Reverse action hydraulic hammer control circuit

BB Danilov and DO Cheshchin*
Chinakal Institute of Mining, Siberian Branch, Russian Academy of Sciences, Novosibirsk, Russia
E-mail: *dimixch@mail.ru

Abstract. The paper describes the mode of functioning of the reverse action hydraulic hammer with piston driven in the positive direction by the energy of air compressed during cocking of the piston by the hydraulic drive. The authors discuss various control circuits of such hydraulic hammers, control sensors, capabilities of the circuits, as well as their advantages and disadvantages.

1. Introduction
Branched underground utility networks are a corporate part of the life activity infrastructure. At the present time, underground piping is laid using the trenchless method. As practice shows, nearly 80% of work in this case is spent for laying of pipes 30–50 long, with a diameter to 0.6 m [1–3].

The common trenchless pipeline laying techniques are vibratory percussion puncturing, ramming and drilling. The first two techniques are mainly implemented using hydraulic puncturing tools and pneumatic hammers both in Russia and abroad [4–6]. These machines feature simple and reliable design, convenient operation, and endurance.

In the recent decades, there is a trend of common employment of hydraulic percussion machines in the world. As against pneumatic hammers, hydraulic machines are technologically more complex and require higher manufacturing precision. Furthermore, their operation is associated with higher standards of maintenance, repair etc. [5, 6]. Nonetheless, hydraulic drives have considerable advantages. Namely, higher capability of increasing impact capacity as compared with hydraulic drives, or increasing efficiency of the machine. Furthermore, automation of the machine operation is possible in terms of adaptation of energy parameters of the machine to rock mass properties.

Thus, hydraulic machines required that their parts and assemblies are manufacture at high precision. Improvement of manufacturing precisions leads to higher labor per part and higher cost per product. This relationship goes along a hyperbolic curve (Figure 1), and cost grows much quicker than labor input.

![Figure 1. Labor input T and cost C of product versus its manufacturing accuracy D.](image)
2. Impact machine main features

The idea of the proposed layout of an impact machine is based on the lower manufacturing accuracy of the conjugate housing–piston parts at the preserved performance efficiency of the machine. This is achievable with seal elements. The power stroke of the piston is implemented under the action of energy of air preliminarily compressed in the power stroke chamber under the action of a hydraulic energy source fed in the backward stroke chamber (cocking chamber).

Sealing of the chambers is ensured by seals which allow reducing the manufacturing precision of the conjugate housing–piston, as well as enable decreasing the labor input of the machine manufacturing and repair, and its cost.

Seal elements disable conventional construction solutions connected with the energy source distribution using grooves and orifices in the housing, which are opened or closed as the piston moves. It is case, it is required to ensure reaction coupling between the piston position and the travel direction of the energy source using noncontact sensors, which means that when the piston position is determined, there is no mechanical connection between the piston and the sensor. Such noncontact sensors differ in the mode of functioning:

—noncontact capacitive disconnectors, to measure capacity of a capacitor with air dielectric entered by a monitored object;
—noncontact inductive disconnectors, to measure parameters of coil inductance with its field entered by a metal object;
—direct-acting and reflection-acting photoelectric sensors. The outlet signal defines the presence or the absence of a certain item which reflects or breaks the visible or invisible light emission from an emitter;
—ultrasonic sensors, based on the ultrasonic echolocation principle;
—microwave sensors, locate an item based on microwave emission;
—noncontact magnetic field sensitive disconnectors, as a simple pair of magnet and a hermetic contact, or Hall sensor [8, 9].

With regard to capabilities of these sensors, there are a few control circuits for the solenoid-operated valve of a hydraulic hammer.

![Figure 2](image)

Figure 2. (a) Control using sensors of end positions; (b) control using distance meter.

Figure 2a shows the hydraulic hammer control circuit with sensors of end positions. In this circuit, positions of the piston in the rear position and at the blow moment are picked up by end position sensors 3 (KD1) and 5 (KD2), respectively. Compressor 12 generates required pressure in receiver 11 connected with chamber 10. Under the action of compressed air in chamber 10, piston 3 is moved forward. At the moment of blow, KD2 is actuated and processor 2 sends signal to valve 4 which
connected hydraulic chamber 7 and the pressure line. The piston gets cocked and air is compressed in chamber 10. As soon as the piston reaches the rearmost position, sensor KD1 is cut out and processor 2 actuates the valve to connect chamber 7 with discharge line.

This circuit is the simplest in terms of implementation and maintenance. The sensors may have short trip distance and digital output, e.g. inductive or photoelectric sensors. The processor may be the simplest circuit based on chip NE555. Such control readily enables adjustment of impact power by means of change in the piston travel length. The piston travel length can be changed using:
— additional sensors (analogous to KD1) set at a certain pitch along the housing and capable to allow switching from one sensor to another;
— adjustable time lag after actuation of sensor KD1.

The control circuit with a distance meter in Figure 2b seems to be more promising. Sensor 3 measures the distance x to the piston end face and sends the data to processor which, depending on the obtained signal, switches valve 4. The main benefit of this circuit is smooth adjustment of the piston travel owing to continuous tracing of the piston position, which enables adjustment of blow energy and frequency.

This circuit can use sensors with analog outlet with sufficient distance of sensing, e.g. photoelectric or ultrasonic sensors. When such sensors are used, the monitored object is mostly immobile during measurement, is moves perpendicularly to the sensing line. In our layout of the hydraulic hammer, the piston moves along the sensing line of the sensor, at a sufficiently high velocity. As the sensor utilize the effect of reflection from the monitored object (light beam or ultrasound wave), they should have sufficiently high sampling frequency to position the piston in due time.

Sensor manufacturers provide such their characteristic as resolution, i.e. the minimum step in the distance measurement. As an object moves along the sensing line of the sensor, we introduce a sensing step. This value shows the travel of the monitored object per one measurement cycle of the sensor.

The sensing step \( h \) of the sensor is governed by the machine specifications and the sensing time (time of measurement):

\[
h = \frac{H t_{\text{meas}}}{0.4 \nu},
\]

where \( H \) is the piston travel; \( \nu \) is the wanted blow frequency; \( t_{\text{meas}} \) is the measurement time.

As a case study, we discuss the sensing step of four different-class sensors: Sharp GP2Y0A02YK0F, HC-SR04, Leuze Electronic ODSL 96BM and Microsonic mic+35 [10, 11]. The hypothetic percussive machine is assumed to have the blow frequency \( \nu = 2 \) Hz and the piston travel length of 500 mm.

**Table 1. Distance metering sensors**

| Sensor                          | Sharp GP2D12 | HC-SR04 | Leuze Electronic ODSL 96BM | Microsonic mic+35 |
|--------------------------------|--------------|---------|---------------------------|-------------------|
| Mode of functioning            | photoelectric | ultrasonic | photoelectric 150–800 | ultrasonic 60–600 |
| Measurement range, mm          | 100–800      | 20–4000 | 100–800                   | 60–600            |
| Effective angle of observation | 2–3°         | 15°     | –                         | –                 |
| Sampling time, ms              | 32           | 50      | 5                         | 64                |
| Declared resolution, mm        | –            | 3       | 0.8                       | 0.025–0.17        |
| Sensing step, mm               | 80           | 125     | 12.5                      | 160               |
It follows from Table 1, sensor Sharp has a sensing step of 80 mm and, thus, can take 6 measurements of the piston positions per one stroke of the piston in case of the assumed hydraulic hammer; these values are 125 mm and 3–4 measurements in case of sensor HC-SR04, and are 160 mm and 3 measurements in case of sensor Microsonic. The quickest-acting sensor is Leuze Electronic with the sensing step of 12.5 mm, which enables 40 measurement of the piston position during the piston travel. Accordingly, with at twice as higher blow frequency, the number of measurements reduces 2 times. This, the proposed circuit ensures adjustability of the piston travel in the percussive machine but imposes high standards on measurement and operation characteristics of sensors in order that they position the piston promptly.

Figure 3 shows the control circuit with across distance metering.

![Figure 3. Layout of hydraulic hammer with across distance meter.](image)

This circuit is similar to the circuit in Figure 2b but with the sensor installed across the travel line of the piston. The piston position is traced using the piston cone. Knowing the piston cone parameter and determining the clearance y variable during the operation of the machine, it is possible to trace position of the piston. Depending on the measured value y, the central processing sends the proper signal to the valve.

In this circuit, the measured distance is several times shorter than in the previous circuit, which allows using both photoelectric and inductive sensors. Moreover, as the sensor is placed between the sealers, the sensor can be unprotected as their location space is beyond the action of the excessive pressure from pneumatic chamber 10 and from hydraulic chamber 7.

Let us discuss the capabilities of such sensors available on the modern market [12, 13].

### Table 2. Distance metering sensors

| Sensor               | Balluff BAW 002H | DPA-M18-764 | IDA 09 | Everlight ITR-8307 |
|----------------------|------------------|-------------|--------|--------------------|
| **Mode of functioning** | inductive        | inductive   | inductive | photoelectric      |
| **Measurement range, mm** | 1–5              | 1–4         | 1.6–5.2| 1–10               |
| **Sampling time, ms**   | 1                | -           | -      | 0.04               |
| **Outlet, mA**          | 0–20             | 4–20        | 1.8–21 | 0–50               |
| **Signal change rate, mA/ms** | -                | 6           | 3      | -                  |
From the analysis of specifications in Table 2, the highest sensibility is a feature of photoelectric sensor ITR-8307. This sensor sensing step $\Delta h = 0.1$ mm, which is sufficient for the actual practice. However, in this case, the response rate of the sensor can be limited by the acceptance rate of the processor. For instance, with processor ATmega328P, the response rate is $120 \, \mu s$ has, which extends the step of the piston positioning by $\Delta h = 0.3$ mm. At the same time, the above described inductive sensors have the sensing step $\Delta h = 2.5$ mm, which allows taking up to 200 measurements within one piston travel 500 mm long.

The major disbenefit of this layout is the need to make the cone surface of the piston, which reduces the weight of the piston and, accordingly, decreases the blow energy. Furthermore, the reflection sensor requires that the surface of the cone is specifically finished and maintained clean during operation.

3. Conclusions

The most promising alternative for the accurate positioning of the piston is the circuit of the across distance metering. The use of logical controllers enables flexible setting of a hydraulic hammer and maximum possible automation of the setting depending on external environment. The further improvement of the control is aimed to determine the best performance of the hydraulic hammers and to design a new alternative of the machine.

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