacement	= 125 cm^3/rev
Rquired Max. Outlet Pressure	= 50 bar
Flow Rate	= 184. lt/min
Rotational Velocity	= 1472 RPM
Unloading valve setting	= 125 bar
Line Diameter at Outlet	= 50.1 mm
Line Diameter at Suction	= 62.5 mm
Outlet Flow Velocity	= 1.55 m/s
Suction Flow Velocity	= 1 m/s

High Pressure Constant Displacement Pump

Type	= PFPR4-10/1.6
Displacement	= 1.51 cm^3/rev
Rquired Max. Outlet Pressure	= 187. bar
Flow Rate	= 1.51 lt/min
Rotational Velocity	= 1005 RPM
Line Diameter at Outlet	= 6.14 mm
Line Diameter at Suction	= 6.14 mm
Outlet Flow Velocity	= .852 m/s
Suction Flow Velocity	= .852 m/s

Overall Line Pressure drop = 6.094849 bar

1 Relief Valve:

Type	= DBD6 10
Flow Rate	= 1.51 lt/min
Pressure Setting	= 200 bar

2 4/3 Directional Control Valve:

Type	= 4WMM10E
Flow Rate	= 1.51 lt/min
Total Pressure Drop	= 187.1 bar
Pressure Drop at inlet	= .003 bar
Pressure Drop at outlet	= .001 bar

Type of Return Line Filter	= R-RF30/20
Filtration Capacity	= 25

Hydra D&S
Design Results
CASEST4.HYD
Date: 24 - 9 -1995, Page 2

3 Clinder:

Type	= CD210 125/56
Pressure Drop	= 181. bar
Pressure Drop with line losses	= 187. bar
Flow Rate	= 1.51 lt/min
Linear Velocity	= .002 m/s
Load	= 2000 N
Piston Diameter	= 125 mm
Supply Line Diameter	= 6.14 mm
Return Line Diameter	= 6.14 mm
Inlet Flow Velocity	= .852 m/s
Return Flow Velocity	= 1.06 m/s
Area Ratio (Piston Side/ Rod Side)	= 1.25

Case Study 5: A hydraulic circuit design is required for a periodic pushing operation. Dwell time between two cycle is 120 s and each cycle requires 15 s. The maximum force required to push the work piece is 50,000 N and velocity during load cycle is to be 0.1 m/s. Maximum system pressure is to be 200 bar.

Solution: Dwell time between two cycle is long enough to use an accumulator circuit. The circuit requires a fixed displacement pump, an accumulator, a 4/3 closed center directional control valve and a double acting cylinder. The proposed circuit can be seen in Figure 4.6.

Data entrance to the program is listed below,

V = 0.1 m/s , ram velocity input.

Because maximum system pressure is to be 200 bar, a 180 bar pressure differential on the ram seems to be enough, so,

Δp = 180 bar, ram pressure drop input.

F = 50000 N, force input.

L = 5 m , equvalent line lenght.

Line type is entered as hose.

The design results as program output are listed below.

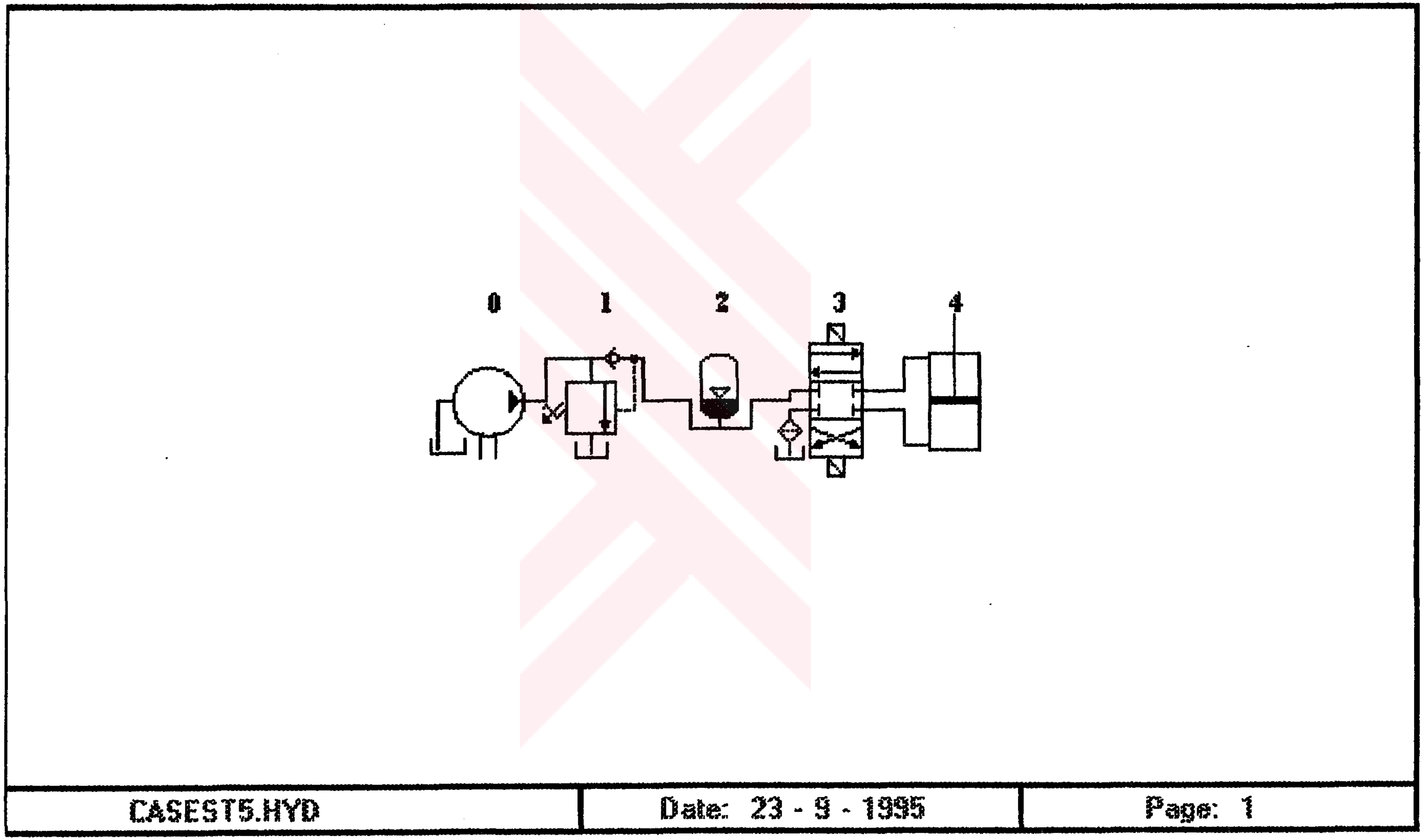


Figure 4.6 Circuit output for Case Study 5

Hydra D&S
Design Results
CASEST5.HYD
Date: 24 - 9 -1995, Page 1

0 Constant Displacement Pump:

Type	= PFPR4-10/2
Outlet Pressure	= 200 bar
Flow Rate	= 2.41 lt/min
Rotational Velocity	= 1126 RPM
Displacement	= 2.14 cm^3/rev
Line Diameter at Outlet	= 6.4 mm
Line Diameter at Suction	= 7.9 mm
Outlet Flow Velocity	= 1.24 m/s
Suction Flow Velocity	= .819 m/s

Overall Line Pressure drop = 2.6 bar

1 Unloading Valve:

Type	= DA10 30
Flow Rate	= 2.41 lt/min
Pressure Setting	= 200 bar

2 Accumulator:

Accumulator Precharged Volume	= 22.9 l
Discharge Flow Rate	= 19.2 lt/min
Maximum Charge/ Work Pressure	= 200 bar
Minimum Work Pressure	= 130 bar
Dwell Time	= 120 s.
Working Time	= 15 s.

3 4/3 Directional Control Valve:

Type	= 4WMM10E
Flow Rate	= 19.2 lt/min
Total Pressure Drop	= 181.7 bar
Pressure Drop at inlet	= .594 bar
Pressure Drop at outlet	= .293 bar

Type of Return Line Filter	= R-RF30/25
Filtration Capacity	= 25

4 Clinder:

Type	= CD210 63/28
Pressure Drop	= 178. bar
Pressure Drop with line losses	= 180. bar
Flow Rate	= 19.2 lt/min
Linear Velocity	= .1 m/s
Load	= 5000 N
Piston Diameter	= 63 mm
Supply Line Diameter	= 10.3 mm
Return Line Diameter	= 15.9 mm
Inlet Flow Velocity	= 3.85 m/s
Return Flow Velocity	= 2.02 m/s
Area Ratio (Piston Side/ Rod Side)	= 1.25

CHAPTER V

CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

Hydraulic power systems are commonly used in industry. One of the reasons for the popularity of these systems is the level of standardization reached on the component level. This makes it possible to design hydraulic power systems for a particular applications using these standard components. However, the design process is, by no means, simple. It requires substantial number of iterations depending on the designer's experience and the availability of components. A computer program to help the designer while going through these stages has been developed. It is ment for the drawing, design and simulation of hydraulic power circuits. The development of such a program is extremely difficult, due to large number of components and thus larger possible combinations of the components. In the preparation of the program, certain design rules are deviced to handle the possible circuits.

It has been found that the generalization of the design and simulation of hydraulic power systems can only be carried out to a certain extent. As a result, the program has certain limitations and thus is useful only for circuits within these limitations. In spite of this fact, it is still an adequate tool as a design as well as a training tool for most applications.

The most significant problem with the program is due to the use of bitmap symbols which makes it difficult to extend the program. A more general program of the same purpose should use a different approach. It would be benefical to create symbol library without bitmap files. Moreover, new component addition to the symbol library should be possible without requiring additional programming.

REFERENCES

[1] A. Hitchcox, HYDRAULICS & PNEUMATICS, (February, 1995).

[2] W.J. Wolfe, HYDRAULICS & PNEUMATICS, (June, 1994).

[3] Henke, R.W., 1983 Fluid Power Systems and Circuits, Penton Publishing Inc., Ohio.

[4] Wolansky, D. William, Nagohosian, J., Henke, R.W., 1977 Fundamentals of Fluid Power, Mifflin , Boston.

[5] R. W. Henke, 1968, Introduction to Fluid Mechanics, Addison-Wesley Publishing Co., Boston.

[6] TS 1306 Fluid Power Symbols.

[7] Rexroth Hydraulics Catalog Information.

[8] Hipaş Hidrolik-Pnömatik San. ve Tic. A.Ş. Catalog Information (1503)

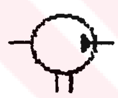
[9] Pinches, M. J., Ashby J. G, 1989 Power Hydraulics Prentice-Hall, Newyork.

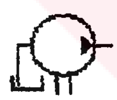
APPENDIX A

SYMBOL LIBRARY

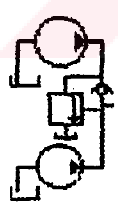
Open Circuit Library

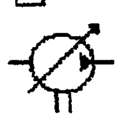
Pumps

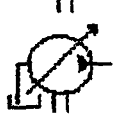

Fixed capacity hydraulic pump

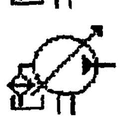

Fixed capacity hydraylic pump with reservoir


Fixed capacity hydraulic pump with reservoir and suction filter

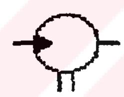

Pump Group; Two fixed capacity hydraulic pump with reservoir and an unloading valve to unload low pressure pump

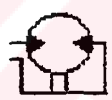

Variable capacity hydraulic pump


Variable capacity hydraulic pump with reservoir

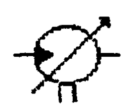

Variable capacity hydraulic pump with reservoir and suction filter

Motors

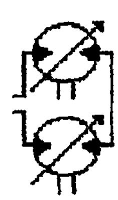

Fixed capacity hydraulic motor with one direction of flow


Fixed capacity hydraulic motor with two directions of flow

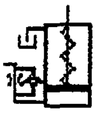

Fixed capacity hydraulic motors with two direction of flow connected in series


Variable capacity hydraulic motor with one direction of flow

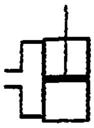

Variable capacity hydraulic motor with two direction of flow


Variable capacity hydraulic motor with two direction of flow connected in series

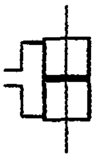
Clinders



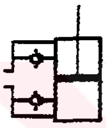
Single acting cylinder with flow control valve returned by spring



Double acting cylinder with single piston rod

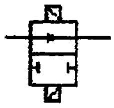


Double acting cylinder with double-ended piston rod

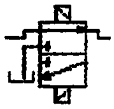


Double acting cylinder with single piston rod and dual bypass ports to unload pump

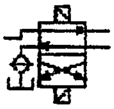
Directional Control Valves



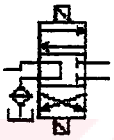
Directional control valve 2/2 with 2 ports and 2 distinct positions



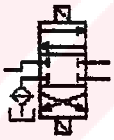
Directional control valve 3/2 with 3 ports and 2 distinct positions



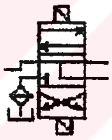
Directional control valve 4/2 with 4 ports and 2 distinct positions



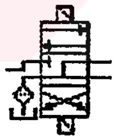
Directional control valve 4/3 with 4 ports and 3 distinct positions



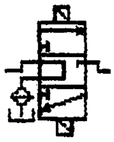
Directional control valve 4/3 with 4 ports and 3 distinct positions



Directional control valve 4/3 with 4 ports and 3 distinct positions



Directional control valve 4/3 with 4 ports and 3 distinct positions

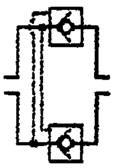


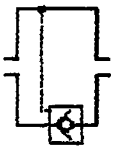
Directional control valve 3/3 with 3 ports and 3 distinct positions

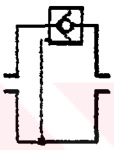
Note that all valves are controlled by selenoid

Check valves

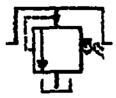

Spring loaded check valve

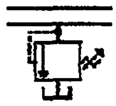

Pilot operated check valves


Pilot operated check valve

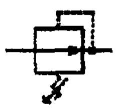

Pilot operated check valve

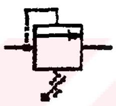
Pressure control valves

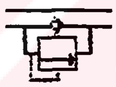

Pressure relief valve

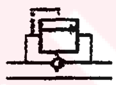

Pressure relief valve

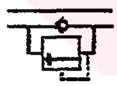

Pressure relief valve


Pressure regulator

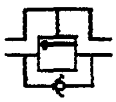

Sequence valve


Sequence valve

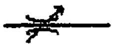

Sequence valve


Counterbalance valve


Counterbalance valve


Counterbalance valve

Flow control valves


Throttle valve


Throttle valve, unit allowing free flow in one direction but restricted flow in the other

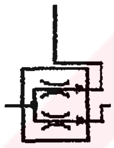

Throttle valve, unit allowing free flow in one direction but restricted flow in the other


Throttle valve, unit allowing free flow in one direction but restricted flow in the other


Throttle valve, unit allowing free flow in one direction but restricted flow in the other


Throttle valve, throttling in both direction


Throttle valve, throttling in both direction


Flow dividing valve

Auxiliaries

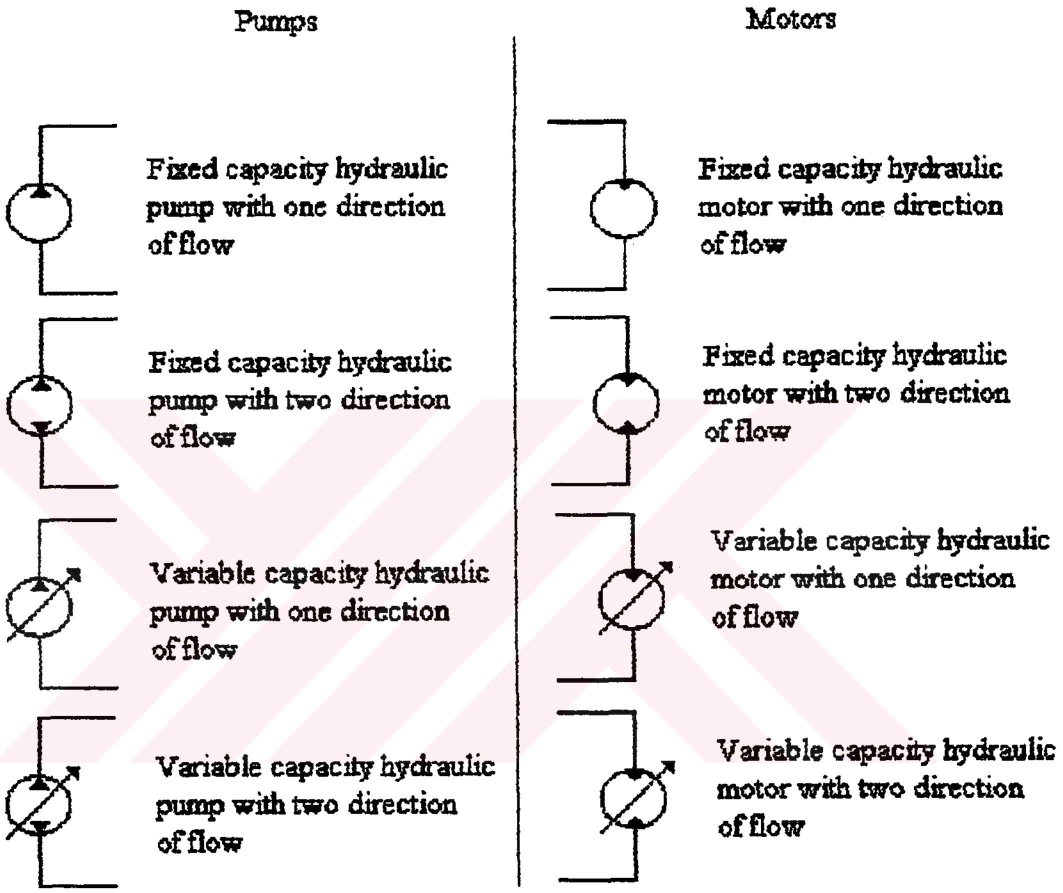

Filter


Accumulator

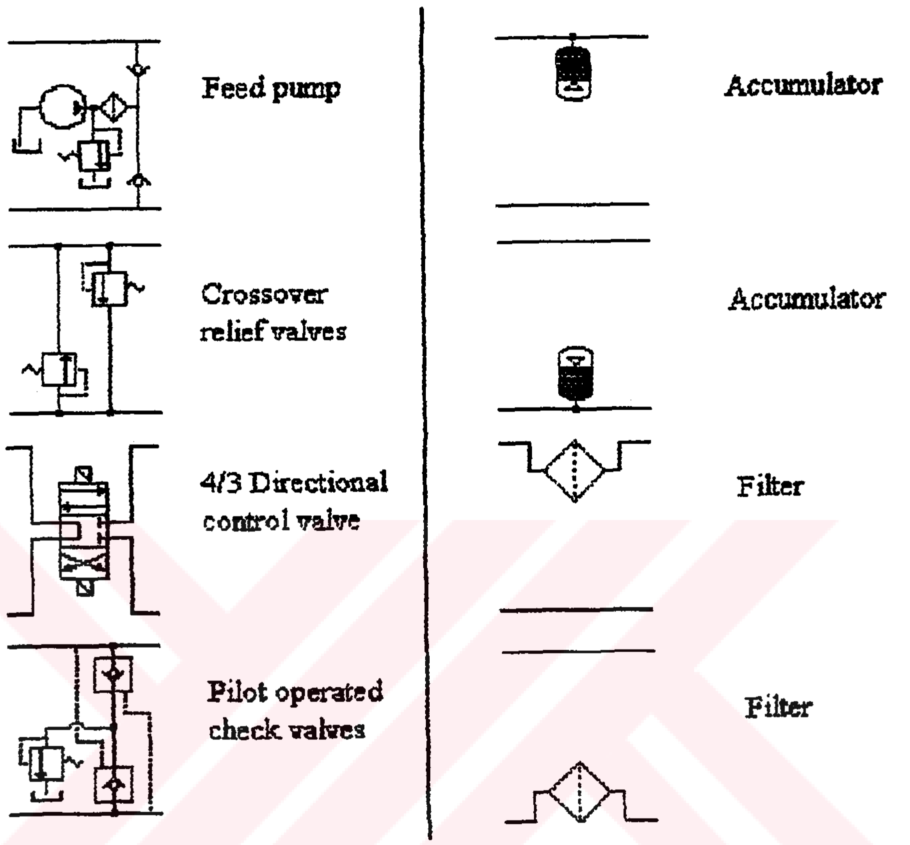

Reservoir


Reservoir

Closed Circuit Library



Auxiliaries



APPENDIX B

FLUID POWER SOFTWARE

Table A.1 Fluid power software.

Software	Applicable components or function	Product software			Design software					
					Symbol library					
		Sizing/Selection	2-D CAD drawing	3-D CAD drawing	Hydraulic	Pneumatic	Electrical	Schematic drawings	Bill of materials	Dynamic simulation
Greer Hydraulics	Accumulators	*								
Parker Hannifin	Accumulators	*								
Tobul Accumulator Inc.	Accumulators	*								
American Cylinder	Clinder & slides	*	*							
Bimba Mfg. Co.	Cylinders & accesories		*							
W. C. Branham	Cylinders, rodless		*							
Compact Air Products, Inc.	Cylinders, air	*	*							
Miller Fluid Power	Cylinders	*	*							
Ortman Fluid Power	Cylinders	*	*	*						
Parker Hannifin, Cylinder Div.	Cylinders	*	*							
Tol-O-Matic	Cylinders, accessories		*							
ATICO. Inc., Internorman Filter	Filters, hydraulic	*								
Parker Hannifin, Hyd Filter Div.	Filters, hydraulic	*								
Hyde Engineering (Millair)	Pneumatic components	*								
PHD Inc.	Pneumatic components	*	*	*						
CalCad	Schematics				*	*	*	*	*	
Fluid Thechnology (PowerCad)	Schematics				*	*		*		
Tech Team (HYDROWORKS)	Schematics				*	*		*	*	
Vickers Inc. (CircuitWorks)	Schematics				*	*		*	*	
CAD Technology Corp.	Symbol libraries				*	*	*			
CADSYM	Symbol libraries				*	*	*			
Delta Eagle Enterprises	Symbol libraries				*	*				
Paragraphics Publishing	Symbol libraries				*	*	*			
Power Air Inc. (SymbolWare)	Symbol libraries					*				
IDAS Engineering (VCCM)	Servo system design	*								*
Boing Computer Services	Simulation & analysis				*	*	*	*		*
Famic (HydrauSim, PneuSim)	System simulation				*	*		*		*
Fluid Dynamics International	System evaluation				*			*		*
HydraSoft	System simulation				*					*
Norgen (Norcalc)	Valves & cylinders, air	*								
Parker Hannifin, Pneumatic Div.	Valves, air	*	*		*	*	*	*		*
Schrader Bellows	Valves, air	*	*		*	*	*	*		*

APPENDIX C

USER'S GUIDE

C.1 Drawing the Circuit

Hydra D&S has two drawing libraries, open circuit and closed circuit symbol libraries. The user can open these libraries by means of "Components" menu bar, Figure A1. When a symbol is used from a library, the other library is not available for the started application.

To draw a circuit first open releated symbol library. In Figure A1, selection of pump library can be seen. After opening the releated symbol library, the user must choose required component, as shown in Figure A2. For the first symbol there is an empty picture box on the drawing table. When the pump is placed on to the first picture box, the program will places a new empty picture box for a new symbol, Figure A3. Note that, the program automatically places a relief valve for the fixed displacement pump, it may be removed if the place is not proper. The program stops automatic picture box placement when an edit operation is made. After that the user must place new picture boxes by clicking on the right, up, or down side of the components.

To delete a component, you first selects the component to be deleted, then choose "Delete Selected" command from Edit menu bar, as shown in Figure A4. If you want to delete the last component, you do not need to select it. To insert a component

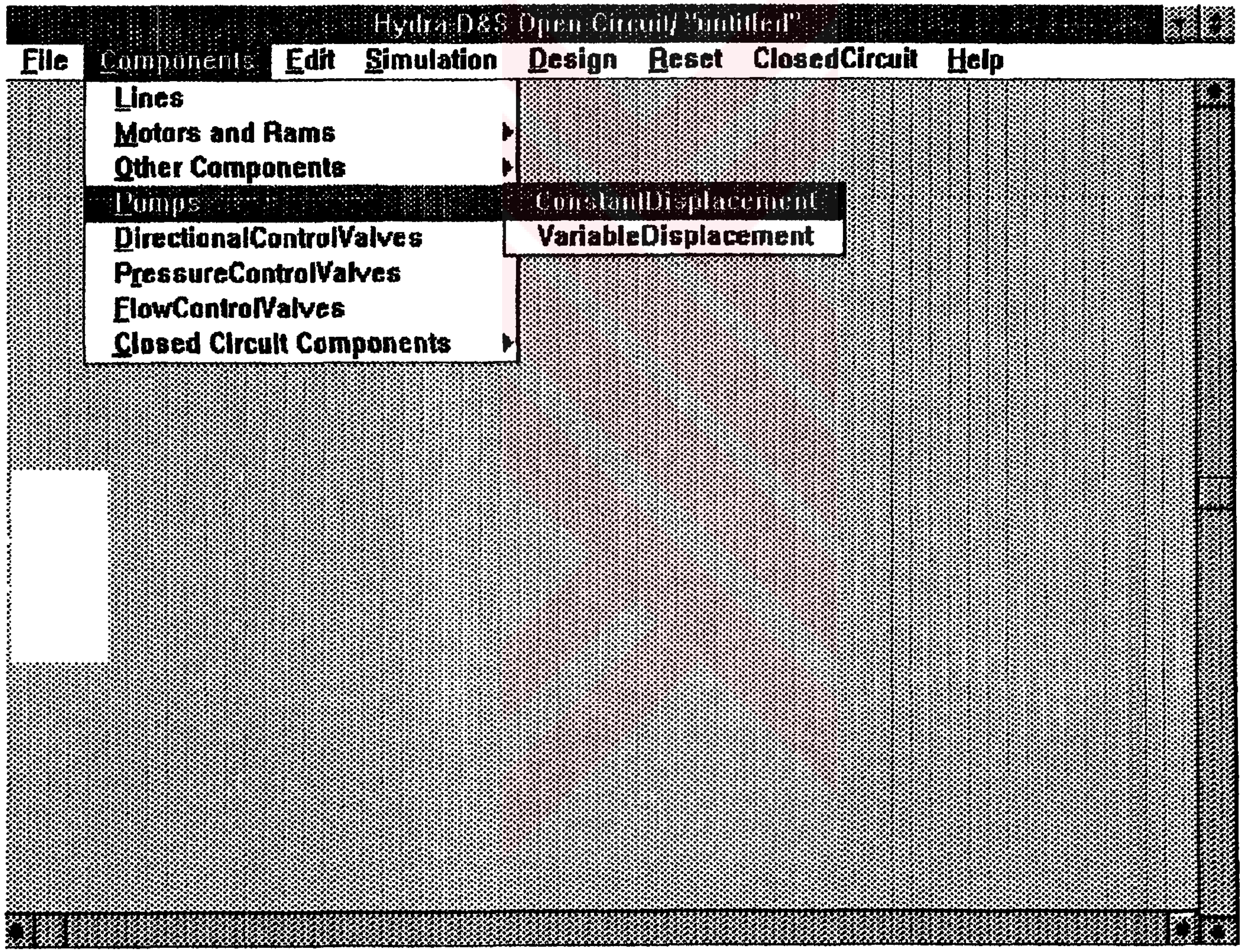


Figure A.1 Selection of symbol library.

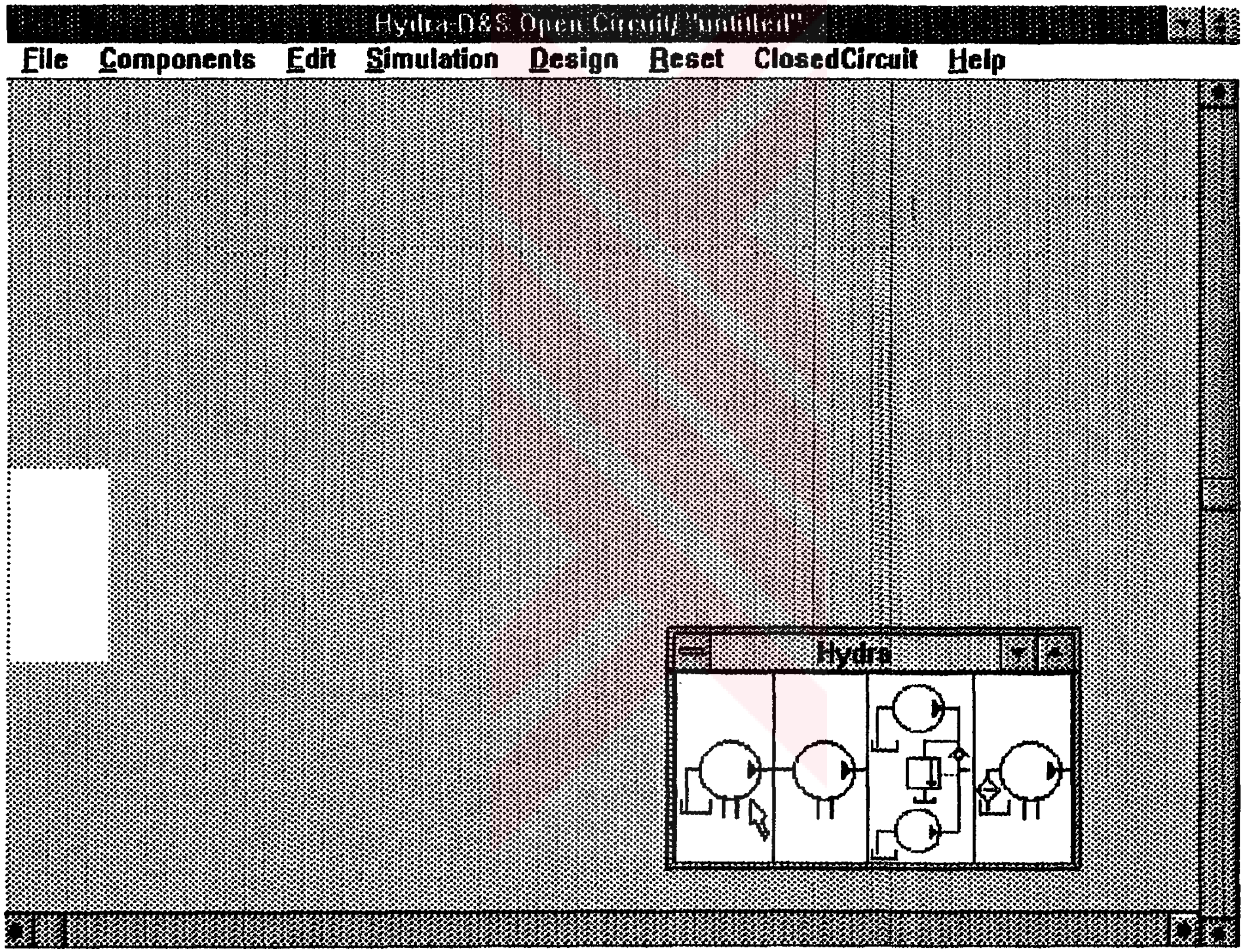


Figure A.2 Appearance of pump symbol library and selection of pump.

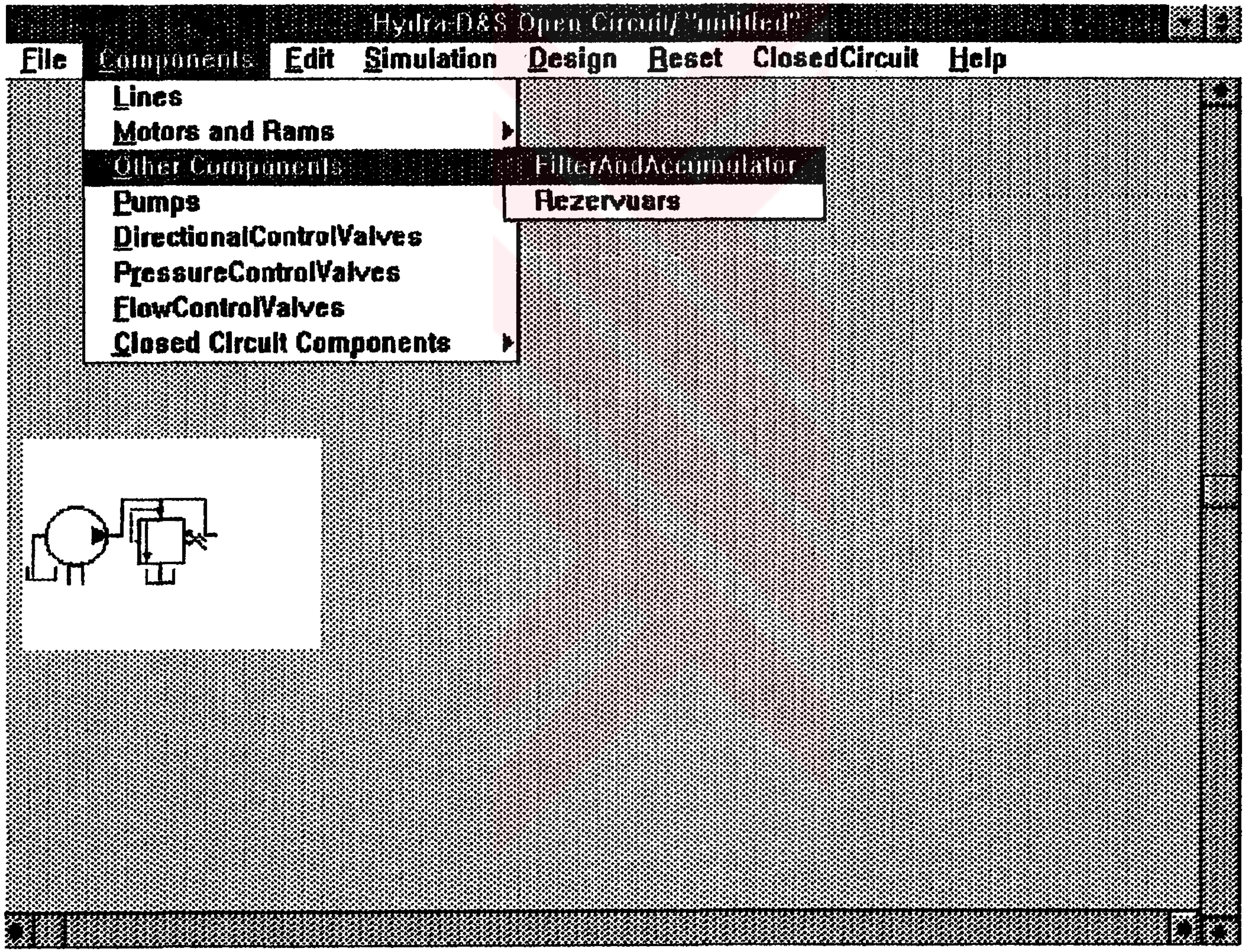


Figure A.3 Placement of the pump and empty picture box.

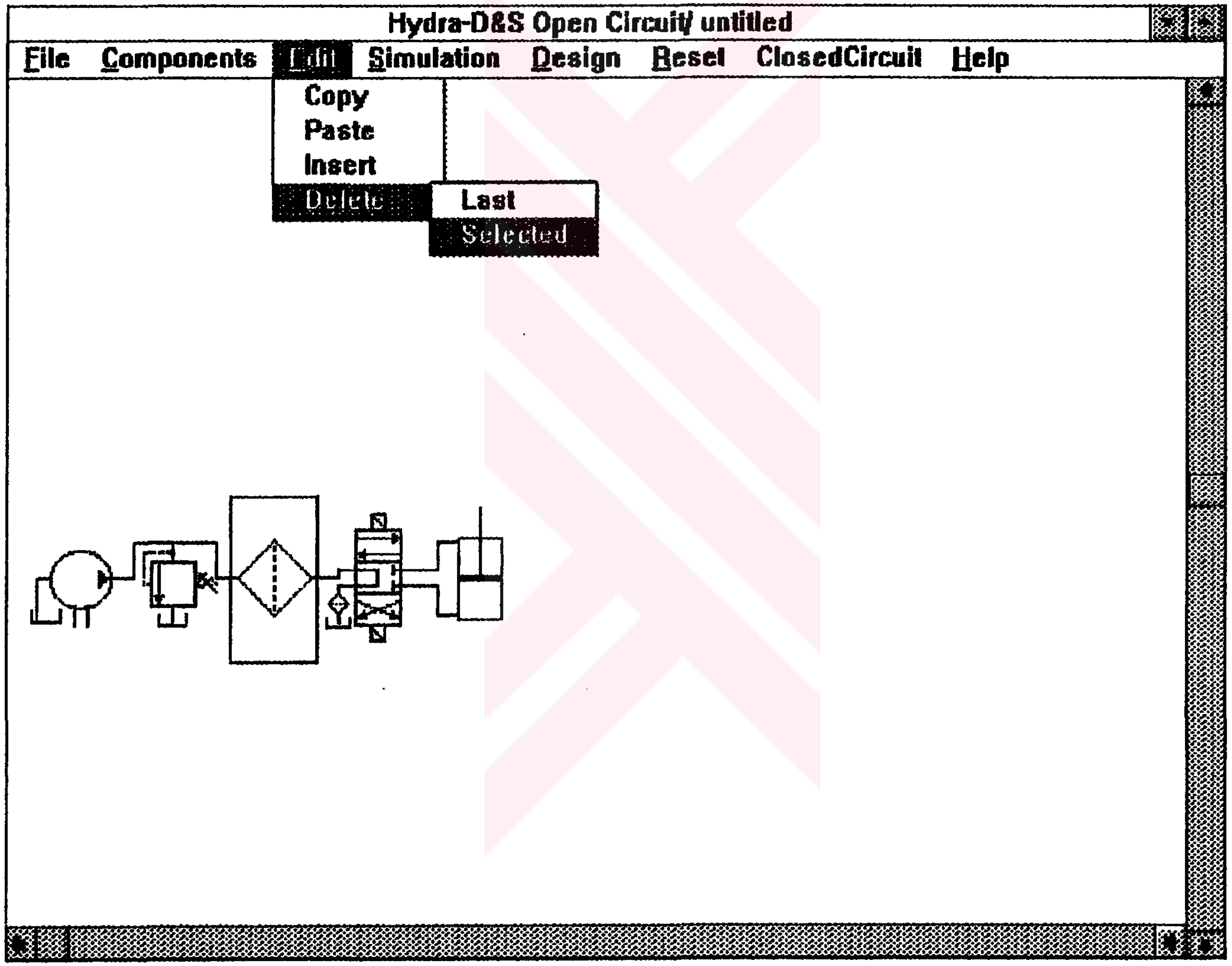


Figure A.4 Appearance of delete operation, choose the component in front of which a new component is to be inserted, then select "Insert" command from Edit menu bar. Moreover, you can use "Copy" and "Paste" commands for the symbols required more than one without opening releated symbol library over and over. To use these commands, select the component you want to copy, then choose "Copy" command. After that select the picture box you want to paste, and finally choose the "Paste" command.

When the circuit drawing is completed print out of the circuit can be taken by using "Print Drawing" command, Figure A.7.

C.2 Simulation of the Circuit

When the circuit drawing is completed, the user can pass to the simulation by choosing "Simulation" command. The user must wait until the program fills the system with fluid. Then the user can start to shift the directional control valves by clicking on the position boxes of the valves and visualize the working of the actuators and other components affected by shifting operation.

On the other hand, if the circuit is one branched and contains a flow control valve then the user can change the setting of the flow control valve and see the responds of the other components. To do this, the user have to click on the flow control valve after simulation command has been selected and system fills with fluid completely. A scroll bar will be displayed. The setting of the flow control valve can be changed by using this bar, Figure A5. There is also a similar property in the Closed

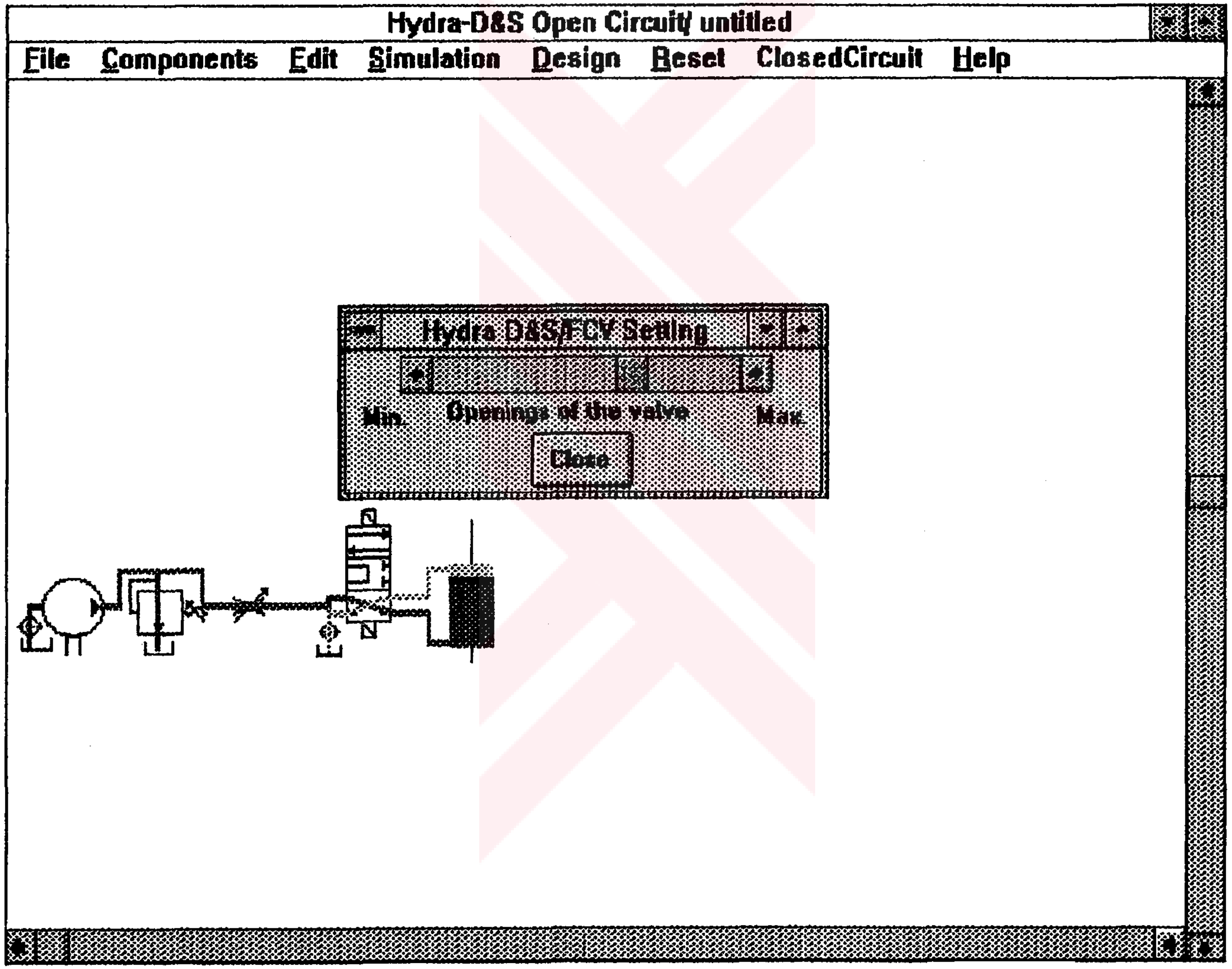


Figure A.5 Appearance of shifted valve and flow control valve setting bar.

Circuit part, the user can increase the load on the actuator by using a scroll bar and visualize the responds of the other components. To do this the user shoul click on the motor after simulation.

C.3 Design of the Circuit

When the circuit drawing is completed, the user can start to design it by using "Start Design" command from Design menu bar, Figure A.6. The program displays data input boxes to take data about actuator output requirements as shown Figure A.7. After actuator data inputs, the program asks for the setting of the components and for the other required information such as filter mesh widht and heat transfer coefficient of the reservoir. When sizing and selection operation ends, the program displays a form on which there is the design information about the first component of the circuit, usually a pump. On this form there are also Next, Previous, and Close command buttons. The user can see other components' information by using first two buttons, or close the form. To open this form again, from design menu bar "Display Design Result" command is to be chosen.

After design, the designer can change setting of a component, such as a flow control valve, and then visualize the effects. To use this property, first "CSP and Show Working Condition" command should be chosen, then select the component to change the setting. A data input box will be displayed which also shows current setting of the selected component. Moreover the user can see the current operating condition by using "Show Operating Condition" command. If setting of a component has been changed previously, the user can use "Show First Design Result" command to see the first design result.

The user can take printout of the design results either for all circuit or for only selected component, Figure A.8. Finally the user can save the complete circuit with design result.

A.4 Component Data Entry

Component data entry is a tool used to enter commercially available components' data to databank files or to remove unnecessary data previously entered. To enter, for example, pump data click on the pumps option button. Data input box will be displayed. At the same time the format of data type will be shown on the form as shown in figure A.9.

To delete any data the user should first choose "Show Data" button then choose component data type. All the information about this component type will be displayed on the form. Then the user can see all data in the databank by using "Show Next" and "Show Previous" buttons, and remove any one among them by using "Remove" button. Moreover printout of the databank files can be taken. For this operation, the user must first choose again "Show Data" button, then choose component type. Finally select "Print Selected" command.

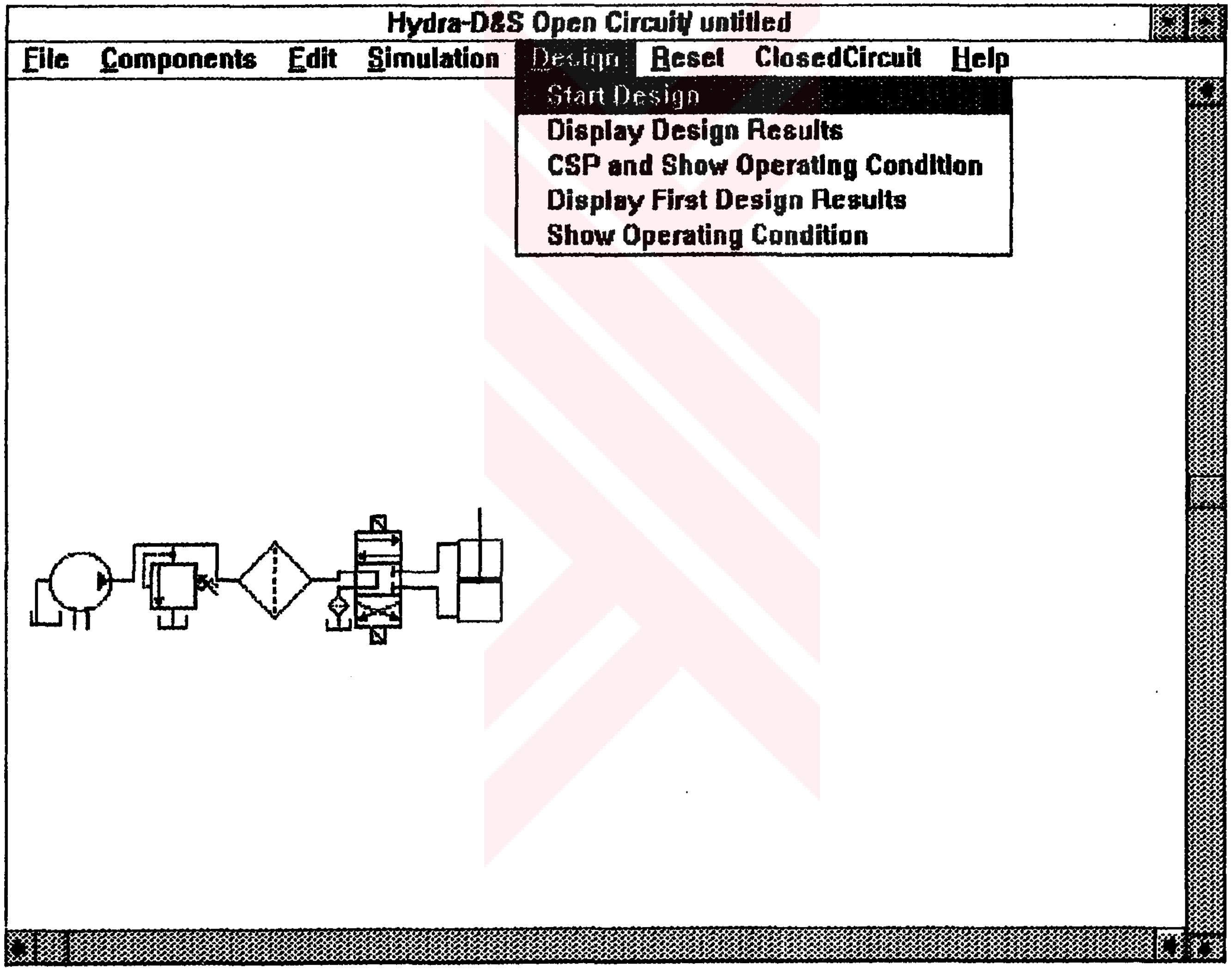


Figure A.6 Starting to design.

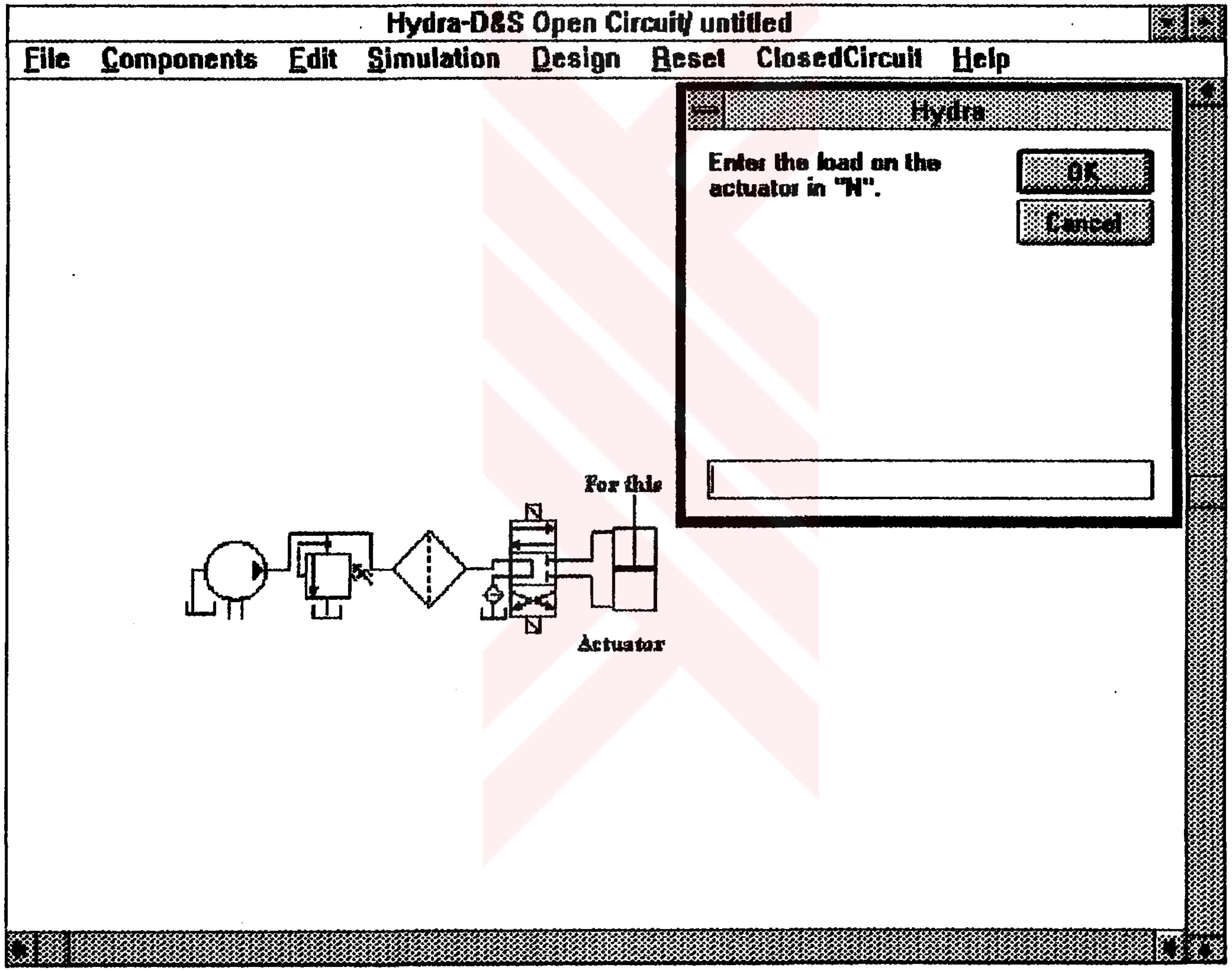


Figure A.7 Appearance of data input box.

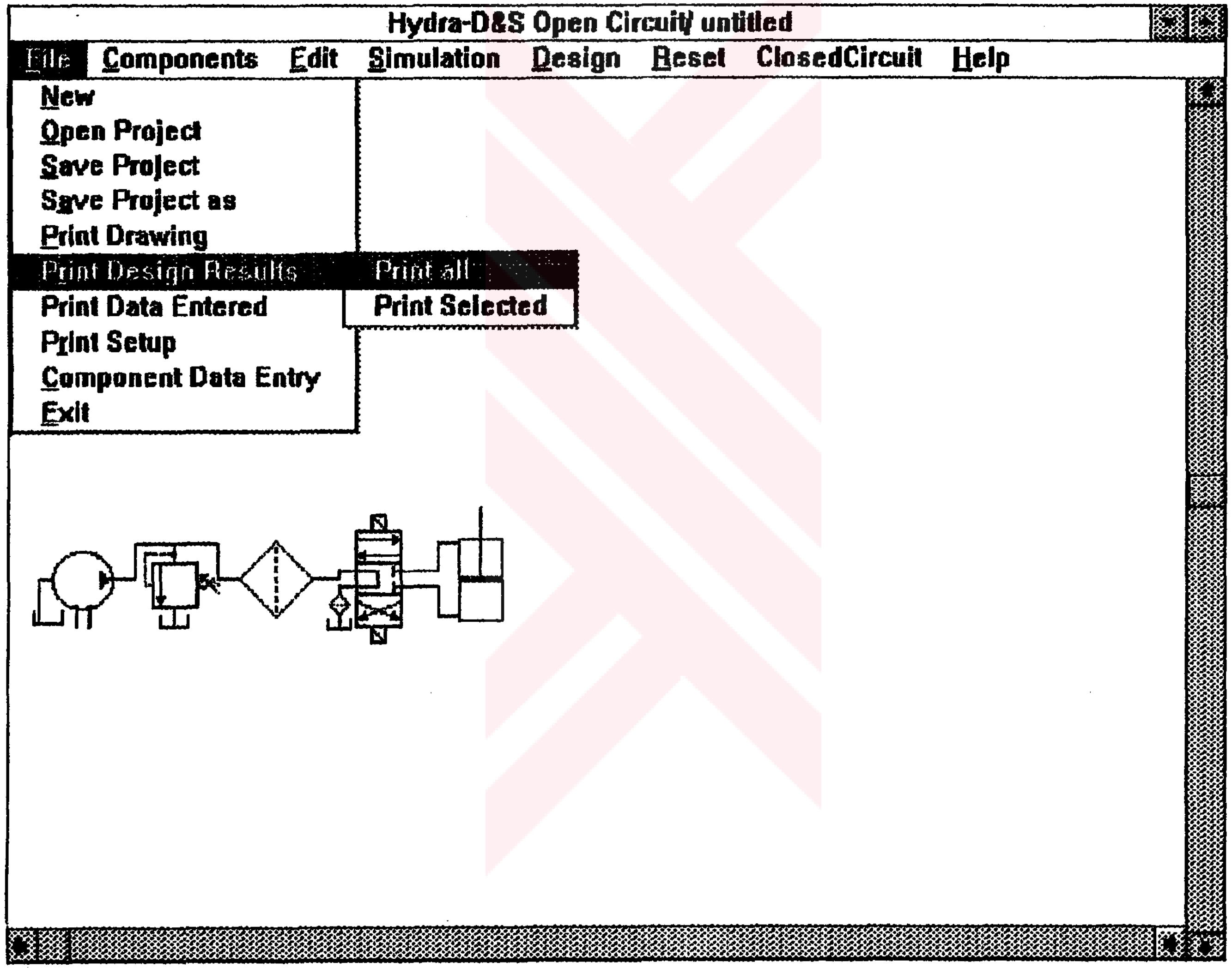


Figure A.8 Printing design result.

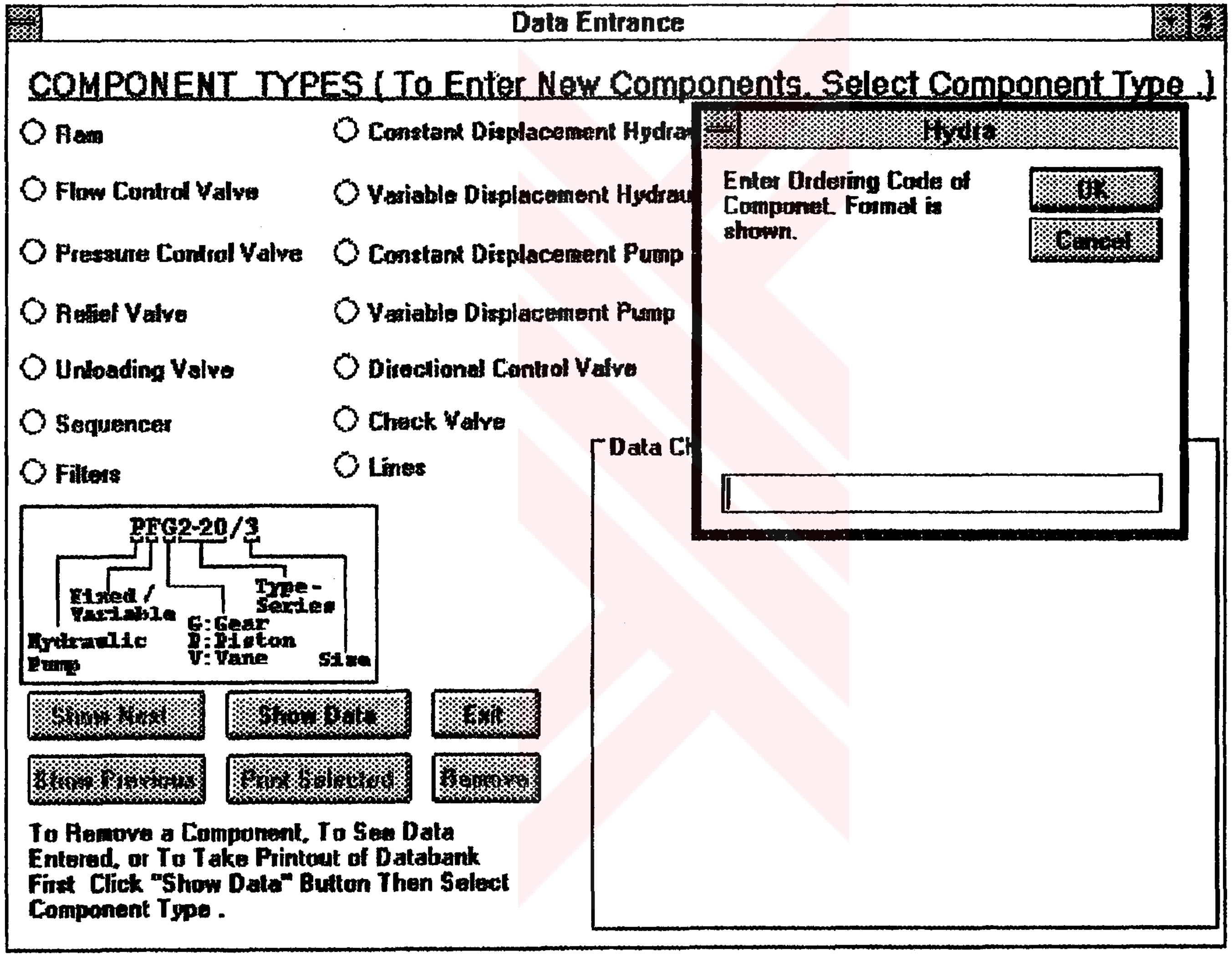


Figure A.9 Appearance of Component Data Entry and data input box.