MMET 303

FLUID MECHANICS & POWER

LAB MANUAL

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About the Author

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PREFACE

This laboratory will serve two purposes. The first is to provide each student with a basic knowledge of fluid mechanics and fluid power. This will provide a good background for those who enter either directly into a fluid power industry or into a related area. Majority of the industries follow fluid mechanics or power principles in the design, manufacture or sale of their product.

The second purpose is to help you learn how to record and present experimental data and to draw conclusions from the results that you have obtained. You will learn to present your reports in a logical format with precise language and graphics, so that anyone who reads your report will clearly understand your findings.

The laboratory contains experiments that can be classified into three broad categories:

1. Fluids power experiments, which involve working with hydraulic and pneumatic circuits to control actuators.
2. Basic fluid mechanics experiments, which will illustrate and augment the basic concepts learnt in the class, such as fluid property measurement.
3. Fluid machinery experiments, which involves performance evaluation of different types of pump configurations.

LAB MANUAL

The lab manual is organized into experiments based on the classification mentioned previously. Some experiments may have an associated appendix. The lab manual is under constant revision, and it would be helpful if you email any error or improvements of the manual to the lab instructor. Supplementary information or corrections to the material in this manual will be provided by the lab instructor in class. The students are strongly encouraged to go through the discussion section for the experiment to be performed, prior to each lab class.

Lab Policy

Groups
Students will be formed into **groups of two on the first lab day**. Once a student has signed up with a group, he or she may not change groups without prior approval of the instructor.

Lab Reports
You will perform the experiment in group, and turn in **ONE REPORT PER GROUP**. Your report should be self-contained, i.e. an engineering technologist should be able to perform the experiment and duplicate your results by reading your report. **DO NOT "adjust"** your data to make them fit what you believe to be an acceptable value. Your report should be an accurate description of the experiment. If your results differ significantly from reference values you should check your settings carefully (calibration, wrong units, wrong calculations, etc.), and do the experiment again. Try to explain any discrepancies but do not "adjust" your data. Lab report format and rubric will be shared as a separate document.

Attendance
Attendance will be taken at the beginning of every lab session. Make up lab activities will be scheduled only for University approved absences or unless the instructor gives prior approval. If you miss the lab, you will be assigned zero grade for that day's experiment and the subsequent lab report. During the lab time, you cannot leave without the instructor's permission.

Students with disabilities
If you feel you are entitled to special accommodations because of a disability, please see me within the first four class meetings. You may also want to review the **Americans with Disabilities Act policy statement**.

Fluid Mechanics Lab Policy
We want to maintain the high-quality conditions of this lab for the students in future years. Thus, it is necessary for you to adhere to the established policy of **NO BEVERAGES, FOOD, NEWS PAPERS, MAGAZINES, TOBACCO PRODUCTS AND ANIMALS** within the Fluid Mechanics lab. You cannot take or use the chemicals, tools, and instruments without the instructor's permission.

Safety
It is required to wear long pants and shoes that cover toes for this Lab. NO SHORT PANTS, SLIPPERS AND TANK TOPS. Safety glasses will be needed for several labs.

Policy Compliance

By signing this form, I verify that I will read, understand, and agree to follow the safety practices required for this course as established by the professor, by the Look College of Engineering, by the Engineering Safety Office, and by Texas A&M University. I will locate all emergency equipment and personal protective equipment (PPE), I will learn how to use the PPE, and I will always use the appropriate PPE for the work that I am doing.

I fully commit to conducting my studies in a safe, healthful and secure manner, in compliance with the *Aggie Honor Code*, the *Engineering Code of Ethics*, and by the established safety rules, in order to reduce risk to myself and others, and to facilitate the safe and successful completion of this Engineering course.

Within the first two (2) weeks of the semester, I will logon to the *Engineering Safety Net* web site at http://engineering.tamu.edu/safety/ and complete the online *Laboratory Safety Training*. If my laboratory work involves the use of tools, I will also complete the online *Shop & Tool Safety Training*. I will complete any other necessary safety training as directed by my professor.

I acknowledge that while in the laboratory, improper conduct and horseplay of any kind that may endanger others or myself will not be tolerated and appropriate disciplinary action will be taken. I will never work in the laboratory alone, and I will never leave an experiment running unattended. I understand that I may be dismissed from this laboratory course for failure to comply with the established safety procedures for this laboratory and with all TAMU & TEES Safety Rules.

First Name: **Family Name:**

UIN:

SIGN: **DATE:**

Experiment 1: Properties of Fluid: Density, Specific Gravity & Viscosity

Objective:
To learn how to measure two important fluid properties – fluid density, specific gravity and viscosity.

Determination of density of a liquid:

$$\rho = \frac{mass(g)}{volume(ml)} \quad (kg / m^3) \tag{1}$$

The density of pure water at 20ºC is 1000 kg/m^3. The experimental result should be within 1% of this value.

Apparatus:

Digital weighing machine, Triple beam weighing scale, 30 mL bottles, various types of oils including engine oil, brake oil, transmission oil and vegetable oil.

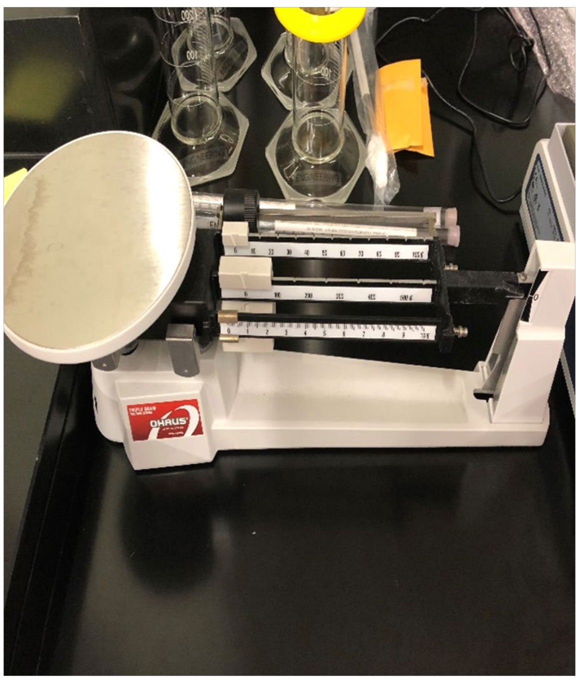


Figure 1: Triple beam weighing scale and digital weighing machine

Figure 2: Bottle and various oils

Procedure:

1. Dry and weigh the bottle.

2. Fill the bottle with liquid.

3. Remove any residue on the outside of the bottle by using paper towel.

4. Now, re-weigh the bottle with the liquid. The mass of the liquid will be the difference between the mass of bottle with liquid and the mass of empty bottle.

5. Calculate the Specific Gravity of the liquid. This will used for comparison with the Hydrometer experiment to determine the specific gravity in the next experiment.

Fluid ______________________________ Temperature ________________________

Run	Mass of empty bottle M1(kg)	Mass of filled bottle M2(kg)	Difference $\Delta M = M2 - M1$ (kg)	Volume of bottle V (m^3)	Density ρ (kg/ m^3)
1					
2					
3					

Table 1: Suggested Presentation of Experimental Data

Determination of Specific Gravity:

Specific gravity, is defined as the ratio of the density of a fluid under investigation to the density of water.

$$SG = \frac{density\ of\ fluid\ at\ a\ given\ temperature\left(T^{o}F\right)}{density\ of\ reference\ fluid\ (water\ for\ liquids\ and\ air\ for\ gases)\ at\ 60^{o}F\left(15.6^{o}C\right)} \qquad (2)$$

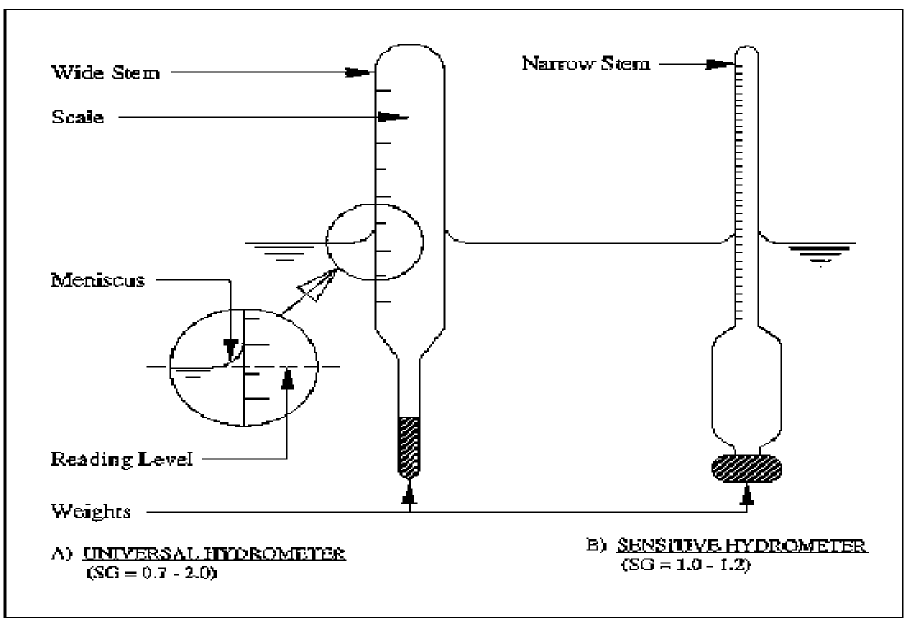


Figure 3: Types of hydrometer

Apparatus:

Hydrometer, graduated cylinder, various types of oils including engine oil, brake oil, transmission oil and vegetable oil.

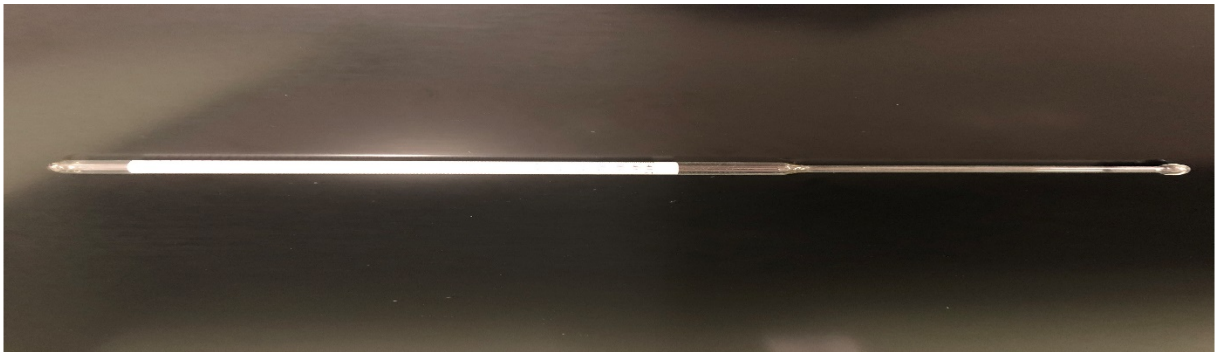


Figure 4: Hydrometer

Figure 5: Graduated cylinders

Procedure:

1. Fill the graduated glass cylinders with a liquid.

2. Carefully insert the hydrometer and allow it to suspend in the center of the graduated cylinder.
   Precaution: The Hydrometer should not touch the walls of the graduated cylinder

3. Once the Hydrometer becomes stationary and is stabilized, read the scale at the free surface
   Precaution: Read the scale at the bottom of the meniscus as shown in Figure 3.

4. Compare the measured value of SG against the calculated value of SG in the density experiment value. Determine the % error.

Determination of Viscosity μ(T, P):

Viscosity is the internal resistance to flow. Viscosity is a fluid property subject to changes in temperature and pressure. The viscosity of a liquid decreases with increasing temperature while the viscosity of a gas increases with increasing temperature.

A Newtonian fluid is defined as a substance in which the shear stress in linearly proportional to the strain rate. For a Newtonian fluid, the relation between shear and stress reduces to

$$\tau = \mu \frac{du}{dy} \tag{3}$$

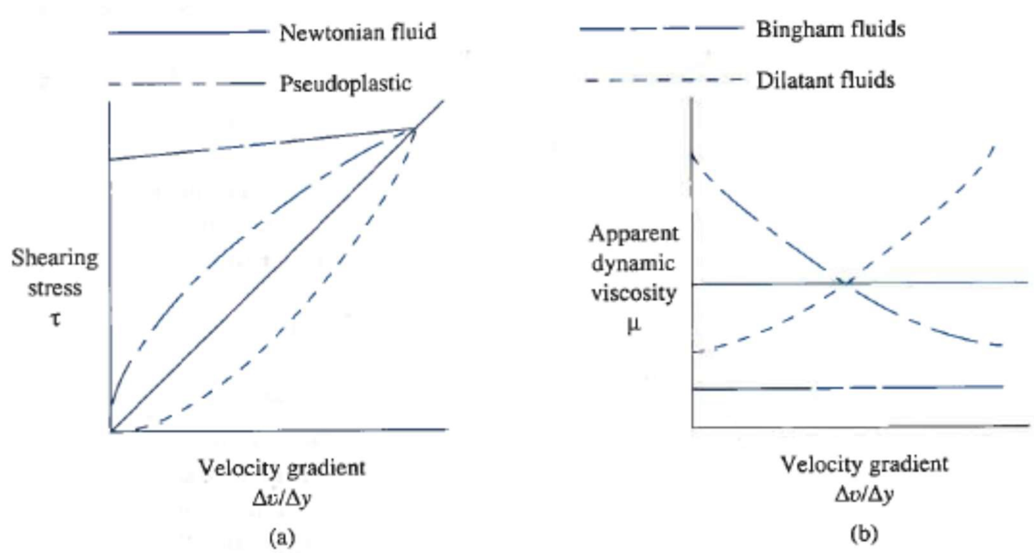


Figure 6: Newtonian vs. non-Newtonian fluids

***Falling Ball Viscometer*:** The technique that requires a low Reynolds number flow is to infer the viscosity (Newtonian) from the rate at which a small sphere falls through a fluid (*Falling Ball Viscometer*). At very low Reynolds numbers (R_D<<1), viscous forces dominate inertial forces. Hence, the nonlinear convective acceleration terms in the Navier-Stokes equations become negligible.

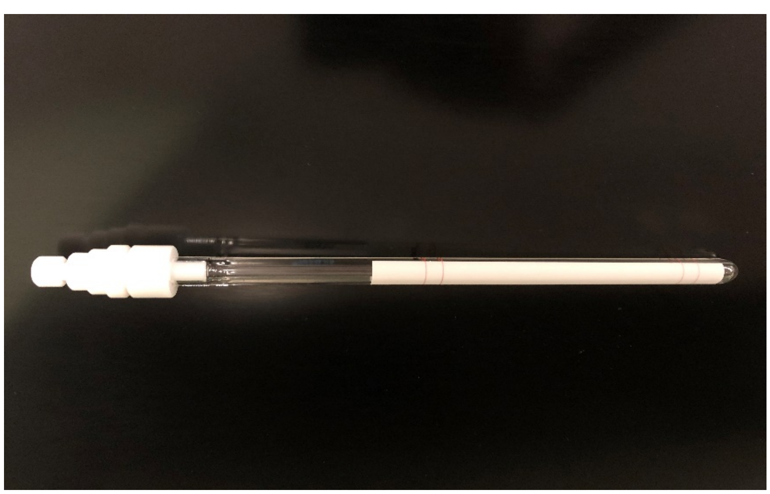


Figure 7: Falling Ball Viscometer

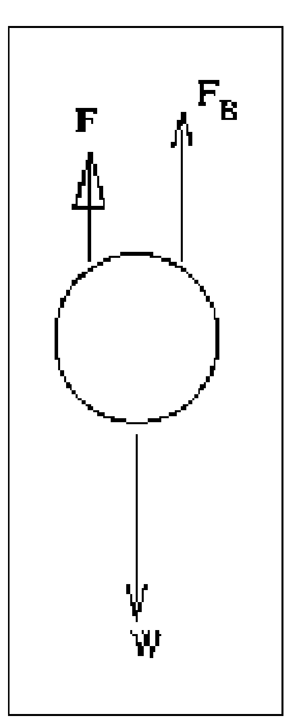


Figure 8: Force diagram for a falling sphere.

Procedure:

1. Determine the density of the fluid(s) under investigation. Also, determine the mass and diameter of the sphere(s).

2. Fill the viscometer with the liquid under investigation.

3. Invert the viscometer upside down so that the ball starts falling into the liquid. Use stop watch to record the time between two red markings on the viscometer.
   Precaution: Begin timing the fall several centimeters below the surface of the liquid to allow the sphere to reach equilibrium.

4. Perform this experiment several times to record the fall time of the sphere in order to obtain an estimate of the terminal velocity, U.

5. Calculate the dynamic viscosity using two equations:

   First Equation:

   $\mu = K(\rho_f - \rho)\,t$ [unit in cP] (4)

   where, ρ_f = density of ball
   8.02 g/cm^3 for stainless steel, 2.7 g/cm^3 for glass
   ρ = density of the hydraulic fluid (g/ml or g/cm^3)
   t = time of descent (mins)
   K = viscometer constant = 35 for size 3 float

   Note: The approximate K for size 1 is equal to 0.3, for size 2 is 3.3 and for size 3 is 35. The viscometer constant is obtained by measuring the time of descent for a standard liquid (e.g. a viscosity standard solution)

Second Equation:

Calculate Reynolds number and verify if it is less than 1. This equation will only be valid that case.

$$\mu = \frac{mg\left(1 - \frac{\pi \rho D^3}{6m}\right)}{3\pi \cdot U \cdot D}. \qquad \text{[unit in Ns/m}^2\text{]} \tag{5}$$

$$\text{if } \mathrm{Re} = \frac{\rho U D}{\mu} < 1 \quad \text{where } \rho \text{ is the density of the fluid.}$$

Note: 1centipoise = 0.001 Ns/m^2

6. Repeat as needed several times for each fluid.
7. Repeat for the stainless steel and glass spheres.

FALLING SPHERE VISCOMETER

Fluid Density ____________________________ Temperature ______________________

Run	Mass M(kg)	Diameter D(m)	Distance ΔL (m)	Time Δt (s)	Velocity U (m/s)	Reynolds Number Re	Viscosity μ (Ns/m^2)

Table 2: Suggested Presentation of Experimental Data

Questions:

(a) How does the diameter and mass of the sphere influence the measurement?

(b) Compare the viscosity values with standard table/graph values.

(c) How do your values of viscosity compare between the two methods and with the accepted values for the given fluids found in your textbooks?

(d) Discuss the accuracy of the results and possible sources of errors.

Experiment 2: Friction Losses in Pipes

Objective:

To investigate the pressure loss due to friction in a pipe and to compare the relationship between the friction factor and Reynold number with empirical data.

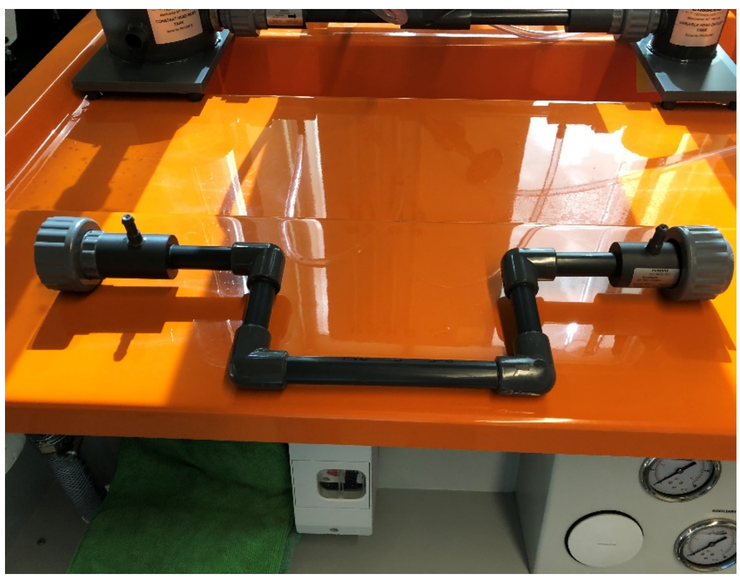
Apparatus:

Hydraulic bench, various pipe fittings including:

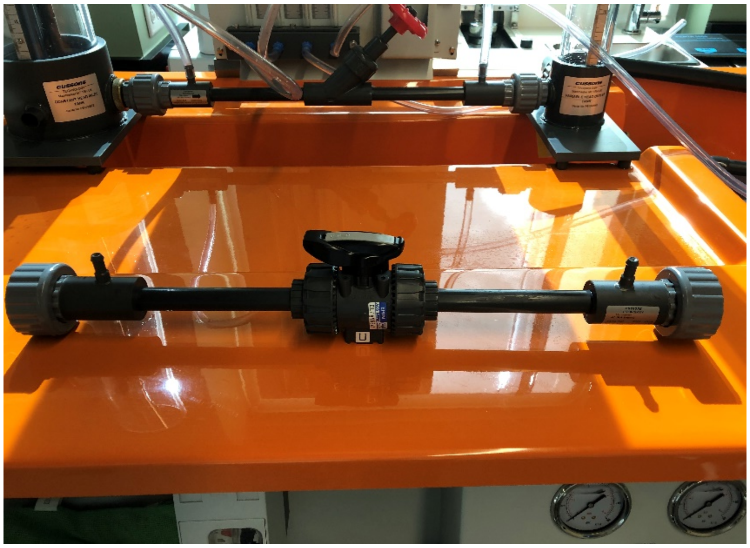
- 7 mm bore test section
- 10mm bore test section

- 10mm bore test section with four bends

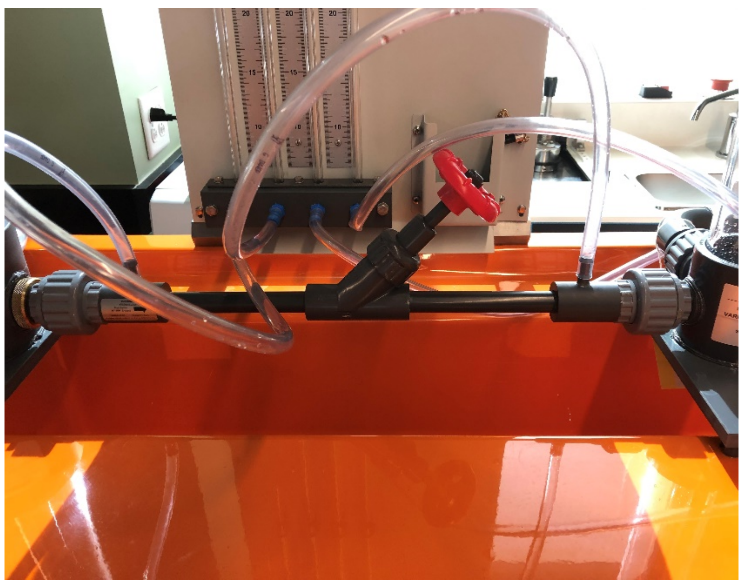
- 10mm bore test section with four elbows



- 10mm bore test section with ball valve



- 10mm bore test section with seat valve



(a) Procedure:

Note: The following procedure is for the 7 mm and 10mm bore test section, the 10mm bore test section with four bends and four elbows.

1. Start the pump and establish water flow through the test section. Raise the swivel tube of the outlet tank so that it is close to vertical. Adjust the bench regulating valve or pump speed to provide a small overflow from the inlet tank and overflow pipe. Ensure that air bubbles are bled from the manometer tubes.

2. Set up series of flow conditions with differential heads starting at 25 mm in steps of 25 mm up to 150 mm and thereafter in steps of 50 mm up to a maximum of 500 mm. At each condition, carefully measure the flow rate using the volumetric tank and a stop watch.

3. Measure the water temperature and find density and viscosity from the tables.

Results & Discussion:

1. For each result, calculate the mean velocity, determine the Reynolds number and the corresponding friction factor f.
2. **For 7mm and 10 mm bore test section:** Plot $\log_e h_L$ VS $\log_e V$. Draw a straight line through the results and measure its slope to express the relationship between h_L and V in form of $h_L \alpha V^n$

Observation and Calculation Table for 7mm and 10 mm Bore Test Section

Quantity of Water Collected (Liters)								
Time to collect water (seconds)								
Q (L/min)								
V (m/s)								
$\log_e$ V								
Re								
$\log_e$ Re								
Inlet head h_1 (m)								
Outlet head h_2 (m)								
Head Loss h_L (m) = $h_1 - h_2$								
$\log_e h_L$								
Friction Factor f								
$\log_e$ f								

For 10mm bore test section with four bends and four elbows:

3. Find out the resistance factor K, both for bends and elbows.

4. For the results for 10 mm pipe used in previous step or by analysis (using the ITT/Gould tables and the analysis performed for equivalent length in Chapter 10), calculate the head loss for an equivalent length of a straight pipe of the same diameter as the test section.

Observation and Calculation Table for 10 mm Bore Test Section with 4 Bends & Elbows

Quantity of Water Collected (Liters)								
Time to collect water (seconds)								
Q (L/min)								
V (m/s)								
$V^2/2g$								
Inlet head h_1 (m)								
Outlet head h_2 (m)								
Head Loss h_L (m) = $h_1 - h_2$								
Resistance Coeff: K								
Friction Factor f								

(b) Procedure:

Note: The following procedure is for the 10 mm ball and seat valves

1. Fully open the valve in the test section. Start the pump and establish water flow through the test section. Raise the swivel tube of the outlet tank so that it is close to vertical. Adjust the bench regulating valve or pump speed to provide a small overflow from the inlet tank and overflow pipe. Ensure that air bubbles are bled from the manometer tubes.

2. Set up series of flow conditions with differential head of 450 mm. Carefully measure the flow rate using the volumetric tank and a stop watch.

3. Carefully close the valve in small but measurable increments, until the valve is fully closed. Record the valve position and measure the flow rate at each valve position.

4. Measure the water temperature and find density and viscosity from the tables.

Results & Discussion:

1. Find out the resistance factor K for both valves.

2. For the results for 10 mm pipe used in previous step or by analysis (using the ITT/Gould tables and the analysis performed for equivalent length in Chapter 10), calculate the head loss for an equivalent length of a straight pipe of the same diameter as the valve test section.

Observation and Calculation Table for 10 mm Bore Test Section with Ball & Seat Valves

Quantity of Water Collected (Liters)								
Time to collect water (seconds)								
Q (L/min)								
V (m/s)								
$V^2/2g$								
Inlet head h_1 (m)								
Outlet head h_2 (m)								
Head Loss h_L (m) = $h_1 - h_2$								
Resistance Coeff: K								
Friction Factor f								
Valve pressure loss ΔP (Pa)								

Experiment 3: Pumps – Series & Parallel Tests

Objective: The purpose of this experiment is to study the head-discharge characteristics of single– and twin-stage centrifugal pumps. We are determining how parallel or series pumps effect a flow: whether it causes the total head or flow rate to increase.

Theory: Pumps are used to move fluids from one location to another by imparting pressure to the fluid. The imparted pressure should be adequate enough to overcome the hydrostatic and hydrodynamic pressure drops (commonly expressed in terms of *head of liquid column*) in the flow system. The pressure provided by the pump depends on its characteristics, such as type, rpm, size, flow rate, etc.

The experimental setup consists of the apparatus mounted in a self-contained modular frame (see Figure 1) and comprises two similar dual speed centrifugal pumps interconnected by an arrangement of pipes and valves which can be arranged so that the performance of a single pump, two pumps in series, or two pumps in parallel can be determined.

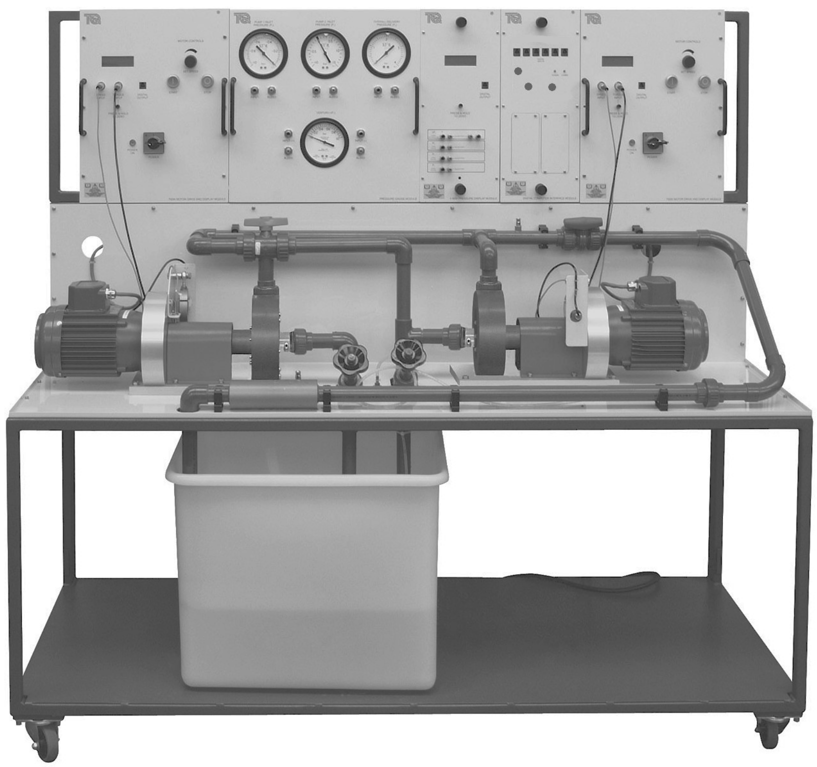


Figure 1. The H83 Two-stage Centrifugal Pump Test Set (shown with all optional instruments)

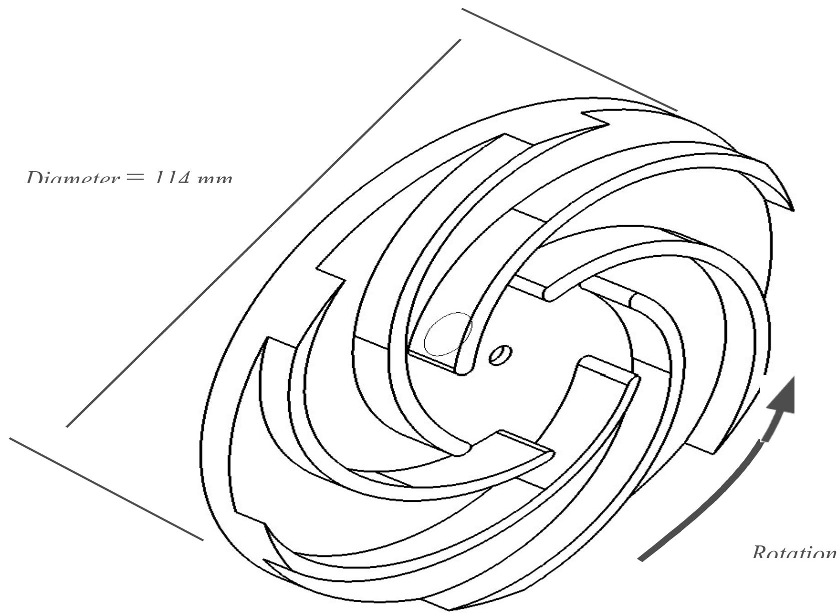


Figure 2. Pump impeller

Procedure:

For this experiment you will carry out four different tests for known steady discharge rates Q in to the hydraulic bench collection tank:

1. **Performance of a single centrifugal pump:**
    a. Create a blank results table similar to Table 3.
    b. Use Pump 1 only. Switch off both Motor Drive isolators.
    c. Close Pump 2 inlet *valve* and set the two-way *valve* to direct flow straight to the delivery pipe (see Figure 6). Fully open Pump 1 inlet and the delivery valve.
    d. Switch on Pump 1 Motor Drive isolator. Start the pump motor and run it to maximum speed.
    e. Use the bleed line to bleed all pressure gauges.
    f. Adjust the motor to the speed needed for the experiment - normally 3000 rev/min.
    g. Make sure the delivery *valve* is fully open. Re-adjust the motor speed if necessary. Record all pressure readings.
    h. In 0.1 bar steps, use the delivery *valve* to increase the outlet pressure. **Do not adjust the inlet valve.** At each step, adjust the motor speed back to its initial setting and take pressure readings.
    i. Plot graphs of efficiency, power input and total head against flow rate. Note: If you use the Digital Pressure Display for this test, H (in Pa) = $P_4 - P_2 \times 100000$.

2. **Parallel operating characteristics of two pumps:**
    a. Create a blank results table similar to Table 3.
    b. Use both pumps. Switch off both Motor Drive isolators.
    c. Open both inlet valves and set the two-way valve to direct flow straight to the delivery pipe (see Figure 7). Fully open the delivery valve.
    d. Switch on both Motor Drive isolators. Start the pump motors and run them to maximum speed.
    e. Use the bleed line to bleed all pressure gauges.
    f. Adjust the motors to the speed needed for the experiment - normally 3000 rev/min.
    g. Record all pressure readings.
    h. In 0.1 bar steps, use the delivery valve to increase the outlet pressure. Do not adjust the inlet valve. At each step, adjust the motor speed back to its initial setting and take pressure readings.
    i. Plot graphs of efficiency, input power and total head against flow rate. Note: If you use the Digital Pressure Display for this test, H (in Pa)= $P_4 - [(P_2+P_3)/2] \times 100000$.

3. **Series operating characteristics of two similar pumps:**
    a. Create a blank results table similar to Table 3.
    b. Use both pumps. Switch off both Motor Drive isolators.
    c. Open Pump 1 inlet valve. Close Pump 2 inlet valve. Set the two-way valve to direct flow straight to the inlet of pump 2 (see Figure 8). Fully open the delivery valve.

d. Switch on both Motor Drive isolators. Start the pump motors and run them to maximum speed. Use the bleed line to bleed all pressure gauges.
e. Adjust the motors to the speed needed for the experiment - normally 3000 rev/min.
f. Slowly adjust the delivery valve to give a suitable delivery (outlet) pressure of 0.3 bar. Re-adjust the motor speeds if necessary. Record all pressure readings.

   Note: Pump 2 inlet pressure is Pump 1 outlet pressure. This pressure is useful for comparison, but not used in the calculations.

g. In 0.2 to 0.3 bar steps, use the delivery valve to increase the outlet pressure. Do not adjust the inlet valves. At each step, adjust the motor speed back to its initial setting and take pressure readings.
h. Plot graphs of efficiency, power and total head against flow rate. Note: If you use the Digital Pressure Display for this test, H (in Pa) = P_4 - P_2 x 100000.

Calculations:

According to the modified Bernoulli equation

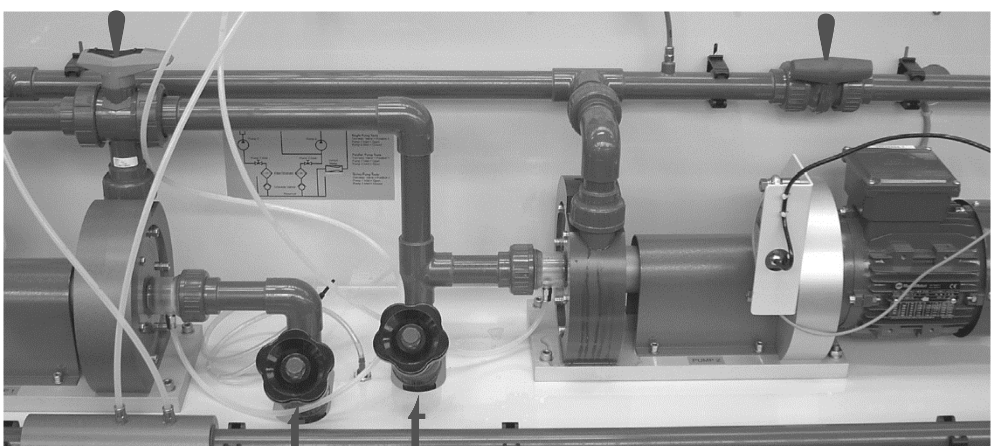
$$p_1 + \frac{1}{2}\rho v_1^2 + z_1\rho g = p_2 + \frac{1}{2}\rho v_2^2 + z_2\rho g = H_f\rho g \tag{1}$$

An equivalent equation can be expressed as:

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2 = H_f \tag{2}$$

where H_f = total hydrodynamic head loss and ρ = density,
and from mass conservation $\rho Q_1 = \rho Q_2$ or for incompressible flows $Q_1 = Q_2$, $v_1 A_1 = v_2 A_2$
if $A_1 = A_2$, then $v_1 = v_2 = Q/A$.

Two-way Valve *Outlet (Delivery) Valve*



Inlet (Suction) Valves

Figure 3. Inlet (Suction) Valves

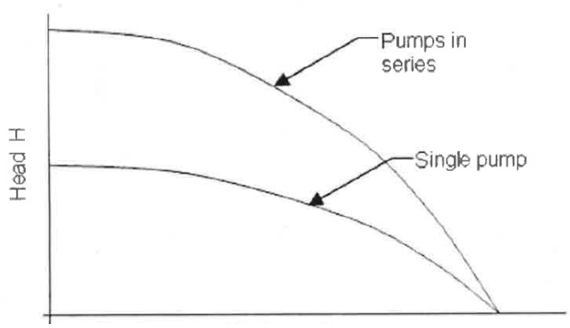


Figure 4. Theoretical Comparison of Head to Flow Rate: Single vs. Series

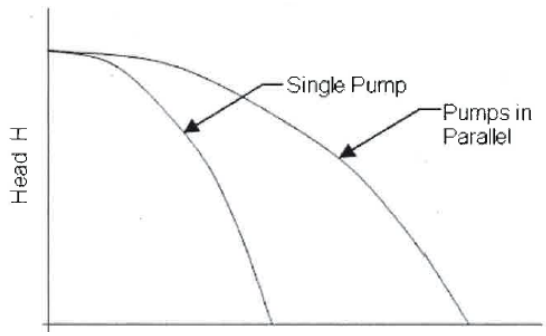


Figure 5. Theoretical Comparison of Head to Flow Rate: Parallel vs. Single

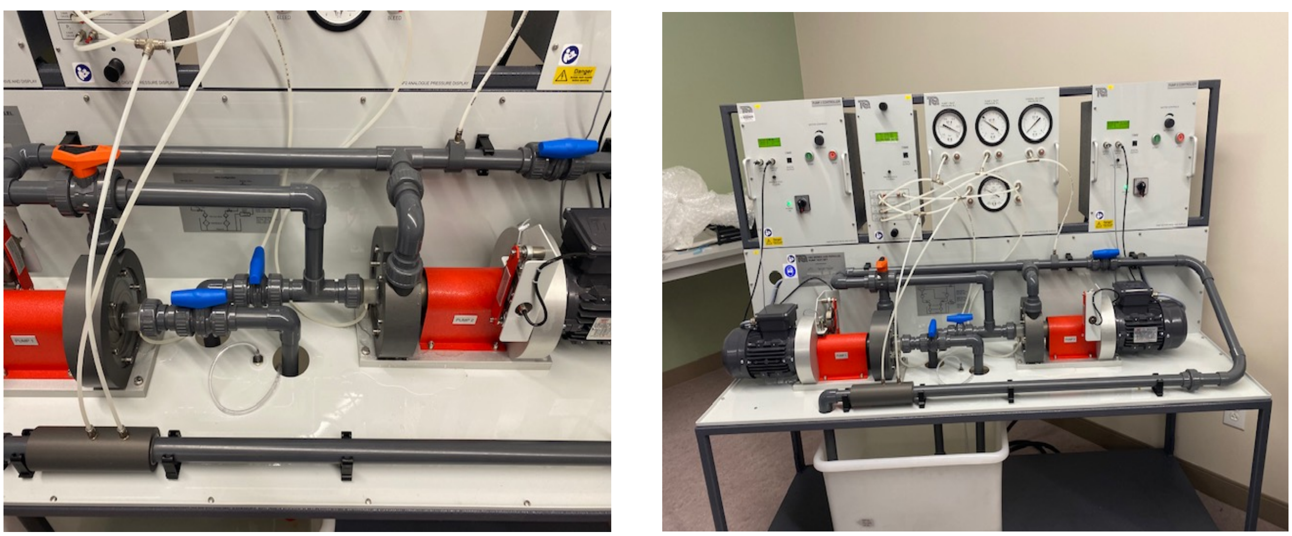


Figure 6. Single Pump Configuration

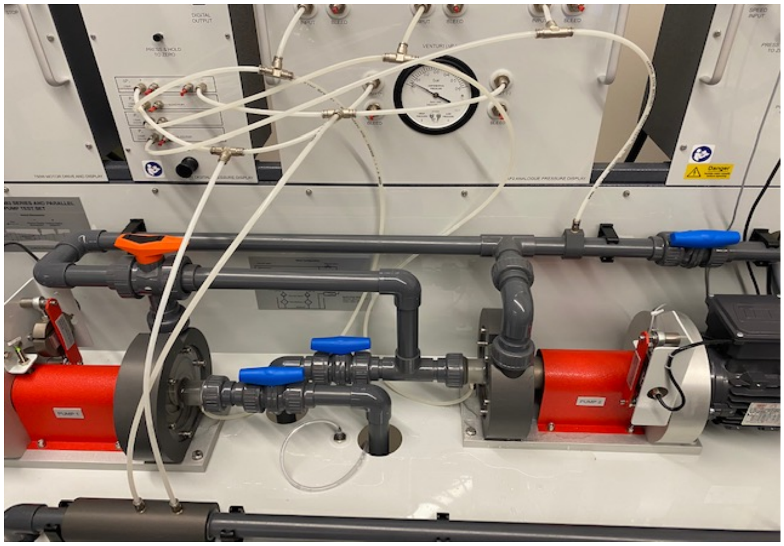


Figure 7. Parallel Pump Configuration

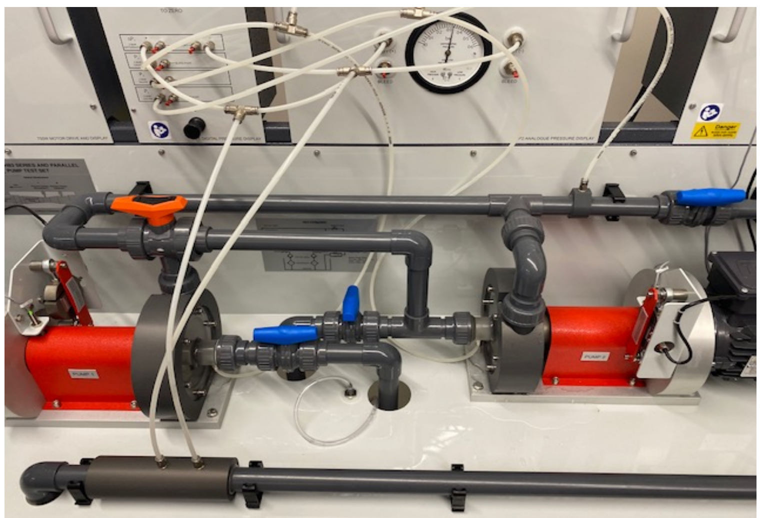


Figure 8. Series Pump Configuration

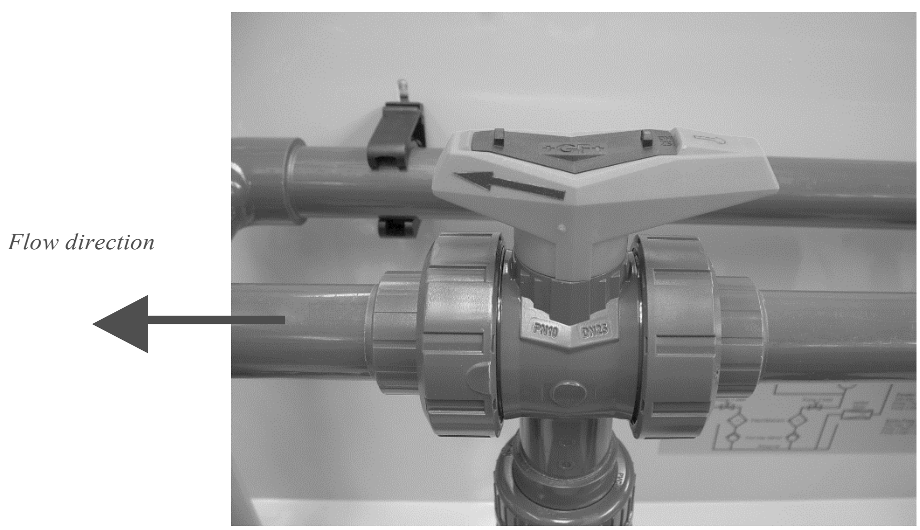
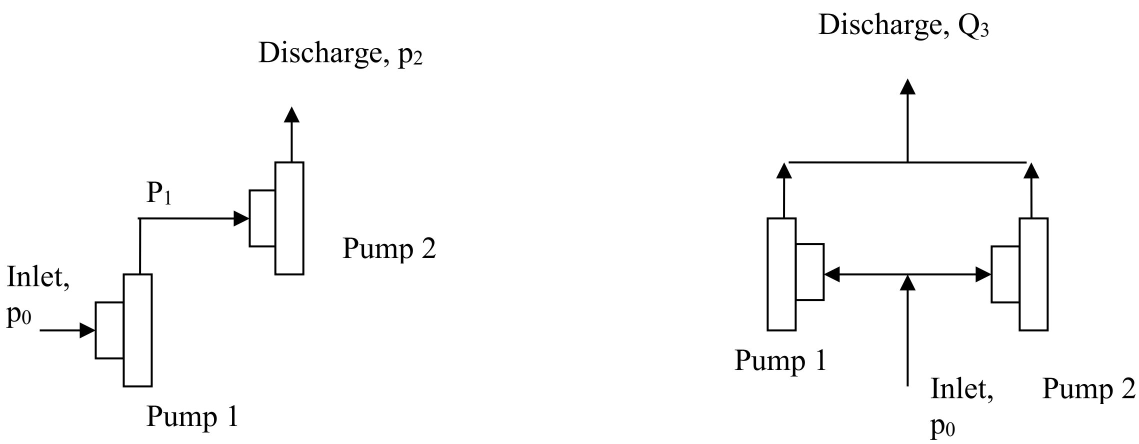


Figure 9. Two-Way Valve

General Notes: Show a neat schematic of the experimental setup. Estimate ρ, μ, etc. for the laboratory conditions.



PUMPS IN SERIES
$p_2 - p_0 = 2\,(p_1 - p_0)$ (3)

PUMPS IN PARALLEL
$Q_3 = Q_1 + Q_2 = 2\,Q_1 = 2\,Q_2$ (4)

Figure 10. Experimental Set up

Suggested Presentations:

- Prepare *Head vs. Discharge (Flow Rate)* plots for
  - ◊ Single-Stage pump
  - ◊ Two-Stage pumps in series
  - ◊ Two-Stage pumps in parallel.
- Using the energy equation estimate the hydrodynamic pressure loss in the system.
- Determine the maximum Net Positive Suction Head $(NPSH)_{max}$ for the different pump configurations.
- Verify if you are able to reproduce the theoretical comparisons shown in Figure 4 & 5. As well as the Equation relationships shown in Equations (3) and (4).

Table 1. Technical Details

Item	Details
Dimensions	Length 1670 mm, Depth 650 mm, Height 1590 mm
Weight (with both Motor Drives)	139.5 kg
Operating Environment	Altitude up to 2000 m Temperature range 5°C to 40°C Maximum relative humidity 80% for temperatures up to 31°C, decreasing linearly to 50% relative humidity at 40°C Overvoltage category 2 (as specified in EN61010-1). Pollution degree 2 (as specified in EN61010-1).
Pumps	Centrifugal Total Head 120 kN/m^2 Maximum Flow Approximately 2.2 L/s
Pump Motors	3 Phase Induction Maximum Speed 3000 rev/min

Table 2. Notation

Pump Inlet Static Pressure	p_I	N/m^2
Pump Delivery Static Pressure	p_O	N/m^2
Volumetric Flow Rate	Q	m^3/s
Pump Speed	N	rev/min or rad/sec
Power Input to Pump	W_1	Watts
Hydraulic Power of Pump	W_2	Watts
Losses (W_1-W_2)	L	Watt
Efficiency of Pump	η	%
Impeller Diameter	D	m
Pipework Internal Diameter	d	m
Pump Total Head	H	Pa or N/m^2
Acceleration due to gravity	g	m/s^2
Torque	T	Nm
Viscosity	μ	Pa.s
Water Density	ρ	kg/m^3

Pump Performance: $p_O Q - p_I Q = W_1 - L$
Head: $H = p_O - p_I$
Hydraulic Power: $W_2 = (p_O - p_I)Q$
Efficiency: $\eta = \frac{W_2}{W_1}$
Power Input: $W_1 = \frac{2\pi NT}{60}$
Flow Rate: $Q_{actual} = C_d A_1 \sqrt{\frac{2\Delta p}{\rho\left(\frac{A_1{}^2}{A_2{}^2} - 1\right)}}$

Where:
A_1 = Venturi Inlet Area (m^2) [d_1 = 27.2 mm]
A_2 = Venturi Throat Area (m^2) [d_2 = 18.5 mm]
C_d = Coefficient of discharge of venturi meter = 0.986
ρ = Water density (kg/m^3) - For clean water @ room temperature, use 1000 kg/m^3 for calculations)
Δp = Pressure drop across the venturi (Pascals or N/m^2) => $\Delta p/\gamma = h$, Pressure head drop across venturi (m)

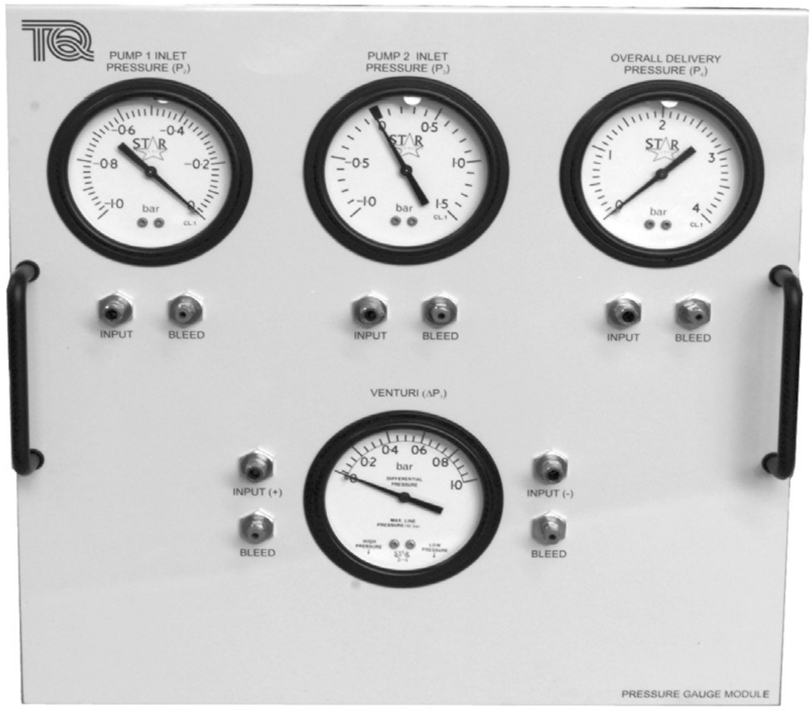


Figure 11. Digital Pressure Display

P_2 = Inlet of pump 1
P_3 = Inlet of pump 2
P_4 = Combined pump outlet pressure (delivery)

Table 3. Data Recorder

H83 Two-stage Centrifugal Pump Test Set				**Test Type:** Single/Parallel/Series/Suction							
Pump 1 Inlet (Suction) Pressure P_2 **(bar)**	**Average pump inlet pressure (Parallel Tests only)**	**Pump2 Inlet (Suction) Pressure** P_3 **(bar)**	**Outlet (Delivery) Pressure** P_4 **(bar)**	**Total Head** H **(kPa)**	**Pump 1 Speed** N **(rev/min)**	**Pump2 Speed** N **(rev/min)**	**Venturi pressure difference** (Δp)	**Flow (L/s)**	**Total Power Input** W_1 **(Watts)**	**Total Hydraulic Power (Watts)**	**Efficiency** (%)
Date:				Atmospheric Pressure:				Ambient Temperature:			

Experiment 4: Basic Hydraulic Circuits & Experiments

BASIC HYDRAULIC CIRCUIT DIAGRAMS

Objective:
To familiarize students with drawing hydraulic circuit diagrams and symbols. To perform various experiments on the Hydraulic Trainer to observe and measure pressure, flow rate, motor speed and direction, and cylinder motion.

Theory:
Graphical symbols emphasize the function and method of operation for fluid power components. Properly drawn graphic symbols convey information that can be easily understood and remembered. Graphic symbols do not serve to indicate size, material or construction of the component. Several similar components, in fact, may use the same symbol but look quite different in actual construction. The organization responsible for the standardization of these graphic symbols is the American National Standard Institute (ANSI). The appendix contains a list of the most common ANSI symbols that you will encounter in Fluid Mechanics Laboratory.

One of the most common items used in fluid power is a valve. Valves control the pressure, rate of flow and the direction of fluid flow in accordance with basic principles of flow. Several valves classified by their function are listed in the following table.

Pressure control	Flow control	Directional control
Pressure relief	Fixed	Two way
Hydraulic fuse	Variable	Check
Pressure reducing	Compensated	Shuttle
Sequencing	Deceleration	Three way
Unloading	Electro hydraulic	Four way
Counter balance pressure switches	Flow divider	Limit switch

Pressure control valves limit and reduce pressure, sequence hydraulic operations by stepping system pressure and counterbalance such external loads as vertical presses to prevent falling by maintaining back-pressure on the underside of the press cylinder. They are also used to unload slack cycle circuits at low pressure to reduce power consumption and provide switch signals at specified pressure to interact hydraulic systems with adjacent electrical controls.

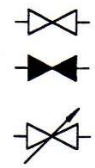
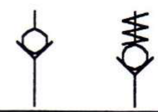
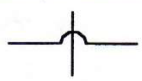
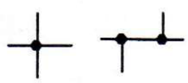
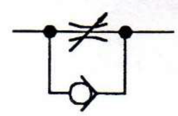
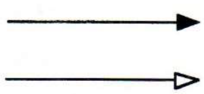
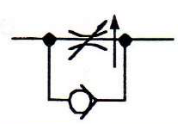
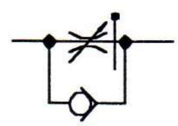
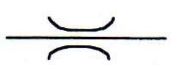
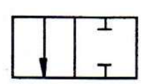
Flow control valves vary the fluid flow using restriction in fluid passages, which may be fixed, variable or flow/pressure compensated.

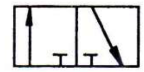
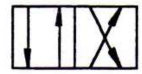
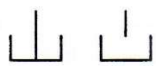
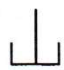
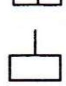
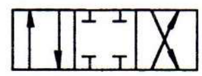
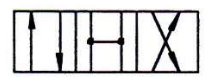
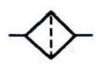
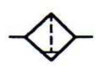
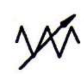
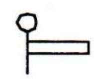
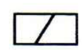
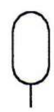
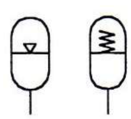
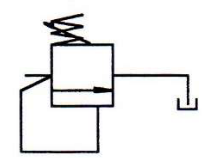
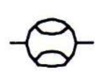
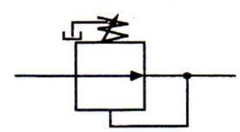
Directional control valves are used to check, divert, shuttle, proportion and manage the flow. Compensation valves are commonly included in this category.

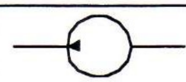
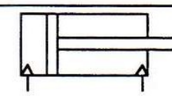
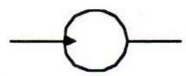
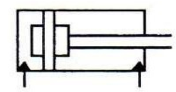
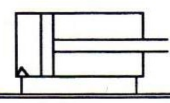
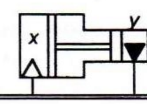
Appendix:

Graphic symbols used for fluid power diagrams:

Graphic symbols emphasize the function and method of operation of fluid power components. The following is a list of the standard graphic symbols commonly used in this manual.

A. LINES, RESERVOIRS, STORAGE DEVICES		B. VALVES AND VALVE COMPONENTS	
Main line		Shut-off valve, manual, *non-adjustable* Normally open normally closed *adjustable*, normally open (gate valve)	
Drain line		check valve free; spring-loaded	
Line crossing		restrictor valve, adjustable	
Lines joining		one-way restrictor valve, adjustable	
Hydraulic flow direction Pneumatic flow direction		pressure compensated restrictor valve, adjustable	
Flexible line		temperature compensated restrictor valve, adjustable	
Line with fixed restriction		2- way, 2- position flow control valve ("way" refers to flow paths; "position" refers to possible states)	

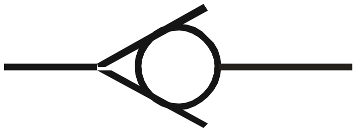
		3-way, 2-position flow control valve 4-way, 2-position flow control valve	 
reservoirs: *vented reservoir* line below fluid level; line above fluid level drain line into reservoir *pressurized reservoir*	  	4-way, 3-position flow control valve, closed center (all ports are unconnected in center position) 4-way, 3-position flow control valve, open center	 
general hydraulic filter general pneumatic filter with a manual drain (separator cum filter)	 	Valve controls: variable spring ; lever electric solenoid control	  
accumulator, simple gas loaded ; spring loaded	 	pressure relief valve (variable relief pressure)	
flow meter		pressure reducing valve	

C. FLUID POWER DEVICES			
hydraulic pump		double-acting cylinder (pneumatic)	
Hydraulic motor (rotary actuator)		double-acting cylinder with cushions (hydraulic)	
single-acting cylinder		pneumatic-hydraulic pressure intensifier	

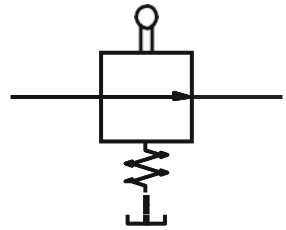
Apparatus

The Hampden **MODEL H-FP-223-14/P** provides a portable means of demonstrating hydraulic and pneumatic principles and the circuitry associated with each.

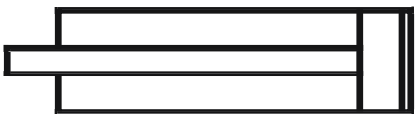
The hydraulic portion of the trainer consists of: A motor driven gear pump, the necessary filter devices, various commonly used hydraulic devices, instrumentation for flow and pressure, and hoses with quick-disconnect fittings for ease of connection. The hydraulic supply is pro- vided by a 10-gallon reservoir and is supplied to a manifold for convenient connection to the pressure, drain and tank. The pump is started with a simple pushbutton station containing a start and stop pushbutton station containing a start and stop pushbutton, a pressure relief is provided to protect against excessively high pressures. All of the major components, located on the trainer panel, include the appropriate schematic symbols for easy identification of the parts. The parts are all industry standard and include a wide variety to provide a well-rounded exposure to the equipment and experience with how they all operate.
A key to the hydraulic symbols are found in Figures 1a, and 1b.



CHECK VALVE

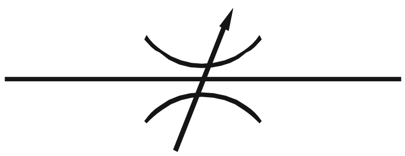


DECELERATION VALVE

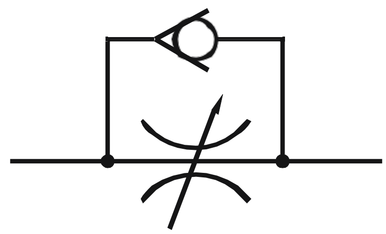


DOUBLE ACTING
CYLINDER #2

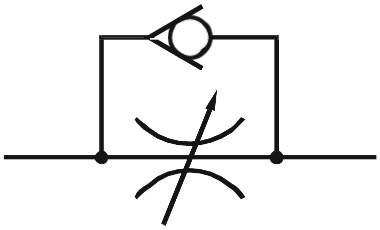
DOUBLE ACTING
CYLINDER



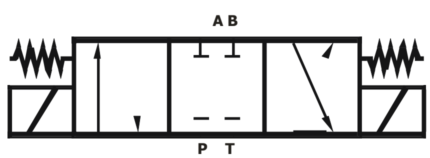
NEEDLE VALVE



FLOW CONTROL VALVE

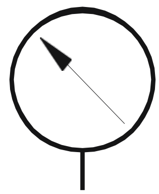


FLOW CONTROL VALVE

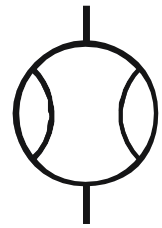


4-WAY CLOSED CENTER
DIRECTIONAL CONTROL VALVE
SOLENOID OPERATED

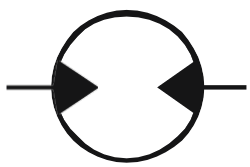
Figure 1a



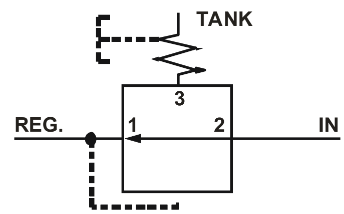
PRESSURE GAUGE



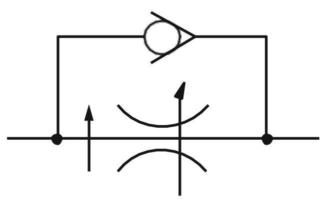
FLOWMETER



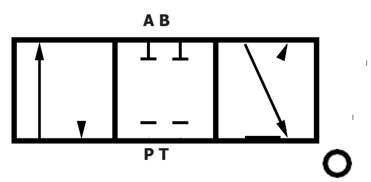
HYDRAULIC MOTOR



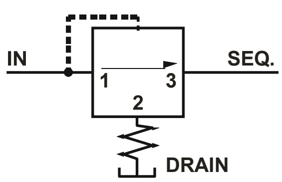
PRESSURE REDUCING VALVE



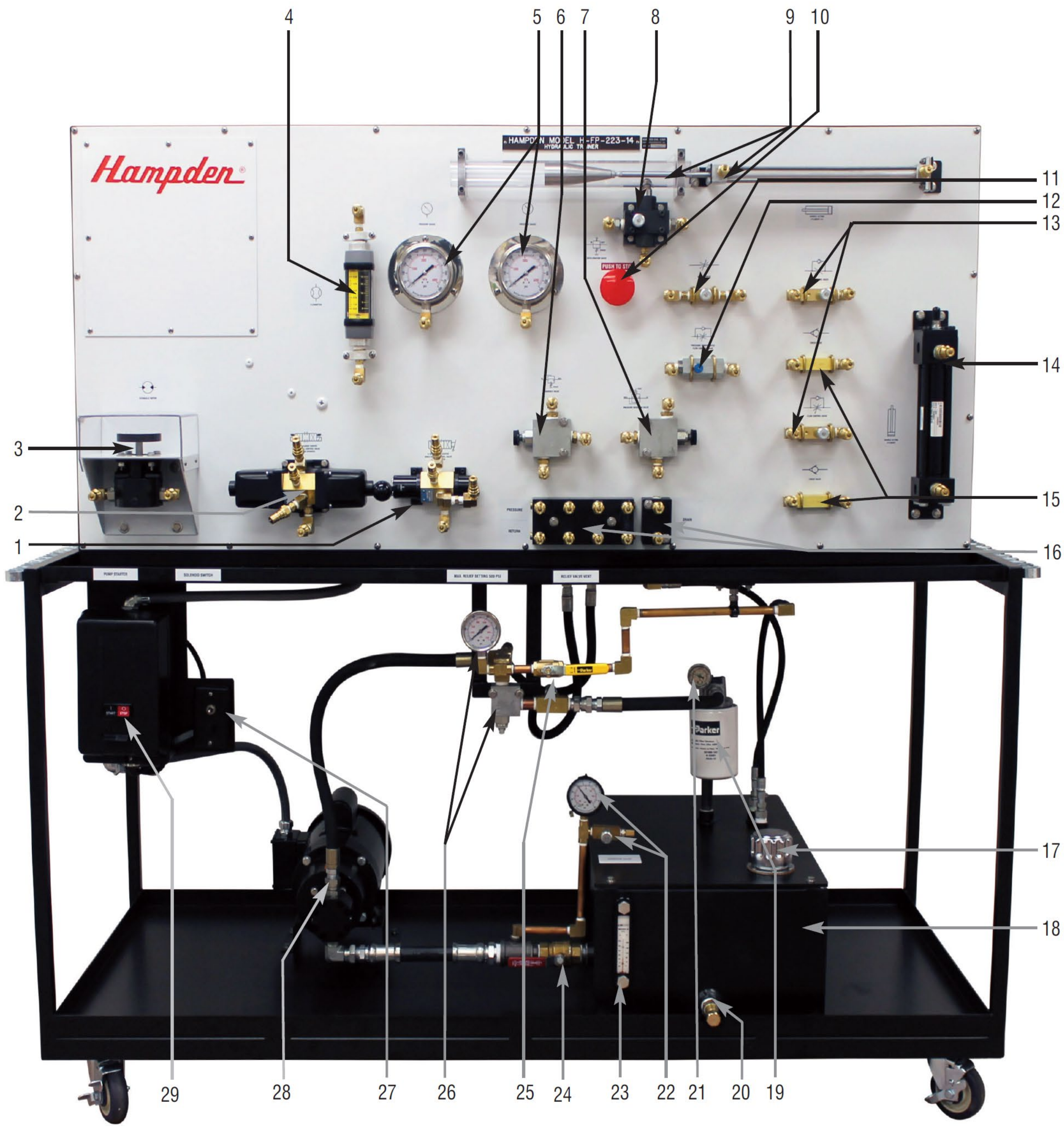
PRESSURE COMPENSATED
FLOW CONTROL VALVE



4-WAY OPEN CENTER
DIRECTIONAL CONTROL VALVE
LEVER OPERATED

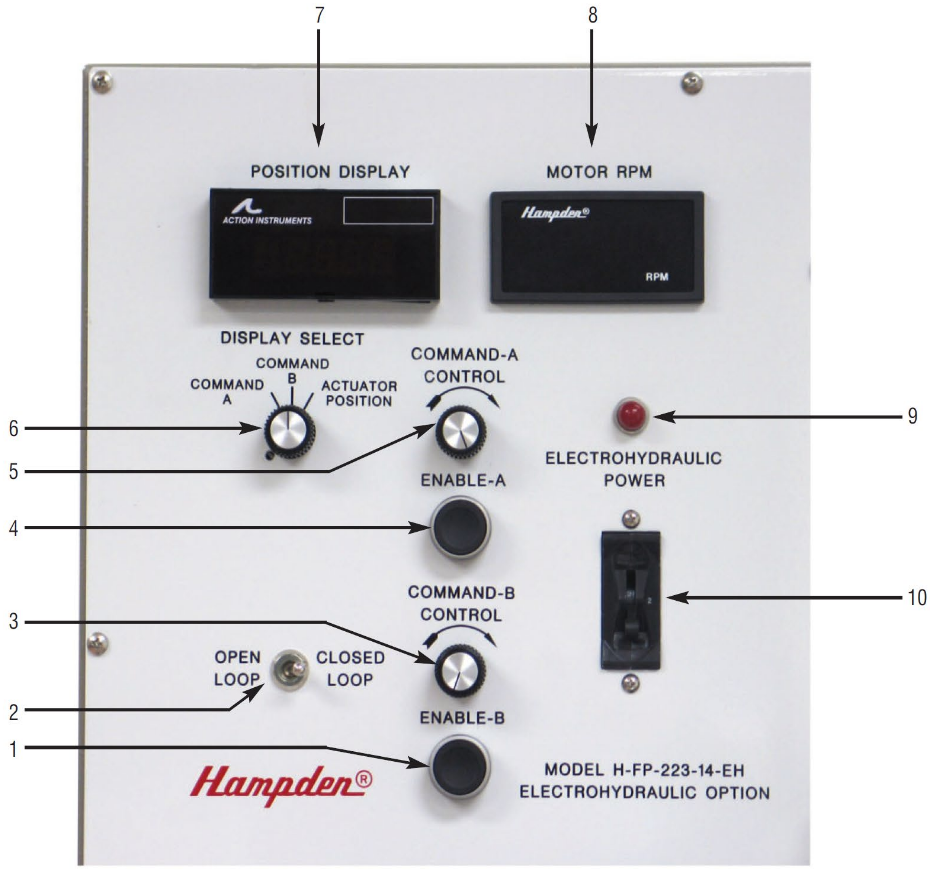


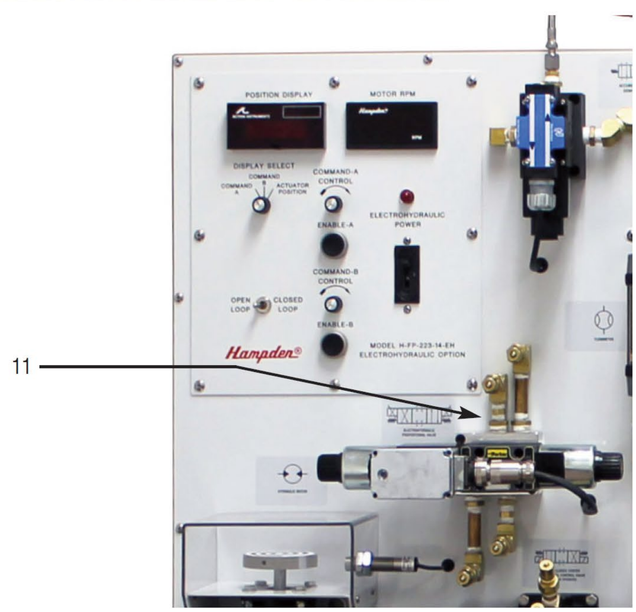
SEQUENCE VALVE



1. Control valve—lever operated, 4-way, open center directional
2. Control valve—solenoid operated, 4-way, closed center directional
3. Hydraulic motor
4. Flowmeter
5. Pressure gauges
6. Sequence valve
7. Pressure reducing valve
8. Deceleration valve
9. Hydraulic cylinder, 12" stroke
10. Emergency **STOP** button
11. Needle valve
12. Pressure compensated flow control
13. Flow control valves
14. Hydraulic cylinder
15. Check valves
16. **PRESSURE**/**RETURN**/**DRAIN** manifold
17. Reservoir cap
18. 10 gallon reservoir
19. Hydraulic filter
20. Drain
21. Filter pressure gauge
22. Aeration valve and gauge
23. Level indicator/thermometer
24. Pump inlet valve
25. Pressure relief valve
26. Pressure regulator and gauge
27. Solenoid switch
28. Pump/motor
29. Motor **START**/**STOP** switch

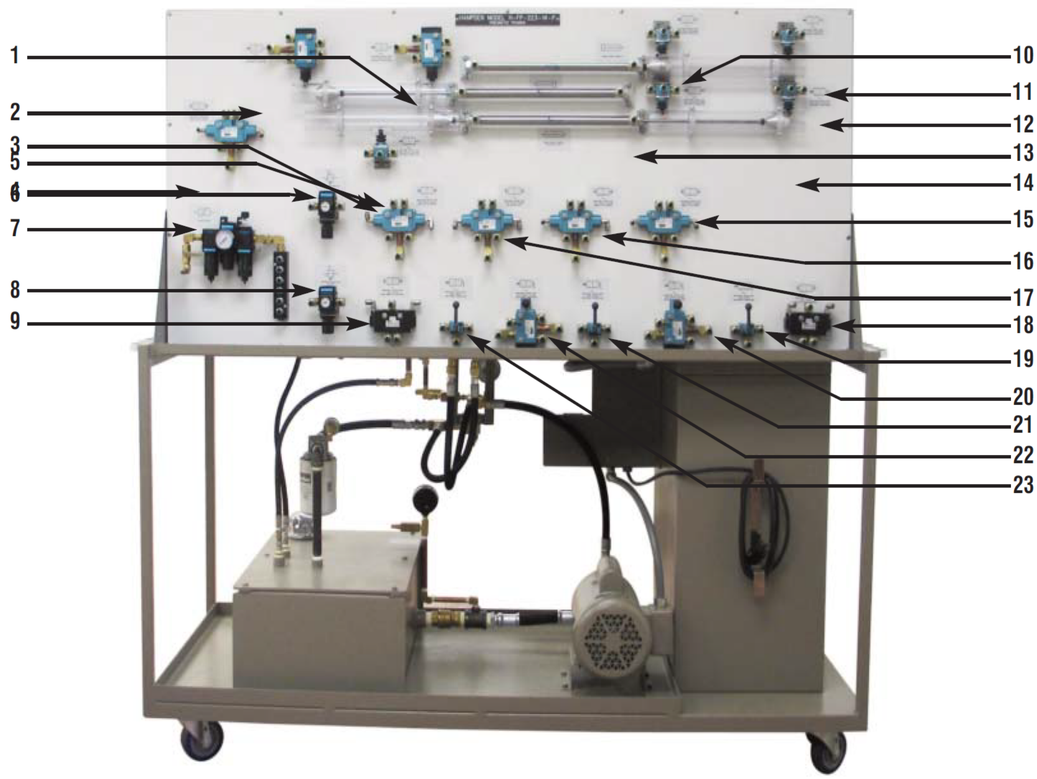
Figure 1
Hampden H-FP-223-14 Hydraulic Trainer





1. Position B command pushbutton
2. Open/closed loop control switch
3. Command B position setting potentiometer
4. Position A command pushbutton
5. Command A position setting potentiometer
6. Position display meter selector switch
7. Position display meter
8. Hydraulic motor RPM display meter
9. Electrohydraulic power **ON** light
10. Electrohydraulic power **ON**/**OFF** circuit breaker
11. Electrohydraulic proportional valve

Figure 2
Hampden H-FP-223-14-EH Hydraulic Trainer—Control Panel - ***Option***



1. Directional 4-way Control Valve (CAM)
2. Directional 4-way Control Valve (CAM)
3. 3-way Control Valve CAM Operated, Spring Return, 2 Position, Non-Passing
4. Directional Control Valve, Remote, Air Operated, 4-way, 5-port, Double
5. Directional Control Valve, Remote, Air Operated, 4-way, 5-port, Double
6. Regulator, 2-125 PSI
7. FRL with 5 Micron Filter
8. Regulator, 2-125 PSI
9. Control Valve, 3-way, 2-position, Remote
10. 3-way Control Valve CAM Operated, Spring Return, 2 Position, Non-Passing
11. 3-way Control Valve CAM Operated, Spring Return, 2 Position, Non-Passing
12. Double Acting Cylinder, Single Rod
13. Double Acting Cylinder, Single Rod
14. Double Acting Cylinder, Double Rod
15. Directional Control Valve, Remote, Air Operated, 4-way, 5-port, Double
16. Directional Control Valve, Remote, Air Operated, 4-way, 5-port, Double
17. Directional Control Valve, Remote, Air Operated, 4-way, 5-port, Double
18. Control Valve, 3-way, 2-position, Remote
19. Control Valve, 3-way, 2-position, Lever Actuated
20. Control Valve, 4-way, 5-port, Hand
21. Control Valve, 3-way, 2-position, Lever Actuated
22. Control Valve, 4-way, 5-port, Hand
23. Control Valve, 3-way, 2-position, Lever Actuated

Figure 4
MODEL H-FP-223-14-P Pneumatic Trainer - *Option*

General Operating Instructions

Step 1. Fill the tank with hydraulic fluid so that it is at least half way up the site glass.

Step 2. Plug the unit into a receptacle

Step 3. Turn on the electro hydraulic control panel circuit breaker

Step 4. Select the experiment you want to do and connect the hydraulic lines as shown.

Step 5. Observe the feed line from the motor and make sure the valve is on bypass.

Step 6. Start the motor and slowly but steadily change the valve from bypass to the system manifold. Observe the pressure gauge. Do not allow the pressure to exceed 500 PSI (3447) KPA. Fluid temperature must not exceed 150° F (66°C).

Step 7. Upon completion return the valve to bypass to depressurize the system and stop the motor.

Step 8. Disconnect hydraulic lines and reconnect if you are going to do another experiment. Only connect and disconnect lines with the pump off and the system depressurized (feed valve in bypass). Note fluid will be present in the lines so be careful when removing connections.

RPM MEASUREMENT AND CONTROL

Theory

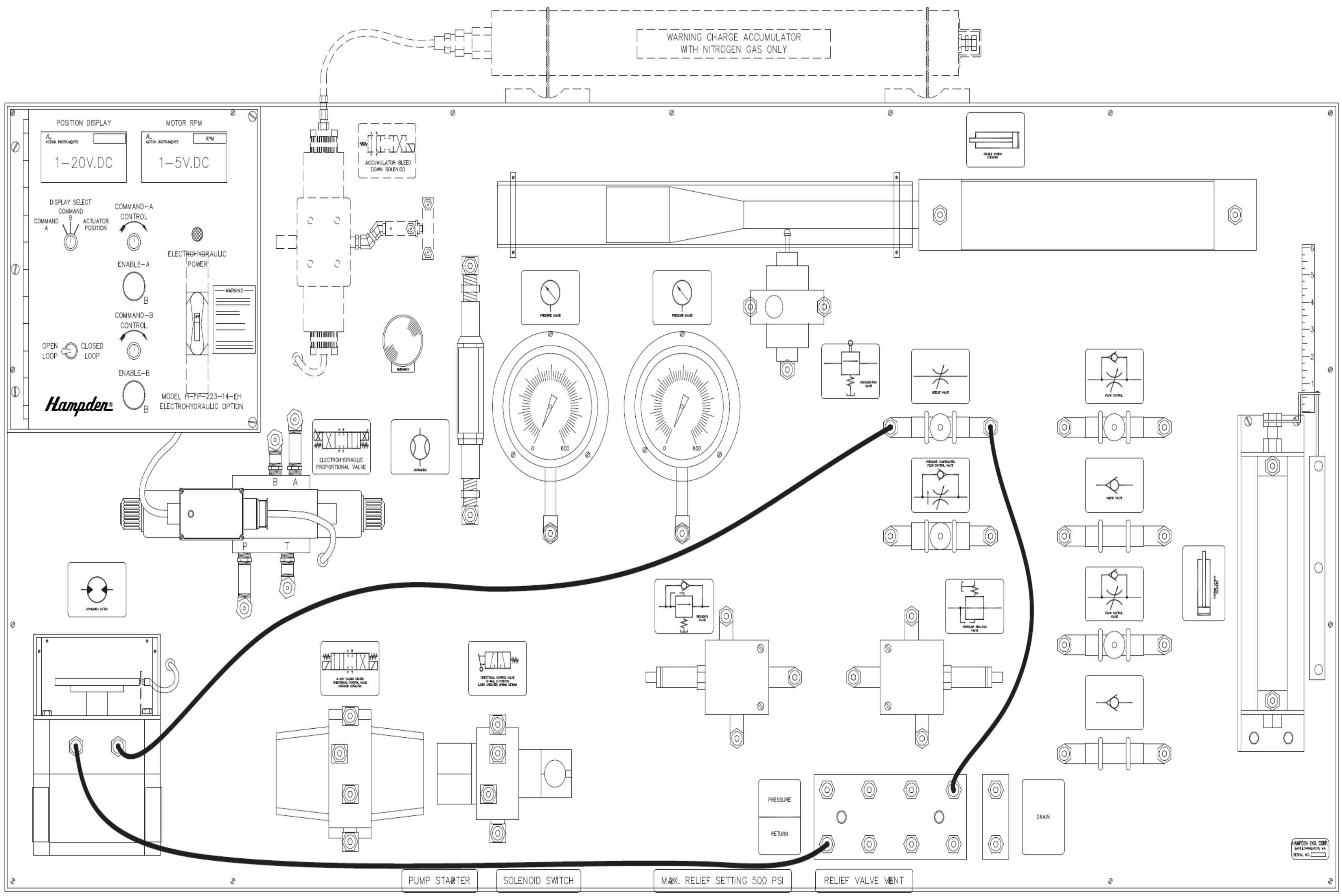
The rate that hydraulic fluid flows against an object determines how fast the object moves. In this case, a hydraulic motor rotates when hydraulic fluid forces it to turn. The rate at which it rotates is shown on the Motor RPM meter on the electrohydraulic control panel and will measure rotation rate in excess of 1800 RPM. A magnetic sensor pulses each time a gear tooth moves past it, sending the information to a tachometer board. The output of the tachometer board sends the information to the Motor RPM meter, which displays the turning rate of the motor. Flow can be controlled when the fluid passes through a control valve. Controlling the flow controls the speed of the motor. The wider the opening of the valve, the more fluid will flow through it and the faster the motor will rotate, as seen on the Motor RPM meter. As the valve moves toward the closed position, the motor slows down. The Motor RPM meter not only displays the speed the motor is turning, but also shows RPM changes too small to observe by looking at the motor itself.

Procedure

1. With the pump off, connect the hose lines as shown in the Experiment 1 connection diagram.
2. Ensure the pump inlet valve between the tank and pump is open.
3. With all hose lines connected, turn on the hydraulic pump by pushing the **START** button on the manual starter.
4. Slowly open the pressure relief valve. This valve must be opened slowly to prevent a pressure surge. Gauge pressure should read 500 psi (35 bars).
5. Slowly open the flow control valve on the panel, until the hydraulic motor begins to turn, and observe the Motor RPM meter.
6. Open the flow control valve wider to increase speed and observe the change on the Motor RPM meter.
7. Open and close down the flow control valve taking notice of the Motor RPM meter.
8. Close the flow control valve.
9. Close the pressure relief valve and turn off the pump with the **STOP** button on the manual starter.

Questions

1. What did you observe when you first opened the valve?
2. What caused the hydraulic motor to rotate?
3. What happened when you opened and closed down on the flow control valve?
4. How is the rate of the rotation of the hydraulic motor displayed?



Experiment 1 Connection Diagram—RPM Measurement and Control

OPEN LOOP MOTOR CONTROL

Theory

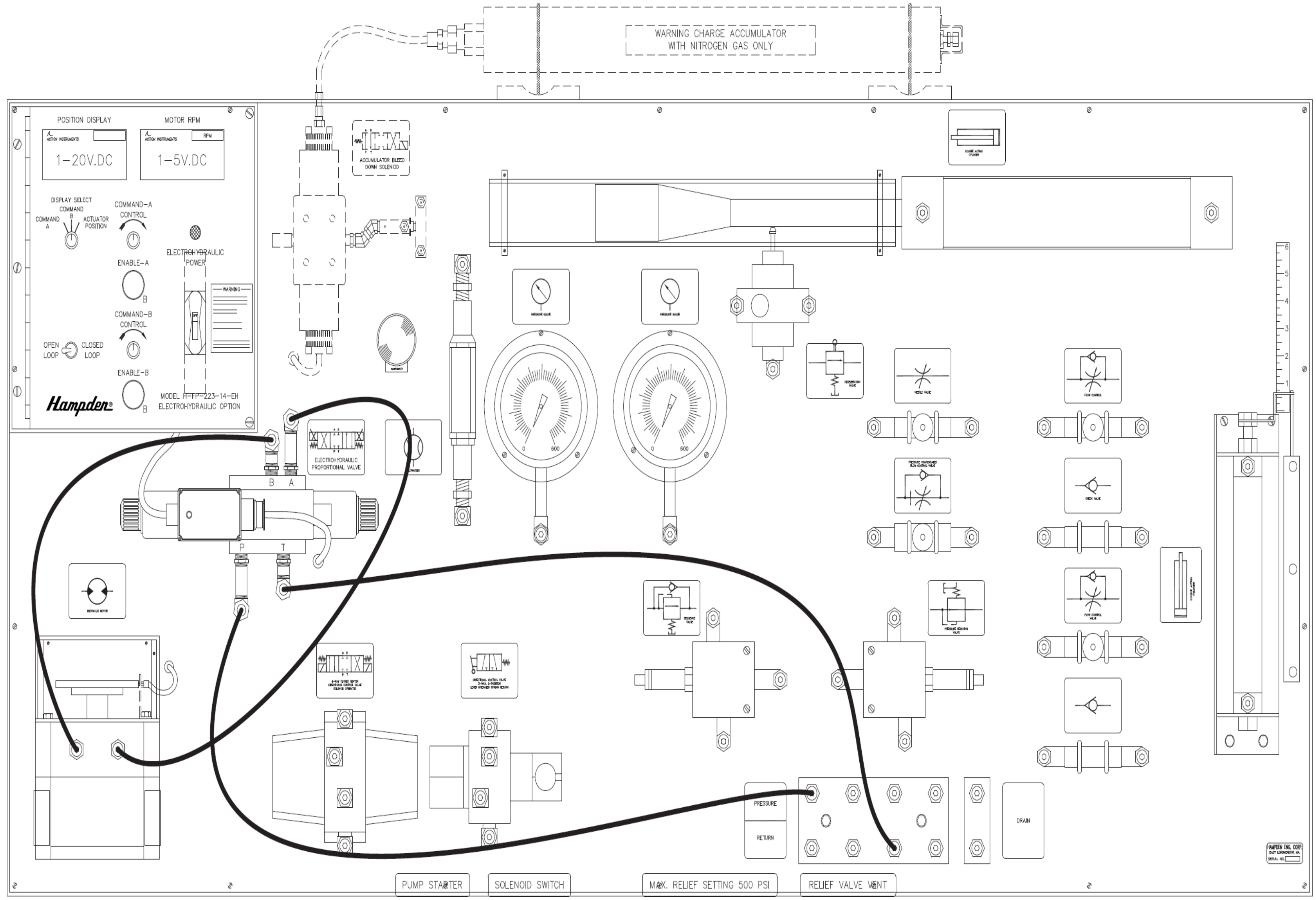
The proportional directional control valve is bi-directional. It has both an A solenoid and a B solenoid. When Solenoid A is energized, it sends the hydraulic fluid in one direction. When Solenoid B is energized, it sends the fluid in the opposite direction. The hydraulic motor is also bi-directional, so it will turn in either direction depending upon whether it is receiving fluid from the Solenoid A port or the Solenoid B port. Since the valve is controlled by an analog command, the motor speed is controlled by the amplitude of the signal going to the valve. The setting of the potentiometers on the electrohydraulic control panel determines the signal going to the proportional directional control valve when the corresponding button is pushed. With open loop control, the command signal is sent to a device. The receiving device responds by doing what the signal tells it to do, but does not return a signal back to it. Both the speed and direction that the motor turns are determined by the signal sent to the proportional directional control valve.

Procedure

1. With the pump off, connect the hose lines as shown in the Experiment 2 connection diagram.
2. Ensure the pump inlet valve between the tank and pump is open.
3. With all hose lines connected, turn on the hydraulic pump by pushing the **START** button on the manual starter.
4. Slowly open the pressure relief valve. This valve must be opened slowly to prevent a pressure surge. Gauge pressure should read 500 psi (35 bars).
5. Ensure the toggle switch is set for *open loop*.
6. Set the electrohydraulic control panel selector switch to **COMMAND A**.
7. Turn the Command A control potentiometer to the right and observe the Position Display.
8. Change the selector switch to **COMMAND B**.
9. Turn the Command B control potentiometer to the left and observe the display.
10. Push and hold the **ENABLE A** button and observe the direction the motor is turning.
11. Release **ENABLE A** and push the **ENABLE B** button and notice the direction the motor turns.
12. Release **ENABLE B** and turn the Command A potentiometer to the left and the Command B potentiometer to the right.
13. Push and hold the **ENABLE A** button again and observe the direction of the motor.
14. Release **ENABLE A** and push the **ENABLE B** button and observe the direction of the motor.
15. Close the pressure relief valve and turn off the pump with the **STOP** button on the manual starter.

Questions

1. Explain open loop control.
2. When we say something is *bi-directional*, what does that mean?
3. How does the setting of the potentiometer affect the hydraulic motor when the respective command signal is sent?
4. How does the motor react with pressing the **ENABLE A** and **B** pushbuttons after the potentiometers were changed to the opposite side. That is, the Command A potentiometer was moved from the right to the left and Command B was moved from the left to the right.



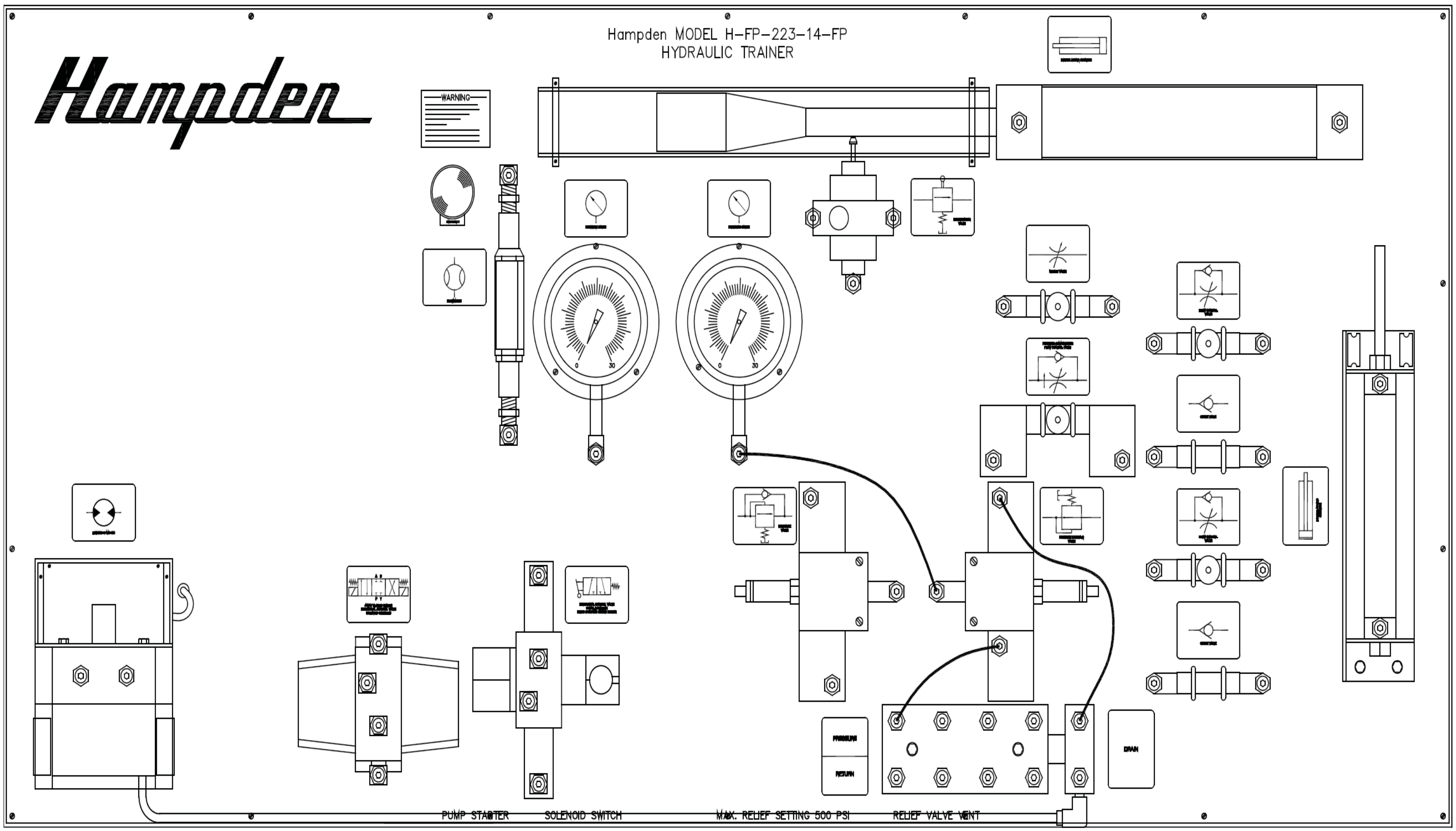
Experiment 2 Connection Diagram—Open Loop Motor Control

HYDRAULIC PRESSURE OBSERVATION

Procedure

Step 1. Follow general operating instructions.

Step 2. Observe pressure gauge on panel.

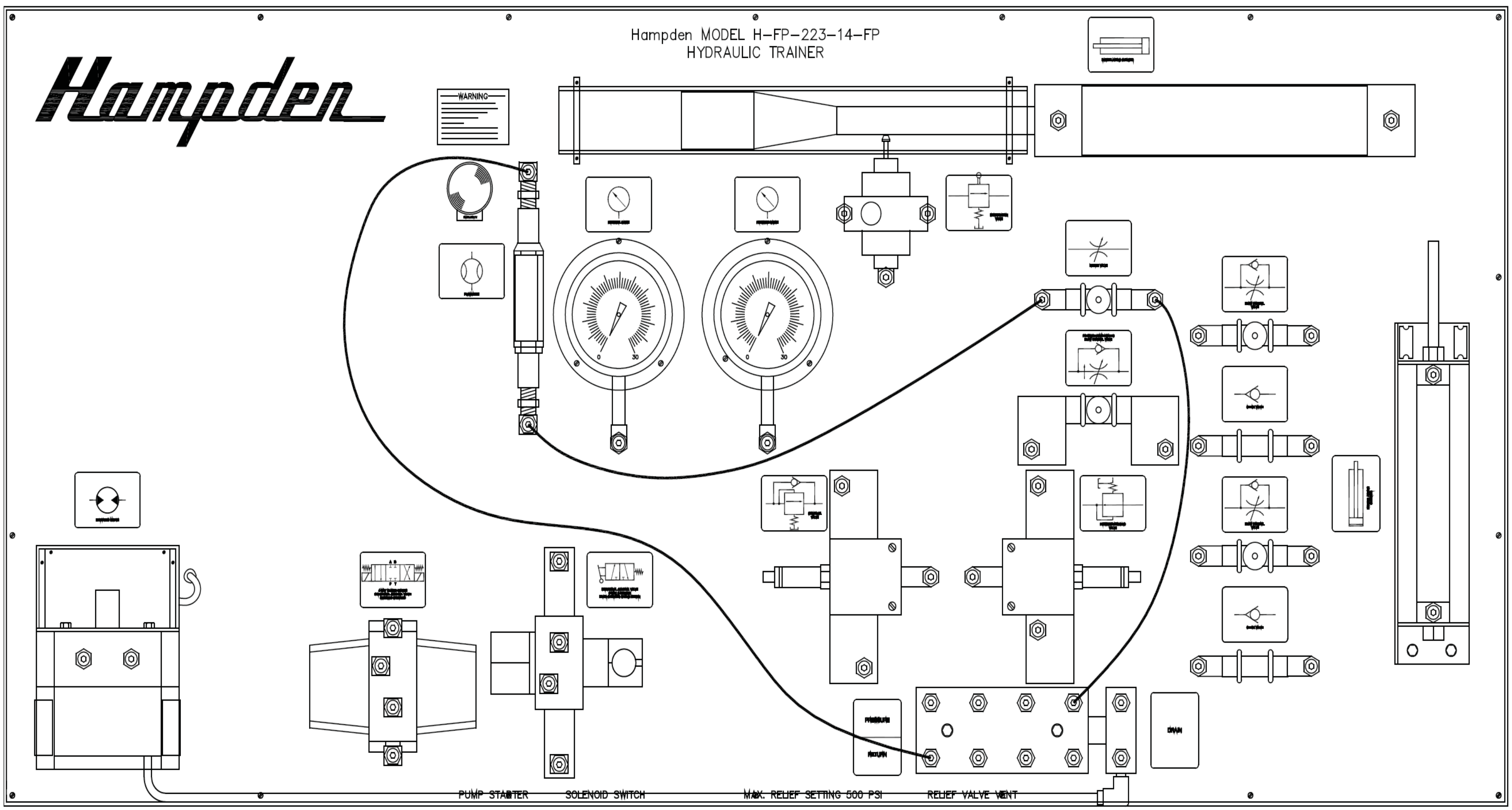


EXPERIMENT #1
HYDRAULIC PRESSURE OBSERVATION

Procedure

Step 1. Follow general operating instructions.

Step 2. Adjust needle valve and observe flow meter.



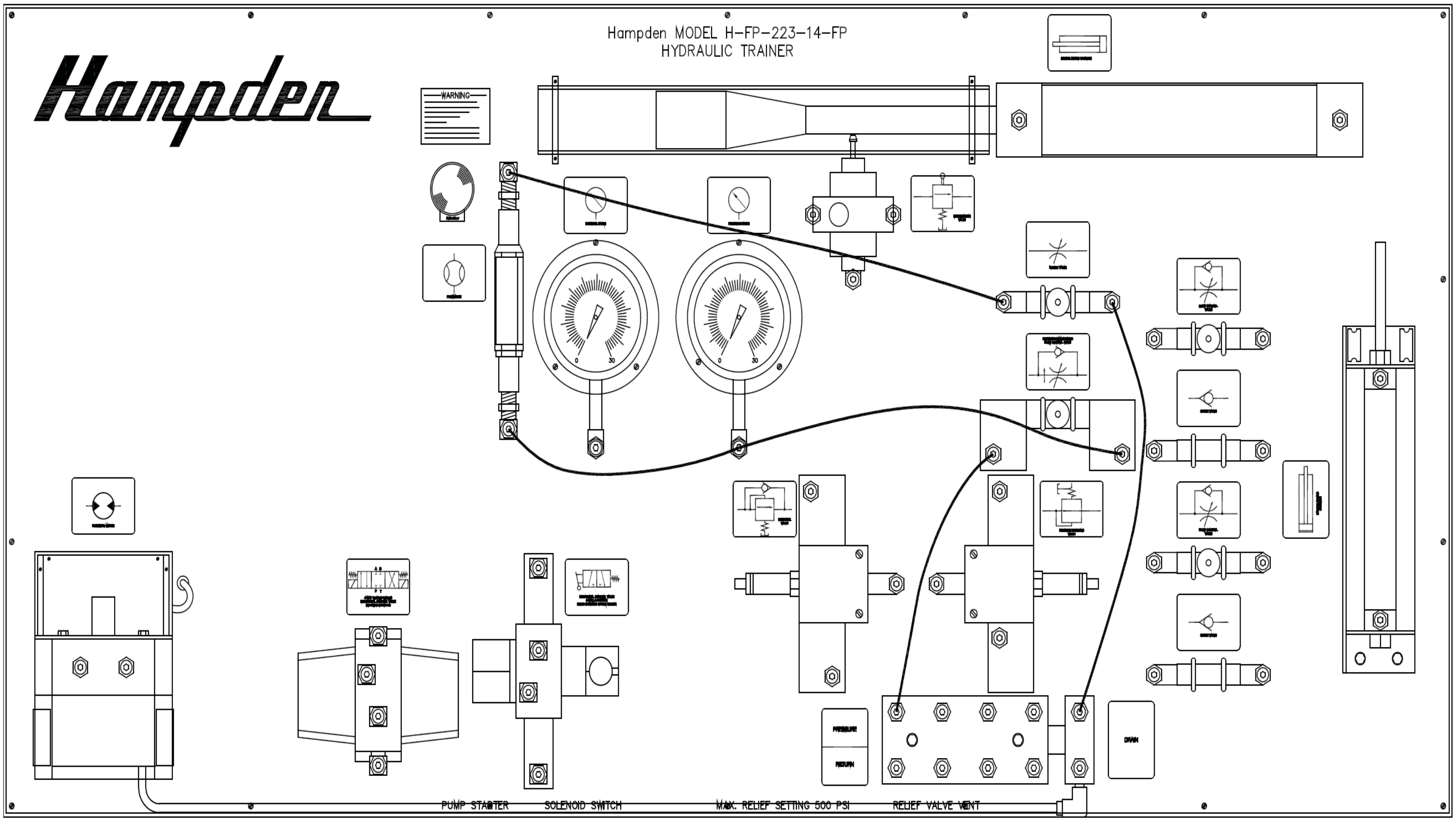
EXPERIMENT #2
FLOW CONTROL MEASUREMENT

PRESSURE COMPENSATION VALVE TEST

Procedure

Step 1. Follow general operating instructions.

Step 2. Observe flow meter.



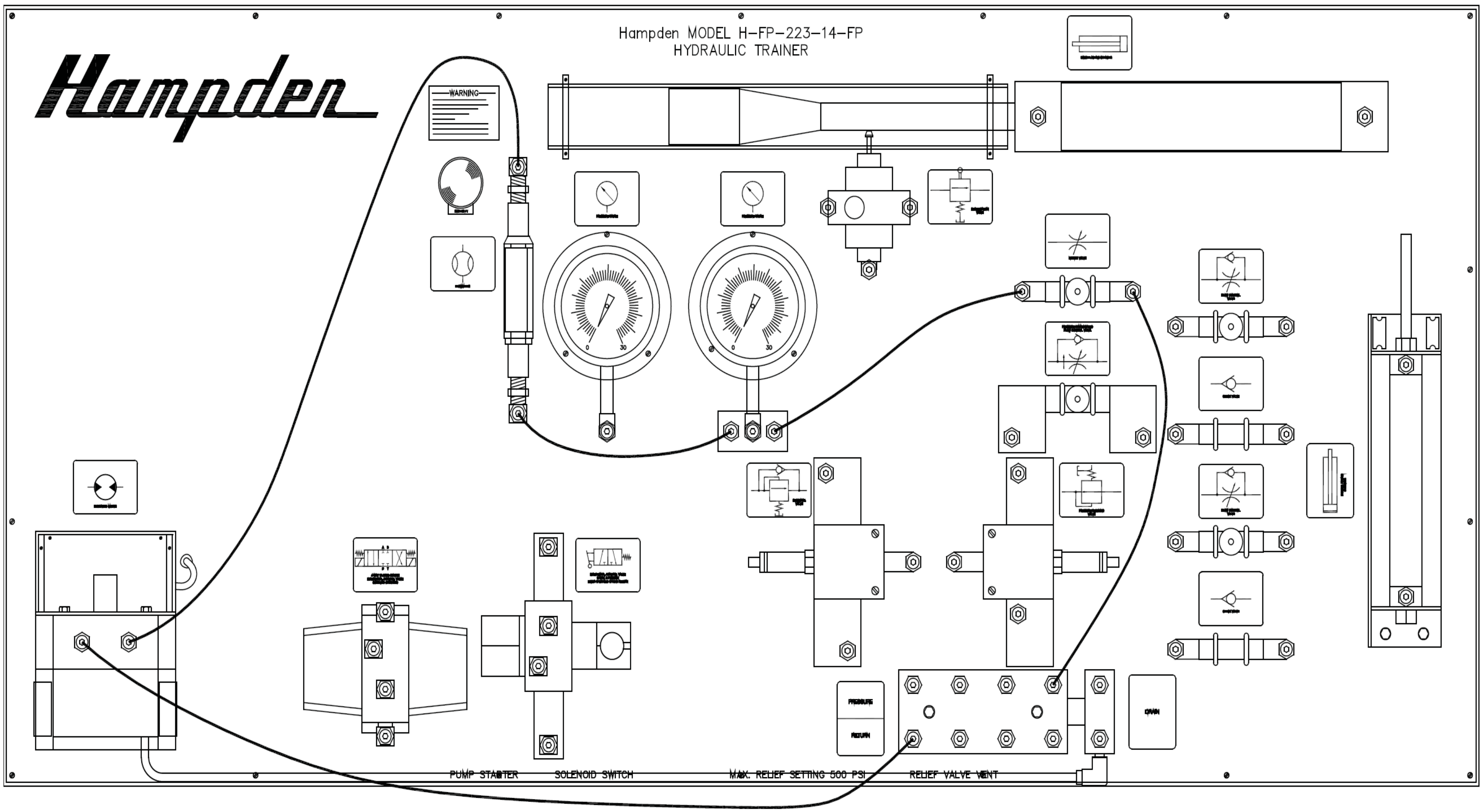
EXPERIMENT #3
PRESSURE COMPENSATING
VALVE TEST

MOTOR SPEED CONTROL WITH FLOW & PRESSURE MEASUREMENT

Procedure

Step 1. Follow general operating instructions.

Step 2. Observe flow meter, pressure gauge, and motor speed.



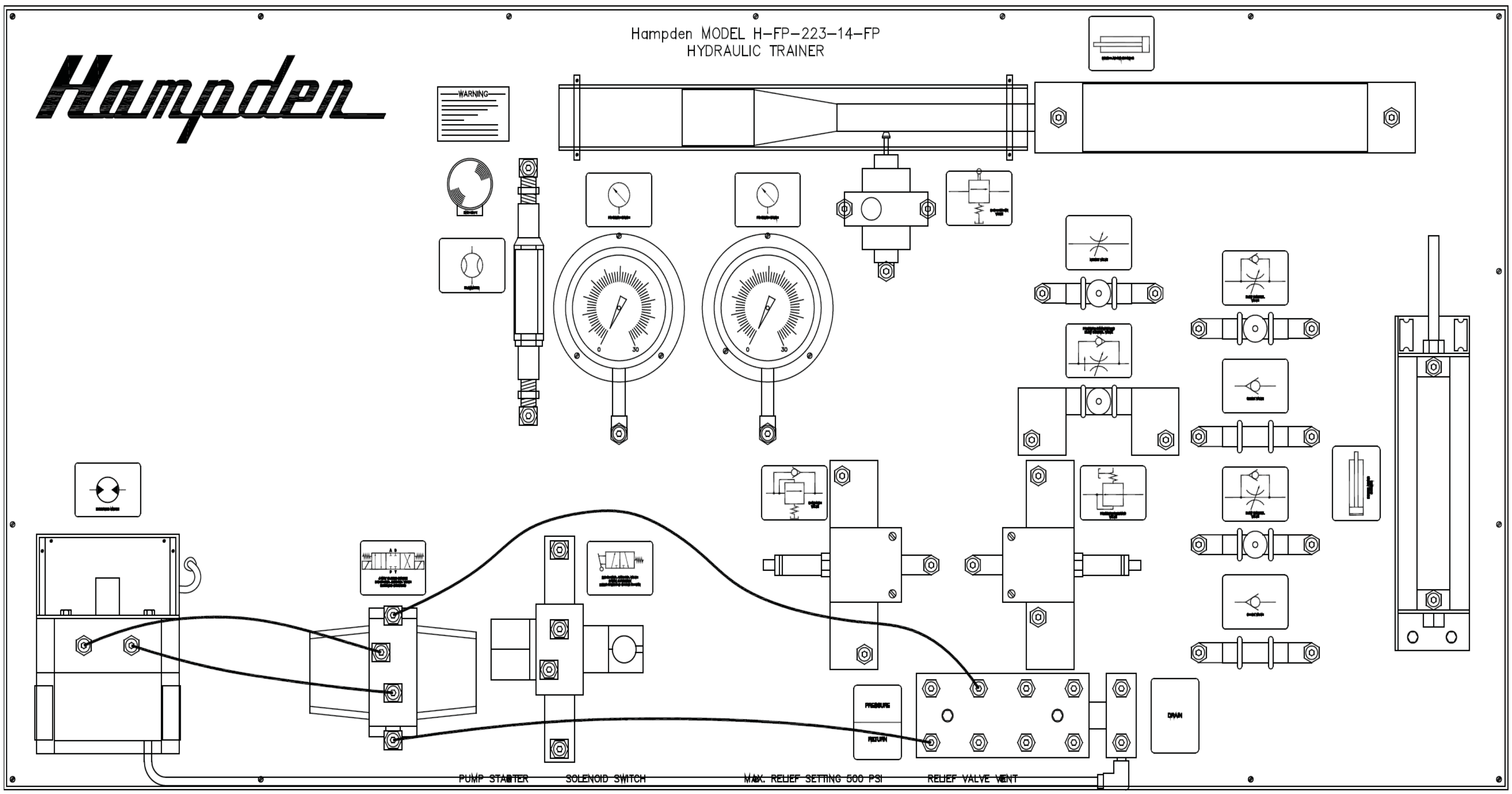
EXPERIMENT #4
MOTOR SPEED CONTROL
w/ PRESSURE & FLOW MEASUREMENT

OPERATION OF MOTOR WITH SOLENOID CONTROL VALVE

Procedure

Step 1. Follow general operating instructions.

Step 2. Observe turning of hydraulic motor.



EXPERIMENT #5
OPERATION OF MOTOR
w/ SOLENOID CONTROL VALVE

BI-DIRECTIONAL MOTOR CONTROL

Procedure

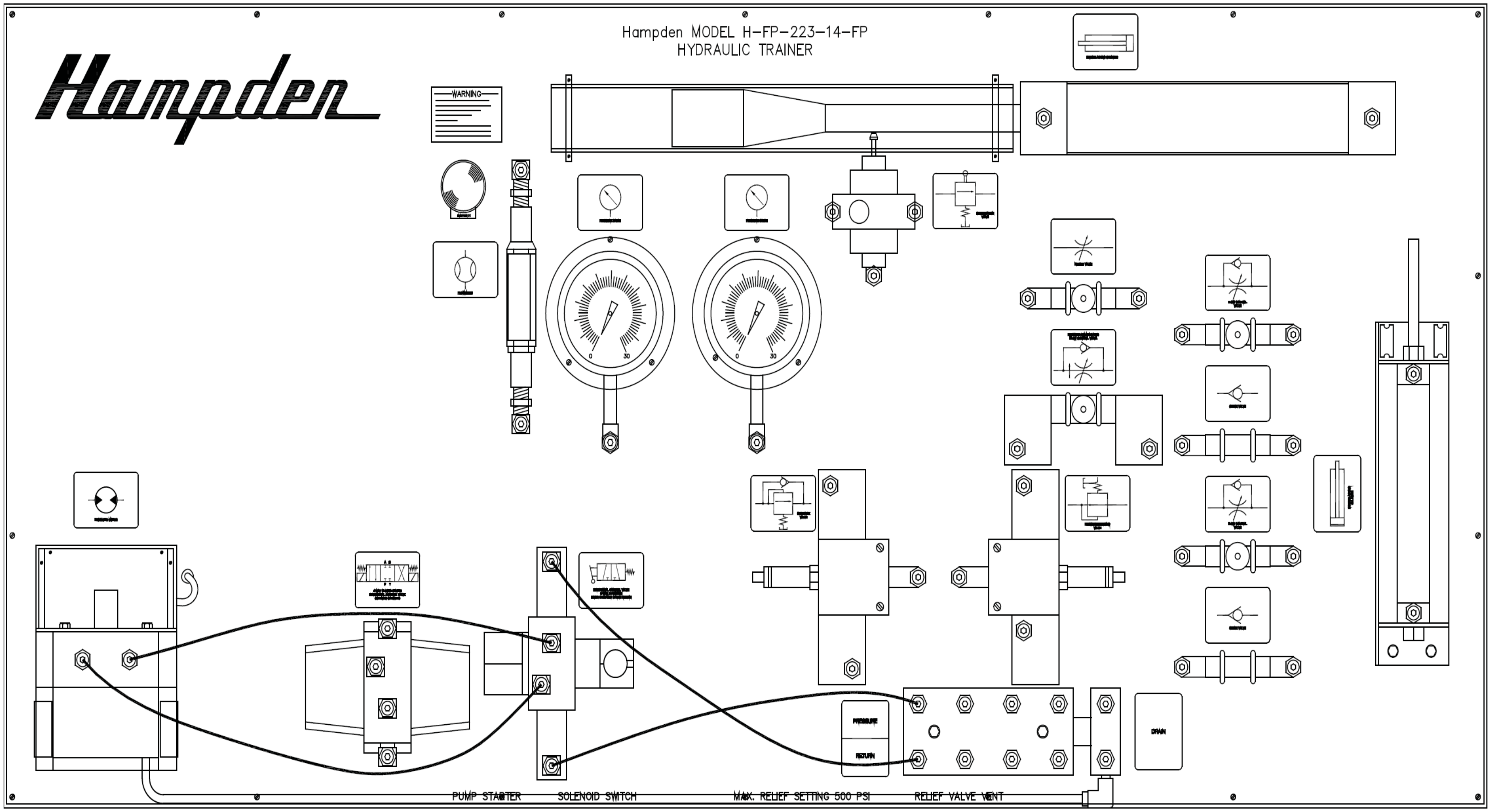
Step 1. Follow general operating instructions

Step 2. Move the manual valve lever in one direction and observe the direction the hydraulic motor turns.

Step 3. Bring lever back to center position.

Step 4. Move the lever in the opposite direction and observe the direction the motor turns.

Step 5. Return lever to the center position.



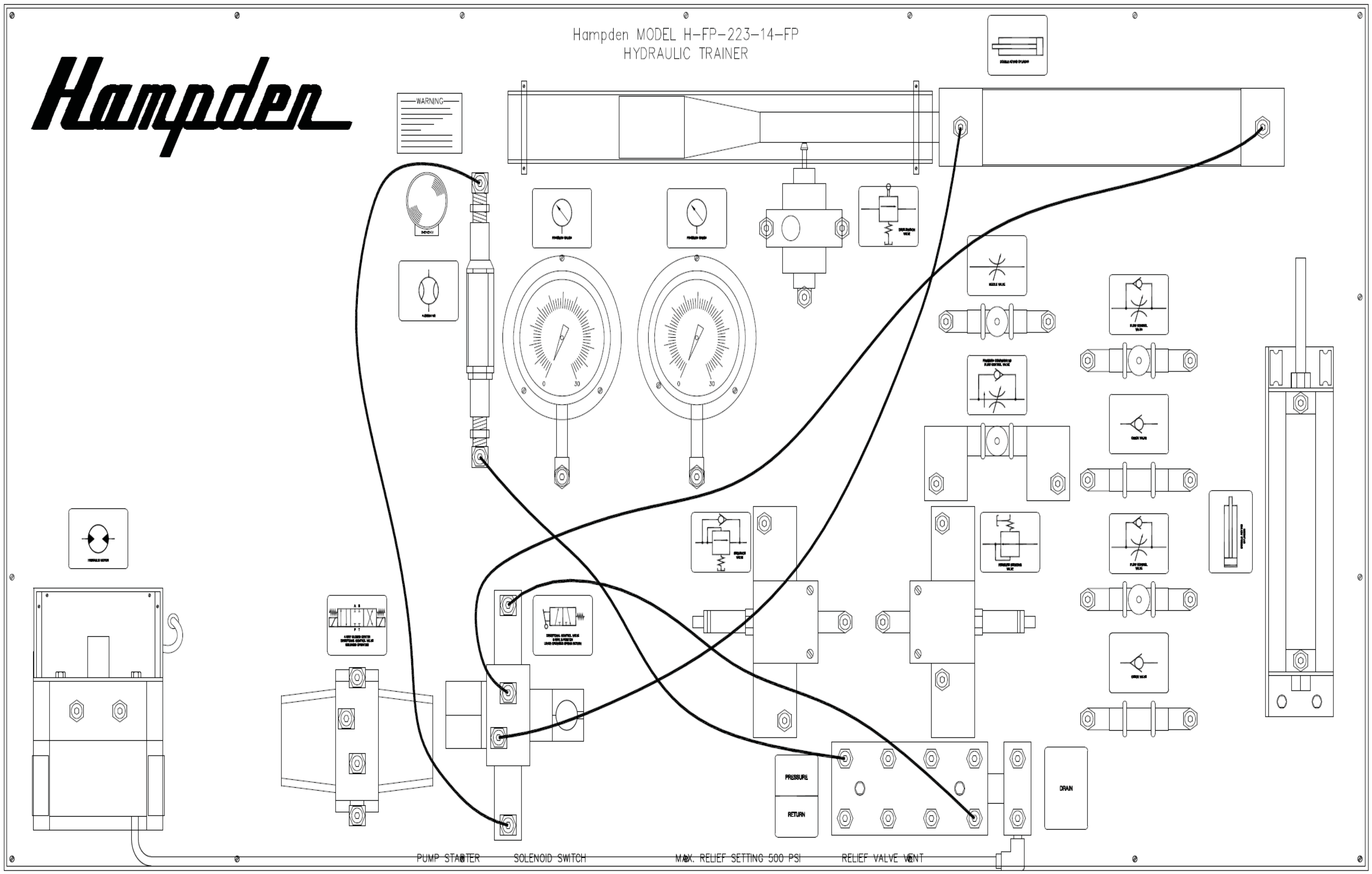
EXPERIMENT #6
BI-DIRECTIONAL MOTOR CONTROL

HORIZONTAL CYLINDER OPERATION

Procedure

Step 1. Follow general operating instructions.

Step 2. Move the manual valve lever back and forth to drive the horizontal cylinder in each direction.



EXPERIMENT #7
HORIZONTAL CYLINDER OPERATION

VERTICAL CYLINDER OPERATION WITH PRESSURE MEASUREMENT

Procedure

Step 1. Follow general operating instructions.

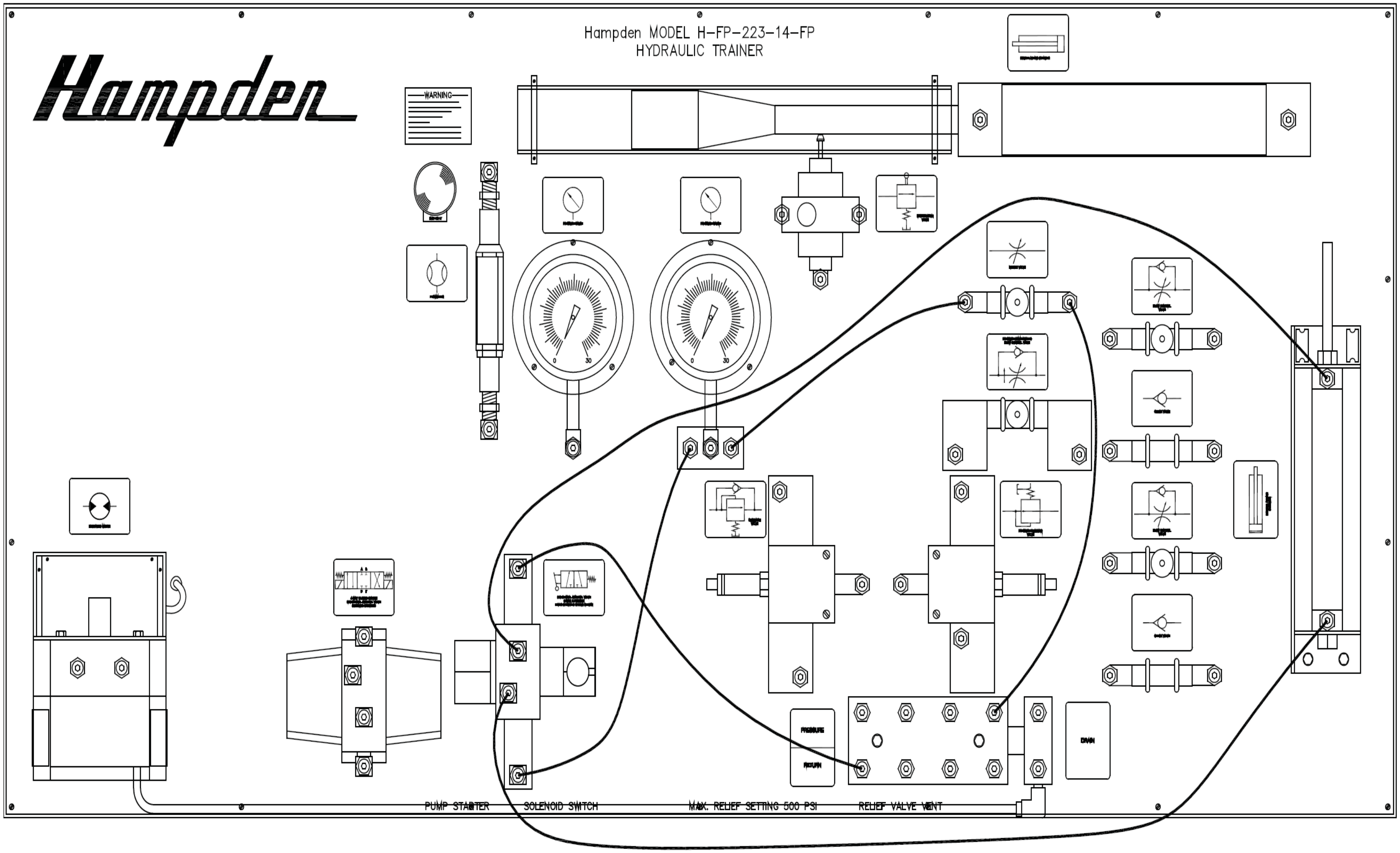
Step 2. Fully open the needle valve and observe the pressure gauge.

Step 3. Move the manual valve lever back and forth to drive the vertical cylinder up and down.

Step 4. Adjust the needle valve to reduce the pressure.

Step 5. Operate the lever again and notice the movement of the vertical cylinder. Step 6.

Repeat step 4 and 5.



EXPERIMENT #8
VERTICAL CYLINDER OPERATION
w/ PRESSURE MEASUREMENT