Hydraulic Rams

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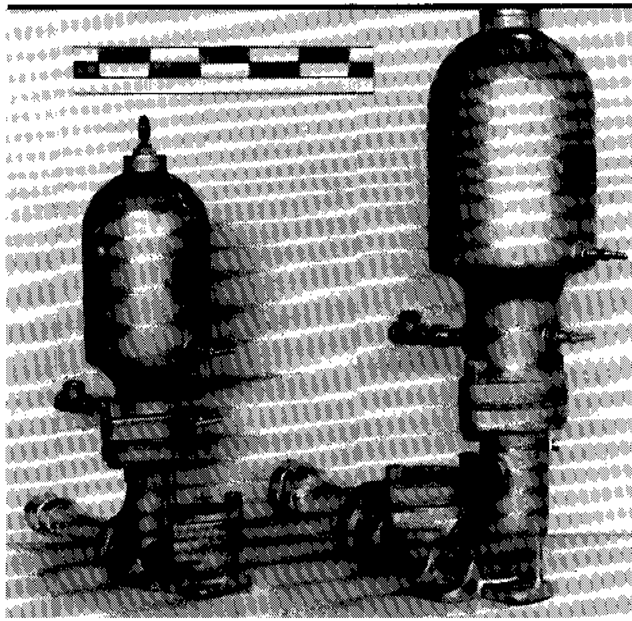
J.H.P.M. Tacke and C. Verspuy



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HYDRAULIC RAMS

In 1987 Peter de Jong of CICAT (the coordinating centre of the development cooperation effort of Delft University of Technology) published: "Hydraulic Rams, a consumers' guide".

This guide summarized the results of research on hydraulic rams, commissioned by the Section of Research and Technology of the Netherlands Ministry of Foreign Affairs.

The research comprised comparative tests of commercially available and newly designed hydraulic rams, and was carried out by the Delft University of Technology and in the field in Rwanda.

The laboratory research has been reported upon in 'World Pumps' (July 1989) by ir. J.H.P.M. Tacke and ir. C. Verspuy. This booklet is based on that article.

Drs. A. Wouters
Coordinator CICAT

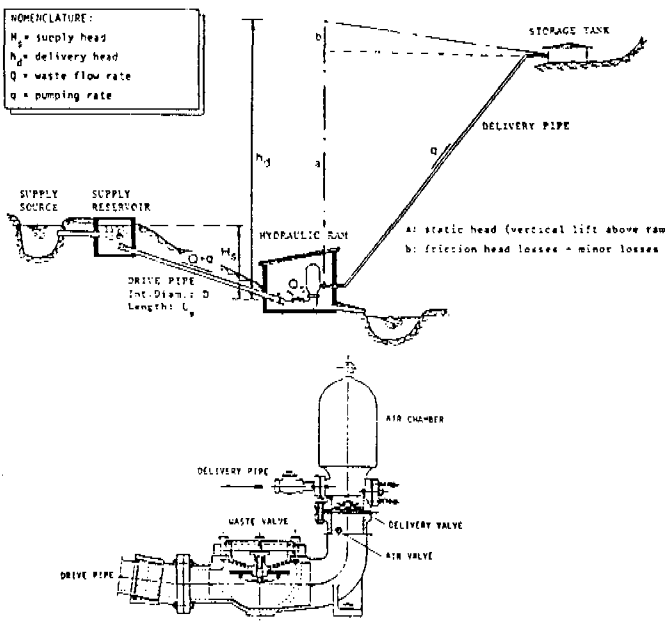

Fig. 1 Typical hydraulic ram installation

HYDRAULIC RAMS

Introduction

The hydraulic ram is an automatic water pumping device that utilizes the energy contained in a flow of water running through it, to lift a small volume of this water to a higher level. The phenomenon involved is that of a pressure surge which develops when a moving mass of water is suddenly stopped (waterhammer.)

Hydraulic rams can be used for pumping drinking-water from a spring or stream to a tank or reservoir at a higher level. A steady and reliable supply of water is required with a fall sufficient to operate the ram. Favourable conditions are mostly found in hilly and mountainous areas with fairly plentiful supplies of water. A well-made ram will pump an appropriate amount of water to a height from about 20 to 30 times the supply head, with an efficiency of about 60 to 70 per cent. Alternatively, hydraulic rams can be used for pumping water to low heads over large distances (up to 10 km or more), i.e. vertical lift can be traded off for horizontal distance.

In the past quite a number of hydraulic rams have been installed and many have given long and reliable service. But in modern times the availability of piped water systems using engine-driven pumps has relegated the hydraulic ram to a comparatively unimportant position. Recently, though, it has revived as a potentially useful component in rural water supply programs in developing countries. Yet, up to now the use of the hydraulic ram in developing countries has not become as widespread as its simplicity, ease of operation and maintenance, dependability and economy would seem to warrant. This has largely been due to the lack of reliable information concerning the limiting conditions under which the ram is applicable and the phenomena governing its action.

In this article the essential features of hydraulic ram operation are described, using a limited number of experimental results. These results are part of the results obtained from a comparative investigation on commercially-available hydraulic rams, carried out at the Delft University of Technology (lit. [4]).

Mode of operation

Fig. 1 shows the various components from which a typical hydraulic ram installation is constructed: supply reservoir - drive pipe - hydraulic ram - delivery pipe - storage tank. The hydraulic ram itself is structurally simple, consisting of a pump chamber fitted with only two moving parts: an impulse valve through which the driving water is wasted (waste valve) and a check valve through which the pumped water is delivered (delivery valve). Surmounting the delivery valve is the air chamber or surge tank. When the ram operates this tank is partly filled with water and partly with air. Connected to the air chamber is the delivery pipe, so that the pressure in the air chamber is the delivery pressure. An inclined conduit, the so-called drive pipe, connects the ram

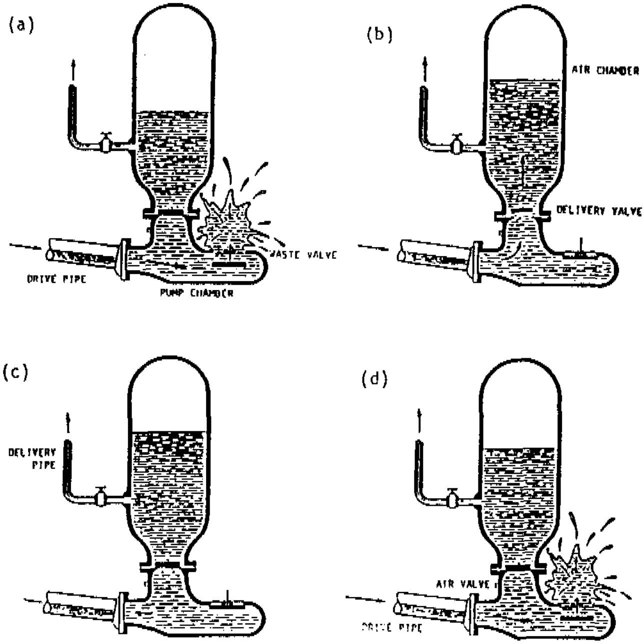

Fig. 2 Operation of the hydraulic ram

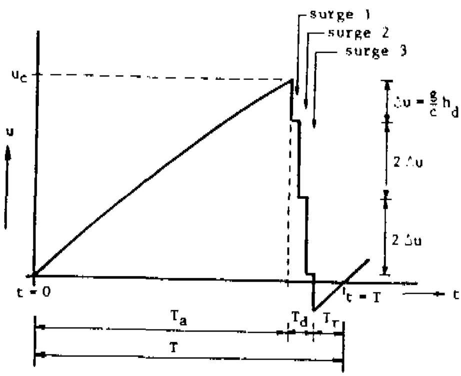

Fig. 3 Velocity u(t) at the downstream end of the drive pipe

body with the water supply. This drive pipe is the essential part of the installation in which the potential energy of the supply water is first converted into kinetic energy and subsequently into the potential energy of water delivered.

The ram operates on a flow of water accelerating under a head H_s from the supply reservoir down through the drive pipe into the pump chamber. The water escapes through the opened waste valve into the surrounding area (Fig. 2a). With the acceleration of the water in the drive pipe the hydrodynamic drag and pressure on the waste valve will increase. When the flow of water through the waste valve attains sufficient velocity, the upward force on the valve will exceed its weight and the valve will slam shut. (In a good ram design the valve closure is rapid, almost instantaneous.)

Thus the flow through the waste valve is abruptly stopped, but since the column of water in the drive pipe still has a considerable velocity a high pressure develops in the ram, locally retarding the flow of water. If the pressure rise is large enough to overcome the pressure in the air chamber the delivery valve will be forced open (Fig. 2b), which in turn limits the pressure rise in the ram body to slightly above the delivery pressure. The front of this pressure rise travels upstream, partly reducing the flow velocity in successive cross-sections of the drive pipe as it passes. In the meantime the remainder of the flow passes through the opened delivery valve into the air chamber. The air cushion permits water to be stored temporarily in the air chamber with only a comparatively low rise in local pressure, thus preventing the occurrence of waterhammer (shock waves) in the delivery pipe. With the propagation of successive pressure surges up and down the drive pipe, water continues to flow into the air chamber with step-wise decreasing velocity until the momentum of the water column in the drive pipe is exhausted. The higher pressure which now exists in the air chamber causes the delivery valve to close, thus preventing the pumped water from flowing back into the ram body, while the water in the drive pipe is flowing away from the ram in the direction of the supply reservoir (Fig. 2c). The 'recoil' of water in the drive pipe produces a slight suction in the ram body, thus creating an underpressure near the waste valve. The underpressure allows the waste valve to reopen, water starts to flow out again, and a new operating cycle begins (Fig. 2d). Meanwhile the water forced into the air chamber, is driven at a constant rate into the delivery pipe to the storage tank at the high level, from which it can be distributed by gravitation as required.

An air valve or snifting-valve is mounted into the ram body to allow a small amount of air to be sucked in during the suction part of the ram cycle. This air is carried along with the next surge of water into the air chamber. The air in this chamber is always compressed and needs to be constantly replaced as it becomes mixed with the water and lost to the storage tank. Without a suitable air valve the air chamber would soon be full of water; the hydraulic ram would then cease to function.

A schematized diagram of the velocity at the downstream end of the drive pipe as a function of time is presented in Fig. 3. The figure clearly pictures the three subperiods that can be distinguished in a complete cycle of operation:

T_a = period of acceleration (wasting); waste valve open, delivery valve

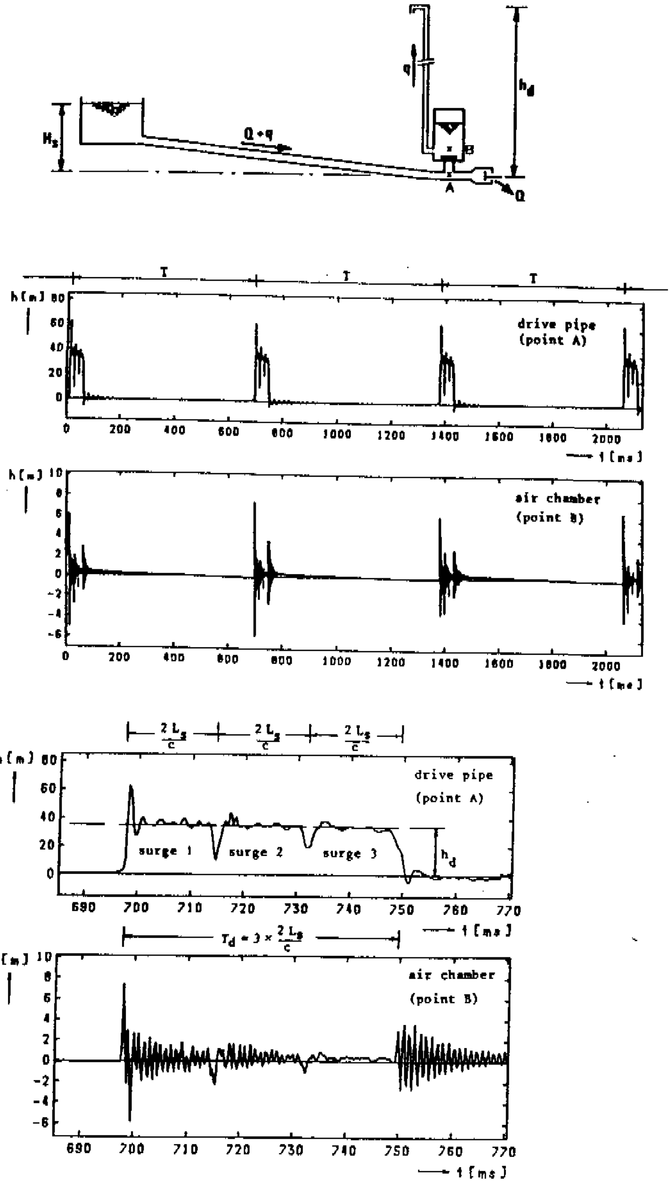

Fig. 4 Pressure ÷ time recordings

closed; positive velocity (towards the ram).

T_d = period of retardation (pumping); waste valve closed, delivery valve open; decelerating flow into the air chamber.

T_r = period of recoil (reverse flow); delivery valve closed, waste valve reopens; negative flow (towards the supply reservoir).

During T_a and T_r the velocity u(t), theoretically described by a hyperbolic tangent function, is almost linear; during T_d the velocity u(t) decreases step-wise in proportion to the delivery head h_d.

Depending on supply head (H_s), drive pipe length (L_s), waste valve adjustment and to a lesser degree on delivery head (h_d) the cycle is repeated with a frequency of about 30 to 150 times a minute (period T = 0.40 - 2.00 s). Once the adjustment of the waste valve has been set, the hydraulic ram needs almost no attention provided the water flow from the supply source is continuous and at an adequate rate and no foreign matters get into the pump blocking the valves.

Physical description

As became clear in the previous section, the action of both waste valve and delivery valve is of paramount importance for a successful operation of the hydraulic ram. A good impression of valve action can be obtained by observing the pressure variations both at the downstream end of the drive pipe, i.e. near to the ram (point A in Fig. 4a) and in the air chamber of the ram itself (point B). As an example Fig. 4b illustrates pressure ÷ time diagrams recorded simultaneously at point A and B of a specific ram installation operating under a supply head H_s = 3.00 m and a delivery head h_d = 35 m. The recording length amply covers three complete periods of the continuous 'heartbeat' of the hydraulic ram. The pressure variations observed during the period of retardation, are shown in detail in Fig. 4c. It should be noted that the diagrams portray the pressure variations as measured relative to the local quasi-static pressure; besides, for convenience all pressures were converted to pressure heads ($h = p/\rho g$) before being plotted.

It can be seen from the figures that, indeed, after a relative long period of acceleration a sudden pressure rise is created in the ram body (moment of waste valve closure). Within a few milliseconds this pressure rise drops to a value approximately equal to the delivery pressure ($h = h_d$), thus indicating that the delivery valve has opened. This may also be observed from the pressure ÷ time recording for the air chamber, in which both opening and closing of the delivery valve are distinctly marked by sudden pressure fluctuations, the first because of the sudden flow of water into the air chamber, the latter due to the rebound of the water tending to flow back out of the air chamber. The propagation of successive pressure waves, moving at an acoustic wavespeed (c) up and down the drive pipe during the period of retardation, may be apparent from the pressure recording at point A. (Note: for water in a steel pipe the wavespeed c ≈ 1400 m/s.) With the propagation of successive pressure surges (each surge requiring $2L_s/c$ second to move up and down the drive pipe) the velocity of the water in the drive pipe decreases step-wise in proportion to the magnitude of the pressure surge ($h = h_d$): $\Delta u = {}^g/_c\, h_d$; see Fig. 3. Therefore, for a given waste valve setting (i.e. for known

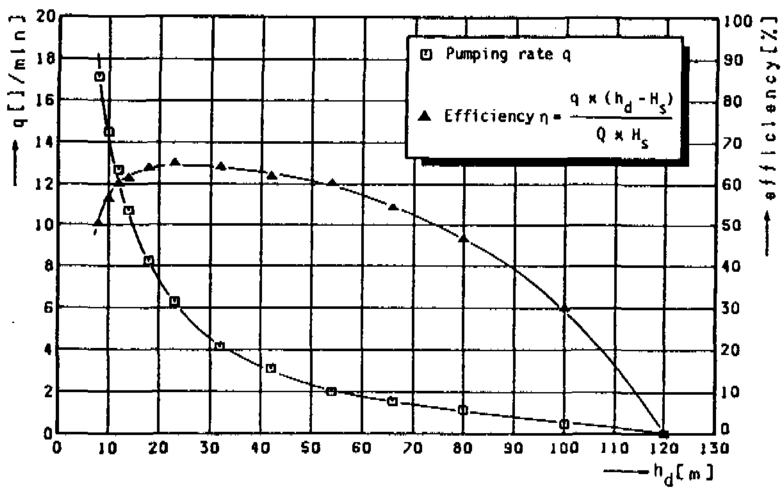

Fig. 5 Performance characteristics, 2 $^1/_2$"-hydraulic ram
H_s = 2 m; Q = 100 l/min; T = 1 s.

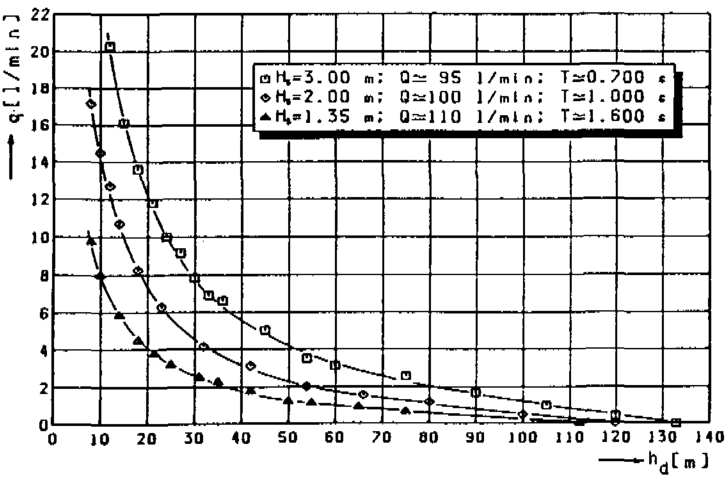

Fig. 6 Effect of supply head on ram performance, 2 $^1/_2$"-hydraulic ram

velocity u_c of the weater in the drive pipe at waste valve closure), the number of surges (N) observed during the period of retardation is determined by the delivery head h_d (when h_d decreases, Δu decreases and N increases). In this case ($h_d = 35$ m) it was found that N = 3, see Fig. 4c, resulting in the velocity steps as already shown in Fig. 3.

From Fig. 3 two volumes of water can be established, V_w and V_d, by integration of u(t) with respect to time and multiplication by the cross-sectional area of the drive pipe:

$$V_w = \frac{\pi D^2}{4}\left[\int_0^{T_a} u(t)\,dt + \int_{T_a+T_d}^{T} u(t)\,dt\right]$$

$$V_d = \frac{\pi D^2}{4}\int_{T_a}^{T_a+T_d} u(t)\,dt$$

Finally, from these expressions the waste flow Q can be obtained from:

$$Q = \frac{V_w}{T}$$

and the pumping rate q from:

$$q = \frac{V_d}{T}$$

Performance characteristics

For the end-users of the hydraulic ram installation the pumping rate q is the first consideration, since this amount should meet their demand. Given an available source supply the pumping rate q of a hydraulic ram is primarily determined by the supply head H_s and the delivery head h_d. As an example Fig. 5 shows performance characteristics compiled from measurements taken on a commercially-made 2 $^1/_2$"-hydraulic ram operating under a supply head $H_s = 2.00$ m. It can be seen from the figure that the hydraulic ram can pump much water for low delivery heads, but as the delivery head increases the pumping rate decreases as might be expected. Fig. 5 also pictures efficiency versus delivery head; the efficiency curve shows that this specific ram can pump water with an efficiency of about 60 % over a broad range of delivery heads.

An increase of supply head H_s increases the pumping frequency (more beats per minute) and by that the pumping rate q increases. This may be noted from Fig. 6 showing q,h_d-curves resulting from experiments carried out on the same 2 $^1/_2$"-hydraulic ram, for $H_s = 1.35$ m, 2.00 m and 3.00 m respectively.

Commercially-made hydraulic rams are available in various sizes, covering a wide range of source supplies. The size of the ram (traditionally given in inches) usually denotes the nominal diameter (D) of the drive pipe. The larger the size of the ram the more water is required to operate the ram and the more water can be delivered to a higher level. For example, Fig. 7 compares ram performances for various arrangements of supply and delivery heads for two rams of the same manufacture but of different size: an 1 $^1/_2$"-ram and a 2 $^1/_2$"-ram respectively. It may also be observed from the figure that a small amount of water with 'plenty' of fall (e.g. Q ≈ 40 l/min; H_s ≈ 3 m) will deliver as much water as an arrangement using plenty of water having only a small fall (Q ≈ 100 l/min; H_s ≈ 1.50 m).

Finally, eliminating the effects of supply

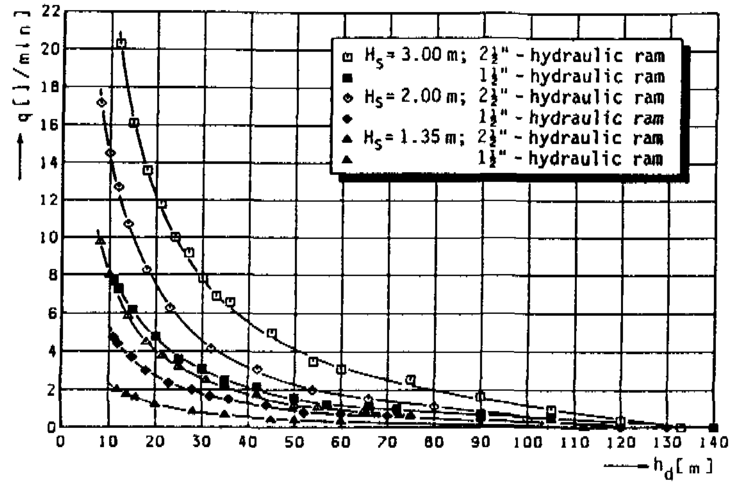

Fig. 7 Effect of ram size on ram performance,
2 1/2"-ram: Q ≈ 100 l/min,
1 1/2"-ram: Q ≈ 40 l/min.

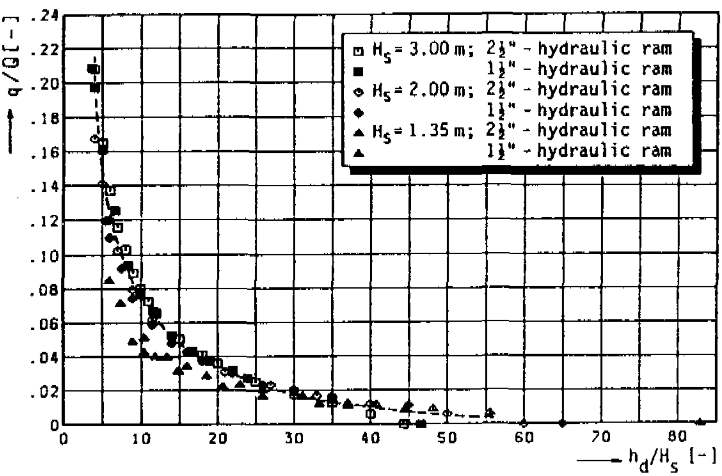

Fig. 8 Flow ratio versus head ratio

head (H_s) and ram size (D) leads to a dimensionless curve depicting flow ratio (q/Q) versus head ratio (h_d/H_s); see Fig. 8. The objective of this figure is to establish trends rather than absolute values. The figure illustrates that for the higher supply heads the dimensionless ram performances tend to be similar. (Some divergence is observed for the lower supply head, partly owing to the length of drive pipe used in the test installation (approx. 12 m), which is somewhat on the large side for a supply head H_s = 1.35 m.)

It must be noted that the foregoing performance characteristics have been obtained from experiments taken on two commercial hydraulic rams and in a way are restricted to these specific rams. However, general conclusions on ram performance as portrayed in the figures may be found to be true for any well-designed ram, but the exact shape of the curves and the magnitude of the numerical values will vary according to the particular design. Detailed information on performance characteristics of twelve commercial rams are included in lit. [4].

Summary and conclusions

In this article it is sought to clarify hydraulic ram operation, using a limited number of results obtained from a more comprehensive analysis (lit. [4]).
The hydraulic ram owes its pumping capacity to two facts. For one thing the action of two (simply constructed) valves, for another the high value of the wavespeed (c) at which pressure waves propagate through a liquid in a pipeline. The latter implies that the drive pipe of the hydraulic ram installation must be made of strong, rigid material (small elasticity), and that the water in the drive pipe must be free of air (small compressibility).
Starting from the motion of the two valves, the pumping cycle of a hydraulic ram can be divided into three (sub-)periods: acceleration - retardation - recoil. For each period the velocity of the water at the downstream end of the drive pipe as a function of time is briefly discussed. With the aid of high-frequent pressure recordings, special attention is paid to the period of retardation; it is in this part of the pumping cycle that the actual pumping takes place.
More information concerning a mathematical model and results of laboratory tests are available (lit. [4]), but there is a lack of results from field tests.

Conclusions relating to the performance characteristics of the hydraulic ram are:
- given an available source supply the pumping rate (q) is primarily determined by the supply head (H_s) and the delivery head (h_d).
- an increase of the delivery head (h_d) decreases the quantity pumped per cycle (V_d) and by that the pumping rate (q) decreases.
- an increase of the supply head (H_s) increases the pumping frequency and by that the pumping rate (q) increases.
- the larger the size (i.e. drive pipe bore) of the ram, the more water (Q) is required to operate the ram and the more water (q) can be delivered to a higher level (h_d).

These conclusions were found to be in conformity with the fore-mentioned mathematical model as well as with experimental results. They can also be drawn from the few results in this article concerning one specific type of hydraulic ram.

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