

Method for controlling the hydraulic pump flow following an imposed frequency law for AC motors

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Abstract. The efficiency improvements of the hydraulic systems could be accomplished by integrating the electronics and computer engineering. The hydraulic power is the most suitable for control techniques implying real-time correlation between the pressure and flow. The paper presents the way we have controlled the hydraulic power by varying the pump flow as direct proportion to its AC motor frequencies. We have written the specialized software for controlling the frequency following an imposed law. By using the Texas Instrument and Arduino devices, we have controlled the AC motor speed with an inverter, so that the experimental set up for the entire electro-hydraulic system approved the useful and expected results for the external gear pump.

1. Introduction

During the last years, there were developed wide spread design techniques regarding the efficiency improvements for the hydraulic systems, by integrating the electronics and computer engineering as final goal for accomplishment of intelligent systems. The main aims of these activities are the increasing efficiency of the entire systems, the smart control by using specialized drivers, electronic components and software, as well as the challenge of real time analysis of the system performances in order to improve them.

The hydraulic power is the most suitable parameter for control techniques implying the possibility of flow and pressure value correlation during the pump and motor functioning as parts of the system. All the hydraulic systems should have a hydraulic pump as supplier and this one could be with constant or variable flow. The pumps with constant flow are cheaper, but the efficiency is smaller comparing to the systems supplied by pumps with variable flow, as we may apply the comparison with Rexroth products, for instance.

If we aim to vary the hydraulic flow, there are two main methods: the volume control or the resistivity control. The first one implies the variation of the pump flow working with variable pressure depending on the motor load. The second one consists in modifying the local resistance inside the feed or discharge pipes with constant pressure values by using a variable hydraulic resistance. Usually, the first controlling way is chosen when there are high working power values and the second one is applied when a rapid power transfer (inside the range of 7...10 KW) nearby high accuracy are imposed, even though the efficiency is decreasing. An intermediate solution, by using the both method is preferred, in order to minimize the power losses and to increase the dynamic performances.

Consequently, if we use the constant flow pump, which is cheaper, we have to find a way for applying the resistive method for flow variation taking into account the demands for increasing efficiency. The



most common used plans for skilful carrying out such solutions taking into account the efficiency improvement are:

- the pump pressure variation according to the pressure imposed by load value depending on time;
- adding together all the flows passing through the valve connected with the tank;
- the flow control could be done through a throttling controller put in deviation with the element.
- the using of accumulator of hydraulic energy for the entire system.

From all we have presented above, we may infer the most important idea is the entire system efficiency maximization and control, according to the variable load depending on time, so that the hydraulic system becomes an intelligent one.

The paper [1] presents the way used for transforming a classic hydraulic power–supply unit into an intelligent one. There are two main advantages: the control of the supplied pressure according to an imposed law as well as the minimum energy consumption when the hydraulic power is not needed in the system. The solution applied for the Bosch hydraulic system comprises a pressure control valve, a pressure transducer and a temperature transducer for adapting the pressure supplied to the fed system according to the needs of the actuated load. The accomplishment of smart system was done by including the electronic controller that performs the following tasks:

- it assures the interface between the PC and the controlled system;
- it generates and amplifies the control signals for the proportional equipment of the controlled system;
- it affords data acquisition of analog and digital signals;
- it generates digital control signals;
- it assures the display and setting of certain functional parameters.

The paper [2] proposed a genuine solution for decreasing the energy consumption by using a displacement variable pump driven by a speed variable motor whose rotational speed is controlled with an inverter. Usually, the displacement-variable pump operates in small displacement conditions, during which the energy is poor. Currently, one of the ways to deal with this situation is to use a quantitative pump driven by speed variable electric motor. It is reported the energy consumption could be reduced by 20% and more comparing to classic solutions. This type of actuation system is applied to an electric excavator with its own hydraulic system, consisting of two main parts: the electro-hydraulic power source and the hydraulic control system. When the operator gives the command signals there are proportional to the actuator velocities. The controller takes the input and the measured quantities, such as pressure, powers, displacements, flow and speed of the electric motor. According to the set strategy, the controller analyzes the command automatically and sends the voltage signals directly to the motor converter and other specific signals for the hydraulic equipment of the system.

The paper [3] presents an approach for a new working concept for variable delivery external gear pump comprising a mechanism that changes the displaced flow per shaft revolution. A movable slider placed at the gear lateral side affords variable amount of flow displaced by the unit per revolution, so that there are kept all the advantages of conventional fixed displacement external gear pumps. The principle of achieving variable timing is analytical described deeply based on geometry of the gear. The most important idea is to compute the boundaries of the displacement by keeping the tooth contact points inside the limit of line of action, which characterizes the gear geometry.

This paper presents a method for controlling the flow of external gear pump by varying the frequency of its AC motor according to an imposed law. In order to do this, we have analysed the theoretical relationship between pump flow and rotational speed of the electric motor. The next goal was to implement the specific software for imposing the law for speed variation by using the inverter and the Texas Instrument equipment. The direct proportion of pump flow to its rotational speed was pointed out using the experimental set-up of the hydraulic system, which could be considered an intelligent one, because of its advantage of increasing efficiency.

2. The proposed hydraulic system

As it is very well known, the hydraulic power-supply unit efficiency, which implies the system efficiency too, could be improved if we may control better the flow maintaining a constant or variable pressure according to the law imposed for the external load. In order to achieve this goal, it has been chosen the hydraulic external gear pump, whose flow could be controlled by varying the rotational speed of its AC motor.

The AC motor has the advantage of controlling the speed very accurately by using the appropriate software for the inverter as its operation principle affords. The proposed system is working with an AC motor squirrel cage form and its speed could be varied by changing the electric tension according to an imposed law, or by changing the working frequencies. The first solution is simple and is not dependent on the dynamic parameters. For our purpose, it has been chosen the latter method, due to the available advantages of the frequency converters. Consequently, an inverter controlled by genuine written software would provide the system required frequencies meaning an imposed law for flow variation finally.

Working with a variable frequency controlled for the AC motor, it is actuating the hydraulic external gear pump, so that a variable flow will be supplied in the system.

The hydraulic system is presented in Fig. 1, whose components are: P – the hydraulic gear pump; Rz – tank; M – AC motor; Encoder – rotational speed encoder for the electrical motor; Inverter – the inverter for the AC motor speed control; Ssig – safety valve; QT – flow transducer; PT – pressure transducer; 4/3 HD – hydraulic distributor; HM – hydraulic motor; SE – rotational transducer.

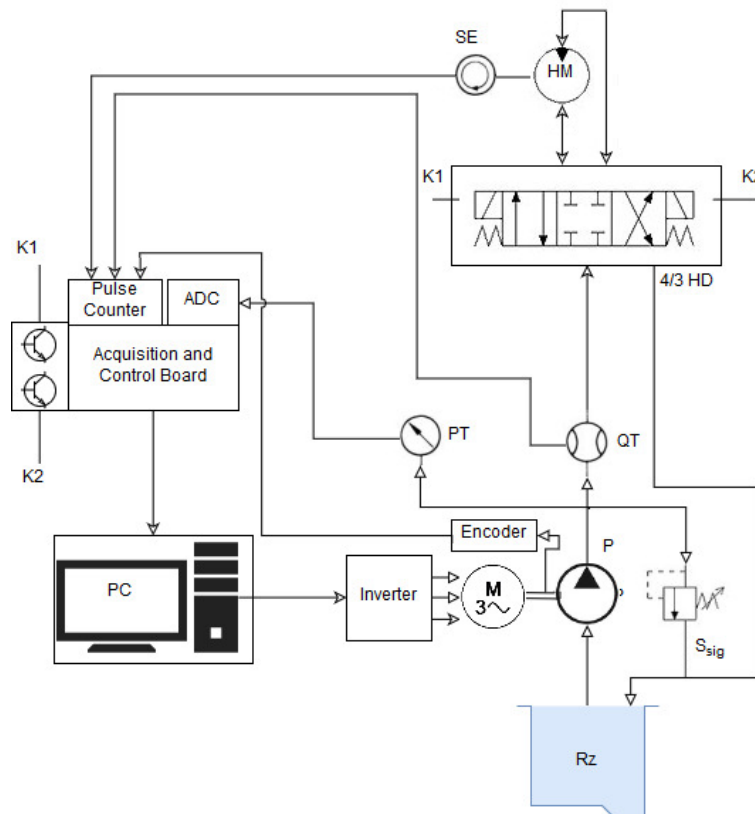


Figure 1. The schematic of the hydraulic system.

The AC motor is controlled by the inverter and is equipped with an encoder for rotational speed because it is a controlled parameter. The external gear hydraulic pump P supplies a variable flow in the system, if its rotational speed is following a variation law. The pressure and flow values are recording by using flow and pressure transducers, QT and PT, that are sent to the data acquisition system. The PC, Acquisition and Control Board, as well as the Pulse Counter are gathering the

information and provides the step value for frequency, so the new rotational speed of the pump motor will be achieved. Meantime, the load actuated by hydraulic motor HM that is controlled by the 4/3 hydraulic distributor HD, will generate a pressure value. Consequently, the hydraulic power could be maintained inside an imposed range in order to keep the maximum efficiency. The rotational speed of the hydraulic motor could be monitored with the rotational speed sensor SE.

3. The control software

The method for variation the rotational speed of the AC motor supply frequencies becomes very widely used because of electronic component development, such as frequency converters. The main advantages are the entire speed range of the machine is allowed to be used as well as the dynamic parameter could be controlled by fast torque/current loop and slower speed/position loop. We have to remind there are some limitations regarding the decreasing of torque and magnetic field if the limits of frequencies are over-passed. The state-of-art control techniques described two main directions, which are used: field oriented control and torque oriented control.

We will describe the method we have used for frequency variation following an imposed law. The main platform we have used is made by Texas Instruments based on Dual-Core Delfino microcontroller 32 bit floating point designed for 3 phases inverter with current, voltage and temperature protection. We may use the signal processing performance with maximum 200 MHz, which enables very complex mathematical operations, starting with floating-point unit, trigonometric function unit and arriving finally to the complex mathematical unit. There are two main processors working together with two control law accelerators that provide the advantage of reducing the time necessary for processing complex mathematical control loops.

This microprocessor control unit with two cores allows the real-time control up to four main parameters due to the higher processing power, or it may split the control for two parameters on one side and communications and diagnostics for the other side.

When it works in isolated mode, this platform needs only 3.3 V due to the boost convertor for 5 V by changing the configuration of the jumpers. The board comes ready equipped with two encoder input headers and input circuitry required for usual 5V passive or active encoders.

Another critical advantage for our application we have to mention is the integrated isolated jTAG emulator for safe programming, debugging and communication with PC, allowing us to use the LABVIEW software for monitoring the process and data acquisition.

The flow chart of the written software is presented in Fig. 2. At first we have to make the setup actions for: two external pins numbered 4 and 5, four pins we will use for the interrupts, the two signals from the transistors used for placing the distributor in the central position, the registers we have to work with during the control process. We have set the variables for current and voltage measurement channels.

The motor is supplied with 230 V at 50 Hz and the goal is the rotational speed control as well as the phase current control. The current value limitation was made by using the electrical resistance and the relay is working when the voltage on the capacitor reaches the safe limit. Meantime the microcontroller temperature is limited to 80°C. During the working period of 50 ms, there are numbered the interrupts and there are stored the frequencies values. For the AC motor, we have started with the frequency equal to 41 Hz and then we have decreased it with the step of 3Hz until the value of 7Hz is achieved.

The Labview software was used for keeping the relationship between the Texas Instrument platform and the Arduino board during the operation of varying the frequency values.

Finally, we may record the values for the rotational speed of the AC motor rod, the hydraulic pressure values after the external gear pump, the pulses of the flow transducer and the rotational speed of the hydraulic motor.

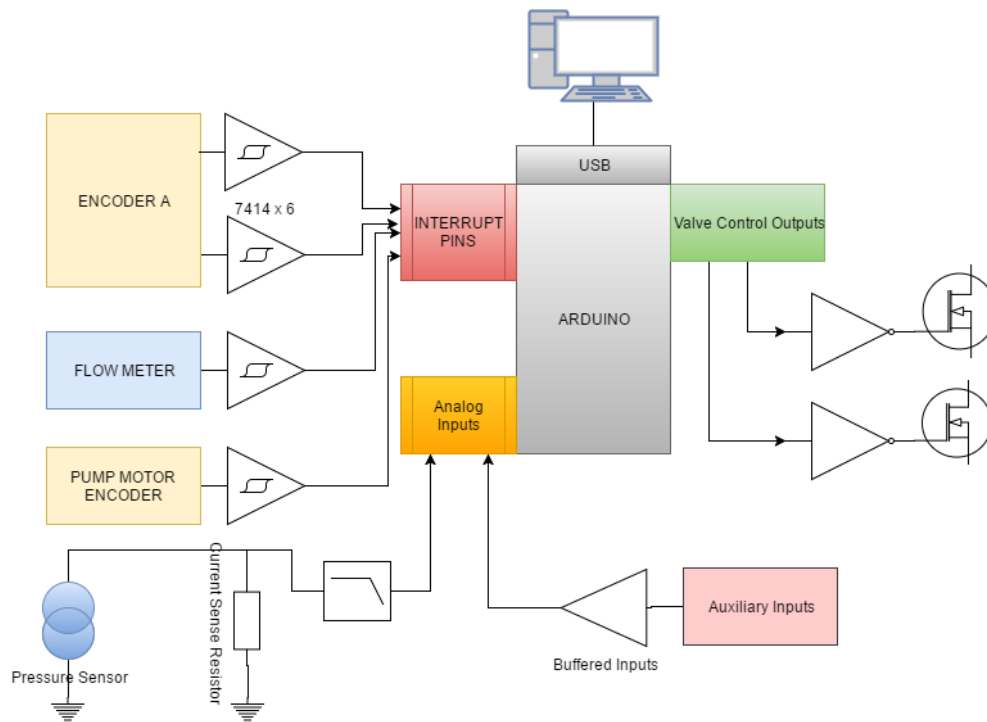


Figure 2. The flow-chart of the written software.

4. Experimental results

The experimental set-up was done for a hydraulic system supplied by the gear pump presented in Fig. 3. The external gear pump 1, whose rotational speed is varied as function of frequency law of the AC motor, provide a variable flow feeding the hydraulic motor 2. The electronic control was done by using the Texas Instruments Platform 3 and Arduino device 4. The genuine software implemented on the PC 5 monitors the entire process using the genuine proposed software.

The experimental results acquired during the control process are presented in Fig. 4 and 5. The Fig. 4 points out the direct proportionality between the pump flow and rotational speed whose step variation is depending on frequency step 3Hz too.



Figure 3. The experimental set-up.

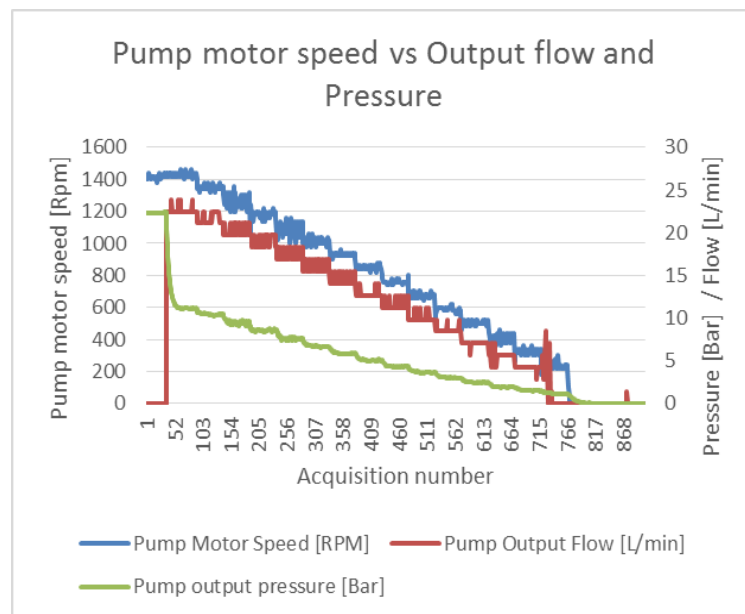


Figure 4. The variation of pump flow and pressure as function of AC motor rotational speed.

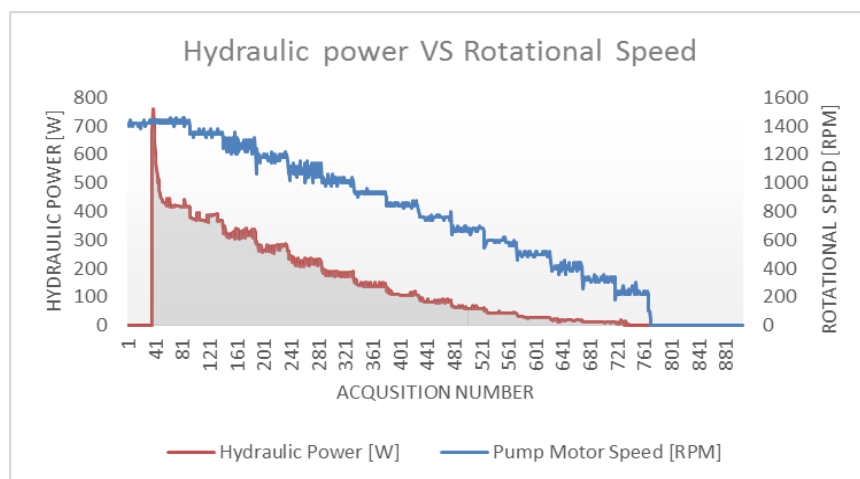


Figure 5. The variation of hydraulic power.

The fig. 5 shows the variation of hydraulic power as function of AC motor speed, so we may observe a peak value for power due to the slow decreasing of pressure when the load is coupled. Meantime, the resonance effect appeared when low values of frequency was used, such as 38 Hz and 44Hz.

5. Conclusions

The paper describes the method used for increasing the efficiency of a hydraulic system by varying the pump flow. The hydraulic power is the most suitable parameter for control improving, taking into account that the flow variation could follow an imposed law and meantime the system pressure is depending on the load value during the entire process. It was pointed out the proposed method for pump flow variation as consequence of the direct proportion of flow to rotational speed of the pump electric motor. The better way of varying the speed of AC motor for instance, is by following an imposed law for its frequency versus time. In order to do this, there were written specialized control software for the Texas Instruments board and for Arduino, using the C++ and LabView programming

languages. Therefore, the signals were sent to an inverter, so that the rotational speed was acquired and the hydraulic power was controlled.

As future work, we aim to include PID controller in the system, as well as working with more complex law for frequency variation. Finally, we may optimize the system parameters according to the real time efficiency.

6. References

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