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LIFTING PLATFORM WITH ENERGY EFFICIENCY SYSTEM

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Reducing energy consumption is a current issue, widely analyzed and debated in specialized publications, and the direct implications on the environment cause an even greater concern to find solutions in this regard.

The subject of this article is the demonstration of the principle of recovery of the potential energy of descent in a lifting platform, achieved by integrating an energy efficiency system in the hydraulic installation of the platform drive, to reduce energy consumption. The proposed energy efficiency system contains two main elements: a linear hydraulic motor with the role of pressure multiplication and a pneumohydraulic accumulator for storing the recovered energy, which relate to a series of devices and connecting elements to fulfill the purpose. The article presents experimental results obtained at the verification of functionality of potential energy recovery principle patented by INOE 2000-IHP [1].

Keywords: energy efficiency; potential energy recovery; scissor lift; drive system

1. Introduction

Lifting platforms are used in many fields for lifting loads that can vary from a few tens of kg to thousands of kg, sometimes even tens of thousands of kg, and the lifting heights can be of the order of meters or tens of meters. There are fixed or mobile platforms, and their actuation is done by one or more cylinders whose energy is provided by internal combustion engines or electric motors.

Platforms perform repeated lifting-lowering cycles, especially those used in warehouses, manufacturing facilities, shops, etc., the potential energy of the lowered load being wasted and converted into heat, which brings another disadvantage to the system. Potential energy recovery would help increasing the energy efficiency of these equipment and, implicitly, reducing energy consumption and pollution.

Potential energy recovery has attracted a lot of interest, being intensively studied and disseminated, especially in excavators, as they perform numerous

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lifting-lowering cycles with workloads. The drive system of the platform is very similar to the drive system of an excavator arm.

Several techniques are used for the recovery of potential energy, but the most popular is the transformation of the hydraulic drive installation into a hybrid installation, which includes at least one energy storage element that can be: hydropneumatic (diaphragm accumulator, piston) [2-5], electric (batteries, supercapacitors) [6] or kinetic (flywheel). Other techniques refer to regeneration methods, the implementation of new equipment generation of energy control and management strategies, etc. [7-11].

An important aspect in energy recovery is to identify that part of a complex installation that offers the opportunity to recover as much of the energy that is lost as possible, but with a minimum cost. Thus, in paper [12] the authors identified three energy-consuming systems in an excavator: the thermal engine system, the hydraulic drive system of the excavator and the hydraulic drive system of the cylinders of the arm, the handle, the bucket and the rotary engine. Only a percentage of 7.7% of the total energy consumed is used for actual work by the three cylinders, the rest of the energy is used by the other systems, and some is lost. All these drive systems can provide energy for recovery. In the paper [13], the excavator drive system was modified in order to improve energy efficiency, by adding a pneumohydraulic accumulator operated by a proportional distributor and a hydraulic motor, making it 10% more efficient compared to the conventional system. Another potential energy recovery and regeneration device consisting of a hydraulic motor, inverter and accumulator was integrated into the drive system of an excavator leading to the regeneration of approximately 45% of the potential energy of the boom lowering and presented in the paper [14]. The theoretical research mentioned in the work [15] shows that the energy recovery system containing a flywheel for energy storage and a regeneration circuit implemented in the drive system of the excavator arm is 13% more efficient than the flywheel recovery system.

In hydraulic lift platforms where the fixed-flow bidirectional pump is driven by an asynchronous motor powered by a frequency converter, research results show that significant energy savings are achieved [16]. Consumption is 10% lower than the classic system with a fixed pump driven by an asynchronous motor, because the modernized drive system uses 67% energy compared to the standard one, but the modernized solution is 100 euros more expensive. In [17], two energy recovery methods for forklifts were compared: an electrical one and a hydraulic one. The research results showed that both modes are suitable and provide energy savings of up to 36% for the electrical system and up to 45% for the optimized hydraulic system. The energy recovered in the case of an industrial elevator [18] where the storage is done with the help of an accumulator combined with an acid battery is 5÷32%. In article [19], an electrohydraulic forklift was studied and it was shown that it is possible to use an electric servo motor to control a hydraulic lifting system and recover energy. The potential energy recovered in the descent phase reached a maximum percentage of 66%.

Kinetic or potential energy recovery domain is very large, but the applications based on electrohydraulic systems with bidirectional reversible servo pumps [20-31], the direct drive hydraulic (DDH) motor [32-36], systems with multiple chamber cylinders [37-39], and many others have good results and notable performances.

The large companies producing hydraulic equipment develop new, complex and high-performance systems (e.g. Syntronix system, pumps with electronic secondary control, press modules from *Bosch Rexroth*, Drive Controlled Pump (DCP), variable AC-speed and frequency drives, controllers from Parker Hannifin, Programmable Logic Controllers, converters from *Eaton*, servomotors, brushless DC motors, PMSM, operating and monitoring system from *Moog*, and so on), which reduce energy consumption.

Heavy-duty vehicle manufacturers are making great strides in potential energy recovery, with most achievements being hybrid systems with high energy recovery capabilities. Japanese company Komatsu claims that the hybrid version of a 22 t excavator achieves fuel savings of 25÷30% compared to the standard model, but the cost of the machine is 25÷50% higher. The Swedish company Volvo announced that the hybrid electric charger offers 10% fuel savings and higher performance than traditional variants. US company Caterpillar has developed a 50 tonne hybrid excavator where energy has been recovered from arm operations and they claim an average fuel economy of 25÷30%, with the machine running 5% faster than the standard system.

The recovery energy varies depending on each system specifications and operating conditions. Compared to modern energy recovery systems promoted in the specialized works mentioned above and involving last generation components, the presented system is much cheaper and suitable for the purpose for which the platform was designed (maximum load of 320 kg and lifting height of 1250÷1300 mm), at an affordable price for a beneficiary.

2. Materials and Methods

2.1. Hydraulic diagram and physical model of the lifting platform with energy efficiency system

The energy efficiency system of the lifting platform consists in the implementation of some components in the hydraulic system, with minimum costs, that aim to achieve a partial recovery of the potential energy of the load, in the lowering phase of the platform.

The classic hydraulic system of the platform (presented in Fig. 1) consists of an electro-hydraulic unit that transmits energy, by means of hydraulic oil, to a linear hydraulic motor to perform the mechanical work of lifting (the lifting cylinder, HC1), vertically, a load placed on the platform nacelle. The recovery system is interconnected in the platform drive system and contains a second linear hydraulic motor with the role of pressure multiplier (multiplier cylinder, HC2), a hydropneumatic accumulator (accumulator, HA) and several distribution and control devices. The power flow is directed, in the lowering phase of the platform, from the load to the accumulator after passing through the linear pressure multiplier motor, and in the lifting phase with recovered energy, the energy flow is directed from the accumulator to the load.

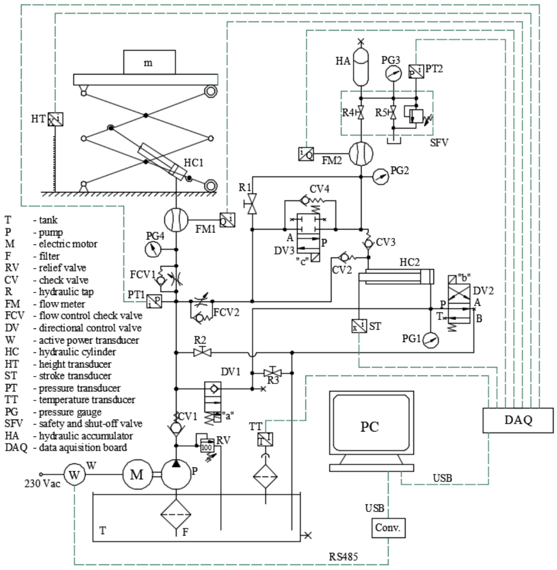

Fig. 1. Lifting platform with energy efficiency system - hydraulic diagram [1]

Fig. 2. Lifting platform with energy efficiency system - physical model

The components of the hydraulic system (Fig. 1) are: T - oil tank, P - pump, RV - relief valve, F1 - filter, CV1, CV2, CV3, CV4 - check valves, R1, R2, R3, R4, R5 - hydraulic taps, FM1, FM2 - flow meters, FCV1, FCV2 - flow control check valves, DV1, DV2, DV3 – directional valves, HC1, HC2 - hydraulic cylinders, HA - hydraulic accumulator, M - electric motor, SFV - safety and shut-off valve. The operating parameters of the hydraulic installation (pressure and flow) are monitored using pressure gauges PG1, PG2, PG3 and PG4, pressure transducers PT1 and PT2 and flow meters FM1 and FM2. Hydraulic oil temperature is monitored with a TT temperature transducer, electrical consumption is recorded with an active power transducer W, and platform displacement and linear hydraulic motor displacement are recorded with height transducer HT and stroke transducer ST. All transducers are connected to a DAQ data acquisition board and a PC computer, together forming the data acquisition system.

The technical characteristics of the main elements are: electric motor (M): $P = 0.75\ kW$ and $n = 1450\ rpm$; gear pump (P): $V_g = 3.2\ cm^3$ and $p_n = 250\ bar$; relief valve (RV): $Dn = 6\ mm$, $p_n = 160\ bar$; linear hydraulic motor (HC1): *Φ50.8/Φ31.76/406.4 mm*; linear hydraulic motor for pressure multiplication (HC2): *Φ63/Φ40/350 mm*; hydraulic accumulator (HA) $V = 5\ dm^3$; $p_n = 400\ bar$ with safety and shut-off valve (SVF); 4/2 directional control valves (DV2, DV3); 2/2 directional control valve (DV1); check valves (CV1, CV2, CV3, CV4): $Dn = 6\ mm$; flow control check valves (FCV1, FCV2), see Figure 1 and Figure 2.

2.2. The principle of potential energy recovery

The energy efficiency system of the lifting platform uses the principle of potential energy recovery which is as follows: the platform performs several liftings and lowerings of the load vertically, for lifting using energy from the electrical network, and for lowering no energy from the network is used. The lowering of the platform takes place under its own weight. Part of the potential energy of descent is taken up by means of the hydraulic oil and transmitted to the linear hydraulic motor for multiplying the pressure and then to the accumulator which stores it. Afterwards, the energy stored in the accumulator is used to lift the load vertically again.

So, the operation of the platform with recovery system contains three working phases: I-lifting, II-lowering and III-lifting with recovered energy. The first two phases are repetitive (*i* - number of iterations) and aim to charge the accumulator to its maximum capacity, the third phase of raising the platform with recovered energy follows after reaching the maximum pressure in the accumulator, and the lifting of the platform takes place by discharging the accumulator. In **phase I**, lifting, the motor powered from the electric network drives a pump that sends hydraulic oil under pressure to a linear hydraulic motor (HC1) to drive the platform lift mechanism. At the same time, the fluid reaches the annular surface of a linear pressure multiplier hydraulic motor (HC2) leading to the withdrawal of its rod, and the fluid from the piston chamber is discharged to the tank through the directional control valve (DV2) switched to field "b". Valves R1, R2, R3 and R4 are closed.

A pressure relief valve protects the hydraulic system from overload, and a throttle controls the speed of lifting and lowering the platform.

In **phase II**, of descent, the electric motor is no longer actuated, the directional control valve (DV1) is actuated on the "**a**" field, and the fluid arrives simultaneously on both sides of the HC2 piston. As a result of the difference of the two areas, the piston will make the stroke, and the oil in the rod chamber at a higher pressure will enter the accumulator (HA) of the recovery system since valve R4 has been opened. Valve R5 and pressure relief valve provide accumulator protection against overpressure. The accumulator (HA) is charged whenever the platform descends (*i*), until the maximum working pressure is reached.

After charging the accumulator (HA), by opening valve R4 and actuating field "**c**" of the directional control valve (DV3), **phase III** takes place (lifting with recovered energy). The platform is lifting with the help of the energy stored in the accumulator up to a certain level (corresponding to the available energy recovered). To reach the maximum level, it is necessary to actuate the electric motor, similar to phase I.

The transfer of potential energy between the system components, corresponding to the 3 working phases, is diagrammed in Fig. 3, Fig. 4 and Fig. 5 thus:

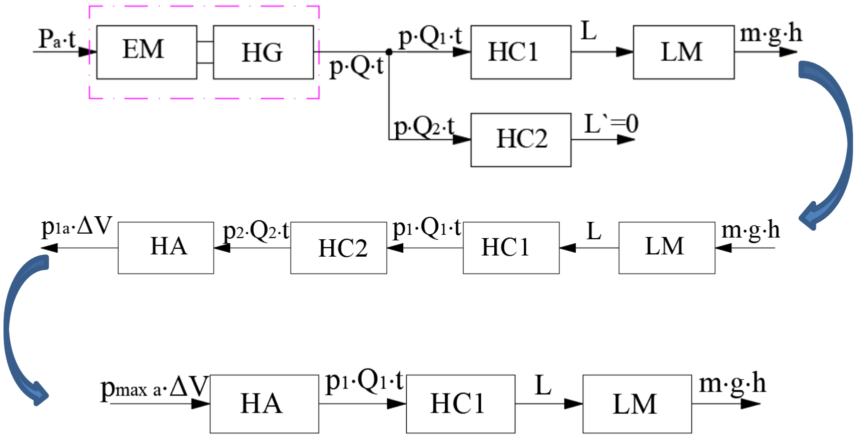

Fig. 3. Lifting with electricity consumption (Phase I)

Fig. 4. Lowering and recovering potential energy (Phase II)

Fig. 5. Lifting with stored and reused potential energy (Phase III)

The mathematical expressions of energy transfers, corresponding to the 3 phases, are:

Phase I $$P_a \cdot t \rightarrow p \cdot Q_1 \cdot t = L = F \cdot d = m \cdot g \cdot h = E_p \quad (1)$$

Phase II $$E_p = m \cdot g \cdot h = L = F \cdot d = p_1 \cdot Q_1 \cdot t = p_2 \cdot Q_2 \cdot t = p_{1a} \cdot \Delta V \quad (2)$$

i

Phase III $$p_{max\,a} \cdot \Delta V = p_1 \cdot Q_1 \cdot t = L = F \cdot d = m \cdot g \cdot h = E_p \quad (3)$$

The role of HC2 in the chain of transmission of potential energy from HC1 to the accumulator is to raise the value of the oil pressure so that it is possible to store the energy in the accumulator (phase II) and to create a pressure drop necessary in phase III, when recovered energy is used for rising platform up to a certain level, and after that the motor is turned on to continue the lifting up to the maximum level.

3. Experimental results

Numerical and graphical data obtained and recorded from the tests show the time evolution of pressure at HC1, HC2, HA, flow rates at HC1 and HA, platform lift height (platform course), HC1 course, oil temperature and the power absorbed from the electrical network. The test referred to below was carried out for a preload of the pneumohydraulic accumulator (AS5P360CG8) $p_0 = 32\ bar$, with an initial volume $V_0 = 5\ l$ and a no load placed on the table nacelle $m = 0\ kg$. The own mass of the platform is m_0.

3.1. In **phase I**, lifting the load (mass platform $\boldsymbol{m_0}$) the pressure value recorded in the piston chamber HC1 has a maximum, after which it decreases slightly and registers an almost constant level around the value $\mathbf{50}\ \boldsymbol{bar}$ throughout the lifting course of the platform.

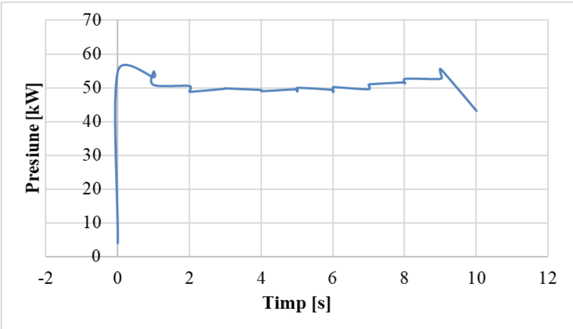

Fig. 6. Pressure evolution in the HC1 piston chamber, Phase I

During the stationing of the platform, the pump is stopped, and in the hydraulic circuit the pressure to keep it in position is approx. $\mathbf{43}\ \boldsymbol{bar}$. The lifting time of the platform corresponds to the duration of the HC1 course.

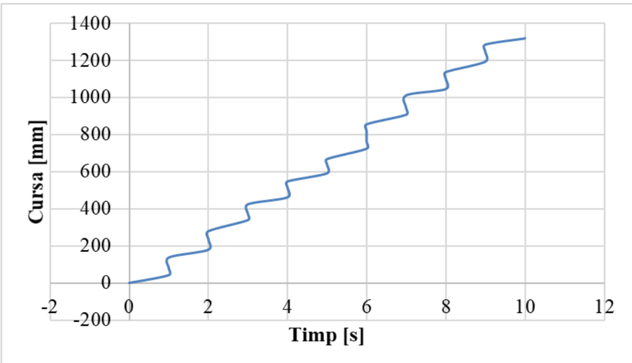

Fig. 7. Lifting course of the platform, Phase I

3.2. In the **phase II**, when the load is lowered, the fluid coming out of the HC1 piston chamber is led to the HA, after its pressure value is multiplied by HC2.

During the first descent of the platform, throughout the duration of the phase, the pressure in the accumulator increases from 32 bar to 38 bar but there is also a slight tendency to decrease the pressure in the accumulator, due, among others, to heat transfer with the outside.

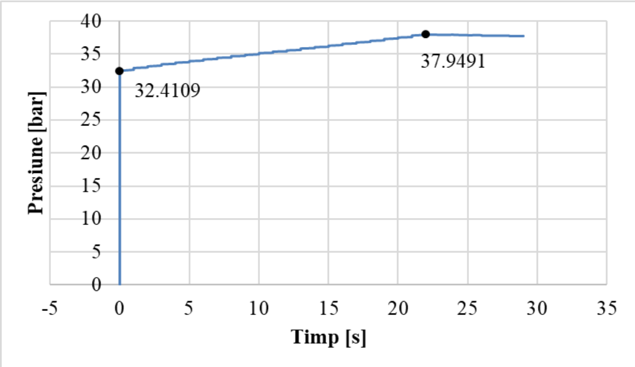

Fig. 8. Accumulator charging, Phase II (first lowering)

On the second descent, the pressure in the accumulator increases from 38 bar to 43 bar, on the third descent the pressure value reaches 48 bar and on the last (partial) lowering a final value is reached 50 bar.

A part of the load's potential energy accumulates with each descent into the accumulator causing its pressure to increase to a maximum value, at which point an equilibrium is reached between the pressure in the piston chamber HC1 and that in HA, directly proportional to the multiplication factor of HC2, equal to the area ratio $(63^2/(63^2-40^2)=1.675)$, and the platform can no longer descend under its own weight.

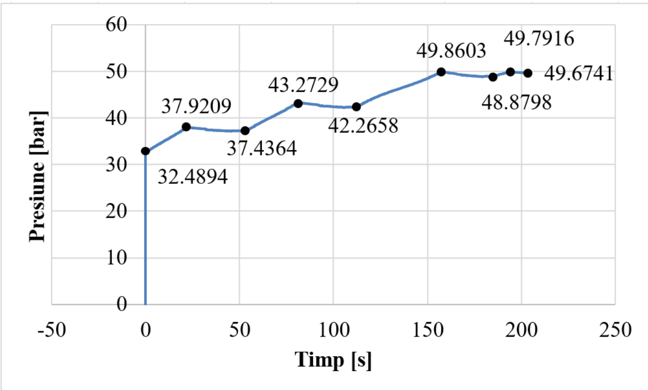

Fig. 9. Accumulator charging, Phase II (for successive descents)

It is observed that after 3.11 consecutive descents, the platform stops lowering. If the lowering of the platform is no longer possible, due to the balance between the pressures in the piston chamber HC1 and the pressure in HA (incomplete lowering), valve R3 is actuated.

Therefore, the potential lowering energy (mgh) recovered is not transformed into electrical energy, but is transmitted through the hydraulic oil to an accumulator that stores it in the form of hydropneumatic energy $(p_{max\ a}\Delta V)$, from where it is reintroduced into the system when lifting loads.

3.3. Lifting the load with recovered energy is possible in **phase III**, which is achieved by opening the hydraulic path from HA to HC1, without operating the pump unit. The lifting of the platform takes place partially until the stored energy is consumed, as shown in the graph below. To continue lifting to the desired height or complete the course, the platform drive system is connected to the electrical network (phase I).

The energy stored after the 3.11 descents was used to lift the platform, the course achieved being 381 mm (out of a total to 1300 mm be measured during the lifting).

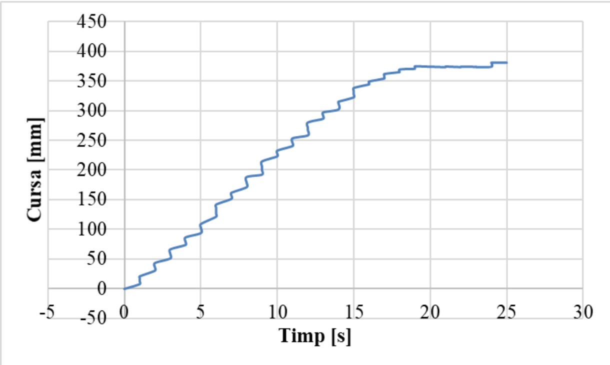

Fig. 10. Lifting course of the platform with recovered energy, Phase III

The program created in LabView for executing platform commands and data acquisition allows lifting and lowering by operating the buttons "**Ridicare+retr cil**", "**Coborâre, înc. acum**", "**Ridicare din recup**" and "**Ridicare maxima**" (“Lifting and cylinder rod withdrawal”, “Descent and charging the accumulator”, “Lifting from recovery” and “Maximum lifting”), and displays numerically and/or visually, in real time, information on the pressures in the lifting cylinder and accumulator, the power of the electric motor, the course of the platform and the course of the lifting cylinder, the flow rates at the lifting cylinder and accumulator, the ON/OFF mode of actuation of the electromagnets, the oil temperature. The results are displayed graphically for the mentioned parameters and can be numerically exported as a txt or xlsx file. In Fig. 11 shows how to charge the accumulator by performing successive lifting and lowering courses.

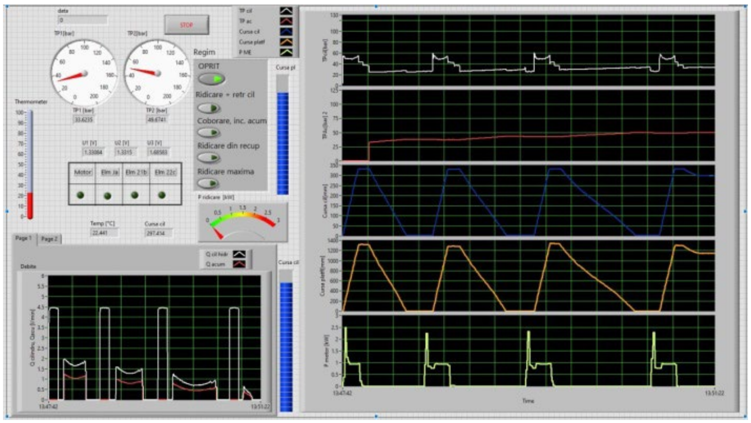

Fig. 11. Successive lifting and lowering courses (*i*), Phase I + Phase II

In Fig. 12 shows how to discharge the accumulator by making the platform run with recovered energy.

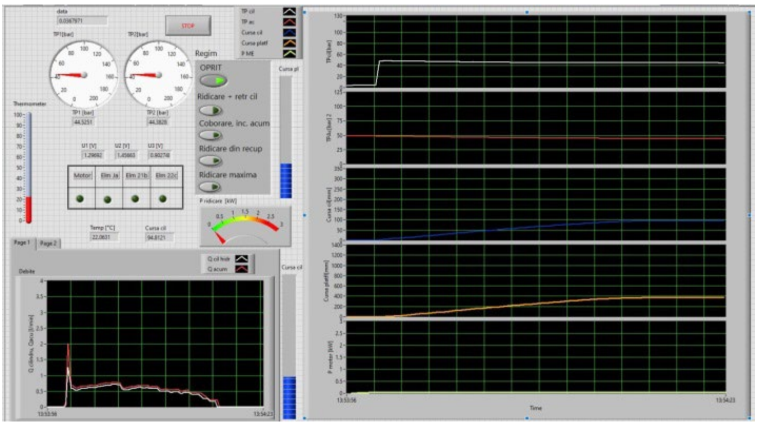

Fig. 12. Accumulator discharge, Phase III

Partial realization of the platform course with recovered energy causes the pressure in the accumulator to decrease, but to a value greater than the precharge pressure, which means that the accumulator will reach full pressure again with fewer descents.

4. Discussion

The energy stored or released by the accumulator during its working can be expressed as:

$$E = \frac{V_0 p_0^{\frac{1}{k}}}{k} \int_{p_1}^{p_2} p^{-\frac{1}{k}} dp = \frac{V_0 p_0^{\frac{1}{k}}}{k-1} \left[p_{2a}^{\frac{k-1}{k}} - p_{1a}^{\frac{k-1}{k}} \right] \tag{4}$$

where p_0 and V_0 are the nominal volumes of the initial charge pressure of the accumulator, respectively; p_{1a} and p_{2a} are the minimum and maximum working pressures of the accumulator, respectively, while k is adiabatic exponent, in this case. The stored energy is then converted into mechanical work to lift the load:

$$E = mgh \tag{5}$$

where m is mass, g is gravitational acceleration and h is the height to which the platform is raised.

But the efficiency of the system can be calculated much more easily from the acquired data. As a result of the successive liftings and lowerings, the accumulator was charged with potential energy of lowering which caused a lifting course of the platform of *381 mm* out of a total of *1300 mm*. This means that 29% out of the course was performed only with the energy stored during the 3.11 consecutive descents, and this percentage can be defined as a global rate of the energy efficiency system. By dividing the percentage of height achieved with recovered energy by the number of descents that led to charging the accumulator, the rating of the energy efficiency system is obtained:

$$\eta = \frac{x}{h} \cdot \frac{1}{N_c} \cdot 100 = \frac{381}{1300} \cdot \frac{1}{3.11} \cdot 100 = 9.4\ \%, \tag{6}$$

where x - the platform course performed only with recovered energy; h - the established lifting height of the platform; N_c - the number of descent courses.

This efficiency was not quantified with the energy remaining in the accumulator after performing the lift course with recovered energy.

The amount of recovered energy is transposed into the lifting height and also covers the energy losses of the system, since the pump is not actuated. In addition, the recovery lift starts from the lowest level at which the platform is located, which is the most unfavorable position from the energy point of view.

According to the data acquired in this experimental trial, it emerged that the rate of the energy efficiency system has a positive value and that at a complete lowering the system recovered potential energy to perform 9.4% from the established lifting height of the platform, a value comparable to the numerical data obtained and presented in [12].

From a functional point of view, the principle of energy efficiency through potential energy recovery for the presented assembly is validated by the experimental data, but the system must be optimized by correlating certain functional parameters, so that the energy recovery is maximum. From simulation, after optimizing the parameters, a percent of about 25% for potential energy recovery and reuse is obtained.

The recovered energy has a greater value, the greater the potential energy (mgh) when the load is lowered. Since g it is a constant, there remain two variables that influence the energy: mass and height. However, the height is usually imposed by the application, and the mass also varies according to the application, as well as the limits imposed by the platform builder. The most favorable case to obtain the maximum recovered energy is when the platform is used for lowering large loads and lifting small masses, which is impossible to do all the time. On the other hand, the energy stored in the accumulator ($p_{\max a}\Delta V$) depends on its technical characteristics: the volume and the precharge pressure. A large volume of the accumulator would require a large number of descents, and a small volume would not allow storing too much energy; likewise, a high precharge cannot allow the accumulator to charge, and a low precharge would lead to a large number of descents to reach the maximum pressure in the accumulator. Therefore, a correlation between the value of the mass to be lifting /lowering and the technical characteristics of the accumulator would be necessary. The significant difference between the 9.4% efficiency obtained in my article and the values obtained by large companies can be explained by several factors: state-of-the-art technologies and high-quality components and materials, hybrid systems, optimized functional parameters.

5. Conclusions

The energy efficiency system accomplished according to the solution patented by INOE 2000-IHP and implemented in the platform's drive system is functional and meets the purpose for which it was created.

The potential energy recovery principle is validated by the calculated efficiency value, which, for the test carried out, is positive and equal to 9.4%.

The achieved energy economy is comparable in value to that obtained and disseminated in the international specialized literature [11, 12, 14].

A further increase in efficiency is possible by correlating the value of the load to be lifted with the technical characteristics of the hydropneumatic accumulator or by completing this technical solution with: new elements from a constructive point of view, regeneration circuits, energy control and management techniques, AI techniques or joining several elements and techniques.

A benefit/cost calculation is needed to motivate the implementation of the solution to increase energy efficiency, because this can lead to an unjustified cost.

R E F E R E N C E S

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