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Technical Paper

A coordinate method applied to partitioned energy-saving control for grouped hydraulic presses

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ABSTRACT

As applications of forming equipment become increasingly widespread, the demand for low cost and significant energy-saving schemes gets stronger and stronger. A partitioned energy-saving control for drive system was first proposed to match the installed power of hydraulic system with the demanded power of grouped hydraulic presses, in which the drive system is partitioned into several drive zones according to the load profiles of different operations. The configuration and strategy of the control for grouped hydraulic presses are constructed. Based on the control, a coordinate method is then proposed to coordinate this multi-press system and ensure the forming processes of each hydraulic press successive, in which the operations relating to the forming parameters are controlled by position of the slider, and the other operations are controlled by time. Meanwhile, the forming operation in a hydraulic press begins with the end of the forming operation in the former one. Coordinate time error between two successive presses is modified to improve the accuracy of each operation. The method is applied to a multi-actuator system, and result shows orderly coordinate performance even with interference.

1. Introduction

Due to mounting concerns about global warming and climate change, manufacturers are facing pressures from government and general public to increase their energy efficiency and reduce carbon footprint. As a result, the demand for more energy-efficient processing machinery, especially those for energy intensive manufacturing processes, has been increasing. Metal forming is one of these energy intensive processes. Among forming equipment, hydraulic presses characterized by high power weight ratio, high stiffness, and high load capability have found applications in many industries such as automotive, aerospace, and ship building. However, a key component of hydraulic press – the hydraulic drive systems have an energy efficiency as low as 6%, which has become a major obstacle to achieve energy efficient manufacturing [1].

Many approaches have been attempted to improve the energy efficiency of hydraulic systems. One approach is to match the pump flowrate with the operation requirement to reduce the power consumption [2], and the basic idea is to control the flow supply via the feedback of the loaded pressure [3], while also improve the control performance [4]. Some researchers proposed regeneration methods, by using a hydraulic accumulator to recover the kinematic energy or a flywheel to store the inertia energy [5,6]. The potential energy of the vertically moving load can also be harvested and returned to the hydraulic drive systems [7–11]. Furthermore, the electric-drive-based direct pump control method has been proposed to replace a valve control in an electro-hydraulic system, which has shown improved operating efficiency [12–14].

Another approach with particular potential is the use of digital hydraulics, which has been proposed several decades ago but only achieved significant development in recent years [15]. Digital pump concepts have been analyzed, where individual cylinder in a piston pump can be switched on or off with valves, allowing the distribution of flow in intervals between several outlets [16]. Digital hydraulics has considerable advantages over analogue technology with regard to efficiency, redundancy, robustness, and component standardization. Studies have shown that digital hydraulics can greatly reduce energy loss (especially during partial load) when compared to traditional systems [17–19]. Furthermore, these digital pumps can be shared by two or more actuators to reduce the amount of partial load, which allows a reduction of installed power [16].

Hydraulic systems with multi-actuators have found many applications on production lines. If digital hydraulics is used, the digital

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pumps have to be shared by a group of actuators which have different power demand at different time. Therefore, the operation of the digital pumps (which form the drive system) has to be coordinated in order to meet the demand from each actuator while minimizing energy consumption. In this study, we extend the concept of the shared digital pumps and propose a partitioned energy-saving control method of drive system for grouped hydraulic presses. The proposed method is based on the concept of multi-drive to multi-actuators. A drive system composed of several motor pumps is partitioned into several drive zones according to the load profiles to provide energy for all hydraulic presses in a group. The same drive zone is shared by operations with approximate power requirement in previous work, which leads to energy savings. However, the coordinate control of drive zones to meet the demand of coordinate working for grouped hydraulic presses is not so straightforward that a coordinate approach with time error modification based on the hydraulic system in a group is proposed, which attained good scheduling effect.

2. Partitioned energy-saving control strategy

The complete cycle of a forming process using hydraulic press generally includes fast falling (FF), pressing with slow falling (PF), pressure maintaining (PM), unloading (UD), fast returning (FR) and slow returning (SR). Among these steps, PF is known as main operation because it incurs the largest power demand and the longest time, while the others are deemed as the auxiliary operations. The installed power of drive system in a hydraulic press (HP) has to meet the maximum power requirement of the PF operation. However, the demands of power for auxiliary operations are much less than that of the PF operation, which leads to mismatch between the installed power and the demanded power during auxiliary operations. Moreover, the time consumed by the auxiliary operations accounts for most of the whole working cycle, which makes the hydraulic press run at the low energy efficiency level at most of the time. Meanwhile, the hydraulic press could spend significant time at waiting/idling state between two working cycles. In some applications, the idling time could be as long as nearly half of the working cycle. While idling, all pumps of the drive system are in the state of unloading, and all the electricity consumed dissipates into the environment. These issues are main causes of the low energy efficiency in hydraulic press system.

To solve the problems, a partitioned control method for grouped hydraulic presses with configuration shown in Fig. 1 was proposed to achieve energy savings. A drive system composed of several motor-pumps is the only power source to provide energy for all hydraulic presses in the group instead of having one drive unit for each press. The drive system is partitioned into several drive zones according to the load profiles of different operations. That is, a drive zone is a subset of motor-pumps with total installed power matching the needed power of corresponding operations of hydraulic presses.

As shown in Fig. 2, for each hydraulic press the energy needed by the sequence of operations in a cycle of forming process as well as during idling is provided by different drive zones. This leads to shorter idle time of drive zones than that of grouped hydraulic presses. The total idle time ΔT_{idle} shortened can be expressed as:

$$\Delta T_{\mathrm{idle}} = (n - m)T_{\mathrm{c}} \quad (1)$$

where n is the number of hydraulic presses, m is the number of drive zones, T_{c} is the time of a working cycle.

Since power demand during auxiliary operations is much lower than that of PF, only one drive zone needs to have installed power matching that of the grouped hydraulic presses (Fig. 3). For other drive zones, the installed power can be much less and the total

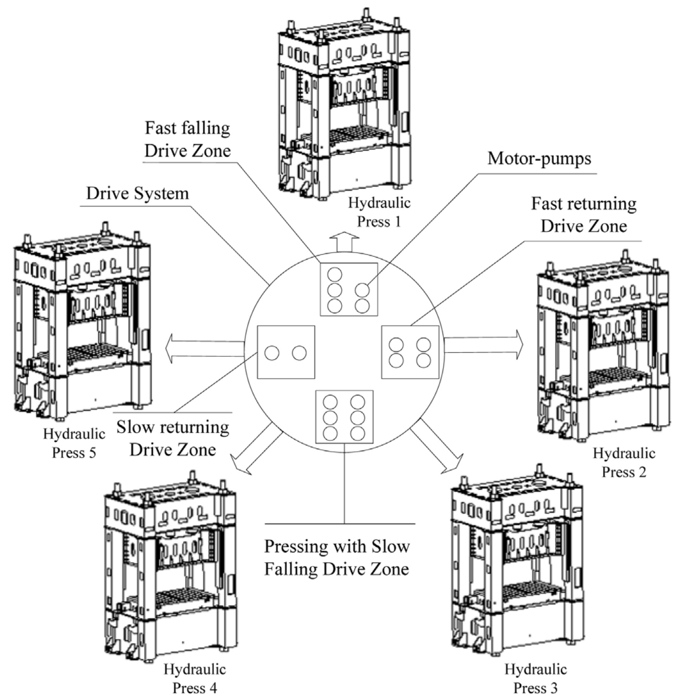

Fig. 1. Configuration of drive system and grouped hydraulic presses.

installed power ΔP_{r} of hydraulic system reduced can be expressed as:

$$\Delta P_{\mathrm{r}} = nP_{\mathrm{r}} - \sum_{i=1}^{m} P_{\mathrm{r}i} \quad (2)$$

where P_{r} is the needed installed power of hydraulic presses, $P_{\mathrm{r}i}$ is the installed power of drive zones.

Therefore, with shorter idle time and less installed power, the partitioned energy-saving control for a hydraulic press group has great energy saving potential. However, for the partitioned control method to work complicated coordination of operations on the grouped hydraulic presses is needed as they share the same drive system/drive zones.

3. Configuration of hydraulic system in a group

3.1. Connection between drive system and hydraulic presses

The motor-pumps in a drive zone work in parallel and provide energy for the corresponding operations of each hydraulic press through a public output port. In order for different hydraulic presses to share the drive zones, a valve matrix with rated flow matching the output flow is designed to connect a drive system composed of m drive zones and a group of n hydraulic presses (see Fig. 4).

The elements of a valve matrix are on-off valves or combination of valves with on-off function. The valve matrices can be divided into two parts, i.e. loading module and idle module. The former one is responsible for controlling the on-off state of oil circuit from a drive zone to a hydraulic press, and the latter one is used to unload the drive zones in the idle time. In the valve matrix, the input port of each row is connected to one output port of a drive zone, and the number of rows is m. The output port of each column in loading module is assigned to one hydraulic press, and the number of columns is n. Meanwhile, the output port of the idle module is connected to the tank.