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Energy-saving Methods for Hydraulic Presses Based on Energy Dissipation Analysis

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Abstract

Hydraulic presses are large energy consumers in metal forming processes. In order to reduce carbon intensity and improve the energy efficiency, the overall carbon emissions of hydraulic presses was firstly analyzed. For a series of intermediate energy conversions in working processes, it is essential to understand and identify the energy dissipation characteristics of the investigated presses. Then, some energy matching methods for hydraulic drive system and a group of hydraulic presses in manufacturing system were presented to implement energy reduction. Finally, the proposed methodology shows a great energy-saving potential in sheet metal forming hydraulic presses.

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Keywords: Carbon emissions; Hydraulic presses; Energy efficiency; Energy matching; Energy-saving

1. Introduction

The growing demand of energy and material resource has led to increasingly serious climate change. In 2013, the carbon emissions in the world set another record up to 36.1 billion tons [1]. Hydraulic presses are a mainstay in metal forming processes, owing to their ability to deliver high forming pressures; however, they are also large energy consumers [2, 3]. In 2013, China produced about 2 million metal forming presses. If the average power demand of one of these presses is 40 kWh, more than 280 billion kWh will be consumed per year, which is comparable to the total energy consumed by Spain in 2014 [4]. If 20% of the energy consumption was reduced, more than 57.1 billion kWh would be saved per year, which could reduce 47.62 million tons carbon emissions, it is equivalent to the amount CO_2 absorption of 5.83 million hectares forest a year [5]. Over the past several decades, much research has been performed on the efficiency and energy consumption of hydraulic presses [6, 7].

Energy losses generate from each part of hydraulic system in the way of energy transmitting. A perusal of the current literature reveals a number of developments in energy saving targets in hydraulic driving system which 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 [8-10], integrated valve which can minimize pressure drop by reducing pipeline connections [11], and energy accumulator which can bring down machine's installed power by providing large flow and absorb pressure pulse in a short time [12, 13], are all effective methods to save energy.

Another researches approached this issue from the design of hydraulic control system as power match, a widely used system is load sensing system. The basic idea of the load sensing (LS) technique is to control the flow supply via the feedback of the highest loaded pressure [14]. And the study is focused on the control method of the pressure and flow to follow the load change [15-17]. This system leads to the challenging controller design due to the presence of nonlinearity and high-order dynamic characteristics [18-20]. The energy saving effect of these methods above is extremely limited, which reduce energy consumption by optimizing the state of hydraulic system at working stage only.

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Summarizing the findings above, it can be claimed that, the energy saving method and low carbon design of hydraulic press mainly focused on operation processes. In fact, we believe that low carbon design should be a life cycle process, it will not be achieved without analysis and quantification of the carbon emissions during manufacturing and working processes of a hydraulic press. In this paper carbon emissions and energy dissipation in hydraulic press were understood and identified. In order to reduce carbon intensity and improve the energy efficiency, some energy matching methods for hydraulic drive system and a group of hydraulic presses in manufacturing system were presented.

2. Carbon emissions analysis of the hydraulic press

Reduction of carbon emissions of hydraulic presses are an essential way to achieve low carbon manufacturing in various manufacturing system environments. To achieve this, the Life Cycle Assessment (LCA) methodology is applied to understand and characterize the life-cycle carbon emissions of the presses. The life-cycle carbon emissions include direct carbon emissions, energy carbon emissions and material carbon emissions.

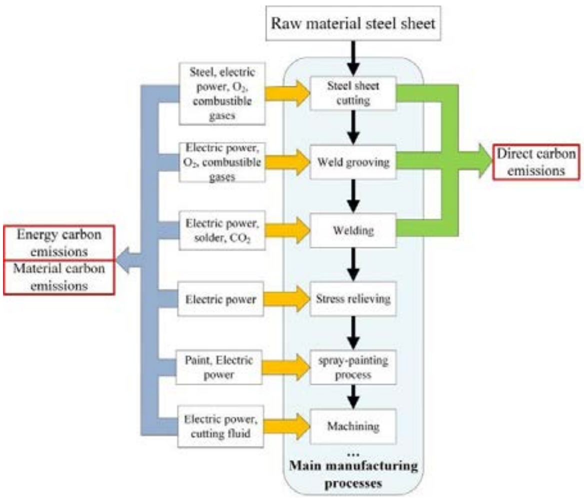

Fig. 1. System boundary in the carbon emissions analysis.

Carbon emissions in operation stage of hydraulic presses are main caused by energy consumption, so these emissions could be characterized by the quantification of energy dissipation. Hydraulic presses manufacturing stage is one of the main contributors of carbon emissions. It aims to find the potential to control carbon emissions in the equipment's manufacturing stage. The processes included in the system boundary are raw material acquisition, steel sheet cutting, weld grooving, welding and stress relieving, spray-painting and machining process. The scope omits the following factors which not directly related to the manufacturing processes: transportation, storage and some aided processes. The system boundary of the carbon emissions analysis in the manufacturing stage is shown in Fig. 1.

A typical part of hydraulic presses, the slider, as the research object, for the manufacturing stage of this part includes all of the typical processes of a hydraulic press. The functional unit of the system was defined as a hydraulic press slider which connects piston rod and hydraulic cylinder. The calculation models of carbon emissions in each process of the manufacturing stage (raw material acquisition, steel sheet cutting, weld grooving, welding and stress relieving process) were established to study the key factors affecting carbon emissions.

The results was show in Table 1 and 2, it could be concluded that the use of raw material of steel sheet is the largest contributor to carbon emissions in the manufacturing stage of hydraulic presses. Welding is the second largest contributor to the carbon emissions, and the groove shape is the most critical factor for the consumption of welding wire. In addition, compared to other stress relieving methods, vibration ageing has a great advantage in controlling carbon emissions than annealing under the requirement of the design [21].

3. Quantification of energy dissipation in hydraulic press

Understanding and identifying the energy dissipation characteristics of hydraulic presses are a necessary precondition for energy-saving in operation stage. For a series of intermediate energy conversions in working processes, hydraulic press system is newly divided into six parts based on the characteristics of each component's energy conversion, as shown in Fig. 2.

The working procedure of the hydraulic press system under single operating condition can be expressed as a state transformation that the original characteristic state which is electric energy changes into required characteristic state which is deformation energy through serial media characteristic states by using a group of units. Based on the energy conversion characteristics of each unit, the system can be divided into six parts, respectively are electrical- mechanical energy, mechanical-hydraulic energy, hydraulic-hydraulic energy, hydraulic-mechanical energy, mechanical-deformation energy and thermal-thermal energy, which is different from traditional method which divide hydraulic system into traditional power supply units, control units, executive units and auxiliary units based on their functions [7,22].

Different units have their own energy dissipation characteristics. It's impossible to implement the real-time monitoring of each unit's output and input in the actual production conditions. So energy dissipation of each unit can be calculated indirectly in the field conditions. However, in order to get a simplified model of large and medium-size hydraulic press system's energy dissipation. The relatively small proportion of energy consumption can be simplified even ignoring. Based on the conservation law of energy, model of system's energy dissipation can be simplified into Equation (1) as follow:

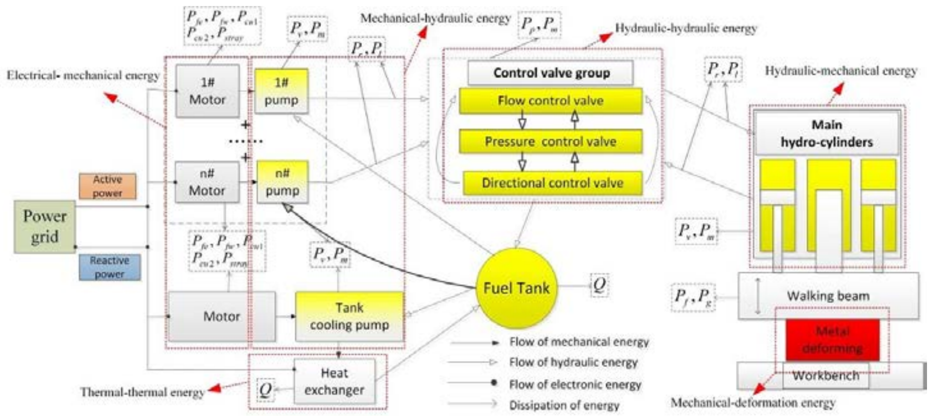

Fig. 2. The basic energy flow of hydraulic press system [7].

Table 1. GHG emissions of the slider in manufacturing stage

Manufacturing stage	Raw material acquisition	Raw material transport	Steel sheet cutting	Weld grooving	Welding	Stress relief process	Total GHG emissions
Percentage	94.39%	0.41%	0.06%	0.01%	2.64%	2.49%	60560kg CO_2eq

Table 2. The total emissions' components

Components	Steel metal	Electricity	Welding wire	GHG(direct emissions)	CO_2 (consumption)	Diesel	O_2	C_3H_8	Total GHG emissions
Percentage	94.39%	2.53%	1.43%	0.96%	0.55%	0.07%	0.06%	0.01%	60560kg CO_2eq

$$E=\sum_{i=1}^{Z}\left(\sum_{j_1=1}^{m(i)}E^{w}_{i-j_1-\text{motor}}+\sum_{j_2=1}^{n(i)}E^{w}_{i-j_2-\text{pump}}+\sum_{j_3=0}^{s(i)}E^{w}_{i-j_3-\text{twcv}}+\sum_{j_4=1}^{r(i)}E^{w}_{i-j_4-\text{pipe}}+\sum_{j_5=1}^{k(i)}E^{w}_{i-j_5-\text{cylinder}}\right)+E_{\text{metal forming}} \tag{1}$$

where, E is the electrical energy input, $E^{w}_{i-j_1-\text{motor}}$, $E^{w}_{i-j_2-\text{pump}}$, $E^{w}_{i-j_3-\text{twcv}}$, $E^{w}_{i-j_5-\text{cylinder}}$ respectively are the energy losses of motor j_1, pump j_2, TWCV j_3, pipe j_4, cylinder j_5 in operation process i; $E_{\text{metalforming}}$ is the single-period deformation energy; Z is the number of process stages; $m(i)$, $n(i)$ $s(i)$, $r(i)$, $k(i)$ are the number of motors, pumps, TWCVs, pipes, cylinders in operation process I.

Finally, large sheet stamping hydraulic press was taken as the object to verify the validity of this method and the main reasons of low efficiency are founded that load characteristics don't match with drive mode.

4. Energy-saving method for hydraulic press

Based on the analysis of energy dissipation in hydraulic system, two methods to improve the matching degree between the output and input power were proposed.

4.1. The energy saving method for energy conversion efficiency promoting of hydraulic pump and motor

From the quantification of energy dissipation in hydraulic presses, energy loss in conversion accounts for a large proportion. Motors and pumps are the drive units in hydraulic system, which are the source of the energy consumption. An energy saving method for the efficiency promotion in energy conversion units, pumps and motors in the hydraulic system is proposed. In a certain condition, in order to achieve the optimal match between the motors and pumps with the optimum energy efficiency, the motor speed and the pump displacement are associated controlled. In this condition, it can be achieved that the output energy of the pump is maximum with a minimal energy input of the motors.

The drive unit energy saving method of the control system is shown in Fig. 3. According to the efficiency characteristics of pumps and motors, the control method was used to achieve the match between the pump and motor. The rotational speed n of motor was controlled working on high efficiency, which is called the optimal speed n_{best}. Then, calculated the displacement q_t of pump which is the corresponding theoretical optimal input displacement q_{tbest}. At this point, it is the theoretical optimum matching results for the motor and pump driven unit.

This method was used to the drive units of a 100T hydraulic press in a variable conditions, the variable displacement pump driven the variable frequency AC motor in hydraulic system shows a great potential of improving the energy efficiency by 22.6% compared to the traditional control method.

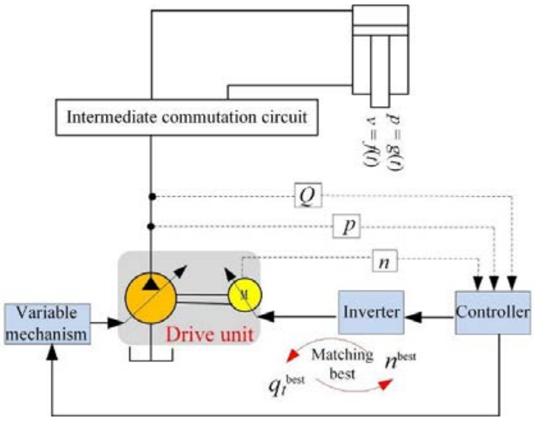

Fig. 3. The controlling schematic of energy-saving method for driven unit.

4.2. An energy saving method for hydraulic press group

The mismatch between the installed and demanded power of the hydraulic press has been another problem caused inefficient energy consumption. In order to solve this problem an energy saving method for hydraulic press group is proposed.

In the hydraulic press group as shown in Fig. 4, a drive system composed of several motor-pumps is set as the only drive system to provide energy for all hydraulic presses. And the drive system is partitioned into several drive zones according to the load profiles of operations in grouped hydraulic presses. Each drive zone with installed power matching the needed power of operations with close demanded power is employed by grouped hydraulic presses in the corresponding operations. Different drive zones provide energy for each hydraulic press in the order of the corresponding operations which could also reduce the average installed power of the presses.

The scheduling scheme approach was used to avoid the conflict of the demand for the same drive zone. The physical structure of hydraulic system and the coordinate method of multi hydraulic presses have been researched to achieve the control of the method, which can also reduce the idle time of drive system and shows great energy-saving effect. The structure of hydraulic press and scheduling process is shown in Fig. 4. This method was used to six rapid sheet metal forming with a 20 MN hydraulic presses, the forming efficiency increased by 15% from 20% to 35%, which is achieved by eliminating the waiting time of drive system and the redundant motor-pumps of each operation.

5. Summary and conclusions

Within this paper the overall carbon emissions of hydraulic presses was firstly analyzed based on Life Cycle Assessment (LCA) methodology. For the much larger energy consumption in forming process, the energy dissipation characteristics of the investigated presses was identified according to a series of intermediate energy conversions. Based on the above analysis, the energy efficiency of hydraulic presses could be further improved.

Some energy matching methods presented to solve the mismatch problem between load and power in hydraulic system. The variable frequency AC motor was used to drive the variable displacement pump to achieve the match between the output power in hydraulic drive system and the load power consumption for a single press. In order to further implement the energy reduction in manufacturing system, energy matching control method for a group of hydraulic presses was presented, which could also reduce the average installed power of the presses. The proposed methodology shows a great energy-saving potential in sheet metal forming hydraulic presses.

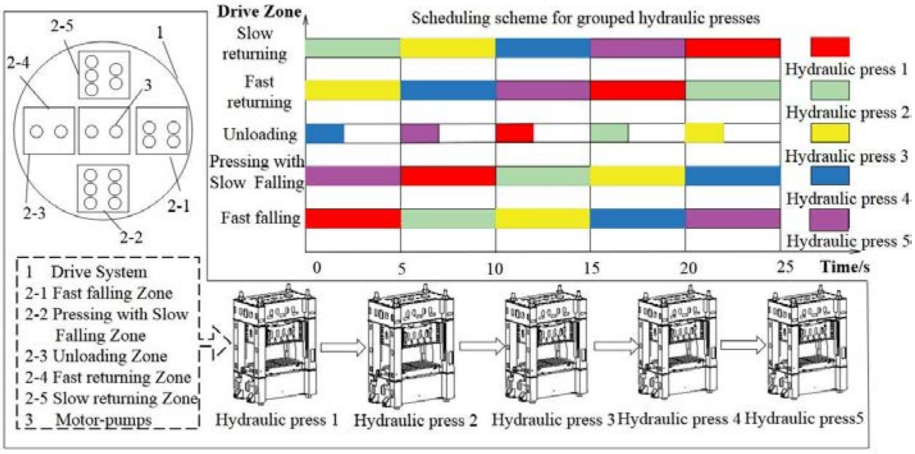

Fig. 4. Structure of hydraulic press and scheduling process in the method.

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