ENERGY REUTILIZATION AND BALANCE ANALYSIS IN A HYDRAULIC CRANE

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ABSTRACT

Up to now a lot of energy saving methods and strategies have been applied in some hydraulically driven equipment. However most of them are concerned with how to minimize hydraulic energy supplies to improve their energy utilization. In this paper, a drive concept with energy reutilization is presented from the start-point of energy balance relation. An assistant system with an accumulator and balance cylinder is used to drive Joint 1 of an example crane together with Electro-hydraulic Load-Sensing (ELS) system. The practical measurement proves its feasibility. The energy balance analysis is completed. The results show that the drive concept can improve its energy utilization in the crane.

KEYWORDS: Energy saving, hydraulic crane, ELS system, accumulator, energy reutilization

INTRODUCTION

In the past people did not recognize the importance of energy saving but pursue the performances of components and systems to fulfill a defined function. For the recent decades the situations have been changed. With the wide application of hydraulically driven machines, more research interests have been given in the energy saving measures and strategies due to fuel economy, environmental requirement, etc. Therefore a lot of energy efficient ways have been applied in different kinds of hydraulic equipment, such as load-sensing systems and secondary controlled power units [1]. However most of them are concerned with how to minimize the hydraulic energy consumption to improve their system efficiencies.

Hydraulic cranes are typical mobile machines. Their common characteristic is that they can be used to move and lift a mass load from a position to another one. It is known that different kinds of LS technologies have been used to improve their energy efficiencies. However energy utilization in hydraulic cranes is still unsatisfactory [2]. So it is necessary to get clear knowledge about the sources of their power losses in order to improve their energy utilization.

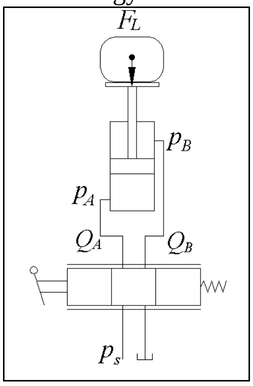


Fig. 1 Valve controlled cylinder

The simple circuit of valve controlled cylinder, shown in Fig.1, is used to lift a mass load. Its power transmission is depicted as follows:

$$P_{loss} = P_{in} - P_{mech} \tag{1}$$

For the downward movement F_L is overrunning, therefore P_{mech} is negative. In this situation P_{loss} (their majority may be changed into heat) is from two parts, one is from hydraulic power of pump P_{in} and the other is from the gravitational power P_{mech} done by the load when the direct force actuated on the cylinder is a mass load. The former is unnecessary power consumption and can be reduced by the use of different load sensing technologies and control strategies. The latter is the necessary cost for the velocity and motion control of cylinder and load. Here the hydrostatic equation doesn't consider kinetic energy. So the energy losses in the system are from not only from hydraulic pump but also from mass load.

For the upward movement F_L is resistive and P_{mech} is positive. So the supply energy from pump drives the load and does useful work.

Very typically the overrunning or resistive forces on the cylinders of a hydraulic crane exist alternatively when it moves a load.

Therefore the measures and strategies to save hydraulic power P_{in} cannot finally reduce energy losses as

minimum as expected, especially for multi-joint operation in crane systems. It is one of the reasons why energy utilization in industrial cranes is poor. The authors [2] have suggested that energy reutilization in hydraulic cranes would be an interesting and valuable topic.
In fact energy regeneration is not a new concept. Much has been reported concerning its applications of different energies. The kinetic energy storage in public service vehicle have been used widely [3-4]. In metal forming machines kinetic and potential energy recovery has achieved practical benefits [5]. All the experiences are helpful to develop a concept to reutilize energy and minimize throttling losses in hydraulic cranes.

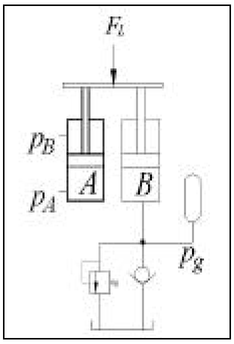


Fig. 2 Driving principle of energy reutilization

In this paper our investigation is aimed at a way of energy reutilization in a hydraulic crane from the start-point of energy balance equation. When equation (1) is changed into equation (2), it is possible that P_{loss} could be reduced and P_{in} could be saved.

$$P_{loss} = P_{in} - (P_{mech} + P_{acc}) \quad (2)$$

where, P_{acc} is storage power in the accumulator.
The hardware realization of equation (2) is simply shown in Fig.2, where Cylinder A is the joint cylinder driven by hydraulic pump and Cylinder B is the balance cylinder.

APPLICATION IN AN EXAMPLE CRANE

The above concept of energy reutilization is used for the drive of Joint 1 in an example hydraulic crane in Fig.3.

(1) An Example Crane

The crane is a Loglift loader. It has four main DOFs: rotating, lifting, transferring, and telescope.
The crane is driven by an ELS system. Its overall configuration is described in Fig.4. The choice of ELS system in test is to achieve good behavior, stable and fast response [6]. Four hydraulic functions are supplied by one common pump.

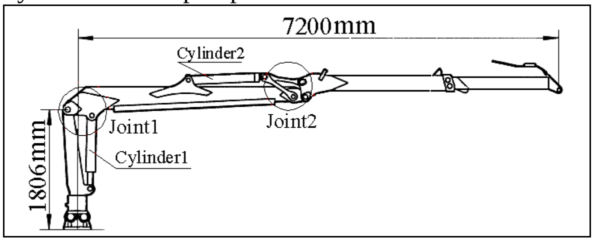


Fig. 3 An example hydraulic crane

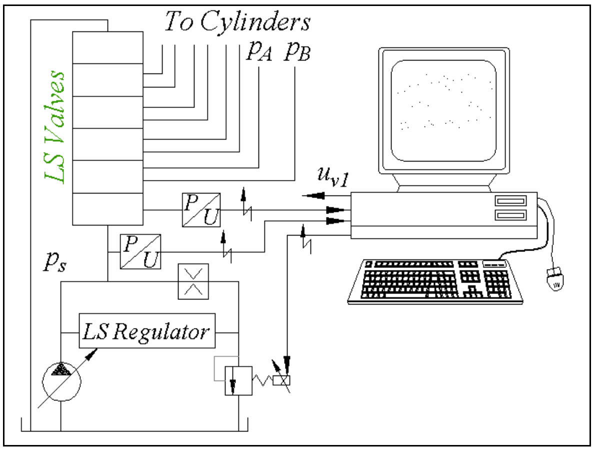


Fig.4 The crane system set-up

(2) Experiment and Result

The measurement situation mainly consists of the following:

- The assistant system in Fig.2
- The crane boom in Fig.3
- The ELS crane system, shown in Fig.4, is used to drive Joint 1. During the practical measurement other joints have no movement.
- The relevant measurement equipment and software.
- The measurement process at charge pressure p_{g0}=0 or 7.5MPa is completed when m_L=500 kg.

When p_{g0}=0 the assistant system has no obvious effect on the operation of Joint 1 except for additional friction forces. Therefore it is reasonable to regard the system at p_{g0}=0 as the original crane system.
Fig.5 and Fig.6 show the practical changes of measurement parameters: stroke position y_1, cylinder pressure p_A, pump pressure p_s and gas pressure p_g at p_{g0}=7.5 MPa. Compared with the original crane system, the following results can be drawn:
For the downward motion p_s has no change and p_A is greatly reduced, shown in Fig.5.
For the forward motion p_s and p_A is greatly reduced, shown in Fig.6
Therefore it is reasonable and feasible for the drive concept to improve the energy utilization in the hydraulic crane.

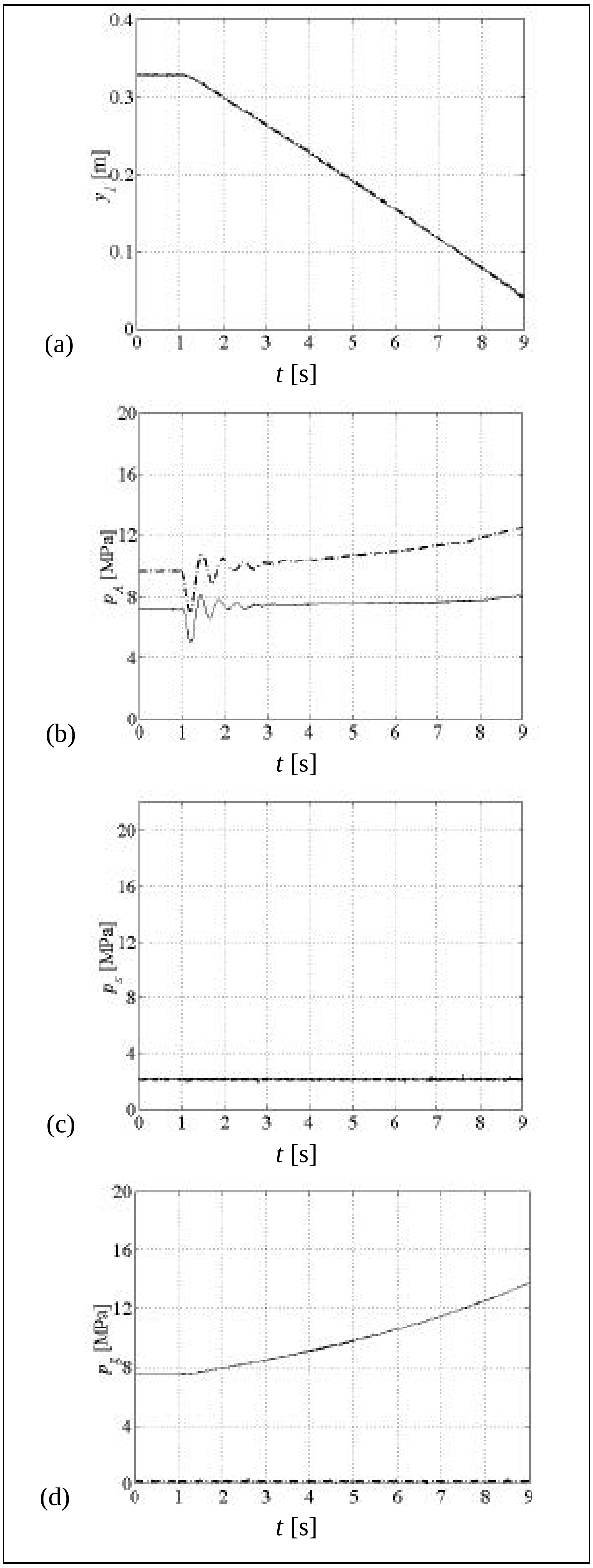


Fig.5 Measurement for the downward

_._._._._. p_{g0}=0.0MPa

———— p_{g0}=7.5MPa

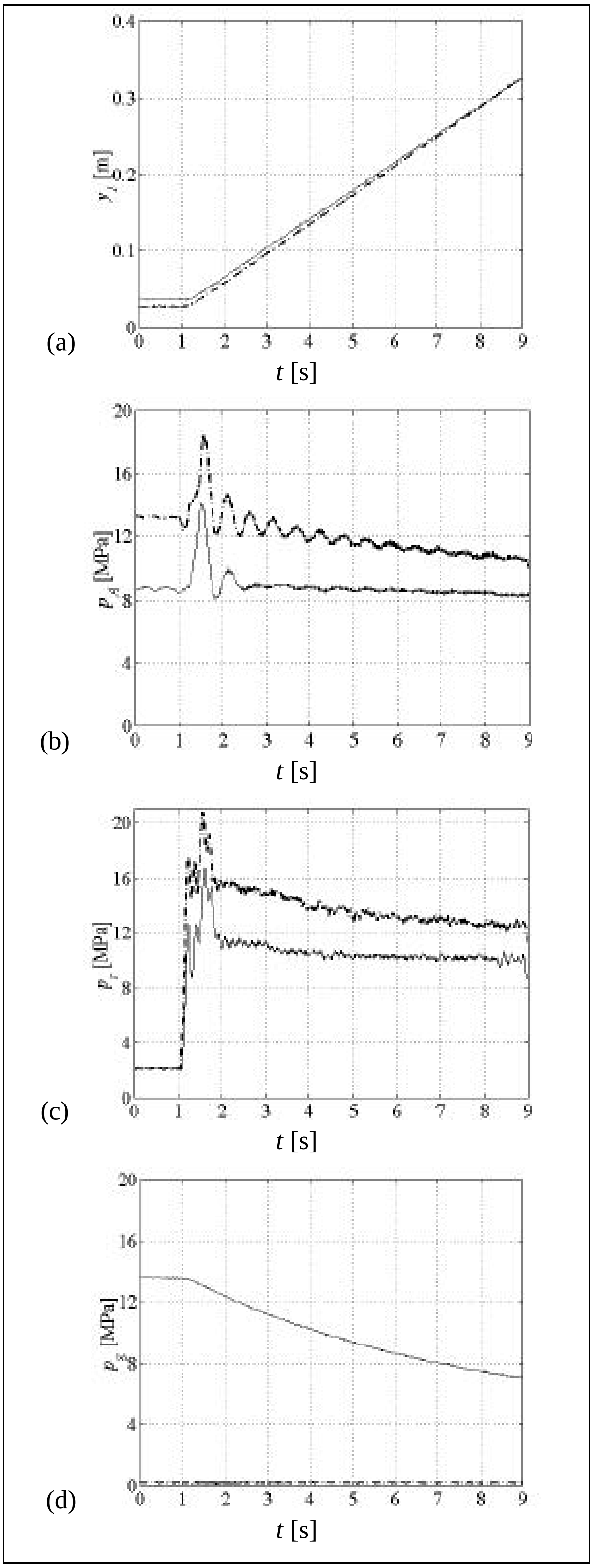


Fig. 6 Measurement for the upward movement

_._._._._. p_{g0}=0.0MPa

———— p_{g0}=7.5MPa

ENERGY EVALUATION AND BALANCE ANALYSIS

The measurement describes the real changes of y_1, p_A, p_s and p_g. The energy transmission is evaluated for their measurement process.

(1) Assumptions

The following assumptions are set in order to compare and analyze conveniently:

a. Cylinder 1 has the same start/end point and displacements. For the practical measurement it is open loop control of cylinder position.

b. A simple process for the accumulator is introduced wherein the gas volume follows an isothermal compression followed by an adiabatic expansion according to the ideal gas law relationship:

$$p_g V_g^n = constant$$

V_g is the gas volume of the accumulator.

c. All the calculation is hydrostatic analysis without consideration of dynamics and kinetic energy as well as friction, leakage, etc.

(2) Mathematical Models

Power and energy transfer in the crane system can be evaluated according to the following models:
The power loss P_{loss} and the energy loss E_{loss} in valves are calculated by equation (3) and (4), respectively.

$$P_{loss} = \sum_{i=1}^{k} (P_{in} - P_{mech}) \quad (3)$$

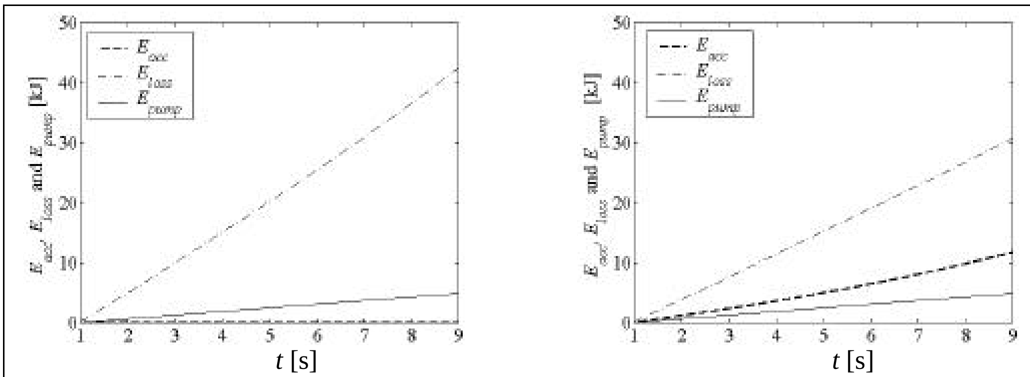
$$E_{loss} = \int_0^t P_{loss} dt \quad (4)$$

The pump supply energy E_{pump} is given by

$$E_{pump} = \int_0^t p_s Q_s dt \quad (5)$$

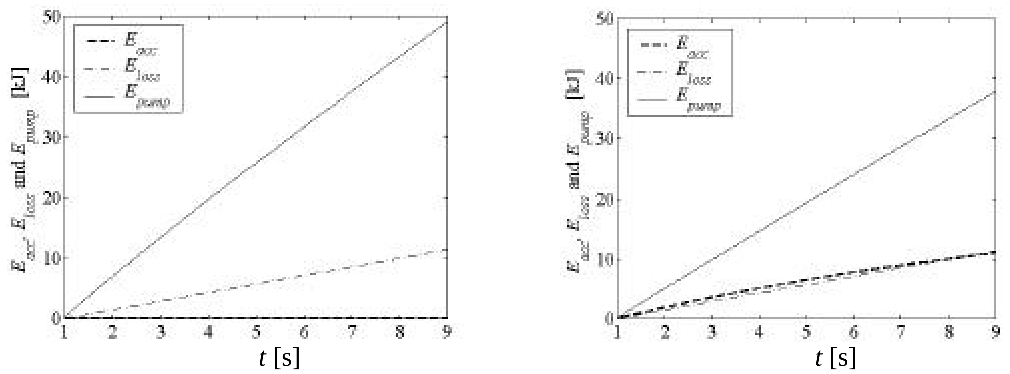
The storage energy in the accumulator is defined as follows:

$$E_{acc} = \int_0^t p_g dV_g \quad (6)$$



(a) Calculated at p_{g0}=0 (b) Calculated at p_{g0}=7.5MPa

Fig.7 Energy analysis for the downward movement (E_{acc}: storage energy)



(a) Calculated at p_{g0}=0 (b) Calculated at p_{g0}=7.5Mpa

Fig.8 Energy analysis for the upward movement (E_{acc}: reutilization energy)

Table 1 Energy analysis for the measurement

m_L (kg)	p_{g0} (MPa)	Movement	E_{pump} (kJ)	E_{loss} (kJ)	E_{acc} (kJ) Storage	E_{acc} (kJ) Reutilization
489	0	Down	04.893	42.503	—	—
489	0	Up	48.948	11.338	—	—
489	7.5	Down	04.893	30.808	11.695	—
489	7.5	Up	37.925	11.338	—	11.023

(3) Energy Calculation

Based on the above assumptions, Fig.7 illustrates the energy transmission process for the downward movement, where pump supply energy has no difference at p_{g0}=0 or 7.5MPa. However at p_{g0}=7.5MPa the energy losses are much less than those at p_{g0}=0 for the accumulator stores some of them. Fig.8 shows the energy transmission change for the upward movement. Pump supply energy at p_{g0}=7.5MPa is less than that at p_{g0}=0 for the accumulator can release the energy that is helpful in driving the load. At the same time the assistant device doesn't cause extra loss.

Thus the drive concept can reduce energy losses in the crane system and save hydraulic energy supply during the experimental process.

(4) Energy Balance Analysis and Discussion

Energy transfer for the experimental process is shown in Table 1. It is obvious to reveal the following energy balance equation:

$$E_{pump} = E_{mech} + E_{loss} + E_{acc} \quad (7)$$

Where,

E_{mech} is mechanical energy that is resulted in by lifted load and link weight. It is positive when the load is lifted up. Otherwise it is negative.

E_{acc} is also sign-variable when the accumulator stores energy from the system or releases energy into the system.

When E_{acc}=0 in equation (7), the energy balance equation for the original crane systems without the assistant device can be described as follows:

$$E_{pump} = E_{mech} + E_{loss} \quad (8)$$

Equation (8) quantitatively shows a simple fact that hydraulic energy reduction is not the sole measure to improve energy utilization. Equation (7) presents a possible way to guarantee better energy utilization and higher system efficiency. Of course it requires pre-condition that cylinder 1 could have an outstroke and instroke motion for a typical duty cycle and reasonable parameter set.

CONCLUSIONS

1. Energy utilization in hydraulic cranes is poor even if LS system is used. Therefore energy reutilization is very necessary and valuable, especially for some heavy-duty cranes.
2. The proposed drive for energy reutilization can save hydraulic power and reduce energy losses. It is evident that it has obvious advantage over the original crane system in the improvement of energy efficiency.
3. The further work is to find the wide adaptation and possibility to improve energy utilization as much as possible for all the work paths in the crane workspace.
4. Its good experiment in an example crane will encourage its extensive application in other lifting machinery.

Acknowledgement

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