O 21. DYNAMIC PERFORMANCE OF A HYDRAULIC SYSTEM DRIVEN BY A VARIABLE SPEED AC ELECTRIC MOTOR WITH ELECTRO-HYDRAULIC LOAD SENSING

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ABSTRACT: Hydraulic systems, transforming the mechanic energy into hydraulic energy to transfer it to a different mechanic system, are one of the most important R&D fields regarding energy saving. Many studies are carried out regarding energy saving in hydraulic systems, thus relatively more efficient system designs are improved step by step. In this study, a hydraulic test rig is used to simulate a 500 kN press brake metal forming machine driven by a variable speed with the aim of energy saving. In the drive system of the press brake machine, variable speed-controlled AC electric motor is used to drive a constant displacement a gear pump. By means of an electro-hydraulic load sensing method, the load pressure and flow rate under the specific operation condition are measured and send to this information to the control system for varying speed of the electric motor. Thus, the gear pump can provide the system requirements not more. This method can reduce to energy consumption. However, the dynamic performance of this drive system must be analyzed and compared to that of a proportional valve controlled conventional constant speed drive system to recognize the dynamic capability of the proposed variable speed drive method in the press brake machine. For this aim, the cycle phases of the press brake machine are simulated in experimental test rig to compare the dynamic performances of both drive options under different part load conditions. According to obtained results, prospective suggestions are presented.

Keywords: Hydraulic systems, press brake machine, energy saving, variable speed drive, dynamic performance

1. INTRODUCTION

Hydraulic systems are mainly used in many mobile machine and industrial applications. Because these systems have got a huge power density accordingly to their structure and it is easy to distribute such huge powers via a hydraulic system. The hydraulic pump which converts the mechanical energy to the hydraulic energy is generally driven by an electric motor in industrial applications (i.e. presses, casting machines etc.). After the flow is generated by a hydraulic pump the flow, the pressure and the direction of this flow are controlled by hydraulic valves. Finally, the hydraulic energy reconverted to the mechanical energy by hydraulic actuators as hydraulic motors or hydraulic cylinders. It is possible to occur many energy losses during this transmissions. There are a lot of different points that these loses are seen in a hydraulic system. They are generally caused by volumetric and mechanic loses on pumps and hydraulic actuators, the flow leakages in the pipelines and valves, the pressured drops especially in connection fittings and valves etc. The system efficiency is described the difference between input power and output power. Generally, overall efficiency of a hydraulic system is about % 40 (Stelson, 2011). On the other hand, these loses cause not only the low efficiency but also over heating problems. To increase the energy efficiency and prevent the overheating problems, the people who design the hydraulic systems in the field have been working on by designing smarter circuits, making proper pipe installation, using more efficient circuit elements etc. Besides, component and system producer companies spend considerable effort to improve their components and increase the performance and efficiency. Moreover, they make researches for more efficient and smarter system concepts and solutions by integrating different disciplines such as engineering with hydraulic engineering. Historically, for energy efficiency purpose, by-pass valves, hydraulic accumulators, multi pump systems and variable displacement hydraulic pumps are used. Today, the variable speed drive systems as the most recent concept have been started to be used.

There are a lot of different concepts to control the speed in a hydraulic system for the energy efficiency. There are mainly two options. The first one producing all capacity of the system then controlling the

speed of hydraulic system by the help of hydraulic valves. The second one is producing how much it is required. The second option is always friendly for energy saving but it is not same for the dynamic performance aspect (Çalışkan, 2018; Demirkesen, 2017; Lovrec, 2008). There are basically two different way to implement the second concept. First one is variable displacement pumps. These pumps work with hydraulic load sensing principle. There is always a hydraulic signal from the load line and there is always an internal hydraulic signal for pump and the pump always compares these signals and produce the flow accordingly the pressure differences between them. The second one is variable speed electric motors. These motors work with electro-hydraulic load sensing principle. There is always an electric signal from a pressure transmitter in the load line and there is always another electric signal from another pressure transmitter in main pressure line for motor driver and the motor driver always compares these signals and makes the motor rotate accordingly the pressure differences between them.
As it is known there are two different electric motor for such these applications. The first one is servo motors. They provide energy efficiency and the required dynamic performance. But their costs for investments, services and spares are too expensive to be implemented often. The second one is AC electric motors. They provide also energy efficiency but the required dynamic performance. Generally, it is experienced that the dynamic performance of the variable speed AC electric motors with electro-hydraulic load sensing do not correspond the required dynamic performance without some applications.
In this study, a hydraulic test rig is used to simulate a 500 kN press brake metal forming machine driven by a variable speed with the aim of energy saving. In the drive system of the press brake machine, variable speed-controlled AC electric motor is used to drive a constant displacement a gear pump. By means of an electro-hydraulic load sensing method, the load pressure and flow rate under the specific operation condition are measured and send to this information to the control system for varying speed of the electric motor. A real working scenario of 500 kN press brake machine was handled in order to prove that the variable speed AC electric motor not only saves the energy buy also corresponds the required dynamic performance for this application. A test rig was built to make experimental study to search the energy consumption and the dynamic performance of a hydraulic system which is driven with fixed and variable speed. Then the results will be evaluated.

2. MATERIAL AND METHOD

2.1. Characteristics of the Press Brake Machine

The press brake machines basically include a moveable table connected mechanically to two hydraulic cylinders which work simultaneously. This structure is a big part of stable main body which includes electronic and hydraulic systems. A press brake machine is used to press and shape the steel sheets for the others manufacturing process.
In this study, a press brake machine whose capacity is 500 kN is considered to investigate. The main reason behind this selection is there are approximately 5000 quantities press brake machines manufactured annually in Turkey (Machine Magazine, 2018). The characteristic of the considered press brake machine are given in Table 1.

Table 1 The technical characteristic of the considered press brake machine

Technical Features	Symbol	Value	Unit
The Diameter of Piston Rode	ØD	125,00	mm
The Diameter of Piston Bin	Ød	120,00	mm
Cylinder Quantities	SS	2,00	Adet
Working Pressure	P	200,00	Bar
The Force of Pressing	F_A	500,00	kN
The Flowrate	Q_P	34,00	l/dk.
Stroke	S	220,00	mm
The Velocity of Pressing	V_a	21,00	mm/s
The Load Weight	M	1000,00	Kg

In this study, the operation scenario for the minimum thickness steel sheet that the press brake machine is able to press is handled. This operation scenario is given in Table 2. Basically, there are 6 different process in a pressing operation scenario. The first one is the waiting process which is needed to take out the pressed steel sheet and put the new one. The second one is free fall process which the moveable table falls till the level that the pressing process will begin. The third one is pressing process which the steel sheet is pressed. The fourth one is the ironing process which is needed to keep the pressed steel sheet in the same position for a while to give it a better shape. The fifth one is the decompression process which is an important step to decrease the high pressure just a little bit. The sixth one is the back process which the moveable table gets back to the beginning position. All of these processes take 30.8 minutes when a steel sheet is pressed.

Table 2 The operation scenario of the press brake machine

No	Process	Time (minute)		Speed (centimeter/minute)	Flow (liter/minute)	Flow Assumption (liter/minute)	Pressure (bar)
1	Waiting	t1	15	0	0	0	0
2	Free Fall	t2	0,8	15	220,78	34	70
3	Pressing	t3	9,2	1,03	15,2	15,2	100
4	Ironing	t4	2	0,25	3,68	3,68	90
5	Decompression	t5	2	0	0	0	70
6	Back	t6	1,8	2	33,85	33,85	85

In a press brake machine, there are basically three different main systems that are i) mechanic, ii) hydraulic and iii) electronic systems. The hydraulic system is one of the most important system for a press brake machine. Because this system provides all required power for pressing and the remaining movements. The electronic system is the other important system which controls the hydraulic system. There are a number of researches that are stuied on to improve the efficiency of the hydraulic systems (Bostan, 2011; Obut, 2009). The hydraulic system of the press brake machine which is considered in this study is given within Figure 1.

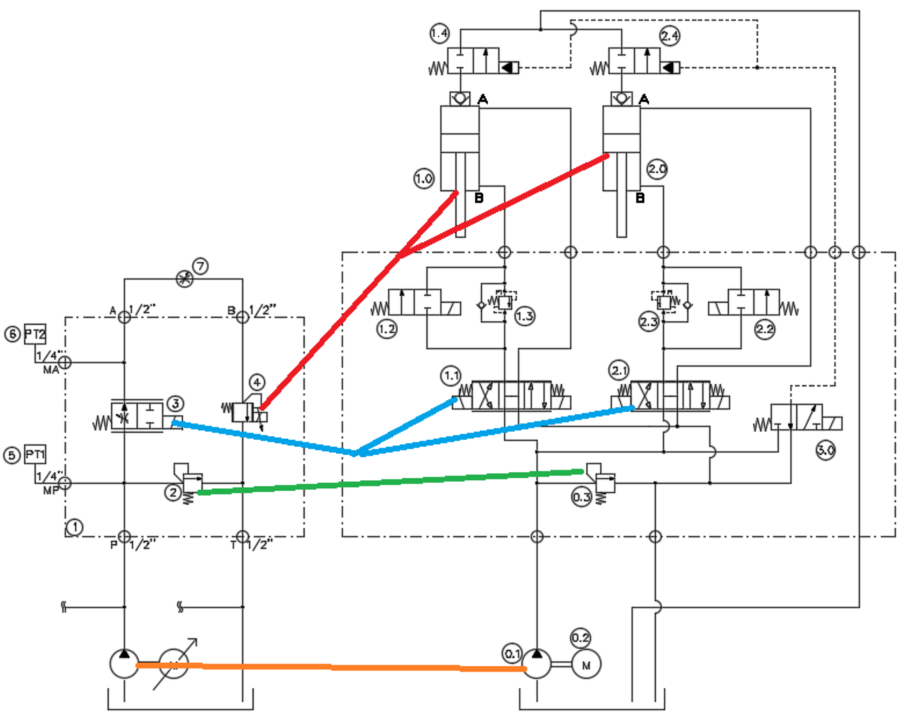

Figure 1 The hydraulic system of the considered press-brake machine (right side) and the hydraulic test rig (left side)

In the hydraulic system of the press-brake machine, there is a fixed displacement gear pump (0.1) driven by an AC electric motor (0.2) which is fixed speed. There are two proportional directional control valves (1.1; 2.1) to control the movements of the cylinders. There are two hydraulic cylinders (1.0, 2.0) to provide required power to moveable table for the processes. The maximum required power is calculated according to the pressing process because this process needs the maximum power for pressing and shaping. This process is only %18 of the total process. It means that the system always produces %100 capacity for only single %18 part. This is the critic point the energy loses are caused.

2.2. Hydraulic Test Rig

To implement a comparative experimental study, a hydraulic test rig has been used. The hydraulic test rig can represent the considered press-brake machine in the perspective of hydraulic system. Therefore, the hydraulic cycle of the press-brake machine was simulated by the hydraulic test rig which is composed of a number of components numbered as 1) hydraulic manifold, 2) pressure relief valve, 3) proportional flow control valve, 4) proportional pressure relief valve, 5-6) pressure sensors, 7) flowmeter sensor, 8) gear pump, 9) AC electric motor and 10) hydraulic reservoir as shown as Figure 1. In order to simulate the considered press brake load, proportional pressure control valve was used. For maintaining and setting the drive speed of the electric motor, a control system was used. In the control system of the test rig, motor frequency driver, an external controller and a computer were utilized.

2.3. Test Method and Set-up

To search if the variable speed control concept with AC electric motor provides not only energy efficiency but also the required dynamic performance, two different experiments were carried out. The first one was fixed speed method. To implement this, the scenario was loaded into the external controller. And the motor frequency driver was set to turn at 1500 RPM. After that, the second one was variable speed method. To implement this, the same external controller was used without any differences. Because the scenario is the same for both options. But in that time, the motor frequency driver was set to turn accordingly the pressure differences. To provide this, a PID logic was loaded into the motor frequency driver. To get the results a computer was used. That computer has got a system to get the results from sensors. The complete experiment structure and its diagram are seen in the Figure 2.

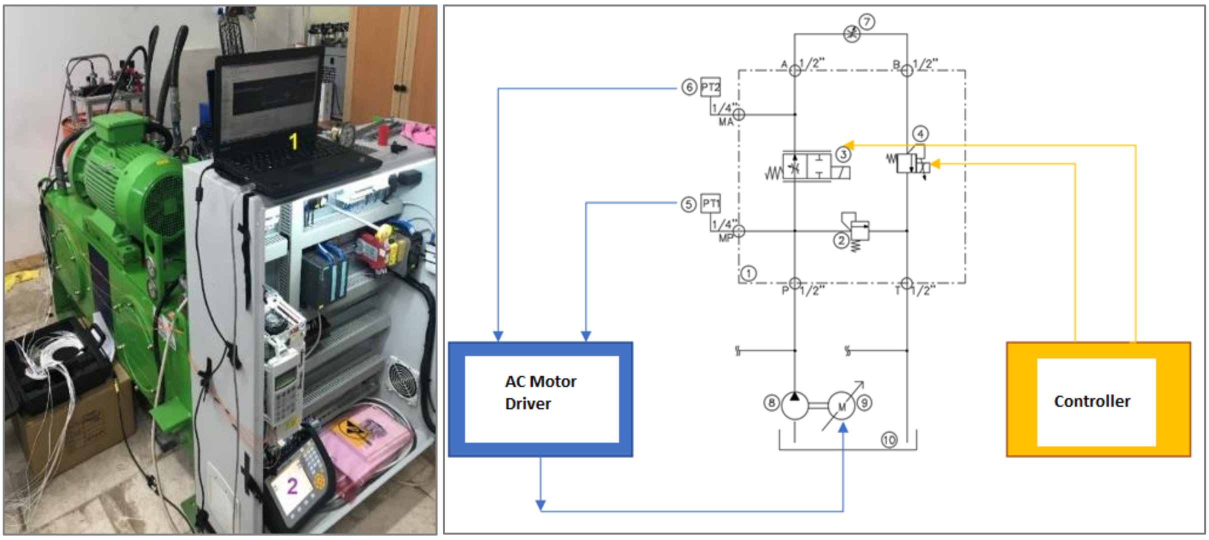

Figure 2 Hydraulic test rig, data acquisition and controller mechanism

The scenario of the press brake machine which was handled is for the steel sheet with minimum thickness which the press brake machine presses ever. There are six different processes for a single material which will be pressed. In that scenario, there is only one assumption made for the decompression process. In reality while the decompression process, the pump is not used, because the aim of this process to make the system relax. In the ironing process, there is a high pressure in the

cylinder and before setting this high pressure free, it is better to reduce it. That is the reason why in decompression process the only action was made to open the valves. Because of this reason, the assumption was made for decompression process is acceptable.
To make a speed control with electro-load sensing, it is required to define a load sense pressure. To define it, the catalogues of proportional valves were searched, and this pressure was set as 10 bar (Eaton, 2009). To make the first test with fixed speed control, the command signal was given to both external controller and the motor frequency driver. The complete process is 30,8 minutes. After it was completed, the results are captured in the computer. To make the second experiment with variable speed control, the command signal was given to the same components. The complete process is 30,8 minutes. After it was completed, the results are captured in the computer.

3. RESEARCH FINDINGS

3.1. Power Consumption Performance

The results for the energy consumption are given in the Figure 5 and Figure 6. When the results are considered, it seems that the system nearly consumed the maximum energy independently from the required energy in fixed speed control method. However, when the results for variable speed control method are considered, the system always try to consume how much it is required.

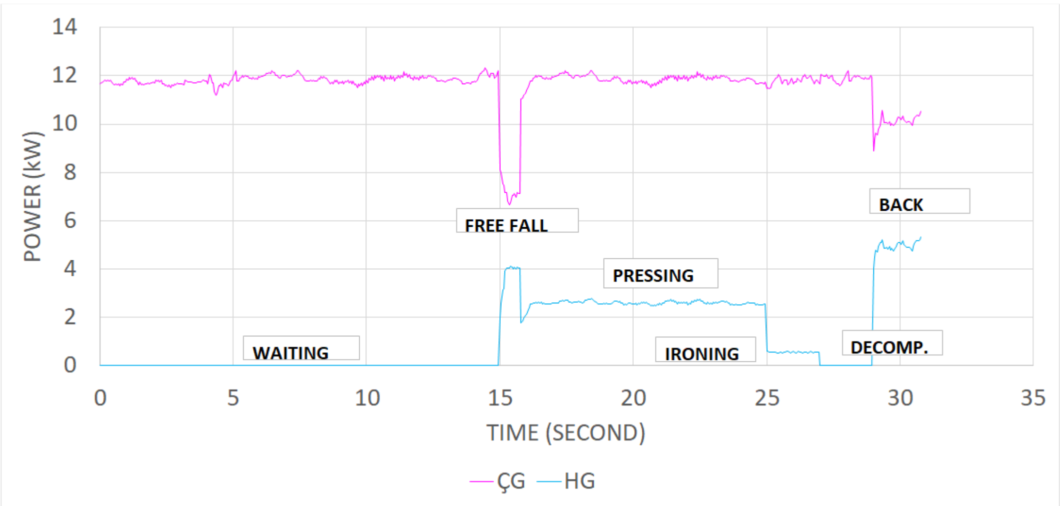

Figure 5 Power consumption graph for fixed speed control

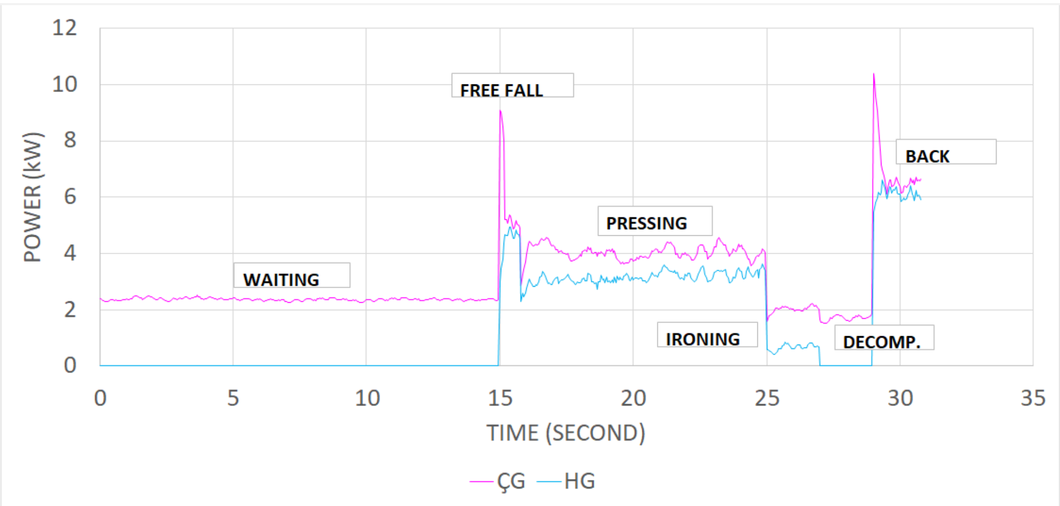

Figure 6 Power consumption graph for variable speed control

3.2. Dynamic Performance

When the graphs within Figure 7 is considered, it is seen that dynamic performance of the variable speed control method displayed as that of the fixed speed control method in the context of pressure. In the graph the red one belongs to variable speed control method and the blue one belongs to fixed speed control method. The only big difference between two methods seems in decompression process. However, this difference can acceptable because the process cannot affect the pressed sheet metal material in the press brake machine. As it is remembered, this process exists only to reduce the pressure of the system. To understand if the dynamic performance of variable speed control method is enough for the real system, it should be compared with the dynamic performance of fixed speed control method. Because in reality, it is often seemed that fixed speed control method is used for press brake machines. When the characteristics of graphs are considered, it can be said that the dynamic performance of variable speed control method is convenient for the required dynamic performance.
The only criteria of dynamic performance is not the pressure. The flow is also an important criterion of dynamic performance. When the graph within Figure 8 is considered, it is clearly seen that dynamic performance of variable speed control method is convenient. There are some little differences between two methods. Especially the red graph belongs to the variable speed control method followed more floating way when compared the one of fixed speed control. This is caused by changing the electric motor rotate period according to the pressure difference.

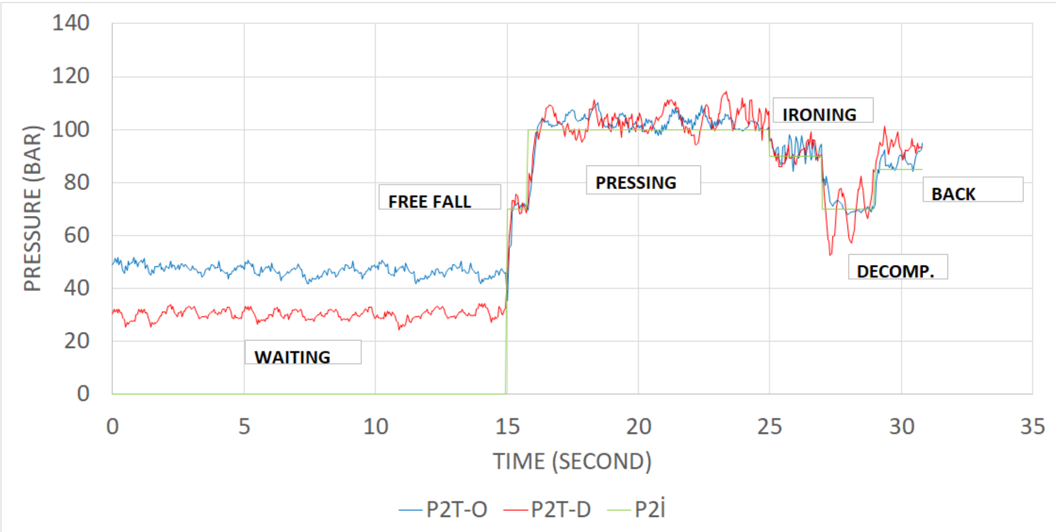

Figure 7 Pressure-time graph for two methods

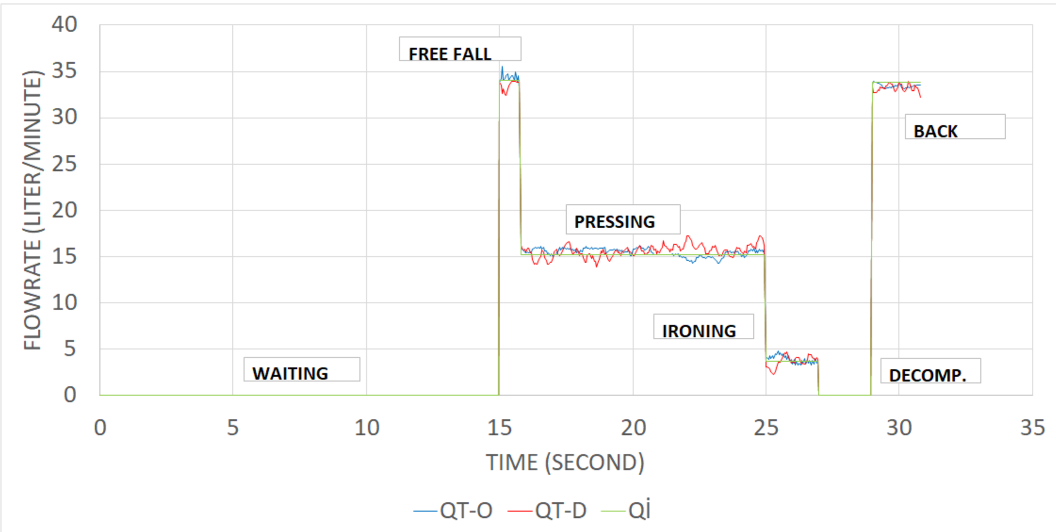

Figure 8 Flow rate-time graph for two methods

4. DISCUSSIONS AND CONCLUSIONS

When the methods are compared according to their average power consumptions (Table 3), the variable control speed method consumed % 70 less energy than that of fixed control speed. Furthermore, the variable speed control method increased the system efficiency from % 10 to % 46. By the help of these results, it is obviously proved that variable speed control method is more useful than that fixed speed control method in the aspect of energy consumption and efficiency.

Table 3 Energy efficiency of the methods

No	Method	Process Time (minute)	İnput Power(kW)	Output Power (kW)	Energy Efficiency
1	Fixed S.C	30,8	11,6189	1,2016	10%
2	Variable S.C	30,8	2,6965	1,2439	46%

According to the results of the conducted experiments, the variances of two different methods according to the ideal scenario are given with in Table 4. When the results given in Table 4 are considered, there are not such big differences between the variable speed method and the fixed speed method.

Table 4 The variances of two methods according to ideal

No	Method	Avarege Variance Over İdeal	Avarege Variance Below İdeal	Compared Values
1	Fixed Speed	4%	5%	Pressure
2	Variable Speed	6%	6%	
3	Fixed Speed	4%	2%	Flowrate
4	Variable Speed	6%	4%	

As a final conclusion, variable speed control method can provide not only energy saving and better efficiency, but also the required dynamic performance. As a future work, a real mechanic structure of a press brake machine can be added to the experiment structure and made a real pressing cycle with a real steel sheet in order to prove if the dynamic performance of variable speed control is convenient for a real pressing cycle or not.

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