Journal of Cleaner Production 139 (2016) 636–645

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

An energy-saving method to solve the mismatch between installed and demanded power in hydraulic press

Lei Li [a], Haihong Huang [a, *], Zhifeng Liu [a], Xinyu Li [a], Matthew J. Triebe [b, c], Fu Zhao [b, c]

[a] School of Mechanical Engineering, Hefei University of Technology, Hefei, China
[b] School of Mechanical Engineering, Purdue University, West Lafayette, IN 47907-2088, USA
[c] Division of Environmental and Ecological Engineering, Purdue University, West Lafayette, IN 47907-2088, USA

ARTICLE INFO

Article history:
Received 15 June 2015
Received in revised form
6 August 2016
Accepted 14 August 2016
Available online 17 August 2016

Keywords:
Energy-saving
Installed power
Demanded power
Match
Hydraulic press group

ABSTRACT

Improving the energy efficiency of hydraulic presses has become an important field of research in low-carbon manufacturing systems. The mismatch between installed and demanded power is the main cause of low energy efficiency among hydraulic presses. This study presents an energy-saving method to solve the problem, where a single drive system composed of several motor-pumps, is partitioned into several drive zones corresponding to load profiles. The system is used to supply power to several hydraulic presses with approximately same installed power. Each drive zone is shared by grouped hydraulic presses in the same operation. Furthermore, a method for scheduling drive zones is presented to share drive zone with no conflict and shorten their idle time. The composition of each drive zone is optimized to match the power demand of each operation to achieve the scheduling schemes. The proposed energy-saving method is applied to a hydraulic press group in the case study. Results show that the energy efficiency of a single hydraulic press in the group is increased by approximately 20% and the average energy consumption can be reduced by 43% compared with the traditional setup.

1. Introduction

Hydraulic presses are widely used in the metal forming process because of their high power-to-mass ratio, high stiffness, and high load capability. Unfortunately, they are also known for their high energy consumption and low energy efficiency. In 2013, the number of metal forming presses was approximately two million in China. Given that the average power rating of the presses is 40 kW, more than 280 billion kWh electrical energy is consumed per year, which is comparable to the total energy consumed by Spain in 2014 (BP Statistical Review of World Energy, 2014). Considering the vigorous promotion of low carbon and energy saving economies in manufacturing process in recent years, reducing the energy consumption of hydraulic systems is crucial. Thus, increasing attentions have been focused on energy-saving methods for hydraulic presses.

The installed power of the drive system in hydraulic press is designed to meet the maximum power demand of pressing operations. However, as the same drive also serves other operations which have lower power demands, mismatches between installed power and demanded power occur. Valve-controlled hydraulic systems have been widely applied in conventional hydraulic systems to transform installed power into demanded power because of their low cost and simple structure. However, valve-controlled hydraulic systems have many drawbacks, such as considerable energy and pressure loss (Grabbel and Ivantysynova, 2005).

An energy-saving, pressure-compensated hydraulic system with an electrical approach was proposed to reduce the usage of controlling valves, while achieving pressure compensation function and regeneration (Wang and Wang, 2014). A common approach used to circumvent mismatch is to control the flow based on load sensing technique (Finzel et al., 2009). And a widely used system is the volume control electrohydraulic system driven directly by various kinds of variable-speed motors, such as variable-frequency motors (Camoirano and Dellepiane, 2005; Su et al., 2014) and servo motors (Zheng et al., 2009). The control of pressure, flow, and

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* Corresponding author. Hefei University of Technology, 193 Tunxi Road, Hefei City, Anhui, China.
E-mail address: huanghaihong@hfut.edu.cn (H. Huang).

http://dx.doi.org/10.1016/j.jclepro.2016.08.063
0959-6526/

Nomenclature

n	total number of the motor-pump
P_i	output power of drive part
$P(t)$	demanded power of hydraulic press
P_i^{m}	output power of the motor-pump i
P_i^{r}	unloading power
η_β	the energy efficiency of operation β
T_β	the time length of operation β
P_{D}	demanded power
k_β	the number of motor-pumps to supply energy
η_i^{m}	the efficiency of motor-pump i
A_{T}	opening area of the throttle valve
C	the constant coefficient
P_{t}	power loss of the throttle valve.
P_{v}	power loss of the valves.
P_{f}	linear loss and local loss.
m	index of the throttle valve
β	operation of hydraulic press
α	hydraulic press
γ	number of hydraulic presses in a group
$h(\alpha, \beta)$	vertical displacement of operation β of hydraulic press α
$A(\alpha, \beta)$	corresponding slider area of operation β of hydraulic press α
c_β	time matching coefficient of operation β
$A_{\mathrm{T}}(\alpha, \beta)$	area of the throttle valve of operation β of hydraulic press α
$T(\alpha, \mathrm{PF})$	pressing time of hydraulic press α,
T	working period of the hydraulic group
$T(\alpha, \beta)$	time length of operation β of hydraulic press α
$P_{\mathrm{C}}(t)$	active power
E_{in}	energy consumption of hydraulic system
η	conversion efficiency from the electric energy into forming energy
E'_β	electrical energy consumption of operation β after using this method

direction of working fluid achieved by controlling rotation speed (Zheng et al., 2010). However, conventional control approaches are based on a linear model. This may not guarantee satisfactory control performance for the servo motor direct drive volume control system; therefore, considerable research has focused on adaptive control approaches (Chen et al., 2008; Ferreira et al., 2006; Lin et al., 2013; Wang et al., 2012). However, these methods increase the complexity of control and do not reduce installed power of hydraulic systems.

Another promising approach is the use of digital hydraulics, which had been proposed several decades ago but only achieved significant development recently (Locateli et al., 2014). Digital pump concepts have been analyzed, in which individual cylinders in piston pumps can be switched on or off with valves, allowing flow distribution to occur in intervals among several outlets (Heitzig et al., 2012), thereby matching the demanded power of an operation. Digital hydraulics have considerable advantages over analogue technology with regard to efficiency, redundancy, robustness, and component standardization. Studies have shown that digital hydraulics can significantly reduce energy loss (particularly during partial load) when compared with traditional systems (Huova and Laamanen, 2009; Linjama et al., 2009; Scheidl et al., 2012). Furthermore, digital pumps can be shared by two or more actuators to reduce the amount of partial load, allowing a reduction of installed power (Heitzig et al., 2012). However, as the hydraulic press itself is not a multi-actuator system, digital pump itself will not improve energy efficiency significantly and is not commonly used in hydraulic presses.

In summary, although the hydraulic press is one of the most commonly used manufacturing systems, the work on mismatching between demanded power and installed power has been limited. This study, by adopting the concept of shared digital pumps, develops an energy-saving method for the operation of drive system in grouped hydraulic presses. Matching between installed and demanded power is achieved by coordinating operations and optimizing the configuration of the drive systems. Meanwhile, the waiting time of drive system is reduced by drive zone sharing, which significantly improves energy efficiency of the hydraulic system.

2. Methods

2.1. Energy characteristics of the hydraulic press

In traditional hydraulic press systems, the drive consists of AC (alternating current) asynchronous motors and variable displacement pumps. Not all the electrical energy is transformed into hydraulic energy because of energy loss in a forming process. The energy dissipation and load profiles of a simple drive system are shown in Fig. 1 (Zhao et al., 2015).

Generally, hydraulic press operations include fast falling (FF), pressing with slow falling (PF), pressure maintaining (PM), unloading (UD), fast returning (FR), and slow returning (SR), and often part or all of these operations are included in a forming process. The function of each operation is shown in Table 1. Among them, FF, PF, FR, and SR are necessary operations, and the others are selected according to the requirements of the forming process. The installed power of the drive of a hydraulic system is designed to meet the maximum power requirement of PF, but the pressing time is much shorter than that of the forming process and the demanded power of other operations is much less than that of PF operation, usually leading to a mismatch between installed power and demanded power, as shown in Fig. 2.

Furthermore, between two successive forming processes, there is a waiting (WT) time for loading and unloading the work piece, which is almost equal to the time of the forming process. When the drive system is waiting, the demanded power is nonexistent and all pumps are in the unloaded state. As the motor-pumps cannot switch on and off frequently, the total input energy is converted into heat and dissipated to the environment according to Fig. 1(a).

The problems mentioned previously lead to low efficiency and high energy loss from the hydraulic press (Zhao et al., 2015). If the installed power of a hydraulic press could be changed during different operations to match the ideal installed power as in Fig. 2, then high efficiceny and low energy consumption would be achieved.