Experiment Instruction

HM150.15 Hydraulic Ram Pump

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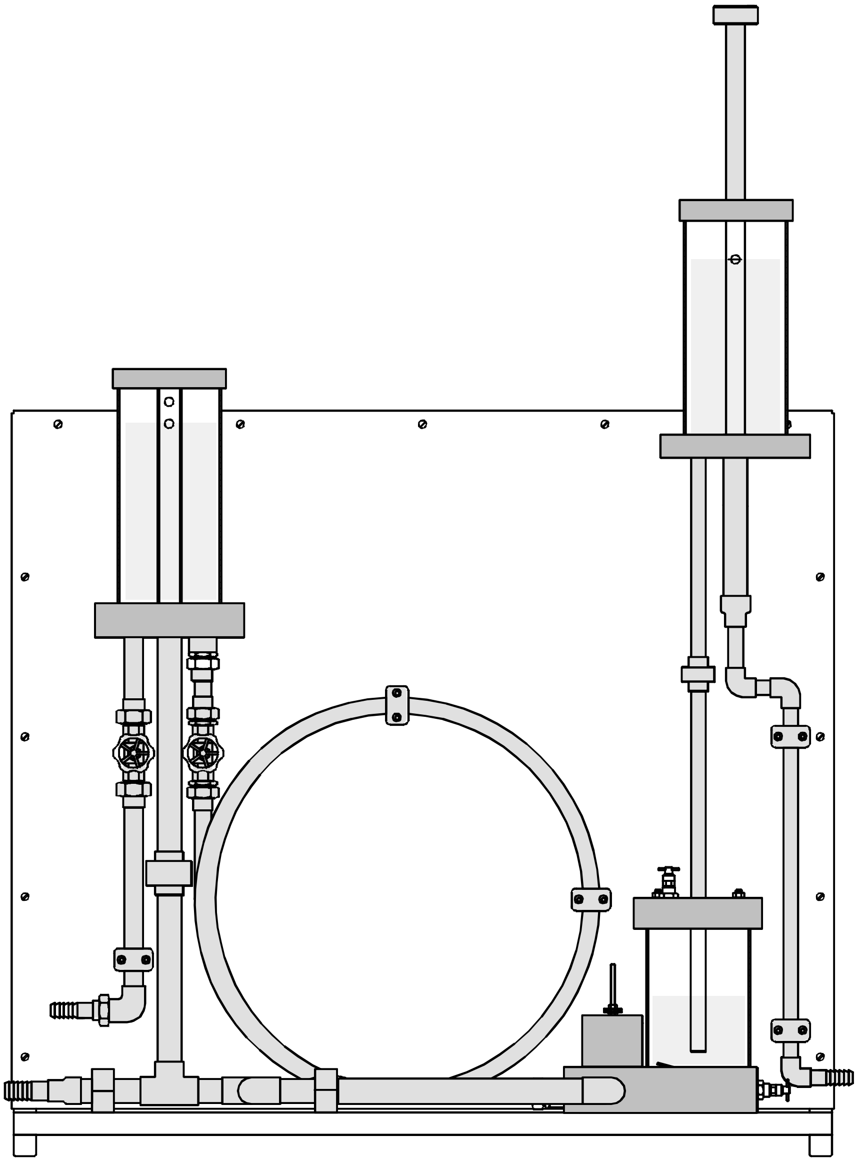

Instructions Manual

Publication-No.: 917.000 15 A 150 12 02/99

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1 Introduction

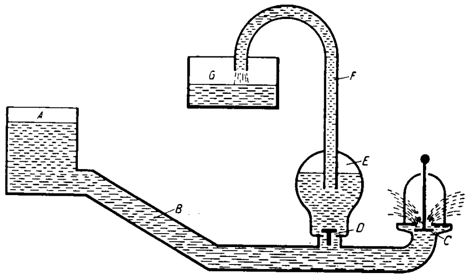

Fig. 1.1 Hydraulic Ram Pump

The **HM150.15 Hydraulic Ram** accessory is used to demonstrate a hydraulic ram pump. Using this type of pump it is possible to pump water to a higher level without the provision of additional mechanical energy. In this process, the kinetic energy in the flowing water is converted into potential pressure energy by very sudden retardation. The generation and effect of pressure surges in pipes can also be demonstrated.

The unit is designed for use with the **HM150 Hydraulics Bench**. Given a sufficient supply of water, the unit can be operated directly from the water mains.

The unit is maintenance-free and is manufactured from corrosion-resistant materials.

Due to its simple construction and clearly visible operation (open valves and transparent vessels), the unit is ideally suited to use for demonstrations in lectures or for student experiments.

2 Unit Description

2.1 Layout and Function of the Unit

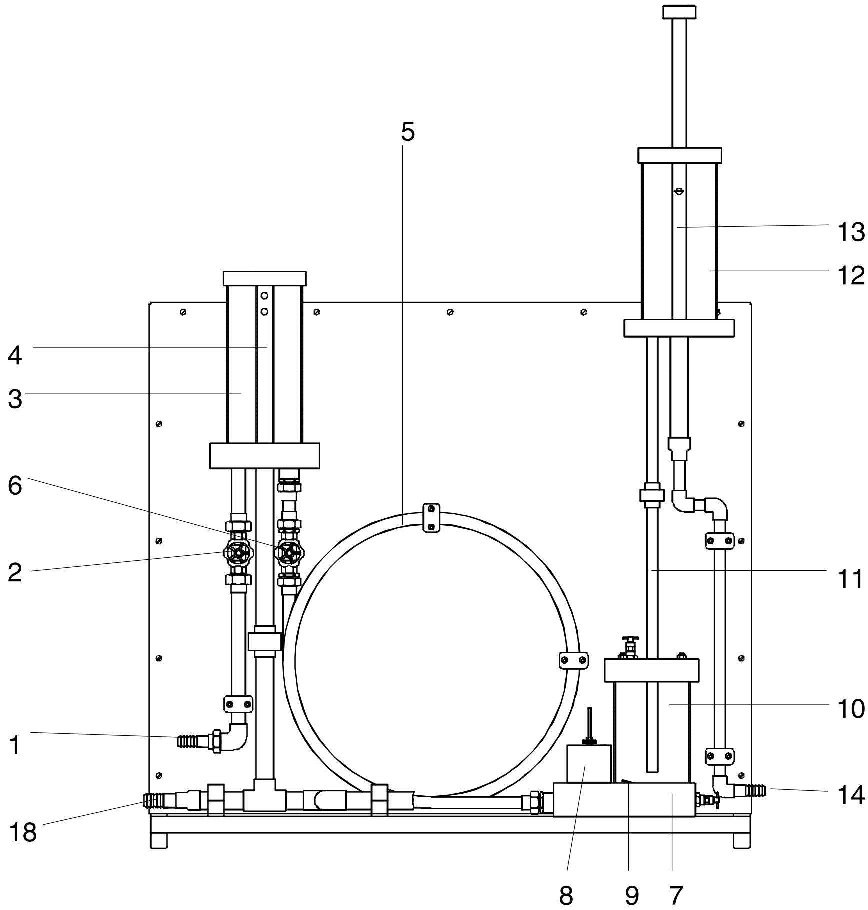

Fig. 2.1 Complete Unit

The unit principally consists of two raised vessels, a pipe, a valve block with air chamber, and the appropriate inlet and outlet fittings.

All components are mounted on a board. The water passes from the inlet connector (1) through the inlet valve (2) into the first raised vessel (3). An integrated overflow pipe (4) keeps the water level constant. The raised container feeds a water pipe (5) of length L. The flow rate can be adjusted using a second regulating valve (6). After flowing through the water pipe, the water flows into the valve block

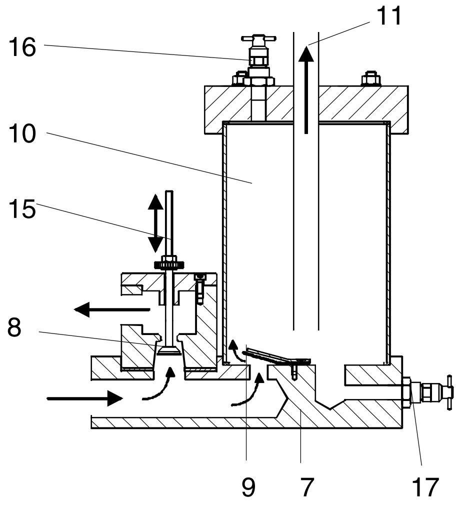

Fig. 2.2 Valve Block with Air Chamber

(7). The weight loaded step action valve (8) is fitted in the valve block. As long as the speed of the water in the pipe is low, this valve remains open and the water passes unhindered into the outlet pipe (18). If the flow of water accelerates, the step action valve is closed abruptly by the force of the flow of water. The increase in pressure in the pipe opens the rubber valve flap (9), also fitted in the valve block, and the water flows into the air chamber (10). From here the water passes through the riser (11) into the second raised vessel (12). The pump head can be adjusted via an adjustable overflow (13). The pumped water emerges at the connector (14).

The water levels can be read off on scales on both raised vessels. The scale origin is at the top of the valve block.

The step action valve can also be operated manually via the valve spindle (15).

The amount of air in the air chamber can be varied using the bleed valve (16). The drain valve (17) facilitates the draining of the air chamber.

2.2 Placing into Operation

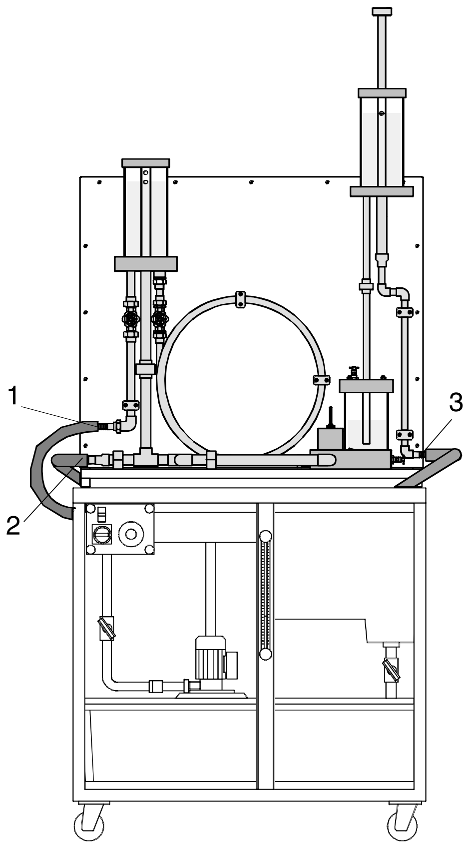

Fig. 2.3 System Placed on HM150 Base Unit

- Place the unit on the **HM150 Hydraulics Bench**.
- Make the connections for the water supply:
  - Either via the inlet valve on the HM150 Base Module to inlet connector (1)
  - Or by connecting a mains water supply to inlet connector (1)
- Water outlet via hose from overflow (2) to HM150 collecting container.
- Water outlet via hose from raised vessel outlet to HM 150 measuring vessel or collecting container (3) .

2.3 Maintenance and Care

- Light encourages the growth of algae. Therefore only store with the vessels drained.
- Do not use any solvents or abrasive cleaners for cleaning.

3 Theory

Using the energy in a flow of water, the **hydraulic ram pump** invented by Montgolfier (1797) enables water to be pumped to a higher level than that from which it originates. This pump makes use of the effect caused by the abrupt bringing to a halt of a flow of water in a pipe; during this process the kinetic energy contained in the water is converted into potential energy.

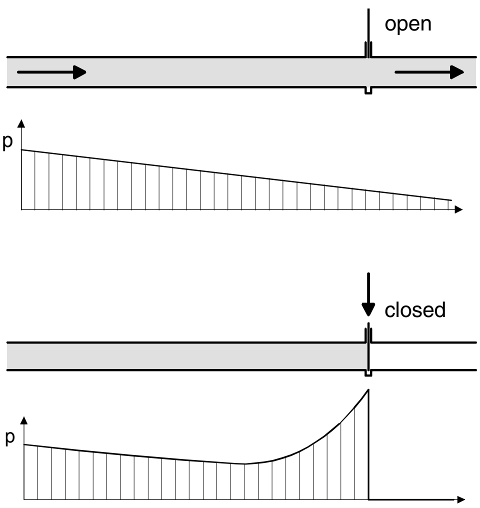

Fig. 3.1 Pressure Pulse on Abrupt Retardation of the Flow

Normally the pressure pulse so generated is undesirable and can lead to serious damage to pipes. Particularly in water turbines with large heads, attempts are made to render this pressure pulse harmless by taking suitable measures in the design and construction. For example, gate valves are only closed slowly. On Pelton turbines, the water jet is initially only deflected on abrupt load shedding, and the nozzle needle then closed slowly. Furthermore, so called surge tanks, which can absorb and attenuate the pressure pulse, are built into the pressure lines.

On the hydraulic ram pump, this effect is specifically provoked by a cyclically closing valve (step action valve). The resulting pressure pulse is dissipated by the water being able to flow through a pressure valve into an air chamber. The air chamber cushions the pulse and facilitates a more or less continuous flow of water up the riser to a second raised vessel.

If a loss-free flow is assumed, the law of the conservation of energy can be applied:

In the case of a loss-free flow in a pipe, the maximum speed of the water that will be achieved for a head of h_1 is:

$$v_1 = \sqrt{2\,g\,h_1}$$

The energy of the water flowing in the pipe is thus:

$$E_{kin} = \frac{1}{2}\,m_1\,v_1^2 = \frac{1}{2}\,m_1\,2\,g\,h_1$$

The energy of water pumped up to a height of h_2 is:

$$E_{pot} = m_2\,g\,h_2$$

Equating these yields:

$$m_1\,g\,h_1 = m_2\,g\,h_2$$

or using the mass flows, the mass flow ratio

$$\mu = \frac{\dot{m}_2}{\dot{m}_1} = \frac{h_1}{h_2}\,.$$

This means that the mass flow $\dot{m}_2$ to be pumped to height h_2 is dependent on the ratio of the heights. The smaller the amount of water, the higher the pump head. This simple relationship is of course only applicable if:

1. The potential energy can be completely converted into speed in the inlet pipe and
2. The kinetic energy can be completely reconverted into pressure.

In practice, imperfectly operating valves and resistances to flow cause losses, such that the actual mass flow ratio is significantly less.

The operation of the hydraulic ram pump is explained in the following sketch:

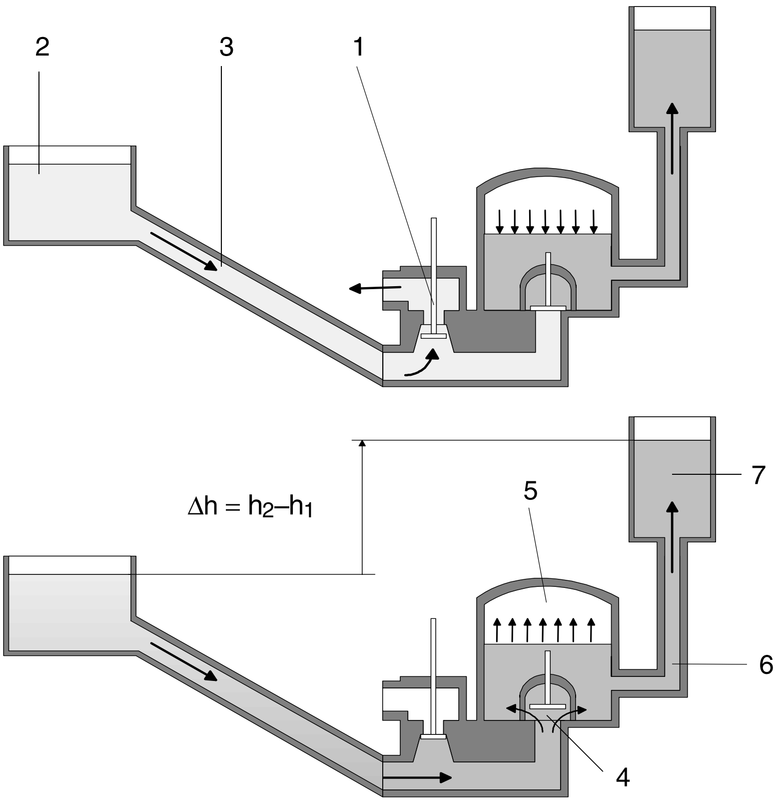

Fig. 3.2 Basic Principle of Operation a Hydraulic Ram Pump

The step action valve (1) is initially open (Fig. 3.1 top). The water starts to flow downwards from the first raised vessel (2) through the pipe (3) and the step action valve to the outlet. The water in the pipe accelerates until the forces on the head of the step action valve become too large and the valve closes. At this moment the column of water in the pipe is heavily retarded and a large overpressure forms at the lower end of the pipe. This opens the non-return valve (4) and the water now flows into the air chamber (5) (Fig. 3.1 bottom). Once the overpressure has dropped to the level in the pressure pipe and the flow into the air chamber has ceased, the step action valve opens again due to its inherent weight and the process starts again from the beginning. The air chamber cushions the pressure pulse with its captive pocket of air and facilitates the continuous pumping of the water through the riser (6) into the second raised vessel (7). Without the air chamber, the water in the riser would also have to be repeatedly accelerated. This would use up a large part of the pressure energy generated and thus significantly reduce the efficiency.

The length of the pipe does not have any direct influence on pumping performance. It affects the cycle time of the pumping action via the mass of water contained in it and the time required for acceleration. A long pipe has long acceleration times and large cycle times. In the case of pipes that are too short, the inherent dynamics of the step action and non-return valves can have negative effects. Due to their inertia, the valves do not have enough time to completely open or close within a cycle.

4 Experiments

4.1 Placing into Operation and Performing Experiments

The hydraulic ram pump is easy to set in operation (controls, see Fig. 2.1).

- The unit is first to be connected to the water supply (HM150) in accordance with Fig. 2.2.
- Close the bleed valve (16) and the outlet valve (17).
- Completely open the regulating valve (6).
- Switch on HM150 pump and open main valve.
- Open inlet valve (2) and fill first raised vessel (3).
- Once the overflow has been reached (4), reduce the feed a little to avoid the water level increasing further.
- Normally the hydraulic ram pump now starts working. If it does not work, the step action valve (8) can be triggered by operating the valve spindle (15) manually.

The water level in the air chamber and riser starts to rise until water reaches the second raised vessel (12).

- The pump head can be adjusted by sliding the overflow (13) up and down.
- The stroke of the step action valve and thus also, within certain limits, the cycle time can be adjusted using the knurled nut on the valve spindle (15).
- By releasing air via the bleed valve (16), the effectiveness of the air chamber can be changed and the effect on the pumping behaviour studied.
- The volumetric flow rate of the pump can be measured using a stop watch and a measuring

container on the outlet (14). Between 20 and 50 s are needed for one litre.

4.2 Determining the Mass Flow Ratio

In the following example experiment, the actual mass flow ratio is to be compared with the theoretical value. To do this the water levels, the volumetric flow rate of the pump and the amount of water lost must be measured.

The pump head is given by the difference in the height of the two water levels.

First raised container: $h_1 = 0.88\text{m}$

Second raised container: $h_2 = 1.15\text{m}$

Pump head: $\Delta h = 0.27\text{m}$

The measurement of the volumetric flow rate of the pump yields 1 litre/40 sec or

$$\dot{m}_2 = 0.025 \text{ kg/s} .$$

The measurement of the amount of water lost is performed at the outlet (18). Here it should be noted that the inlet of water via valve (2) is to be regulated in such a manner that as little water as possible flows though the overflow (4). This additional water would distort the result.

The measurement of the amount of water lost yields 1 litre/14.5 sec or

$$\dot{m}_v = 0.069\text{kg/s} .$$

The total amount of water flowing out of the first raised vessel is given by the sum of the pump volumetric flow rate and the amount of water lost

$$\dot{m}_1 = \dot{m}_2 + \dot{m}_v = 0.094\text{kg/s} .$$

This yields an actual mass flow ratio of

$$\mu = \frac{\dot{m}_2}{\dot{m}_1} = 0.266 \ .$$

Based on the heights, the mass theoretical flow ratio should be

$$\mu_{th} = \frac{\dot{m}_2}{\dot{m}_1} = \frac{h_1}{h_2} = \frac{0.88}{1.15} = 0.765$$

Thus only around 35% of the theoretically possible pump capacity is achieved.

4.3 Determining the Efficiency

The efficiency is defined as the ratio of benefit to work.

Benefit describes the energy of the amount of water pumped, work the energy of the water used. If one uses the mass flows, then one obtains the ratio of the powers

$$P_{in} = \dot{m}_1 \ g \ h_1 = 0.81W,$$

$$P_{out} = \dot{m}_2 \ g \ \Delta h = 0.066W,$$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{0.066}{0.85} = 8.1\%.$$

This is a relatively low efficiency compared to other types of pumps. However, with the apparatus being of simple construction and operated with water, the result is not bad.

5 Technical Data

Dimensions		
L x B x H :	1150 x 640 x 1550	mm
Weight:	40 kg	
Water Consumption:	400	litre/h
Max. Pump Head:	1.15	m
Pipe Length:	2.5	m
Pipe Diameter, Internal:	20	mm