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Experimental Flow Lab for Fluid Mechanics Related to Physiological flows

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BACKGROUND

PRESSURE TRANSDUCERS

Early History

Pressure is almost always measured by the displacement of something against an increasing restoring force. This can be shown by using a simple U-shaped tube manometer. This tube is partially filled with a liquid (often water or mercury). When pressure is applied to one side entrance of the tube, the liquid in the tube is displaced in the opposite direction until the difference in pressure on both sides of the tube equals the applied pressure. This type of device is easily calibrated, and can be used to calibrate other types of transducers.

Most pressure gauges are now in the form of pressure transducers, incorporating a diaphragm or membrane into the system. The pressure to be determined acts on one side of the diaphragm, and a standard known pressure acts on the other side. The pressure being determined will cause the diaphragm to bow in one of two directions. The difference in the many manometers of this type exists only in the method by which the movement of the diaphragm is calibrated and measured.

In early days this movement was detected by attaching a mirror to the part of the diaphragm where maximum angular deflection was expected. A beam of light was then reflected from the mirror and varied according to the extent of the displacement.

A more sophisticated system, the Greer manometer, facilitates the diaphragm itself being used as a mirror. Two beams of light are focused onto the membrane, on either side, and then each beam is reflected into an electrically balanced photoelectric cell. When the diaphragm is bowed, one side becomes a concave mirror and one a convex mirror. The convex side receives less light because the beam is spread out over a larger area, and at the same time the concave side receives a more concentrated beam. This imbalance is recorded as an electrical function on a suitable meter.

Pressure-Strain Transducers

The above mentioned manometers are purely membrane-electrical conductivity related. A superior measurement of pressure can be made with the use of strain gauges. A simple strain gauge relies on the fact that when a wire or metal film is elongated due to variable force, its electrical resistance increases, and upon compression, the resistance drops.

The most common way to couple a strain gauge with a diaphragm involves connecting four wire strain gauges in such a way that they become the four active arms of a Wheatstone bridge, each arm being capable of changing its resistance. The arrangement is such that deflection of the diaphragm causes two gauges to become elongated and two become compressed, giving different values of resistance. Any movement of the membrane will result in a change of voltage output.

In recent years technology has allowed replacement of the wires by slices of semi-conductors, usually germanium or more popularly, silicone. This is beneficial in that the strain sensitivity is greatly increased, (more strain sensitive materials are being used), while at the same time the temperature sensitivity is decreased, to give the maximum true sensitivity of the device. Four such substitutes can be incorporated onto a metal diaphragm to get the desired tension versus compression configuration. Finally the four can be connected to form the four-arm active bridge.

A more recent simplification has been to make the entire diaphragm out of a slice of silicon. The four arms of the bridge are incorporated into the back side of the slice, using light gold wire to connect and activate the four arms. This method has several advantages in that: it avoids bonding silicon to a metal surface, and also allowing very small transducers to be produced, sometimes as small as one to five millimeters in diameter.

Other Applications

Besides application to blood flow, the electromagnetic flowmeter can be used in fields such as chemistry, food industry, and public utilities.

ELECTROMAGNETIC FLOWMETER

Basic Principle

The electromagnetic flowmeter is based on the discovery by Faraday that currents are induced in a conductor which is put in motion through a magnetic field. The induction resulting from this motion is expressed by the vector equation

$$\mathbf{E} = \mathbf{u} \times \mathbf{B}$$

where **E** is the induced electric field, **u** is the velocity of motion, and **B** is the intensity of magnetic induction. The direction of **E** is across the tube of the flowmeter from one side to the other, e.g. from left to right. The velocity **u** is along the flowmeter (back to front), and **B** is perpendicular to the other two vectors (top to bottom). Further derivation and explanation of this equation can be found in a paper by Vincent Cushing on electromagnetic flowmeter (paper no. 2-4-38, 1971 Symposium on Flow -- Its Measurement and Control In Science and Industry).

Advantages of the Electromagnetic Flowmeter

1. Measuring flow in non-Newtonian fluids.

2. Causes no pressure losses.

3. Not effected by: viscosity, temperature, flow symmetry, density, or pressure.

4. No consideration needs to be given to turbulent flow caused by upstream conditions unless very abnormal.
5. Flow can be measured without insertion into, or cutting of tube.
6. Use in chronic or acute experiments.
7. Very high frequency response for DC flowmeter.
8. No need for anticoagulants.
9. Good stability and reproducibility.
10. Setting zero without flow interruption.
11. Distinguishing between forward flow and backward flow.
12. Linear calibration.
13. Commercial availability.

Limitations and Disadvantages of Electromagnetic Flowmeters

1. The fluid must be conductive, or a suitable additive added (depends upon pipe diameter and meter lead length).
2. Possible errors from deposits on tube from some materials.
3. Small signal to noise ratio.
4. Erratic polarization voltage and noise pickup in DC meter.
5. Zero instability on some sine-wave AC meters.
6. Moderate constriction or compression of vessel by flow probe for proper fitting.
7. Mechanical movement artifacts.
8. Complicated electronic circuitry; possible malfunction

Calibration of the Electromagnetic Flowmeter

The following procedure can be used for calibrating the Narco Bio-system electromagnetic flowmeter.

1. Set up the electromagnetic transducer and flowmeter as shown ****. Fill up the system with a normal sodium chloride solution.
2. Set the gain of the flowmeter to 999.
3. Push the zero reference selector and adjust the digital readout to zero using the digital zero control.
4. Push the null selector and turn the in phase and quadrature controls to obtain a zero reading in the electromagnetic flowmeter.
5. Set the digital thumbwheel switches to the flow transducer factor (4.8 L/min). Push the calibrate selector and turn the full scale control to set the same value in the digital display.
6. Push the flow selector.
7. Turn on the pump and set a value of flow by changing the speed of the pump.
8. Decrease the gain of the flowmeter until the digital display shows the same average flow as the rotameter.
9. Using a stopwatch, take the time to collect a known volume or solution and calculate the flow rate.
10. Adjust the gain so that the digital display corresponds to the experimental flow value.
11. Change the flow rate and corroborate the results.

Reservoir --> roller pump --> Electromagnetic transducer --> rotameter -->Reservoir

Digital display

PULSATILE FLOW SYSTEM

DESCRIPTION

The flow system used in the experiments consists of six major components and connecting tubing. The major elements of the flow system are a constant head tank, a piston-cylinder oscillatory pump, a simulated stenosis, a pump, and a fluid reservoir connected in series. There are also electromagnetic flow meter transducers attached to the stenosis.

The constant head tank is elevated with its bottom edge 63 cm above the pump. The electromagnetic flow meter is a Baird Controls Survey Flowmeter Model UFP-6003-DI. The simulated stenosis is modeled as an axisymmetric converging-diverging tube machined out of a 10 cm square piece of plexiglass. The bell-shaped contour of the constriction is defined by the following Gaussian normal distribution :

$$R / R_o = 1 - 0.5 \exp [-4 (z / R_o)^2]$$

where R was the local radius out to the wall, R_o was the radius of the tube away from the stenosis, and z was the axial distance measured from the minimum diameter of the constriction.

In the given model, R_o is equal to 2.54 cm and the radius at the throat of the constriction was one half of R_o (1.27 cm) giving an area reduction of 75%. Also, the effective length of the converging-diverging section was 2* R_o (5.08 cm). The entire model length was 54.43 cm with one end 40.34 cm from the throat of the constriction.

There are a series of 0.066 cm diameter holes in the tube at 0.953 cm intervals along the stenosis. The holes are counter-drilled for number 19-gauge hypodermic needles which have been press-fit into the tube. These allow for pressure measurements along the tube.

The piston-cylinder oscillatory pump consists of a cylinder and piston, and a driving mechanism. The cylinder was machined from a 10 cm square piece of plexiglass. The radius of the cylinder is 2.54 cm. and the total length of the pumping section is 33 cm. A hole 1.91 cm in diameter centered 11.3 cm from the end of the pumping section was drilled and threaded. This serves as the point from which the fluid enters the pumping section. The piston was machined out of aluminum and contained two rubber O-rings which fit snugly into the cylinder, thus preventing any leakage from the pumping section.

The driving mechanism for the system consists of two major parts: a slotted circular steel disc which is attached to the power train, and a linkage bar which connects the piston to the steel disc. The disc was slotted allowing the amplitude of the piston displacement to be varied over a wide range, from 0.0 cm to 11.43 cm. In order to minimize the possibility of damaging the cylinder, the linkage to drive the piston was designed to move parallel to the wall of the cylinder. A variable speed one-half horsepower U.S. Motor used in conjunction with a Tigear speed reducer is used to power the crank-slide driving mechanism with an angular speed which can be varied from 4 to 25 RPM.

The fluid reservoir ensures that there will be an adequate ammount of water in the system and that the constant head tank has room for its overflow. The second pump is used to push the water from the lower reservoir to the higher reservoir. It is a Sarns Portable Pump and operates on 115 volts. The pump can pump at a rate from 0.0 to 4.0 liters per minute. It is simple to operate and control.

EXPERIMENT

1. Turn on the Sarns pump and the flow transducers.
2. Take at least three readings for the rate of flow at five points along the stenosis. One at each end, one at the most constricted part of the stenosis, and two more each equidistant from the

stenosis.

3. Turn on the oscillatory pump and let it run at a slow setting (approximately one quarter power).

4. Use the strip-chart recorder to record the flow fluctuations over time at the five locations.

5. Turn the oscillatory pump up to approximately three quarters power and repeat the last step.

6. Compare the pressures at the five regions over the three different flows. What can be seen about the symmetry of flow at a stenosis at different flow rates?

MOCK CIRCULATORY SYSTEM

DESCRIPTION

The mock circulatory system consists of a pneumatic pulsatile pump and a simulated heart. The 'heart' is constructed of plexiglass with each of the four chambers and the valves approximated to the size of a humans. The valves are of a ball and cage design and will prevent fluid from reentering the previous chamber during the distole phases of pumping.

The single pneumatic power unit is mounted in a custom built walnut formica and extruded aluminum cabinet. The unit operates on a closed gas system. This is done to conserve gas if bottled gas is used. It will operate on bottled gas such as CO_2, helium, or from air furnished by a built-in compressors. Manually controlled gas regulators are supplied. Systolic pressure can be varied from 50 to 250 mm.Hg. Diastolic pressure can be varied from -50 to +10 mm.Hg. Both of these pressures are displayed on pressure gauges. Electric heart rate and systolic timer incorporate two thumb wheel switches and two push button switches. One push button switch starts and stops the electric timer, basic power unit compressor and air supply compressor. The other push button switch allows the timer to cycle the power unit on its own rate selection switch or from an external electrical signal. This allows a second power unit to be cycled by its own timer or to be slaved in rate to the unit. One thumb wheel allows the heart rate to be adjusted from 10 to 120 pulses per minute. The other thumb wheel switch allows systolic duration to be adjusted from 200 to 500 milliseconds.

EXPERIMENT

1. Set the systolic pressure to 130, the diastolic pressure to -30, the rate to 60, and the systolic duration to 300. This approximates an average heart's conditions.
2. Attach a pressure transducer to the left atrium. Use the pressure transducer to find its pressure.
3. Attach a pressure transducer to the left ventrical. Use the pressure transducer to find the pressure here.
4. Attach a pressure transducer to the right ventrical. Use the pressure transducer to find the pressure here.
5. Attach a pressure transducer to right atrium. Use the pressure transducer to find the pressure.
6. Compare the pressures in the different chambers of the heart.