HYDRAULIC LIFTING EQUIPMENT PROVIDED WITH ENERGY RECOVERY

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Abstract: This paper presents the structure and functioning of a new type of hydraulic lifting/lowering equipment, with the functional role of a cable hydraulic winch. It is used in hydraulic lifting/lowering installations, cabled, in order to recover/accumulate important portion of the braking energy, in load lowering phases, and respectively to reuse this potential energy recovered, in load lifting phases. The device is the subject of a patent application submitted by the authors of this paper.

Keywords: Hydraulic winch, recovery of braking energy.

1. Introduction

There is known a wide range of hydraulic cylinders, driven by pressurized hydraulic oil, which are used in lifting/lowering equipment: simple or double effect, with or without resilience, telescopic cylinders, plunger cylinders, etc. Upon lowering the load these cylinders discharge to the tank, through a hydraulic directional valve, the entire volume of oil accumulated in the active chamber during load lifting, without recovering the slightest part of the load potential energy. There are also known hydraulic lifting/lowering installations, with cylinders or rotary hydraulic motors, which recover some of the potential energy of the lifted load. They comprise cylinders or rotary hydraulic motors and hydraulic accumulators. Potential energy recovery is done in the load lowering phase, by directing the hydraulic oil to the pneumohydraulic accumulator. In the accumulator there is an elastic membrane separating two fluid media: nitrogen, which is compressed during the cylinder lowering, accumulating potential energy, and hydraulic pressurized oil, which during the lifting phase, by the expansion of nitrogen is directed to the cylinder / hydraulic rotary motor.

The main disadvantages of these types of installations are:
- the system for distribution of the working fluid, among the supply pump, cylinder / hydraulic rotary motor and pneumohydraulic accumulator is complicated in terms of structure and functioning;
- the cost price of the entire installation is high, since in addition to the supply pump, the hydraulic directional control valve and the hydraulic cylinder, the installation also comprises a second hydraulic directional valve, controlling oil intake/discharge into/from the accumulator, a throttle valve, two pressure relays and a pneumohydraulic accumulator.

2. Activity fields in which the hoisting winch provided with energy recovery can be integrated

The activity fields in which the lifting device provided with energy recovery, type cabled hydraulic winch, can be integrated, with great energy savings, include vertical hoisting installations, which have a common feature: a large number of load hoisting and lowering operations during daily functioning.

One such field is boring (drilling) deep wells, in the oil and gas industry, and also drilling deep wells for supplying water to the large consumers (farms, factories, urban localities, et al.).

Execution of such deep wells is done by means of hydraulic drilling rigs, such as that shown in Figure 1.
Structure of the drilling rig in Figure 1 is as follows: 1 – mud tank; 2- vibrating sieves; 3- suction head and hose sucking the drilling mud; 4- mud pump; 5-motor; 6-pump manifold; 7-drilling winch; 8-standpipe; 9- rotel hose; 10- hydraulic head spout; 11- grab crane (block of mobile pulleys); 12-cable active head; 13-crown-block (block of fixed pulleys); 14-steeple (mast); 15- floor man platform; 16- drilling pipe pile; 17-rig work platform (drilling pipe seat); 18-hydraulic head; 19- kelly; 20- rotating mass; 21- rig work platform; 22- discharge flange; 23- vertical eruption preventer; 24-horizontal eruption preventers lockable on the drill pipes; 25-drilling string; 26-drilling bit; 27- well bottom; 28- flow hose of drilling mud.

Execution of a deep well by means of such a rig goes through the following steps:

a) Digging (drilling) the well, done by using the drilling bit 26, driven in a rotary motion, through the drilling string 25 and kelly 19, by rotating mass 20. During the drilling, the walls of the well hole are protected from crumbling by the drilling mud, which is a dosed mixture of bentonite, trasgel and water. The viscosity of this mixture should be neither too low, in which case it would not provide protection from crumbling of the well hole, nor too high, in which case it would make difficult or even impossible the operation called “flushing of the well”. In the language used by drillers, a good drilling mud is the one which after squeezed in hand, “cakes”.

Fig. 1. Structural diagram of a fixed hydraulic drilling rig
The drilling mud is sucked through the mud tank 1, and discharged, through the hydraulic head 18, into the well which is being drilled, by the mud pump 4, driven by the motor 5. After filling the well hole which is being drilled with drilling mud, the mud is discharged, through the hose 28, into the mud settling sump. During drilling the well hole there is a constant flow, closed loop, of drilling mud, on the route mud settling sump –mud pump-hydraulic head-well hole- mud settling sump.

As the drilling bit 26 advances, between the Kelly and hydraulic head the drill pipes in the pile 16 successively interpose. Each time when the upper end of the drill pipe reaches off the rotating mass, the rotation of the drill string stops, end of the pipe fits into jaws, at the level of the rig work platform 22, and the hydraulic head detaches from Kelly. By means of the drilling winch 7, the grab crane is hoisted 11, till the floor 15, where the floorman attaches the hydraulic head to the end of a drill pipe in the pile 16, and after that the winch lifts the hydraulic head, coupled to this drill pipe, then lowers the unit hydraulic head-drill pipe, down to the level of the pipe fixed into jaws, to which it attaches itself.

There comes a new step of well drilling, for a depth equal to the length of the drill pipe, and after that the next drill pipe is interpolated into the drilling string. The number of drill pipes of the drilling string, equal to the number of hydraulic head hoisting and lowering operations, depends on the final depth of the drilled well.

In the case of deep wells the number of drill pipes used for drilling them is high, because their length is relatively small, as it depends on height of the steeple 14 of hydraulic drilling rig.

b) Extracting the drilling string, step which is initiated after completing drilling the well and consists in successive removal of the drill pipes used to drive the drill bit from the well. Using the winch and crane, each pipe mounted in the drill string is lifted and deposited on the floor man platform, after detaching it from the set of drill pipes mounted.

In this phase of execution the number of lifting and lowering operations made by the winch crane hook is equal to the number of drill pipes which are components of the drill string, and hence proportional to the depth of the drilled well.

c) Tubing the well, step which involves dropping a metal pipe column into the drilled hole, column which is meant to protect against well walls crumbling, after evacuating the drilling mud. Tubing the well is done with sections of metal pipe, of lengths lower than the height of the drilling rig steeple, which is welded between them, to form a continuous linear assembly, similar to that of the drill string.

In water wells, beside the captured aquifer layers, the metal column is perforated, and behind it pearl gravel is poured.

In this phase of execution the number of lifting and lowering operations made by the winch crane hook is equal to the number of sections of pipe components of the tubing column, and thus proportional to the depth of the drilled well.

d) Flushing the well, step which involves evacuating of drilling mud from the well bore. In high depth water wells, this operation is performed using an air compressor, a mammoth pump (air lift system) and the mud settling sump. This pump consists of two columns of different diameters from pipe, of modular lengths lower than the height of drilling rig steeple. The column of smaller diameter, through which air is blown, is welded at the lower end to the large diameter column, through which water is discharged.

To do the well flushing, there are dropped and mounted in a block, using the drilling winch, the sections of the mammoth pump, till close to the "sole" (bottom) of the well. Then the mammoth pump is connected through hoses to the compressor (the small diameter pipe) and the mud settling sump (the large diameter pipe).

In high depth water wells, flushing, rinsing and formation of the pearl gravel filter, which is behind the perforated metal column, take place within days of continuous muddy water pumping, from inside the well to the outside.

In this phase of execution the number of lifting and lowering operations made by the winch crane hook is equal to the number of sections which are parts of the mammoth pump, and thus proportional to the depth of the drilled well.
3. Advantages of the solution proposed for potential energy recovery and storage

There are known cabled winches, consisting of a winding drum, driven by a thermal or hydraulic motor, either external or built-in, which upon lowering the load do not recover any part of the potential energy available, as they are not provided with recovery and reuse systems. Such a winch is the one used in the installation shown in Figure 1.

The solution proposed for the lifting device with energy recovery/reuse consists of a hydraulic winch [1], characterized by the fact that the winding drum, besides the fact that it is driven to rotate by an external hydraulic motor, also includes within it a mechanism for driving a hydraulic pump which, during load lowering phase, fills a cylindrical tank with pressurized oil; the tank has a piston which compresses a set of springs that, during load hoisting phase, by the expansion of the springs, converts the pump into a hydraulic motor, thus helping, by means of the drive mechanism, to rotate the drum, resulting in reduced energy consumption for the external hydraulic drive motor.

The solution proposed for the lifting device offers the following advantages:
- It saves energy consumed to hoist a load;
- It has a highly compact design;
- The device can be adapted to a wide range of loads hoisted, by replacing the set of springs;
- Load hoisting/lowering stroke does not depend on the operational limits of the energy storage system, composed of the hydraulic pump, the piston and the set of springs.

4. Structure and operation of the hoisting device provided with energy recovery

The hydraulic lifting device provided with energy recovery comprises (see Figure 2): a drum 1, closed on the right side with a lid 2, which is driven by a low speed hydraulic motor 3, by means of a flange 4, attached on the left side, inside which there is mounted a crown gear 5, with internal toothing, which can drive by means of a pinion 6 and a coupling 7 an intrinsically safe valve gear pump 8.

The pump is fixed inside a cylindrical tank 9, in a cavity a, in which the drum 1 is housed in a bearing support, which also includes piston 10, against which there rests, by means of two centring discs 11, a set of springs 12, located in another cavity b of cylindrical tank 9. In the drum spindle there is a tubular rod 13, to which a check valve 14 is attached; this rod sets the hydraulic connection between the pump inlet port 8 and cavity b. The tubular rod also communicates, through an external fitting 15, with drainage port e of hydraulic motor 3.

Attached to the hydraulic motor 3, in the area of its supply ports, there is a double check valve 16, which has two ports c and d for connection to a hydraulic drive installation. The entire structure rests on a detachable frame 17.

Before startup the cavity b of tank 9 is filled with mineral oil.

The winch is connected to a hydraulic drive installation operating on mineral oil, as follows: ports c and d are connected to the work circuits under pressure, and port e of drain and return circuit, is connected to an oil tank.

Winch functioning, by phases, is as follows:

Standing under load, is achieved by the fact that hydraulic motor 3 cannot be rotated by drum 1, as long as the double check valve 16 is not unlocked, no pressurized oil existing at ports c or d.

Lowering the load: the port c is supplied with pressurized oil; this port unlocks the valve 16 on the discharge circuit d, and the rotary motor 3 rotates, for instance clockwise, also rotating the drum 1 through the flange 4. At the same time, the crown gear 5 drives the pinion 6 and the coupling 7, thus rotating the pump 8, which sucks oil through the tubular rod 13 from cavity b of the tank 9 and also from the drainage circuit, respectively the fitting 15, and discharges oil in cavity a.

If the piston 10 has reached the stroke end, but the load still needs to be lowered, rotating the drum 1 is allowed as the pump 8 will discharge through the intrinsic safe valve, which will usually be adjusted to the pressure required for maximum compression of the set of springs 12. During all this time working pressure at port c has the minimum value necessary to overcome friction, since rotation torque for pump 8 is provided by the load in lowering.
**Drum stopping** when lowering the load is done by interrupting the supply of the hydraulic motor 3 with working fluid, the valve 16 blocking itself again.

![Diagram](image)

**Fig. 2.** Longitudinal section through the hoisting device provided with energy recovery

**Hoisting the load**: port d is fed with pressurized oil; it unlocks the valve 16 along the discharge circuit c and makes the hydraulic motor 3 rotate, counter clockwise, also driving the drum 1 for hoisting the load. The drum, this time, is assisted by pump 8, which under the influence of oil pressure in cavity a, becomes a motor, rotated in the opposite direction compared to the operation as a pump and takes over some of the torque required for hoisting. During lifting of the load, pressure in cavity a drops, while the set of springs 12 expands, and working pressure at port d progressively increases, the hydraulic motor 3 gradually taking over the entire torque required for hoisting.

If the set of springs 12 has been fully expanded, and piston 10 returns to its original position, and lifting stroke must continue, this is possible as the pump 8 discharges into cavity a through the valve 14, from where it also sucks.

From design stage it is necessary that the set of springs 12 be tailored as clamping force to the maximum load which is to be hoisted. When reducing the maximum load to be hoisted, by means of the same winch, there is the possibility of replacing the set of springs by another one, along with centering discs 11, which are detachable.

Figure 3 shows the hydraulic diagram of the hoisting device provided with energy recovery, which keeps the same notations as in Figure 2.
Fig. 3. Hydraulic diagram of the hydraulic hoisting device provided with energy recovery

Conclusions

- The hoisting device provided with energy recovery can be used in hoisting installations with winches, components of hydraulic drilling rigs, freight and people elevators, anchor winches for ships, etc.
- The solution proposed by the authors of this paper for recovery of potential energy of vertically hoisted/ lowered loads is an application of the principles of reversibility and bidirectionality of constant capacity positive displacement machines, used in fluid power systems.

References