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# PERFORMANCE OF SPEED CHANGEABLE ASYMMETRIC PUMP CONTROLLED ASYMMETRIC HYDRAULIC CYLINDER

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## ABSTRACT

Valves controlled cylinders are applied in many industries and mobile equipment due to their compact structure, high dynamic performance, and ease to drive more than one actuator by a single pump. Nevertheless, the energy-efficient is low, which is caused by the large throttling loss and the simultaneous actuation of the valves' meter-in and meter-out control edges. These losses can be avoided by replacing the valve-controlled system with a pump-controlled system. In a typical pump-controlled asymmetric cylinder system, a complex and big flow circuit is necessary to compensate for the flow difference between the working ports of the cylinder.

**Keywords**: *asymmetric pump, four-quadrant controlling, pump-controlled cylinder, single rod cylinder, energy efficiency.*

## INTRODUCTION

Hydraulic systems have been widely used in industry and mobile machines by virtue of high power density and high speed of response with a fast start, stop and speed reversal possible. It can be classified as the circuit type into valve-controlled systems and pump-controlled systems. Valve-controlled systems are applied in many machines due to their compact structure, high dynamic performance, an easy drive of more than one actuator by a single pump. However, the advantage of such a simple hydraulic drive structure is always connected to its disadvantage of large energy losses, such as throttling loss. It is reported that only 35% of the pump output power was transferred to the actuators. There are therefore many years of efforts to develop hydraulic systems without throttle losses. Pump-controlled systems also called displacement-controlled systems, can eliminate throttling loss completely and have proven themselves in practice for a long time.

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## PRINCIPLE OF WORKING OF SINGLE ROD CYLINDRIC CONTROLLED PUMP

Recently, a single rod cylinder pump-controlled in the research area is one of the hot topics due to its simple structure, low costs, and high output force. In the case of these systems, there exist unequal flow rates at two ports of the cylinder due to its asymmetric structure. And when a conventional pump is used to control this type of cylinder, either a deficient or excess flow rate is always formed in the closed circuit. Hence research has been focused on the compensation method for the unequal flow rates and on improving the stability of the system. There are several solutions for the differential flow compensation problem: the use of a secondary pump combined with an accumulator and valves, the use of a hydraulic transformer. Both these concepts and structures have the drawbacks of high investment costs, increased number of control elements, and required complex control effort. This paper proposes a novel compensation solution based on a newly designed asymmetric pump and the system stability can be improved without much control efforts and additional elements.

## TYPICAL PUMP CONTROLLED SINGLE ROD CYLINDER SYSTEM

The circuit of the symmetric single rod cylinder pump controlled by checking a valve balanced flow of water is shown in fig.1. A servo motor is used to regulate the drive speed of a constant pump. The two ports of the pump are directly connected to the single rod cylinder, the cylinder velocity can be regulated by changing the speed of the motor. An essential part of this circuit is the low-pressure compensation system, which consists of a small pump and an accumulator. Its functions include compensating for the cylinder's unbalanced flow, compensating for the volumetric losses in the closed circuit, and cooling the hydraulic fluid, over two back-to-back connected hydraulic controlled check valves. And pressure relief valves are utilized to limit operating pressure.

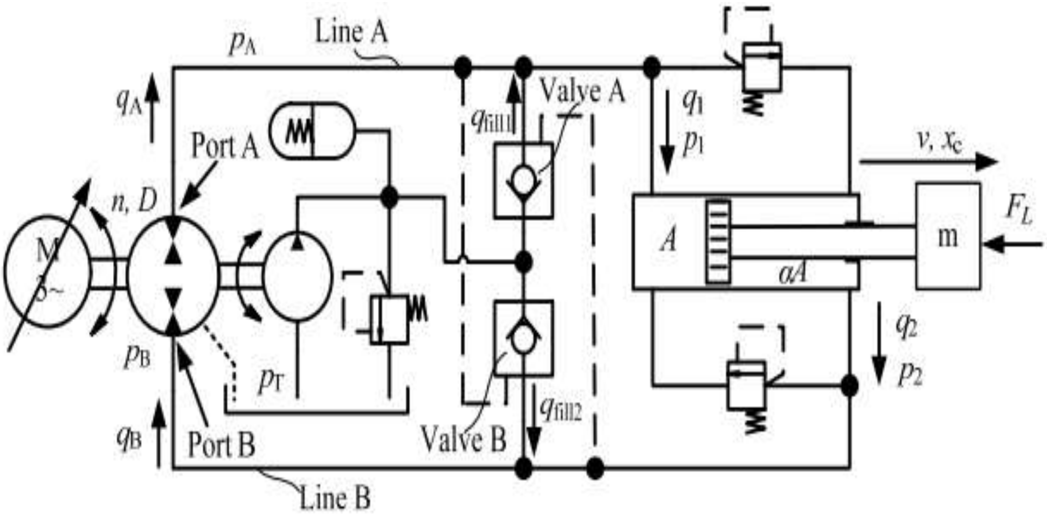


**Figure-1.** Single rod cylinder pump controlled with checking a valve balance flow of water

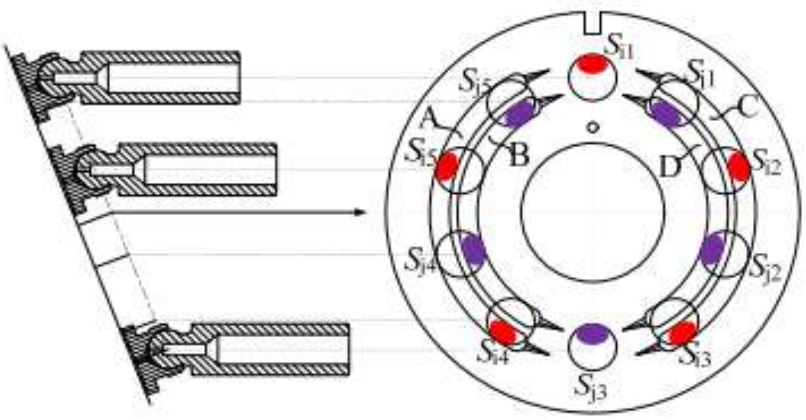
According to the working condition and job demands, many hydraulic systems are required to operate in 4-quadrants. That means that the cylinder and pump can both work as a hydraulic pump or motor. Hence the working process of the pump-controlled single rod cylinder system under 4 quadrants is described as follows. Consider extending the cylinder under resistance load, the pressure in the cylinder rodless chamber is high then it in the rod chamber. So, the rodless chamber is named as control cavity. The pump sucks oil from the cylinder rod chamber through port B, and then the pump discharge oil to the cylinder rodless chamber through port A. The pilot-operated check valve B will be open by the pressure in the rodless chamber. The compensation system supplies low-pressure oil to the cylinder rod chamber. D and n are the displacement and rationing speed of the pump, v is the velocity of the cylinder, $A$ and $\alpha A$ represent the area of the rodless and rod chamber of the cylinder.

Without considering the system leakage, the flow rate output of the pump, $q_{A,}$ and the flow rate into the pump, $q_B$, can be written as $v=D\ n/A$. The flow rate input of the cylinder rodless chamber, $q_A$, is about $A\ v$, and it is equal to the flow rate of the pump port $A$, so the velocity of the cylinder can be written as $v=D\ n/A$. The flow rate output of the cylinder rod chamber, $q_B$, is about $\alpha\ A\ v$. The compensation system should deliver a flow rate, $q_{fill2}$ of $(1\text{-}\alpha)\cdot A\cdot v$ to the mainline $F$. Consider retracting the cylinder under resistance load, the control cavity is the cylinder rodless chamber, the flow rate input the cylinder rod chamber is equal to the flow rate of the pump port $B$, and the velocity can be written as $v=D\ n/(\alpha\cdot A)$. The compensation system should store a flow rate, $q_{fill1}$ of $(1\text{-}\alpha)\cdot A\cdot v$ to the mainline E. And also, consider extending the cylinder under overrunning load, the control cavity is the cylinder rod chamber, $v=D\ n/(\alpha\cdot A)$, $q_{fill1}=(1\text{-}\alpha)\cdot A\cdot v$. Consider retracting the cylinder under overrunning load, the control cavity is the cylinder rodless chamber, $v=D\ n/A$, $q_{fill2}=(1\text{-}\alpha)\cdot A\cdot v$.

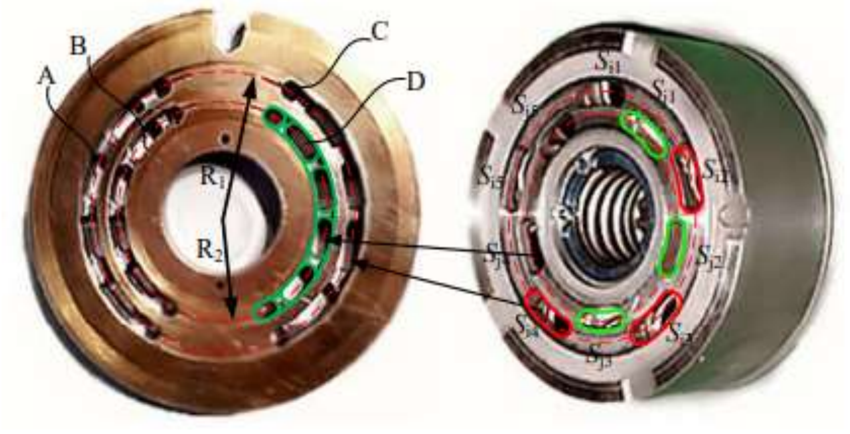
It can be concluded that when the displacement and rotating speed of the pump is a constant valve, the compensation system should deliver a flow rate of *(1-α)·A·v* during extending process and store the same flow rate during the retraction process. In addition, the cylinder velocity will change if the load condition changes.

## ASYMMETRIC PUMP CONTROLLED WITH SINGLE ROD CYLINDER SYSTEM

As mentioned above, for the conventional pump-controlled single rod cylinder, due to the asymmetry structure of the system, the relationship between the cylinder velocity and pump rotating speed depends on the load conditions, so the cylinder velocity stability is worse when the load changes frequency. In order to solve this problem, we have introduced the principle of asymmetric valve controlled asymmetric cylinder system to the pump controlled single rod cylinder system based on a newly designed asymmetric pump. Benefiting from the asymmetric structure of the pump, the flow rates of the cylinder and pump can be balanced basically. Fig.2 gives the working principle and photograph of the valve plate and cylinder block of the newly designed asymmetric pump.



***(a) Working principle of the pump***



***(b) The picture of the Valve Plate and Cylinder Block***

**Figure-2.** Working principle of the Asymmetric Pump and the Picture of the Valve Plate and Cylinder Block

It can be seen that there are four assignment windows on the valve plate, named *A*, *B*, *C*, and *D*. *A* and *C* are on a circle with a radius of $R_1$. *B* and *D* are on a circle with a radius of $R_2$. Windows *A* and *B* are connected to each other by port $A_1$ on the pump end shell cover. Windows *C* and *D* are one-to-one correspondence with pump ports $B_1$ and $C_1$. There are 10 plunger chambers and they are divided into two groups on average. At the bottom of the cylinder block, there are an inner annular array and an outer annular array. The pitch radiuses of these two annular arrays match with the slots *A*, *B*, *C*, and *D* on the valve plate. As shown in Fig.2 (b), the plunger chambers identified as Si, correspond to the outer annular array, and these five pistons suck and discharge oil from the outer annular array only. The plunger chambers identified as Sj, correspond to the inner annular array, and these five pistons suck and discharge oil from the inner annular array only. So benefiting from the asymmetric structure of the flow distribution, the flow rates ratio of the three ports of the pump is about 1: 0.5: 0.5. And we can match the area ratio of a single rod cylinder by changing the piston diameter or $R_1$ and $R_2$ to change the flow rate ratio.

The principle of asymmetric pump controlled single rod cylinder is shown in Fig.3. A servo motor regulates the drive speed of the newly designed asymmetric fixed displacement pump. Ports *A* and *B* of the pump are directly connected to the single rod cylinder, and port $C_1$ is connected to an accumulator directly and tank through a check valve. And also, the accumulator is used to compensate for the differential flow rate caused by leakage and to pressurize the low-pressure chamber over the hydraulic controlled check valves. And pressure relief valves are utilized to limit operating pressure, respectively.

During the extending process, the pump sucks oil from the cylinder rod chamber through port $B_1$, and from the tank or accumulator through port $C_1$. Then the pump discharge oil to the cylinder rodless chamber. During the retraction process, the pump sucks oil from the cylinder rodless chamber through port *A1*.

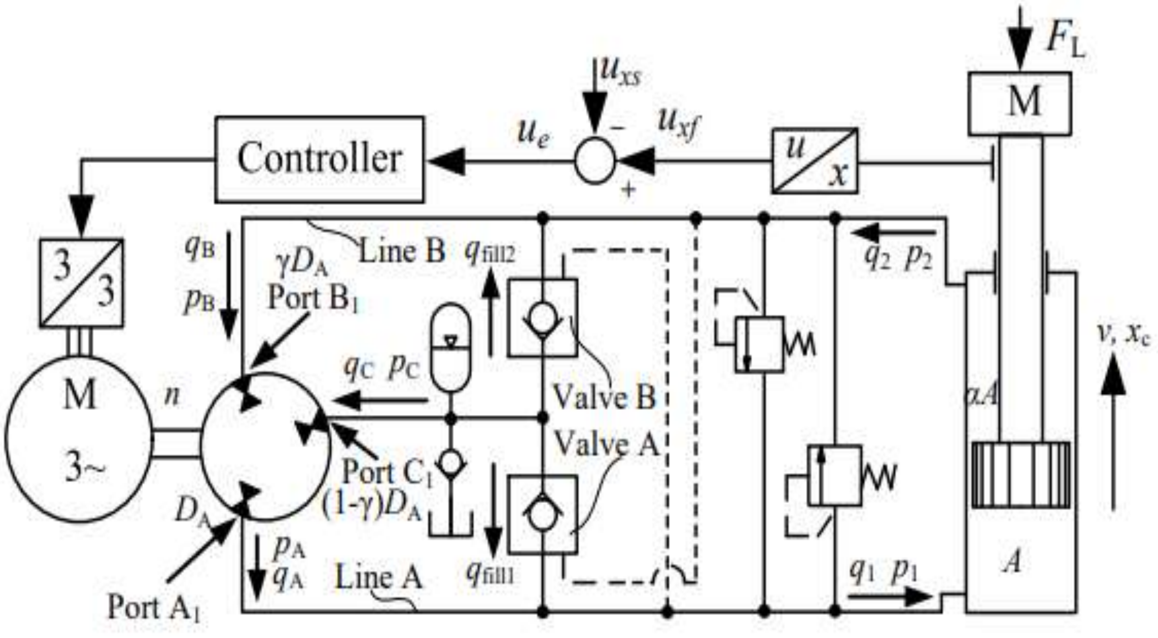


**Figure-3.** Principle of Asymmetric Pump Controlled Single rod cylinder.

Then the pump discharge oil to the cylinder rod chamber and to the accumulator through port $B_1$ and $C_1$. *n* is the rationing speed of the pump, v is the velocity of the cylinder, A and αA represent the area of the rodless and rod chamber of the cylinder. $D_A$, $\gamma D_A$ and $(1-\gamma) D_A$ are the displacements of the pump ports $A_1$, $B_1$, and $C_1$, and γ is the ratio of the displacement between ports $B_1$ and $A_1$. Consider extending the cylinder under resistance load and retracting the cylinder under overrunning load, the control cavity is the rodless chamber, and the rod chamber is pressurized by the accumulator through port $C_1$. Under these conditions, the cylinder velocity can be written as $v=DA\ n/A$. Consider extending the cylinder under overrunning load and retracting the cylinder under resistance load, the control cavity is the rod chamber, and the rodless chamber is pressurized by the accumulator through port $C_1$, the cylinder velocity can be written as $v=\gamma\, DA\, n/(\alpha A)$. As the displacement ratio $\gamma$ is designed to equal the area ratio of the rodless and rod chamber of cylinder $\alpha$, the flow rates in and out of the pump and cylinder match each other basically.

## PUMP CONTROLLED ARM CYLINDER MODEL

Unlike the working condition of the conventional hydraulic cylinder, the load exerted on the cylinder used in the mobile machine varies in large range and is unpredictable. It is difficult to establish the dynamic mathematical model of such a system. In order to have good knowledge about the working performance of the newly designed system and the actuator, benefiting from the computer simulation technique, a multidisciplinary and multi-body dynamics model of the machine is constructed. And also, the performance of the symmetric pump controlled system is studied for comparison.

A simulation model is created in order to analyze the symmetric pump-controlled system and to implement new concepts into the existing machine on a virtual level. A multi-body model coupled with the hydraulic model determines the forces that act on the actuators. The moment of inertia and mass of the machine is taken into account and also the force acting on the bucket can be transmitted to other actuators in real-time. The simulation model is based on SimulationX, which is based on the open-source language Modelica. The model can be seen in fig.4 below.

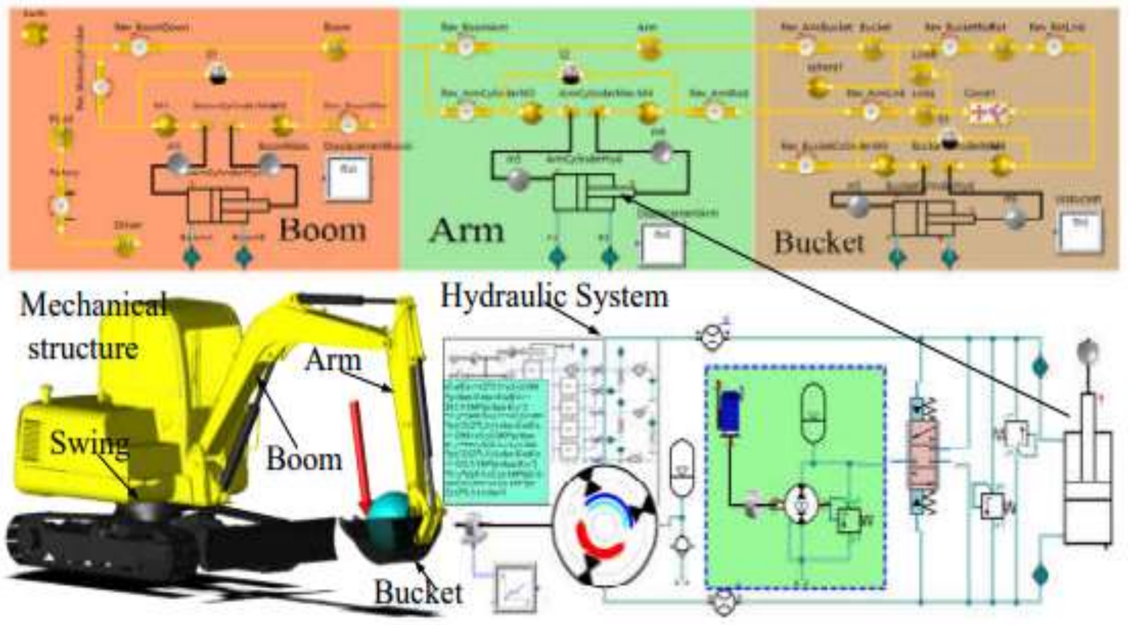


**Figure-4.** Simulation Model of the Asymmetrical Pump Controlled Excavator Arm Cylinder.

As shown in Fig.4, the prototype consists of the hydraulic excavator mechanical structure such as a boom, arm bucket, swing, and so on, and an electro-hydraulic system is constructed based on the circuit shown in Fig.3. For a real variable speed pump controlled system, the response of the servo motor is enough and it can be simplified to a simpler model to reduce the simulation time without much compact on the performance. The newly designed asymmetric pump is a detailed model based on a detailed geometry model using a single piston structure. And a small fixed gear pump combined with an accumulator is used to balance the unbalanced flow rates caused by the leakage and volume loss. Parameters of the shuttle valve are included based on the real structure in the system model, rather than treating it as an ideal switching element as handled in literature. The model can be modified to a symmetric pump controlled system by replacing the asymmetric pump and increasing the displacement of the gear pump. The mechanical structure and asymmetric model have been verified in the team's previous research work. In the model, the arm cylinder stroke is about 720 mm, and the diameters of the piston and piston pole are 85 mm and 55 mm. The displacements of the asymmetric pump are 40 mL/r, 20 mL/r, and 20 mL/r. The flow rate of the compensation system is about 5 L/min.

## CONTROL STRATEGY

Velocity control is widely used in a hydraulic excavators. The operator gives the velocity command by operating the joystick. And then the displacement or rotational speed of the pump changes. The actuator works at the demand velocity. When the cylinder approaches the demand location, the operator relieves the joystick. The actuator stops. But only adopting an open loop to control arm velocity may result in no position accuracy and poor anti-interference ability, the working performance relies on the operator. And it is difficult to realize automatic excavation. For these problems, a strategy of displacement closed-loop control is designed to realize accuracy control of the cylinder. However, the velocity cannot be controlled using only displacement closed-loop control. So the displacement closed-loop control combined with velocity feedforward is put forward. On the base of the position control system, the velocity feedforward is introduced to control the velocity. When the difference between the desired position and the real position is large, the velocity feedforward control plays an important role. And position feedback plays an important role when the difference is small.

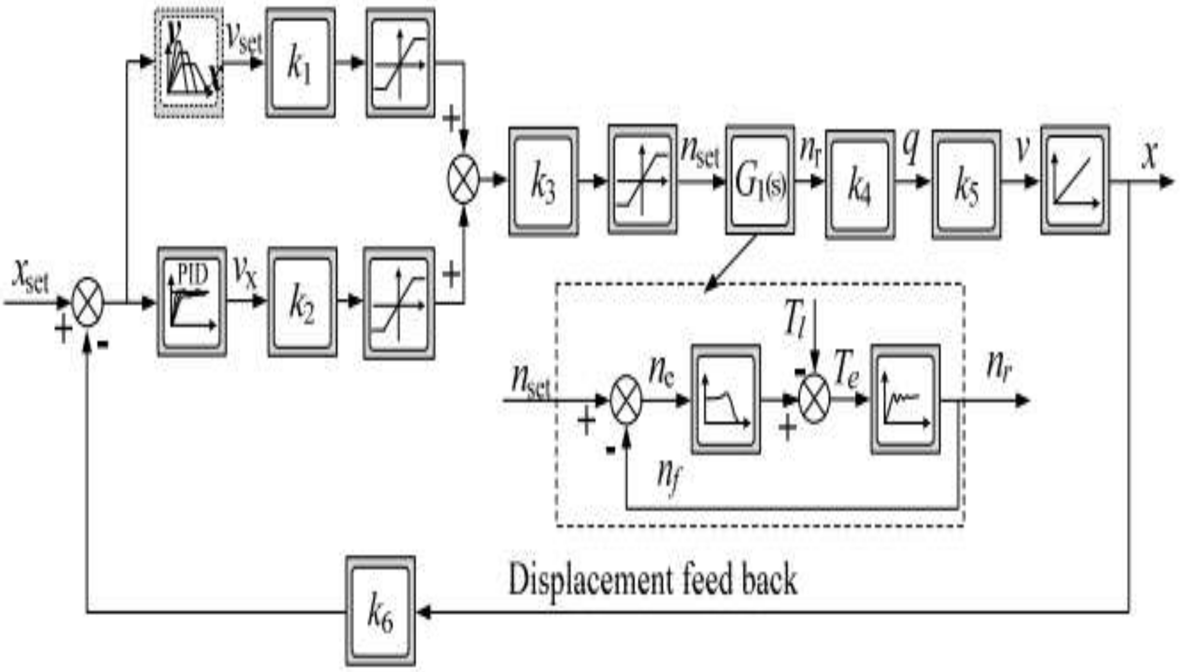


**Figure-5.** Position Closed Loop Control Combined with Velocity Feedforward

If the excavator is in an artificial operation condition, it can get rid of the position closed-loop and just use velocity feedforward to realize velocity control. In this way, the operator gives sets the velocity demand by operating the joystick, the signal is calculated and given to the motor driver to control the rotational speed of the electric motor and so the pump output the demand flow. If the excavator works under automatic operation conditions, when the target position is given, the target velocity signal will be formed by the velocity regulator in a position closed-loop according to the position difference between the target and actual position.

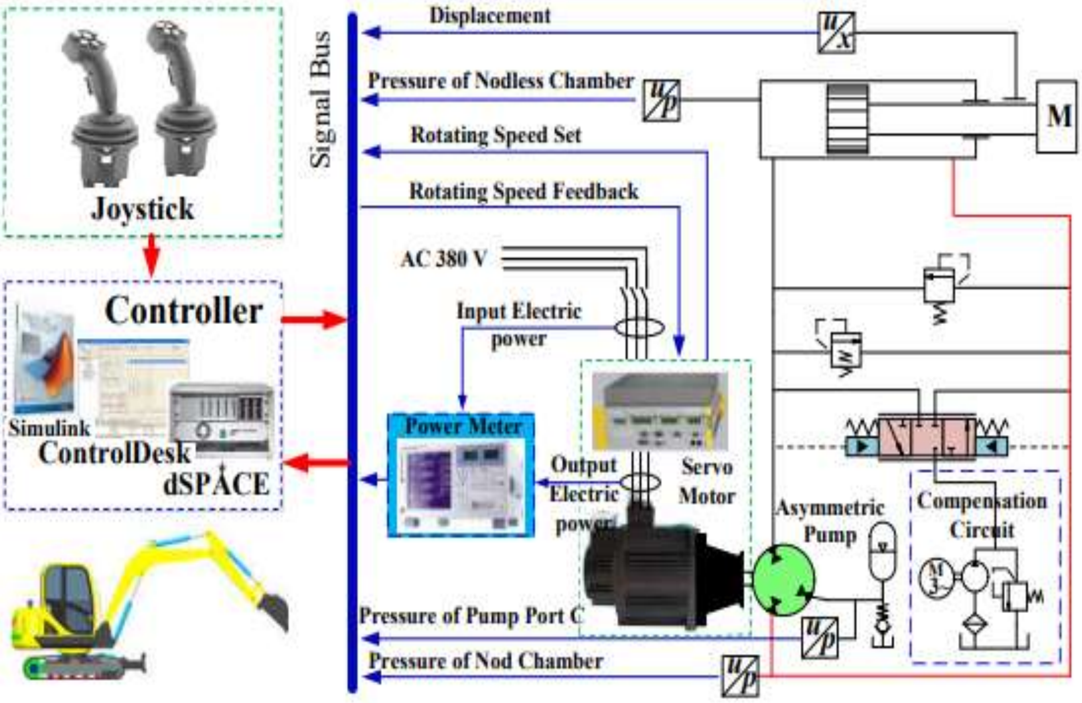


**Figure-6.** Experiment Platform

As shown in fig.5, the operator gives the desired position signal x set, then the controller calculates the desired velocity signal *v* set and $v_x$ to control the speed of the servo motor. And then the velocity and position of the cylinder can be realized. If the velocity feedforward is cut off, then the system works as position control. And also, the controller can be modified to velocity open-loop control if the displacement feedback is cut off.

In order to provide compared data about working performance and energy efficiency, the test of arm cylinder with separate metering in and separate metering out system is driven by an inverter motor is implemented first. After the test of the arm cylinder controlled by a separate metering system, the asymmetric pump-controlled arm cylinder test rig is constructed, as shown in fig.6.

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As shown in fig.6, the arm cylinder is controlled by an asymmetric pump driven by a servo motor. A small gear pump is introduced to compensate for the unbalanced flow caused by leakage.

## CONCLUSION

Compared with the system controlled by a symmetrical pump, with an asymmetric pump, the load value and direction changing have no influence on the cylinder velocity without any feedback. The position closed-loop control combined with velocity feedforward is adopted, and the error of steady-state control is small, only about 0.10 mm. The precision of position control is high enough to meet the automatic mining requirements.

Compared with the separate metering in and metering out system, during cylinder extending, the energy-saving ratio can be increased up to 87.0%. During cylinder retraction, the energy-saving ratio can be increased up to 50.4%. And in a whole working cycle, the saving ratio can be increased up to 75.3%.

## REFERENCES

[1] Hippalgaonkar R., Zimmerman J., Ivantysynova M. Fuel Savings of a Mini-excavator through a Hydraulic Hybrid Displacement Controlled System[C] // Proceedings of 8th IFK International Conference on Fluid Power, Dresden, Germany, 2012, 2: 139-154.

[2] Sprockhoff V. Untersuchungen von Regelungen am hydrostaischen Zylinderantrieb mit Servopumpe[D]. RWTH Achen, 1979.

[3] Berbuer J. Neuartige Servoantriebe mit primärer Verdrängersteuerung[D]. RWTH Achen, 1988.

[4] Quan Z, Quan L, Zhang J. Review of energy efficient direct pump controlled cylinder electro-hydraulic technology[J]. Renewable & Sustainable Energy Reviews, 2014, 35:336–346. [5] Kazmeier B. Energieverbrauchsoptimierte Regelung eines Elektrohydraulischen Linearantriebs Kleiner Leistung Mit Drehzahlgeregeltem Elektromotor und Verstellpumpe, Doctor Dissertation, TUHH, 1998. [6] B. Johansson, P Kaus. Object Oriented and Distributed Modeling of a Multi-domain Aircraft Actuation System[C]// Proceedings of The Fifth International Conference on Fluid Power Transmission and Control, Hangzhou, China, 2001: 344-349.

[5] Kazmeier B. Energieverbrauchsoptimierte Regelung eines Elektrohydraulischen Linearantriebs Kleiner Leistung Mit Drehzahlgeregeltem Elektromotor und Verstellpumpe, Doctor Dissertation, TUHH, 1998.

[6] B. Johansson, P Kaus. Object Oriented and Distributed Modeling of a Multi-domain Aircraft Actuation System[C]// Proceedings of The Fifth International Conference on Fluid Power Transmission and Control, Hangzhou, China, 2001: 344-349.

[7] Lodewyks J. Differentialzylinder im Geschlossenen Hydrostatischen Getriebe[D]. RWTH Achen, 1994.

[8] Feuser A, Dantlgraber J, Spath D. Servopumpenantriebe Für Differentialzylinder[J]. Ölhydraulik und Pneumatik, 1995, 39(7): 540-544.

[9] Daniel Boehm, Claus Hollander, Thomas Landmann. Hybrid-Antriebe bei Raupenbaggern – Konzepte und Losungen[C]// 3th Hybridantriebe fur Mobile Arbeitsmaschinen Fachtagung, Karlsruhe， Germany ， 2011, 2: 117-124.

[10] Chen Mingdong, Zhao Dingxua, Ni Tao. Boom Energy-saving System with Closed Oil Circuit in Hydraulic Excavator[J]. Journal of Jilin University, 2012, 42 (5)：1140-1144.

[11] Abubakirov A B, Tanatarov R J, Kurbaniyazov T U, and Kuatova Sh B 2021 Intellectual Grid Modulation and Monitoring Turkish Journal of Computer and Mathematics Education 12(2) 1054-8.

[12] AB Abubakirov, RJ Tanatarov, TU Kurbaniyazov, Sh B Kuatova 2021 ACADEMICIA: An International Multidisciplinary Research Journal 11// Application of automatic control and electricity measurement system in traction power supply system/ 180-186 pages.

[13] AB Abubakirov, QM Najmatdinov, TU Kurbaniyazov, Sh B Kuatova 2021 ACADEMICIA: An International Multidisciplinary Research Journal 11 //Sensor characteristics monitoring and control of single and three-phase currents in electric networks/ 2282-2287 pages

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