and since $s \equiv \omega j$,

$$\frac{y}{x} = \frac{\omega_n^2}{\omega_n^2 - \omega^2 + 2\zeta\omega_n\omega j}$$

resulting in an amplitude response given by,

$$\left|\frac{y}{x}\right| = \frac{1}{\sqrt{\left[1 - \left(\frac{\omega}{\omega_n^2}\right)^2\right]^2 + 4\zeta^2\left[\frac{\omega}{\omega_n}\right]^2}} \tag{2.32}$$

and a phase angle of,

$$\theta = \tan^{-1} - \left(\frac{2\zeta\frac{\omega}{\omega_n}}{1 - \left(\frac{\omega}{\omega_n}\right)^2}\right) \tag{2.33}$$

When the damping ratio is less than 1.0, a maximum occurs in the response plot (Figure 2.16) at the resonant frequency. Hence, if equation (2.32) is differentiated with respect to (ω/ω_n) and set equal to zero, the condition that results is,

$$-4\frac{\omega}{\omega_n}\left[1 - \left(\frac{\omega}{\omega_n}\right)^2\right] + 8\zeta^2\left(\frac{\omega}{\omega_n}\right) = 0$$

$$\omega = \omega_r = \omega_n\sqrt{1 - 2\zeta^2}$$

This should not be confused with a very similiar relationship for the frequency of damped oscillations.

The characteristics for a second-order system are:

1. The natural frequency occurs when the phase angle is $-90°$.

2. The shape of the response is controlled by the value of the damping ratio.

3. The resonant frequency occurs at the peak in the response curve and its height is controlled by the damping ratio.

4. The amplitude response falls off at -12 dB/oct after the resonant peak.

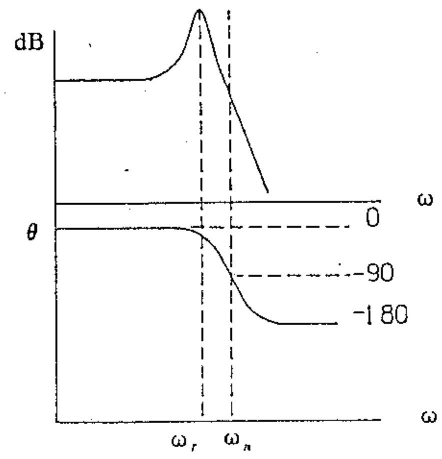

Figure 2.16 Second-Order Frequency Response

EXERCISES

2.1. A hydraulic component, shown in Figure 2.17, consists of flow being divided between an orifice of resistance R and a spring-loaded piston.

(a) Find the relationship between the piston movement y, and the input flow Q_1.

(b) Sketch the expected frequency response.

2.2. A system of components is found to be arranged as shown in Figure 2.18. If,

$k = 10, \qquad H_1(s) = 4s$

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$$G_1(s) = \frac{8}{s(s+2)(s+3)}, \qquad H_2(s) = \frac{2}{(1+4s)}$$

(a) Find the relationship between the output y and the input x.

(b) What is the steady-state value of y/x ?

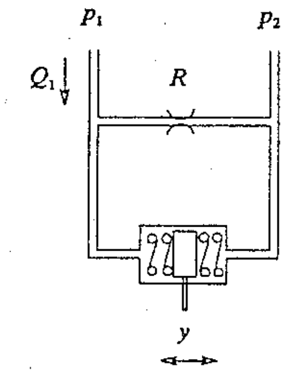

Figure 2.17 For Exercise 2.1

2.3. A process consists of two tanks, as shown in Figure 2.19. The capacitance of each tank is defined as the ratio of the change in quantity of liquid to the change in level. Note that the capacity of a tank is the actual volume. If the flow into the top tank is Q_3, find the relationship between this flow and the level in the second tank. The flow out of each tank is controlled by orifices of resistance R_1 and R_2.

2.4. Find the expression representing the time history of x, if the system represented by the equation shown is subjected to a step input $f(t)$ of unity. The boundary conditions are such that when $t = 0$, both x and dx/dt are zero.

$$450\frac{d^2x}{dt} + 105\frac{dx}{dt} + 10x = f(t)$$

2.5. A hydraulic motor has to produce a torque of 27 N.m for each radian of

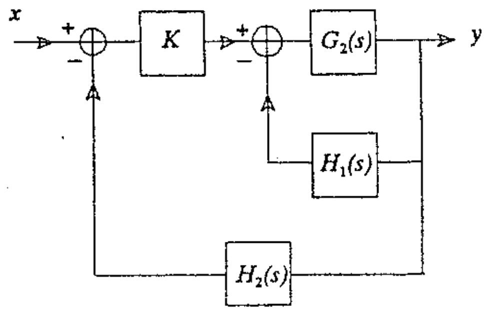

Figure 2.18 For Exercise 2.2

swash plate angle (see Figure 6.4a). The output shaft drives a load consisting of 1.4 kg.m^2 of inertia, and a damping coefficient of 4 N.m.s/rad.

(a) Calculate the damping ratio.

(b) Plot the Bode diagram of the shaft angle against swash plate angle.

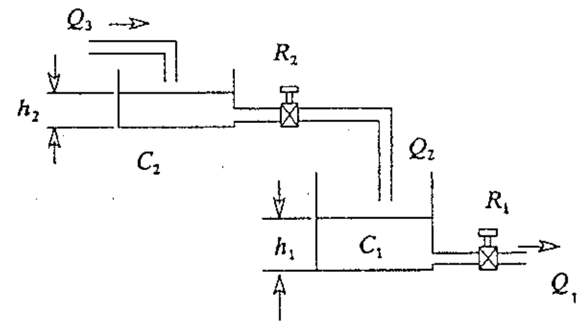

Figure 2.19 For Exercise 2.3

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APPENDIX

EXERCISES AND SOLUTIONS

This appendix is designed to test your understanding of power hydraulics. It is divided into three sections:

A.1 Circuitry questions
A.2 Hydraulic calculations
A.3 Design problems requiring calculations and circuit design.

Answers to the calculations in Section A.2 may be found in Section A.4 at the end of the appendix.

A list of standard metric cylinders appears as Table 4.1 in Chapter 4. In all piston rod strut strength calculations assume a factor of safety of 3.5 and take the modulus of elasticity as 2.1×10^6 kg cm^{-2}. Effective strut lengths for the various types of cylinder mounting may be obtained from Figure 4.16 also in Chapter 4.

A.1 *CIRCUITRY QUESTIONS*

Examine the following circuits. Try to understand their operation and the function of each component. Some of the circuits contain deliberate draughting errors – see if you can find and correct them. Where appropriate suggest simple modifications which could improve the performance of any of the circuits. Answer the additional questions included in some of the problems. To simplify the circuit filters have been omitted from most of the examples. There is generally insufficient detail of the particular application to be precise but where you feel that filtration would be essential make recommendations. It is assumed that in all cases there will be a suction strainer on the pump.

A.1.1

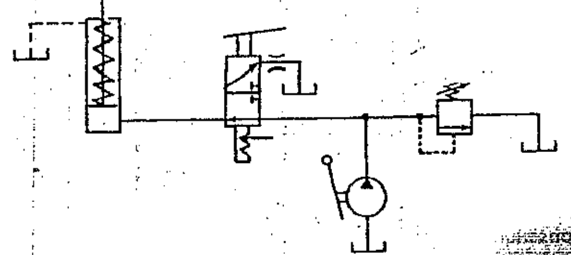

Figure A.1

Correct the draughting error.

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A.1.2

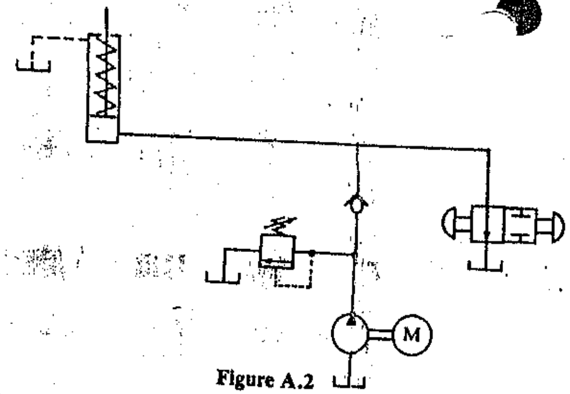

Figure A.2

Correct the draughting error.

A.1.3

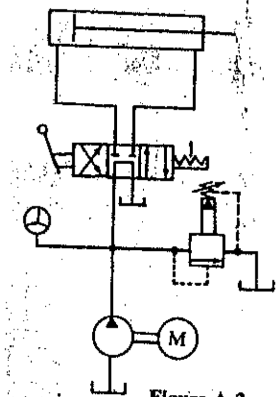

Figure A.3

In the circuit shown in Figure A.3, given that the load induced pressure on the extend stroke is 150 bar and on the retract stroke is 70 bar, and the relief valve pressure setting is 165 bar, draw a pressure–time graph for a complete extend and retract cycle. The graph should start and end with the directional control valve in the mid position. Assume the extend stroke takes 12 seconds and the retract stroke 9 seconds.

A.1.4

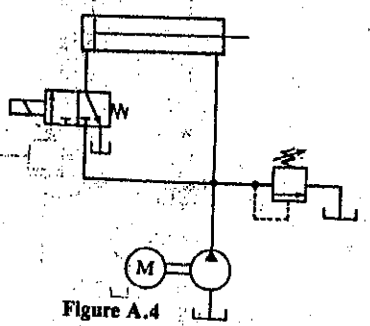

Figure A.4

What are th[...]istics of this circuit and in what circumstances is it most usually employed?

A.1.5

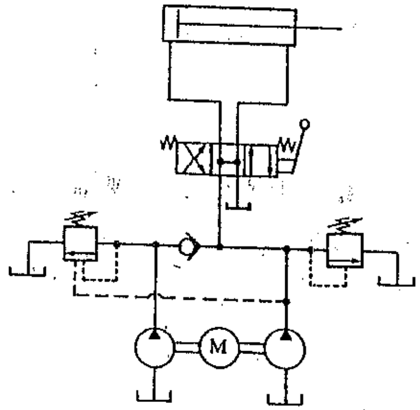

Figure A.5

Correct the draughting error in this figure.

What advantage has this two-pump circuit over a single pump system? Name a particular application where it is frequently used.

A.1.6

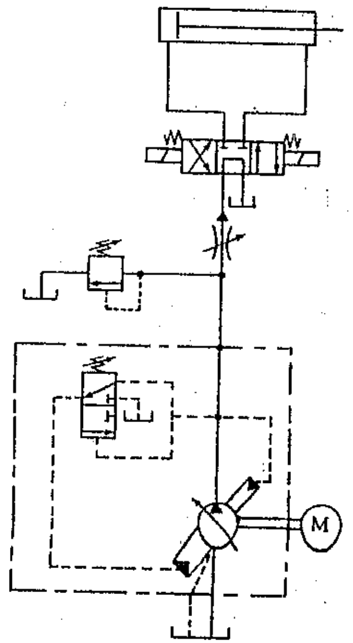

Figure A.6

What advantage has a pressure compensated pump in this application? How can the efficiency of the circuit be improved?

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A.1.7

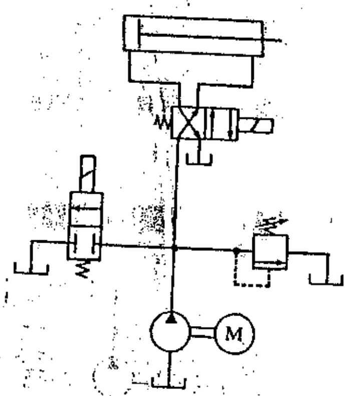

Figure A.7

Should the control circuit fail, what will be the effect on the system? Modify the circuit to 'fail safe'.

A.1.8

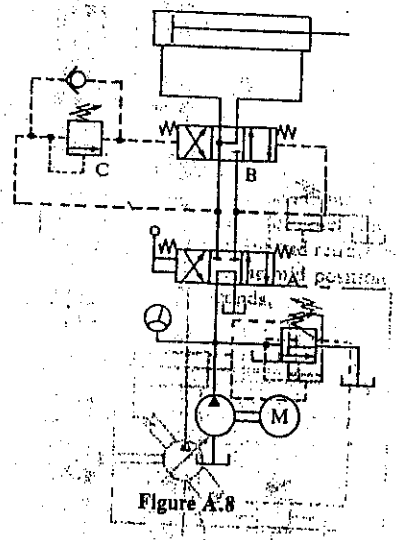

Figure A.8

The cylinder shown in this circuit which contains draughting errors cannot be extended. Using standard valves modify the circuit so that the cylinder can be extended and retracted by the manual directional control valve. The extesd function must be initially high speed changing to slow speed when the pressure induced by the load reaches a specified value.

A.1.9

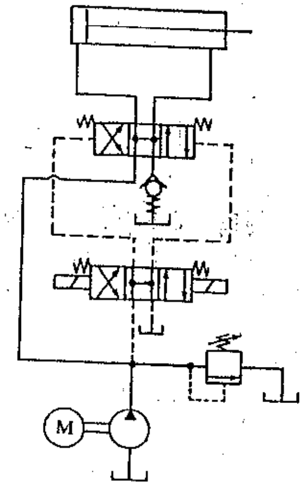

Figure A.9

What is special about the check valve in this circuit and what is its purpose?

A.1.10

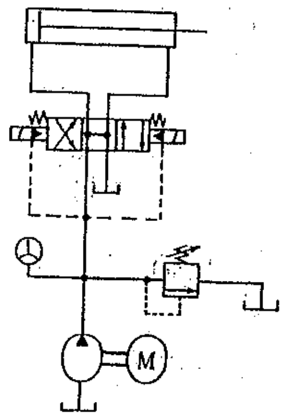

Figure A.10

When this circuit was built it would not operate. Why? Suggest a simple modification to correct this design fault.

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A.1.11

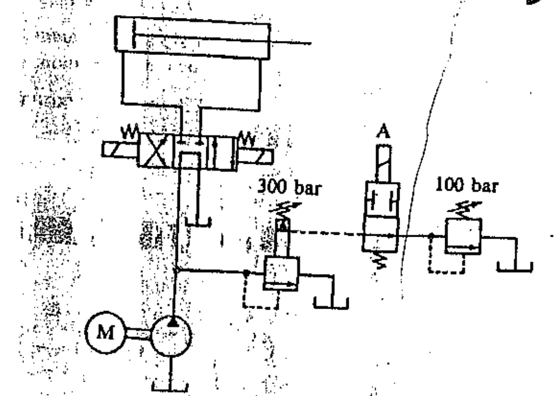

Figure A.11

Solenoid A is energized during the extend stroke but not during retract. How does this affect the function of the circuit?

A.1.12

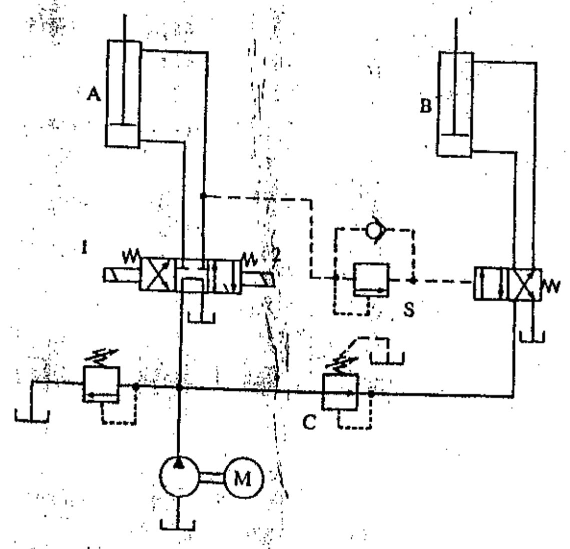

Figure A.12

Correct the draughting errors and determine the sequence of operation of the cylinders:

(a) When solenoid 1 is energized.
(b) When solenoid 2 is energized.
What is the purpose of valve C?

A.1.13

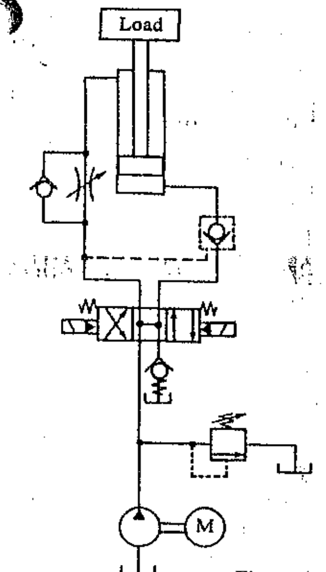

Figure A.13

This circuit is intended to hydraulically lock a loaded cylinder in any position and to control the retract speed. Comment on its suitability and modify if necessary. Suggest a pressure setting for the relief valve if the load is 10 tonnes and the cylinder bore 100 mm diameter.

A.1.14

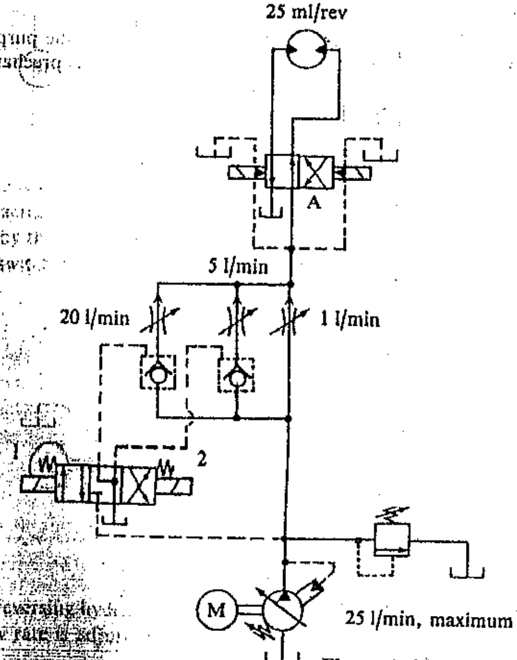

Figure A.14

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Explain the function of the circuit. Why use a double ... valve rather than a single solenoid spring offset valve for A? What type of transition centre condition do you recommend for this valve? If the motor displacement is 25 ml/rev, and with the flow controls set at the values shown, what is the theoretical maximum motor speed possible under the following conditions?

(a) Solenoids 1 and 2 both de-energized.
(b) Solenoid 1 energized.
(c) Solenoid 2 energized.

A.1.15

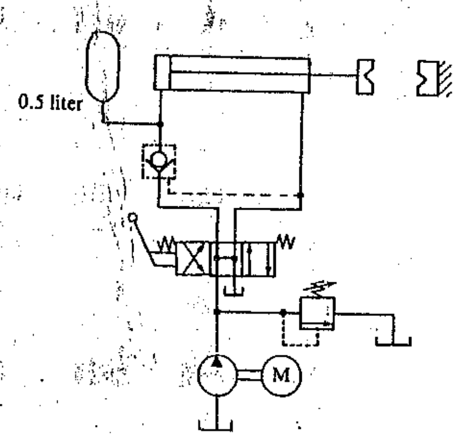

Figure A.15

In this manually-operated hydraulic clamping circuit, what is the purpose of the 0.5-liter accumulator? If the relief valve setting is 200 bar, suggest a gas precharge pressure for the accumulator.

A.1.16

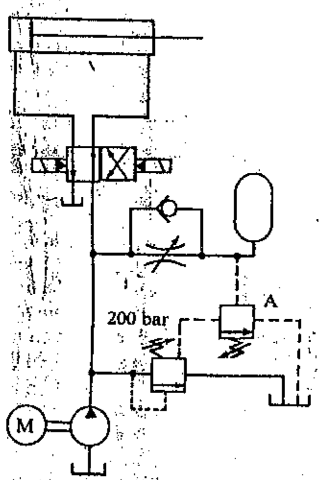

Figure A.16

The cylinder in ... circuit is required to give a single high-speed stroke at infrequent intervals. Comment on its suitability and suggest any necessary modification. What is the function of the flow control valve? Suggest a pressure setting for valve A.

A.1.17

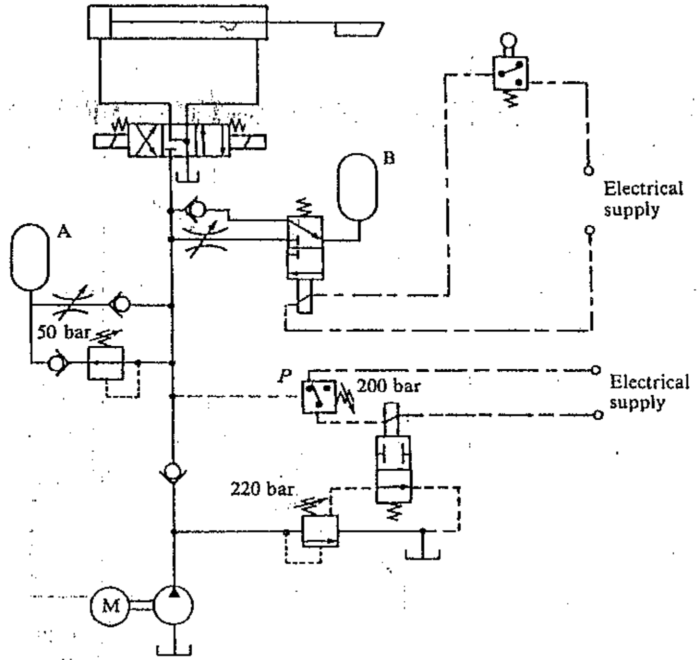

Figure A.17

A cylinder is required to extend initially at high speed but under low load. When the limit switch is actuated the stroke is completed at low speed and high load. Explain how this is achieved by the above circuit. Why are two accumulators used? What is the purpose of the pressure switch P?

A.1.18

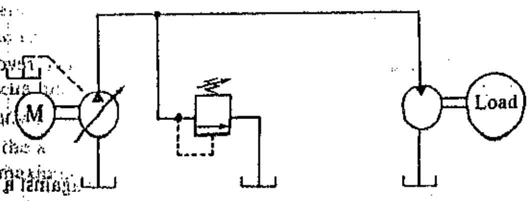

Figure A.18

This non-reversing hydrostatic transmission has a high inertia load and is found to over-run as the flow rate is adjusted to reduce speed. Suggest a suitable modification.

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A.1.19

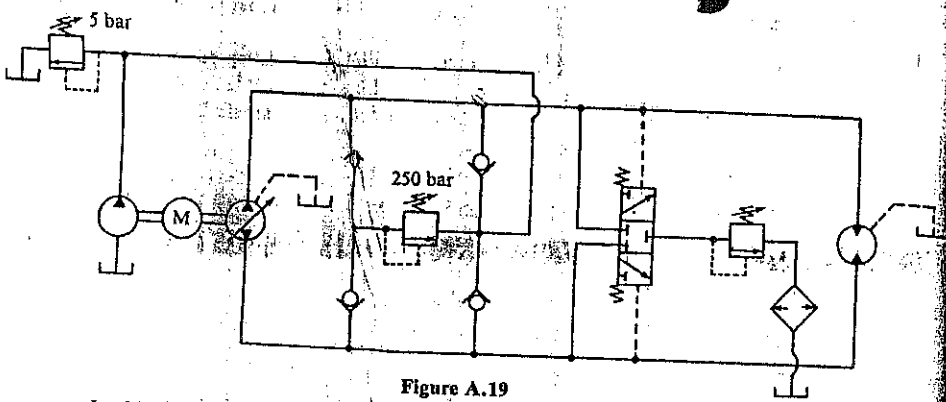

Figure A.19

In this hydrostatic transmission what is the purpose of the portion of the circuit which includes the three-position, three-port directional control valve? What is a suitable setting for the associated relief valve?

A.1.20

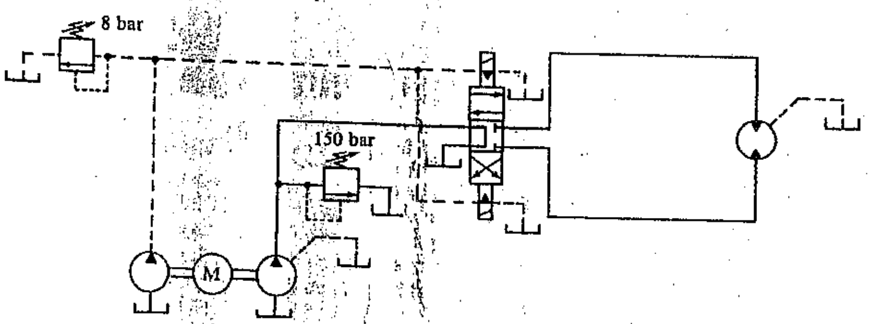

Figure A.20

This hydrostatic transmission is subject to pressure surges when the directional control valve is switched. Suggest modifications to alleviate these surges.

A.2 *HYDRAULIC CALCULATIONS*

A.2.1 A pump having a displacement (swept volume) of 1.7 cm^3 per revolution is driven at 1500 rev/min. If the pump has a volumetric efficiency of 87% and an overall efficiency of 76% calculate:

(a) The pump delivery in liters per minute.
(b) The power required to drive the pump when it is operating against a pressure of 150 bar.

A.2.2 A gear pump delivers 15 l/min against a system pressure of 200 bar at a driven speed of 1430 rev/min. If the input is 6.8 kW and the torque efficiency of the pump is 87% calculate the pump displacement in cm^3 per revolution.

A.2.3 A hydraulic sys··· quires 32 l/min of fluid at a pressure of 260 bar. The pump to be used is a manually-variable axial piston pump having a maximum displacement per revolution of 28 cm^3. The pump is driven at 1430 rev/min and has an overall efficiency of 0.85 and a volumetric efficiency of 0.90. Calculate

(a) At what percentage of maximum displacement the pump has to be set.
(b) What power is needed to drive the pump.

A.2.4 A hydraulic pump having a displacement of 8.8 ml/rev runs at 2880 rev/min. If its volumetric efficiency and torque efficiency are 93% and 91% respectively determine:
(a) The actual pump delivery.
(b) The input power to the pump when it operates against a pressure of 350 bar.

A.2.5 A hydraulic circuit using 25 liters of fluid per minute is supplied by a pump having a fixed displacement of 12.5 cm^3/rev driven at 2880 rev/min. The pump has a volumetric efficiency of 0.85 and an overall efficiency of 0.75. If the system pressure is set at 180 bar by the relief valve calculate:

(a) The quantity of fluid delivered by the pump.
(b) The power required to drive the pump.
(c) The heat generated owing to the excess flow passing over the relief valve.

A.2.6 A hydraulic circuit consists of a fixed-displacement gear pump supplying hydraulic fluid to a cylinder which has a bore of 100-mm diameter, a rod of 56-mm diameter and a stroke of 400 mm. Pumps are available with displacement increasing in steps of 1 ml/rev from 5 ml; the volumetric efficiency is 88% and its overall efficiency is 80%. The pump is driven directly from an electric motor with an on-load speed of 1430 rev/min. Select a suitable pump so that the cylinder can be reciprocated through a complete cycle once every 12 seconds.

A.2.7 A pump having a displacement of 25 ml/rev is driven at 1440 rev/min by a 10 kW electric motor. If the pump's overall and torque efficiencies are 85% and 90% respectively determine:

(a) The quantity delivered by the pump.
(b) The maximum pressure the pump can operate against without overloading the motor.

A.2.8 A pump having a theoretical delivery of 35 l/min and a volumetric efficiency of 90% drives a cylinder having a bore of 110 mm, a rod diameter of 65 mm and a stroke of 700 mm. Determine:
(a) The extend and retract velocities of the cylinder.
(b) The time for one complete cycle.

A.2.9 A pump/accumulator power pack is to supply the fluid flow demanded by a hydraulic system as shown in Figure A.21. The system working pressure is 125 bar and the maximum pressure at the accumulator is 200 bar. Assuming the accumulator pre-charge pressure is 90% of its maximum working pressure. Determine:

(a) The actual pump delivery required.
(b) The maximum volume of fluid to be stored in the accumulator.
(c) The accumulator volume assuming isothermal charge and discharge of the accumulator.

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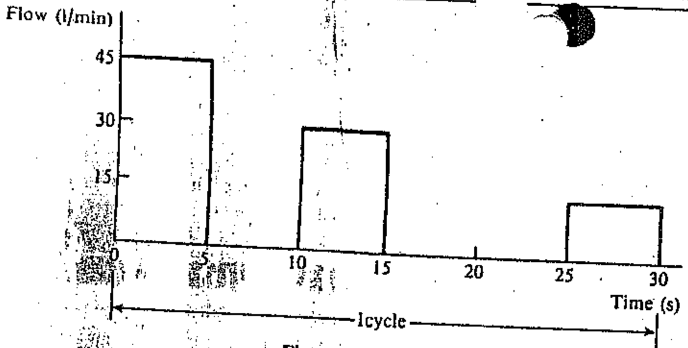

Figure A21

A.2.10 A press cylinder having a bore of 140 mm and a 100-mm diameter rod is to have an initial approach speed of 5 m/min and a final pressing speed of 0.5 m/min. The system pressure for rapid approach is 40 bar and for final pressing 350 bar. A two-pump, high-low system is to be used; both pumps may be assumed to have volumetric and overall efficiencies of 0.95 and 0.85 respectively. Determine:

(a) The flows to the cylinder for rapid approach and final pressing.
(b) Suitable deliveries for each pump.
(c) The displacement of each pump if the drive speed is 1720 rev/min.
(d) The pump motor power required during rapid approach and during final pressing.
(e) The retract speed if the pressure required for retraction is 25 bar maximum.

A.2.11 A pump driven at 1440 rev/min having a displacement of 12.5 ml/rev and a volumetric efficiency of 87% is used to supply fluid to a circuit with two cylinders. If the cylinder dimensions are 63 mm bore × 35 mm rod × 250 mm stroke, and 80 mm bore × 55 mm rod × 150 mm stroke, find the minimum cycle time for both cylinders to extend and retract fully.

A.2.12 A hydraulic cylinder is required to exert a minimum forward dynamic thrust of 25 tonnes and a minimum return dynamic thrust of 15 tonnes. Determine a suitable standard size metric cylinder if the maximum system pressure is 200 bar. Assume that the dynamic thrust is 0.9 times the static thrust. What pressure is required at the cylinder to give the desired thrusts if the effect of back-pressure is neglected?

A.2.13 A hydraulic cylinder as shown in Figure A.22 is to accelerate a load of 50 tonnes horizontally from rest to a velocity of 10 m/min in 50 mm. Take the coefficient of friction (μ) between the load and the guides as 0.1; assume zero back-pressure. Determine:

(a) A suitable size of standard metric cylinder if the maximum allowable pressure at the cylinder is 180 bar.
(b) The fluid flow rate required to drive the piston forward at 3 m/min.

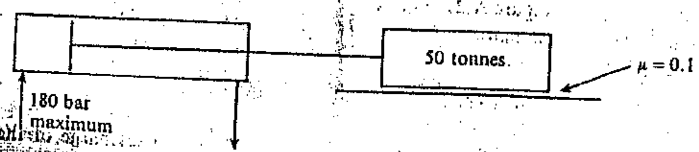

Figure A.22

A.2.14 A cylinder havin[g a bor]e of 50 mm with a rod diameter of 32 mm is used to lift a vertical load of 3 tonnes. The circuit used is shown in A.23. The quantity delivered by the pump is 8 l/min, the relief valve is set at 180 bar and the cylinder extend meter-out flow-control valve is set at 4 l/min. Calculate:

(a) The extend speed.
(b) The pressure reading at gauge P_1 when the cylinder is extending at a steady speed.
(c) The pressure registered on gauge P_1 if the cylinder is extended under no load conditions, i.e. load removed.
(d) The setting of the retract flow control valve in l/min if the retract speed is the same as the extend speed.

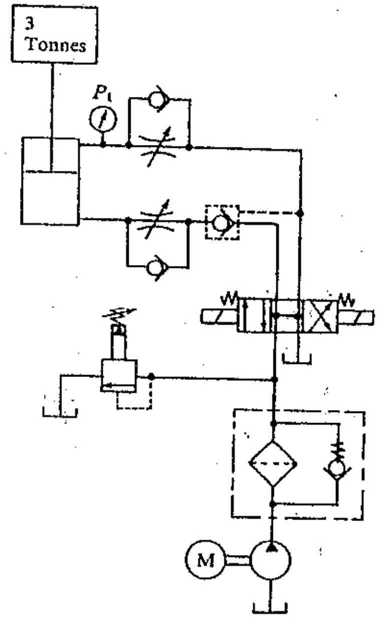

Figure A.23

A.2.15 A hydraulic cylinder is required to lift a 6000-kg load through a vertical height of 4 m. The working pressure is not to exceed 100 bar at the cylinder inlet port; neglect the effect of back pressure. The cylinder is to be front flange mounted, the load fully guided with the piston rod connection being pivoted.

Determine the sizes of a suitable standard piston rod and cylinder bore.

A.2.16 A hydraulic cylinder having a bore of 125 mm and a rod diameter of 90 mm is used to lift a load of 20 tonnes at a maximum speed of 5 m/min. The load has to be brought to rest in the cushion length of 50 mm at the end of the stroke, system pressure being applied to the full bore end of the cylinder during retardation. Determine:

(a) The pressure required to lift the load assuming zero back pressure at the annulus side of the cylinder.
(b) The fluid flow rate to raise the load at 5 m/min.
(c) The average pressure in the cushion during retardation.

A.2.17 A centre lathe head stock is to be driven by a 'constan[illegible]rostatic transmission. The variable-displacement non-reversing hydraulic moto[illegible] a speed range of 300 to 2500 rev/min. The maximum power required at the output of the hydraulic motor is 6 kW. The maximum pressure available at the pump delivery is 125 bar and the pressure drop between the pump and motor is 5 bar. The torque and volumetric efficiencies of both the pump and motor may be taken as 0.85. Assuming an open loop transmission, determine:

(a) The ideal motor displacement and the actual pump delivery required.
(b) The input power required by the pump.

A.2.18 A hydraulic cylinder has to move a load horizontally through a distance of 3 m. The cylinder is front flange mounted and the load rigidly connected to the piston rod and fully guided. The extend force which has to be exerted by the cylinder is 1.6 tonnes and the retract force 0.7 tonne. Assume the effective dynamic thrust is 0.9 times the static thrust.

If the maximum system pressure is limited to 150 bar, determine a suitable standard metric size of cylinder and calculate the actual operating pressure.

A.2.19 A machine tool cylinder is connected regeneratively to give a rapid approach speed of 10 m/min for a stroke of 1 m with a theoretical thrust of 2.5 tonnes. It is then switched to conventional connection to provide a pressing speed of 0.25 m/min for 0.5 m with a theoretical thrust of 10 tonnes. The maximum pressure at the cylinder is to be 200 bar.

(a) Select a suitable standard size metric cylinder.
(b) Calculate the pump delivery required for both parts of the extend stroke.

A.2.20 A hydraulic cylinder having a bore of 125 mm, a rod of 80 mm diameter and a stroke of 350 mm is to fully extend and retract in a total of 15 seconds. The extend thrust to be exerted by the cylinder is 20 tonnes, the retract thrust being 10 tonnes. Determine:

(a) The theoretical system pressure when the cylinder is extending.
(b) The theoretical system pressure when the cylinder is retracting.
(c) The theoretical pump delivery required.
(d) The actual pump displacement if the volumetric efficiency is 90% and the pump driven at 1440 rev/min.
(e) The maximum power input to the pump if the torque efficiency is 85%.

A.2.21 In an open-loop hydrostatic transmission the motor displacement is 0.5 liter/rev and it is to run at 65 rev/min. The pump supplying fluid to the motor is driven at 1440 rev/min. If the torque and overall efficiencies of both the pump and motor are 95% and 85% respectively, determine:

(a) A suitable pump displacement.
(b) The pressure at the motor if the torque required at the motor is 1000 Nm.
(c) The input power to the pump if the pressure drop in the pipework etc. between the pump and motor is 5 bar.

A.2.22 A hydraulic motor is required to develop a torque of 100 Nm at a maximum speed of 600 rev/min. The maximum pressure drop across the motor is to be 150 bar. The torque and volumetric efficiencies are both 0.9. Determine:

(a) A suitable motor displacement.
(b) The flow required to the motor.

A.2.23 A lathe head stock is directly driven by a hydraulic motor. The lathe is used to turn a bar with a maximum diameter of 60 mm. The maximum tangential cutting force on the lathe

tool is 2 kN [illegible] th[illegible]ximum rotational speed of the head stock is 700 rev/min. The maximum pressure set [illegible] the relief valve is 200 bar and the total pressure drop between the relief valve and the hydraulic motor is 10 bar, the back-pressure at the motor being 5 bar. The overall and volumetric efficiencies of the motor are 0.85 and 0.9 respectively. Determine:

(a) The minimum displacement in cm^3/rad.
(b) The flow rate to the motor at maximum speed.
(c) The maximum hydraulic input power to the motor.

A.2.24 A hydraulic motor with a displacement of 475 cm^3/rev is used to drive directly a conveyor drum having a diameter of 0.7 m. The pressure drop over the motor is 140 bar and the actual flow into the motor 48 l/min. The overall and torque efficiency of the motor are 0.9 and 0.94 respectively. Determine:

(a) The torque at the conveyor drum.
(b) The power in kilowatts supplied to the conveyor drum.
(c) The linear speed of the conveyor belt.

A.2.25 A vehicle weighing 2 tonnes is to be driven up a slope of 1 in 10 (1 vertical in 10 measured along the slope) at a speed of 20 km/h. The coefficient of rolling resistance may be taken as 0.1. The vehicle is driven hydraulically by two fixed-displacement motors fitted in the rear wheels which have an effective diameter of 850 mm. The volumetric and torque efficiency of the motors are both 0.95. The maximum pressure drop across the motors is 250 bar. Determine:

(a) The required motor displacement.
(b) The fluid flow from the pump at maximum speed.

A.2.26 A rotating feed table with a mass of 50 kg and a radius of gyration of 0.4 m is driven by a hydraulic motor. The table has to be accelerated from rest to a maximum speed of 120 rev/min in 0.5 second. The maximum pressure drop across the motor is 200 bar. Taking the volumetric and torque efficiencies of the motor as 0.96 and 0.95 respectively, determine:

(a) A suitable displacement for the motor.
(b) The actual pump delivery required to drive the motor at maximum speed if the pump efficiencies are the same as those of the motor.

A.2.27 A hydraulically-powered haulage is used to wind a train of wagons up a drift mine. The weight of the train is 5 tonnes, the slope of the track is 1 vertical in 10 measured along the slope length. The haulage rope is layered on the drum but to simplify the calculation assume that the effective diameter remains constant at 1 m. The track has a length from the haulage to the pit bottom of 1500 m. The haulage rope has a weight of 4 kg/m run. The haulage drum has a weight of 1.5 tonnes when the haulage rope is fully unwound and a radius of gyration of 0.5 m.

The train is to be capable of being accelerated from rest at the bottom of the slope to a top speed of 5 km/h in 10 seconds. The maximum pressure drop across the haulage motor is 300 bar and the torque and volumetric efficiencies of the motor are both 95%.

(a) Calculate the motor displacement per revolution.
(b) Should the haulage have to be stopped halfway to the surface, what would be the maximum possible acceleration on restarting? Take into account the change in drum inertia owing to the haulage rope being wound on to the drum.
(c) If the pump supplying the haulage motor has a volumetric efficiency of 92% and an overall efficiency of 87%, calculate the required displacement per revolution when it is driven at 2200 rev/min.

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(d) What is the input power needed by the pump if the [illegible] and motor is 30 bar?

A.2.28 A closed loop hydraulic system consists of a variable-displacement pump driving a fixed displacement motor as shown diagrammatically in figure A.24.

(a) Show that

$$\frac{\Omega_m(s)}{Y(s)} = \frac{K_p}{d_m}\left(\frac{1}{1+\tau s}\right)$$

where s is the Laplace transform function, K_p is the pump flow constant for a given speed Ω_p, d_m is the motor displacement, and τ is the time constant. (Neglect the fluid compressibility.) The combined leakage coefficient for the pump and motor is λ.

(b) Determine from first principles the response of the system to a unit step input after a time equal to 3τ. Calculate the value of τ. In a particular system the values are

Load inertia, $I = 100$ Nm s^2
Leakage coefficient, $\lambda = 12 \times 10^{-3}$ l/min/bar
Motor displacement, $d_m = 25$ ml per radian
Pump flow constant, $K_p = 5 \times 10^{-3}$ m^2 s^{-1}

(c) Draw a polar plot for the frequency response of the system to an input $\sin \omega t$ for values of ω between 1 and 10 radians per second.

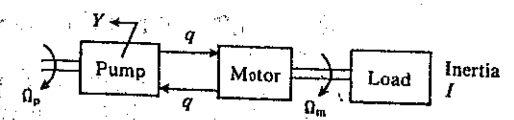

Figure A.24

A.2.29 A dumper truck is to be driven by a reversible flow-controlled hydrostatic transmission. The details of the vehicle and required drive are

Gross weight of vehicle	= 7 tonnes
Number of driven wheels	= 2 (rear wheels)
Rolling resistance	= 100 kg per tonne weight
Rolling radius of wheels	= 0.4 m
Maximum vehicle speed on flat	= 15 km/h
Time to accelerate to maximum speed on flat	= 5 seconds.

The vehicle is to be capable of climbing a maximum gradient of 1 in 4; maximum speed and acceleration on gradient are unimportant.

Variable-displacement pumps are available with maximum theoretical deliveries starting at 20 l/min and increasing in steps of 10 l/min when driven at engine speed.

Fixed-capacity motors are available with capacities starting at 0.1 l/rev in increasing steps of 0.05 l/rev.

The maximum operating pressure of the system is 300 bar. Both pumps and motors have volumetric efficiencies of 0.95, the torque efficiency of the motor is 0.94 and the overall efficiency of the pump 0.9.

(a) Neglecting any pressure drops in pipework select suitable hydraulic pump and motors and determine the input power to the pump.

(b) If the vehicle weight distribution is 70% on the rear wheels, 30% on the front wheels and the coefficient of traction between the drive wheels and the ground is 0.95 determine the maximum gradient up which the vehicle could climb.

A.3 DESIGN PROBLEMS

This section [illegible]

A.3.1 Two [illegible] One machine requires a [illegible] 18 l/min. The [illegible] and 100 bar and may be used separately or at the same time.

Draw a suitable pumping circuit and determine the [illegible] input power required.

A.3.2 A hydraulic power pack is to be used in a test house which undertakes fatigue and reliability investigations. The fluid demand can vary from 5–100 l/min and be at pressures up to 300 bar. The fluid must be pulse free and filtered to $\beta_5 = 75$.

Draw a suitable pumping circuit bearing in mind the importance of system reliability. (If a test is stopped part way through any results will be meaningless.)

A.3.3 A hydraulic cylinder of 1 m stroke is to exert a maximum forward thrust of 0.5 tonne and a maximum retract thrust of 1.5 tonnes. These forces have to be adjustable. The approximate cylinder speed is to be 0.5 m/min extend and 1.5 m/min retract. Draw a suitable circuit showing the power pack, control valves and cylinder. (Do not size any components but indicate the ratio of cylinder bore diameter to cylinder rod diameter which will produce the required relationship between the extend and retract speeds.)

A.3.4 A double-acting hydraulic cylinder has to have the same speed extending and retracting. The speed must be easily adjusted and independent of changes in oil viscosity and the load which always opposes movement. The cylinder must be capable of being positively locked in any position. Any 'kicks' when restarting would be detrimental.

Draw a suitable circuit.

A.3.5 A machine table has to reciprocate continuously for long periods. The operator can select full speed, two-thirds speed and one-third speed. Flow rate into the cylinder for maximum speed is 30 l/min. The speed is to be the same in both directions and within 15% of the selected value. Variations in working pressure can be from 20 to 140 bar.

Design a system for minimum heat generation.

A.3.6 A hydraulic cylinder with a stroke of 1 m is required to exert a forward thrust of 10 tonnes, the retract thrust will normally be 0.1 tonne and to prevent damage to the unit must never exceed 1 tonne. The cylinder is front flange mounted and the piston rod rigidly guided.

If the system pressure is limited to 140 bar calculate a suitable standard size of metric cylinder. If the cycle time is to be 20 seconds, estimate a suitable size of pump. (Neglect all losses.)

Draw a circuit for this system showing the cylinder control valves and power pack.

A.3.7 A double slugger roll crusher is to be hydraulically driven. A layout of the unit is shown in Figure A.25. Two contra-rotating rolls are each driven by a fixed-displacement slow-speed hydraulic motor, the maximum drive speeds being 55 and 65 rev/min for the fixed and sprung rolls respectively. If a piece of non-crushable material enters the rolls and causes them to jam the roll drive must automatically stall off. The sprung roll position is adjusted

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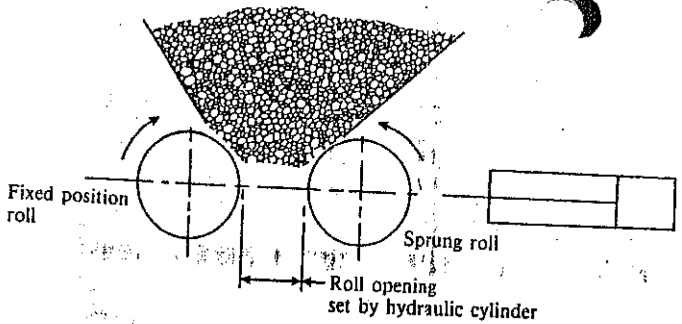

Figure A.25

by a hydraulic cylinder which can be locked to give a minimum distance between rolls but must act as a spring to absorb shock loads. The maximum pressure at the cylinder is to be 200 bar.

Draw a suitable hydraulic circuit. (Note the rolls will have to be reversed if a piece of material becomes jammed between them. Do not draw the electrical control circuit.) The pump is to operate against a maximum pressure of 300 bar. Show the suggested settings for any pressure control valves used.

A.3.8 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 grinds.

Design a hydraulic circuit so that the table moves at the same speed in both directions, 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 the 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 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 the dynamic thrust of the cylinder is 0.9 times the static thrust. Select a standard metric cylinder and determine the relief valve setting for the maximum cylinder thrust of 2 kN. Calculate theoretical pump delivery and pump input power. (Do not draw the electrical circuit.)

A.3.9 A cutting machine as shown diagrammatically in Figure A.26 consists of a rotating cutting head and a sliding horizontal table. The table is driven by a hydraulic cylinder with a stroke of 2 m. The cylinder is to have a rapid approach speed of approximately 3 m/min automatically changing to a slow cutting speed as the pressure increases when the workpiece contacts the cutting head. The slow cutting speed is to be manually adjustable between 10 and 150 mm/min. A retract speed of approximately 3 m/min is required.

The cylinder is trunnion mounted at the rear end and clevis mounted to the table which

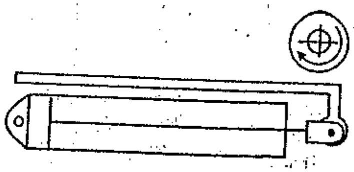

Figure A.26

is rigidly guide[…] cylinder has to exert a thrust of 500 kg during rapid approach and retract and 2500 kg on the cutting stroke. The maximum system pressure is to be 70 bar.

Assume actual thrust is 0.9 times theoretical thrust and select a standard metric cylinder. When calculating the buckling length assume the closed length of the cylinder is equal to the stroke.

Determine the maximum flow required from the pump.

A.3.10 A hydraulic boom is powered by two cylinders (Figure A.27). Each cylinder has a stroke of 0.7 m and exerts a maximum thrust of 6 tonnes on extend and 4 tonnes on retract. The maximum pump delivery pressure is 200 bar and the pressure drop through the pipes and valves may be taken as 10 bar (including back pressure). Cylinders are to be operated by manual valves. Design the circuit in such a way that only one cylinder may be operated at one time. The extend time for either cylinder is to be 10 seconds. Assume the extended length of the cylinder between pivots is twice the stroke for buckling load calculations. Determine a suitable metric cylinder size and pump delivery. Draw a hydraulic circuit.

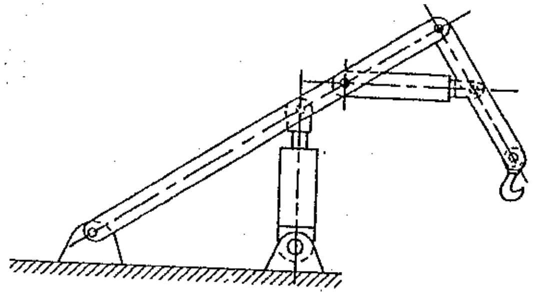

Figure A.27

A.3.11 In a roll mark press the mark, usually a string of characters is formed in relief on the periphery of a roller which is mounted above the machine table as shown in Figure A.28. Components are mounted on the table using quick-release clamps. The table is raised and a

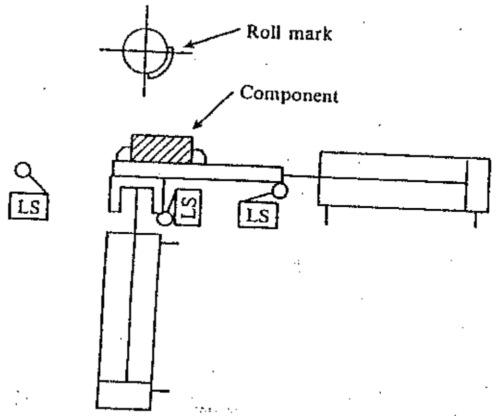

Figure A.28

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... horizontal cylinder 2 tonnes. Both cylinders have a stroke of 250 mm. The required marking rate is 3 components per minute. If it t... seconds to remove a marked component and replace it with a new one, determine the p... and cylinder sizes and draw a suitable circuit.

It is important that pressure is maintained on the vertical cylinder during the extend stroke of the horizontal cylinder and it is suggested that a flow of 4 l/min will be satisfactory for this purpose. Maximum system pressure is not to exceed 140 bar.

A.3.12 A hoist or jigger consists of two 3-groove sheave blocks as shown in Figure A.29. A hydraulic cylinder is attached to the inboard block, the outboard block being fixed. Calculate a suitable standard metric cylinder size if the load to be raised by the hoist is 5 tonnes through a distance of 5 m. (The maximum allowable circuit pressure is 160 bar; neglect all losses.) If the 5 m lift is to take 40 seconds, what pump delivery is required?

Draw a suitable circuit so that the hoist can be stopped and locked in any position.

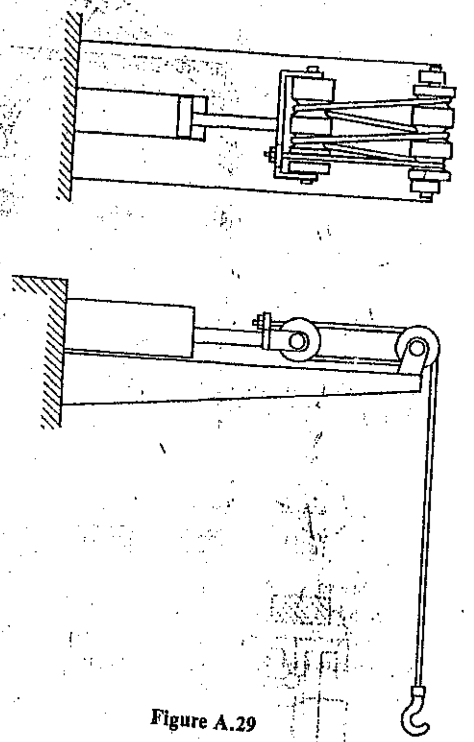


Figure A.29

A.3.13 A large center lathe is driven by a reversible hydrostatic transmission. The chuck speed is to be variable between 40 and 400 rev/min. A 5 kW, 1440 rev/min electric motor is to drive the hydraulic pump which can operate against a maximum pressure of 200 bar.

(a) Design a closed-loop hydrostatic transmission so that as the chuck speed decreases the available torque increases.

... motor displacements, the volumetric and torque efficiencies for pump and motor can be taken as 0.93. Assume the total pressure drop in the pipew... between the pump and motor is 15 bar.

(c) Calcula... the maximum torque available at the motor when running at the minimum speed.

A.3.14 A fairground ride is to have a hydraulic drive. The ride comprises a 15-m diameter disc on which seats are fastened. The disc is horizontal when at rest. Two cylinders are used to tilt the disc to an angle of 45° to the horizontal, the disc being rotated at 4 rev/min. This rotational drive is via a hydraulic motor connected to a rubber tyred wheel 0.6 m diameter which is kept in contact with a 15-m diameter drive track on the disc. The ride must only be tilted out of the horizontal when the disc is rotating. The maximum torque required at the hydraulic motor is 2000 Nm, and the maximum pressure available at the motor is 138 bar. The overall efficiency of the motor is 85% and the volumetric efficiency is 92%.

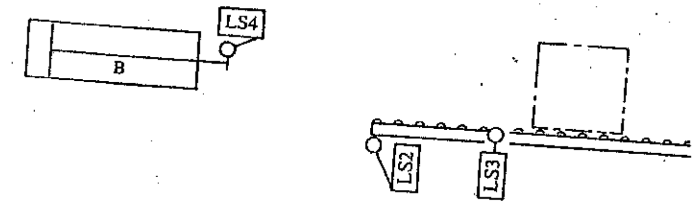
Design a hydraulic system determining a suitable hydraulic motor displacement. Suggest fail-safe features which can be incorporated in the case of pump failure.

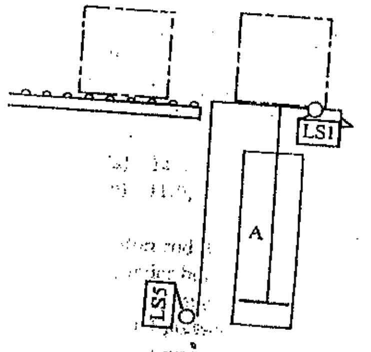
A.3.15 A hydraulically-operated tilting mechanism is to use a rear trunnion mounted cylinder with a rod mounted clevis. The cylinder is to have a stroke of 2.3 m and exert a minimum force of 140 kN in each direction. It is to have a speed of 4.5 m/min on extend and retract and must be capable of being locked in any position against a reversible load.

(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. (Neglect all losses.)

A.3.16





Limit switch	Detects
LS1	Presence of component on platform
LS2	Platform in top position
LS3	Space available on discharge track
LS4	Cylinder B fully retracted
LS5	Cylinder A fully retracted

Figure A.30

A gravity track feeds components to a conveyor transfer point (Figure A.30) 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

... the upper track is clear, the time for one complete cycle is to be 60 seconds. ... The maximum system pressure is to be 140 ... being rigidly ...
Neglecting all losses in the system determine suitabl[e] [stan]dard metric cylinder sizes and the pump delivery rate required. Design a suitable circuit using solenoid operated directional control valves.
Limit switches LS1 to LS5 are used to signal component and cylinder positions.

A.3.17 A track-laying vehicle has a hydraulic motor driving each track. It is to be capable of climbing a gradient of 1 vertical in 10 measured along the slope at a top speed of 25 km/h. The vehicle which has a weight of 8 tonnes and a rolling resistance of 85 kg/tonne is to accelerate from rest to 25 km/h in 10 seconds when travelling horizontally. The hydraulic power pack is driven by a diesel engine having a top speed of 2500 rev/min. The maximum system pressure at the power pack is 300 bar and there is a maximum pressure drop in the pipework between the power pack and the motors of 20 bar. The overall and volumetric efficiencies of both the pump and motor units are 80% and 95%.
Draw a circuit for a closed-loop constant torque hydrostatic transmission. The speed of the vehicle is to be adjustable and it is steered by independently altering the speed of each track.
Determine:
(a) The capacity of the motors driving the tracks if the equivalent outside diameter of the track sprocket wheels is 1.2 m.
(b) The maximum pump capacity to give a top speed of 25 km/h.
(c) The theoretical minimum capacity of the make-up pump if it is directly coupled to the diesel engine.
(d) The maximum output power required from the diesel engine.

A.4 *SOLUTIONS TO SECTION A.2*

A.2.1 (a) 2.22 l/min
(b) 0.73 kW

A.2.2 12.4 cm^3/rev

A.2.3 (a) 88% of maximum displacement
(b) 16.3 kW

A.2.4 (a) 23.6 l/min
(c) 16.2 kW

A.2.5 (a) 30.6 l/min
(b) 12.24 kW
(c) 1.68 kW

A.2.6 22 ml/rev

... (a) 3.32 m/min, 5.09 m/min
(b) 20.9 s

A.2.9 (a) 15 l/min
(b) 2.5 l
(c) 7.45 l

A.2.10 (a) 77 l/min, 7.7 l/min
(b) 69.3 l/min, 7.7 l/min
(c) 42.4 ml/rev, 4.7 ml/rev
(d) 6.4 kW, 5.3 kW
(e) 10.2 m/min

A.2.11 9.46 s

A.2.12 140 mm bore × 90 mm diameter rod
Extend pressure required = 177 bar
Retract pressure required = 181 bar

A.2.13 (a) 80 mm bore cylinder (actual size required is 67 mm bore)
(b) 15.1 l/min

A.2.14 (a) 3.45 m/min
(b) 50.8 bar
(c) 305 bar
(d) 6.77 l/min

A.2.15 Minimum piston rod diameter 64 mm, standard 70 mm
Minimum piston diameter 87 mm, standard 100 mm
Suitable cylinder 100 mm bore × 70 mm rod

A.2.16 (a) 160 bar
(b) 61.35 l/min
(c) Cushion pressure to retard load = 33.9 bar
Cushion pressure to balance forward pressure = 332.2 bar.
Total cushion pressure = 366.4 bar

A.2.17 (a) 14 to 118 cc/rev, 41.5 l/m
(b) 11.96 kW

A.2.18 Piston rod diameter for buckling strength = 34.2 mm (36 mm)
Cylinder bore for extend thrust = 38.5 mm
Use a 50 mm bore × 36 mm rod cylinder
Extend pressure = 89 bar
Retract pressure = 81 bar

A.2.19 (a) Theoretical sizes 79 mm bore × 35 mm rod (standard cylinder 80 mm × 45 mm)
(b) Rapid approach flow = 15.9 l/min; pressing flow 1.26 l/min

(e) 9.5 kW

A.2.21 (a) 28.2 ml/rev
(b) 132 bar
(c) 9.76 kW

A.2.22 (a) 7.41 cm^3/rad (46.5 cm^3/rev)
(b) 31 l/min

A.2.23 (a) 3.45 cm^3/rad
(b) 16.86 l/m
(c) 6.6 kW

A.2.24 (a) 995 Nm
(b) 10.1 kW
(c) 213 m/min

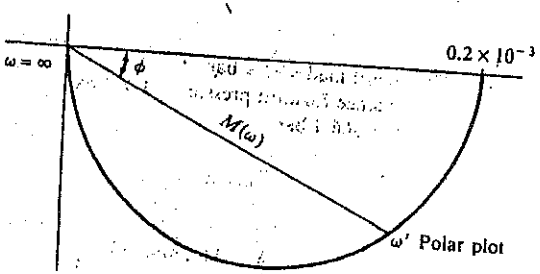
A.2.25 (a) 220 ml/rev
(b) 57.8 l/min

A.2.26 (a) 106 ml/rad (66.5 ml/rev)
(b) 8.3 l/min

A.2.27 (a) 1.648 l/rev
(b) 0.572 m/s^2
(c) 27.3 ml/rev
(d) 34.9 kW

A.2.28 (a) See Section 8.3.1 of Chapter 8.
(b) $\Omega_m = 190$ rad/s for unit step input
$\tau = 0.325$

(c)



$M(\omega) = \{[1^2 + (0.32)^2]^{1/2}\}^{-1} \times 0.2 \times 10^{-3}$
$\phi = \tan^{-1} 0.32$

A.2.29 (a) Motor displacement = 1.07 l/rev (1.1)
Maximum pump delivery = 230 l/min
Input power to pump = 65.6 kW
(b) Gradient rise 1 in 1.8 along slope

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