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Analytical energy dissipation in large and medium-sized hydraulic press

Kai Zhao [a], Zhifeng Liu [a], Suiran Yu [b], Xinyu Li [a,*], Haihong Huang [a], Baotong Li [c]

[a] School of Mechanical and Automotive Engineering, Hefei University of Technology, Hefei, China
[b] School of Mechanical and Power Engineering, Shanghai Jiao Tong University, Shanghai, China
[c] State Key Laboratory for Manufacturing Systems Engineering, Xi'an Jiaotong University, Xi'an, China

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ABSTRACT

Low carbon manufacturing is the specifically scientific problem deriving from two major worldwide challenges – "energy crisis" and "greenhouse effect". Quantifying the energy dissipation in operating condition is the basis to achieving low carbon manufacturing of the high-end equipment, but the energy-saving technologies on large and medium-sized hydraulic press are still in exploration stage. For the purpose of providing guidance for improving of Large and medium-sized hydraulic presses LMHP system's energy efficiency and breaking through the limitations of existing researches, an analytical approach for calculating energy flow in LMHP system is proposed in order to find out the root of low energy efficiency in this research. The traditional classification of Hydraulic presses HP system is not appropriate for analyzing energy flow, so HP system is newly divided into six parts based on the characteristics of each component's energy conversion. Then, in order to avoid the problem of numerous and unknown parameters of theoretical model, the basic formulas of energy consumption are presented so that there are only a few unknown coefficients that would be tested in a series of experiments. Furthermore, a practical simplification method is proposed for LMHP system's energy flow model according to LMHP system's structural features. Finally, large sheet stamping hydraulic press is taken as the object to verify the validity of this method and the main reasons of low efficiency of low efficiency are founded that load characteristics don't match with drive mode.

1. Introduction

Large scale exploitation and utilization of energy resources, especially combustion fossil fuels, have contributed significantly to the development of world civilization, but which also make "energy crisis" and "greenhouse effect" to be global challenges (Root et al., 2003; Kristin and Edeltraud, 2012). Developing low-carbon economy is a global revolution involving production mode, life style, values and national interests, which is a strong complement of ecological civilization (Zhong et al., 2012; Gutowski, 2005). Hydraulic presses (HP) are machine tools using a hydraulic cylinder to generate a compressive force (Olowin, 1969), which are commonly used for forging moulding, blanking, punching, deep drawing, and metal forming operations in many manufacturing fields (Yu, 2006). Large and medium-sized hydraulic presses (LMHPs) with complicated actions, high speed and large tonnage spring up like mushrooms, so that the installed power of which reaches up to hundreds kilowatts is common occurrence. How to improve low-carbon transformation of LMHP is becoming one of the most urgent issues which forming equipment manufacturing industries have to face (Sheng and Yanjie, 2007; FANG et al., 2010).

Energy losses generate from each part of LMHP system in the way of transmitting motion or power. During the past decades there were already many researches focusing on the energy efficiency of HPs. Energy saving targets in hydraulic driving system can be divided into two categories: hydraulic units and hydraulic circuits. Selecting of high-efficiency hydraulic units, such as variable pump which can saving energy by changing its pressure or flow rate in relation to load (Chen and Pan, 2011; Zhang et al., 2001; Takahashi et al., 2010; Minav et al., 2013), integrated valve which can minimize pressure drop by reducing pipeline connections (Yoshida et al., 2010; Chen, 2003), and energy accumulator which can bring down machine's installed power by providing large flow and absorb pressure pulse in a short time (Sun and Virvalo, 2005; Puddu and Paderi, 2013), are all effective methods to save energy. Some researches focus on the design of hydraulic control system to

* Corresponding author. Tel.: +86 1396 669 6141; fax: +86 0551 290 1775.
E-mail address: li122425yu@126.com (X. Li).

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improve energy efficiency by adjusting the hydraulic system state to match well with load variations because of the limitation scope for further increases hydraulic unit's efficiency. The methods of hydraulic control system mainly include closed volume control system (Chen et al., 2008), secondary regulation system (Triet and Kyoung, 2012), hydraulic load sensing system (Darko and Mitja, 2009), variable frequency hydraulic speed regulation system (Camoirano and Dellepiane, 2005), constant pressure system (Van and James, 2013), and negative flow control system (Gao and Pan, 2005; Cristofori et al., 2012).

It can be seen that many technologies showed above have been made to improve hydraulic system's energy efficiency, but hydraulic system is still characterized by low power efficiency. So it is necessary to be clear on the energy dissipation characteristics of HP system, otherwise improving energy efficiency is like proverbial blind men attempting to describe an elephant, that is to say, the answer likely depends on where you're standing on. What is more unfortunate is that some researches about energy dissipation are mainly on hydraulic unit rather than HP system, especially LMHP (Nanjo et al., 2004; Lira and Nam, 2004; Peng and Yang, 2009; Ergin et al., 2012). The reason is that structural feature parameters of each unit, which are all directly or indirectly influence the energy loss of system, are so numerous and unknown that the using of theoretical model of each component becomes impossible. In addition, the system pressure coupling with the energy loss of system is determined by external load, while which is variable. Therefore, in order to provide guidance for comprehensively improving LMHP system's energy efficiency and breaking through the limitations of existing research, this study proposes an analytical approach for calculating energy flow in LMHP system and finding out the root of low energy efficiency.

2. Energy dissipation characteristics of HP system

2.1. The basic energy flow of HP system

Hydraulic press (HP) basing on Pascal's principle is a kind of closed energy conversion systems, namely, "electric energy-mechanical energy-hydraulic energy-deformation energy". For performing intended actions within a cycle, a corresponding energy flow will be built by reconstructing sub-system structure in time sequence, so as to meet demands for the energy characteristic state of executive component.

The basic energy flow of HP system is shown in Fig. 1. The electrical motors not only get active power, but also reactive power

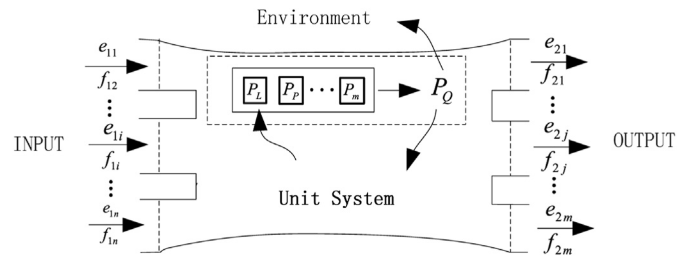

Fig. 2. Analysis of energy in unit.

from power grid. The reactive power doesn't do external work, but it is used for building and maintaining the relationship between magnetic field and electric field, which will return back to power grid. The active power is converted into mechanical energy needed by oil pump and heat exchanger. The oil pumps convert mechanical energy into medium's hydraulic energy, while control valves group which composed by flow control valves, pressure control valves and direction control valves is to make the energy flow get controlled so that the complicated coordination of each sub-system can be realized. Hydraulic cylinders convert part of input energy into mechanical energy, and the other energy is released in back oil circuit. Moved cross beam converts the mechanical energy into deformation energy though dies.

2.2. Energy dissipation characteristics of HP system unit

Each unit in HP system can be regarded as an "open sub-system" with the flow of material and energy, as shown in Fig. 2. So based on bond graph theory (Baliño et al., 2006) the energy exchanged place between two units is called "power port", where there is a pair of power variables: "effort" (such as pressure, speed, force, torque) and "flow" (such as velocity, current, and volumetric flow), and effort multiplied by flow produces power. Therefore, the working procedure of the HP system under single operating condition can be expressed as a state transformation that the original characteristic state which is electric energy $\boldsymbol{x_0}$ (u,i) changes into required characteristic state which is deformation energy $\boldsymbol{x_n}$ (σ,ε) through serial media characteristic states $\boldsymbol{x_1}\ldots\boldsymbol{x_n}$ by using a group of units.

Due to the control modes and structural features of units, different power losses may be generated and transferred into environment, system itself or output medium as heat. Therefore, based on the energy conversion characteristics of each unit, HP

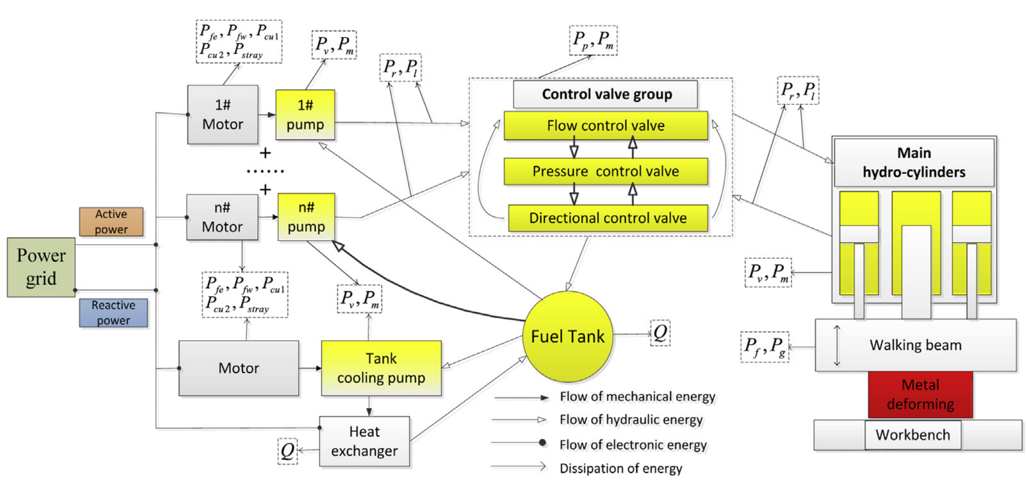

Fig. 1. The basic energy flow of HP system.