PROBLEMS OF MANIPULATOR ROTATION CONTROL, BASED ON AUTOMATION OF MINIEXCAVATOR.

Tomasz Mirosław *
Jan Szlagowski **
Zbigniew Żebrowski **

- *Scientific Industrial Group of Professional Electronics*
RADWAR SA
e-mail: rawarsc@radwar.com.pl
*** Institute of Heavy Machinery Engineering*
Warsaw University of Technology
e-mail: jsz@simr.pw.edu.pl
e-mail: zzebro@simr.pw.edu.pl

Abstract: In this paper advantages of manipulator hydraulic drive automation ware shown. These manipulators are used in unmanned remote controlled vehicles. Problems of movement parameters measurement was upon the question. A simplified method of choosing position sensor for speed and position feedback with lengthened sampling period of hydraulic drivers was presented.

Keywords: mini excavator, hydraulic drive, acceleration measurement, speed measurement, position measurement, positioning accuracy, sampling time., servo vale.

1. Introduction

Development of automation changes feature of human work and live. It enables man to develop his activity in areas which were inaccessible to him few years ago. It makes possible working in dangerous environment condition without taking risk of human health or life. Very often machines without man are sent to dangerous zone. These machines follows theirs programs from their memory or they are remote controlled by operator. When machine is sent to unknown place its very difficult to prepare program which would foresee every possible situation and contain every possible case of acting. So the remote controlling is more effective way of steering machine. But remote control required continues fixed attention of operator. The attention and experience of remote operator must be higher than direct operator, because he depend on information accessible from sensors and with their mistakes. During typical process same simple and easy functions are repeated many times. This functions unnecessary fixed operator attention. During those simply and easy operations tired operator subconsciously rests and makes mistakes. For this reason it is useful to do this operation automatically without operator.
To put these functions on machine the structure of them have to be changed. It must be tended towards taking control over typical function by its deck computer [1.]
This computer receives commands of required operation with its parameters. To provide that operation most effective the deck computer should have appropriate knowledge and acting methods. This part of program with database is called “the expert”. This expert makes analysis of environmental condition , and choose the way of task realisation, according to operator requirements, and effect by itself.
So operator controls machine by commanding.
The functional schema of remote controlled machinery with expert is shown in Fig. 1

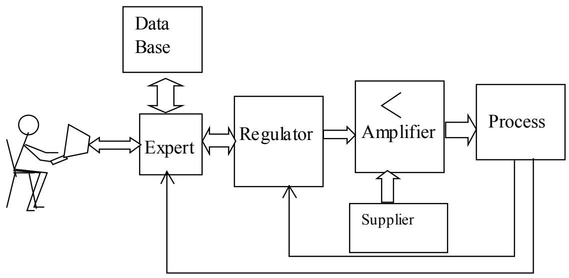

Fig. 1. Functional schema of remote controlled machinery with expert

One of basic operation for remote controlled machines is manipulator positioning and moving things. One of phase of positioning and moving things is rotation to required position, and rotation with controlled speed.

2. Drivers used in self-propelled machines

Very big progress in electronics with power electronics caused development of high precision electric drivers. This drives bases on different kind of electric motors, which provide high torque and wide speed range. It makes it relatively easy to build electrical drive of high positioning accuracy.
When the self propelled machines work outdoor, not only precision of movement is important but energy supply as well.
When pure electric driver is concerned the supply problem is very difficult.
In spite of big and fast progress in electrical energy sources like battery and capacitors, the weight and size of that sources are still to big.
A chemical sources of energy are still most effective because of rate of their weight and size to stored energy quantity.
For this reason the petrol is main source of energy in self-propelled machines with high energy demands.
The chemical energy is converted to mechanical energy in combustion engine. The mechanical energy produced in diesel and other combustion engines is difficult to send and control. So those engines propel electrical generators or hydraulic pumps.
Because of mass to power rate the hydraulic drivers are more popular in high power drives than electric drivers. But precision of movement and easiness of control of electric motors, make that drives very competitive to hydraulic, and they became popular in special machines.
The electrical motors can deliver high controlled torque in wide range of controlled speed.
The speed rate (it means rate of maximum to minimum speed) is over 10 000 what enables high resolution speed and position control. Electric torque motors coupled with bearing make possible of making drives without looses.
But this drives have also disadvantages like low efficiency, and emission of electromagnetic disturbance.

A new sphere of electro-hydraulic drive appeared few years ago. It is developing quickly joining together advantages of those both kinds of drivers. [2]
One of these devices was build by Luccas [3] for driving rudder in passenger aeroplane. It consists of electrical motor propelling hydraulic pump which supply hydraulic accumulator and hydraulic linear motor. It was built as one combined device.

But there is still wide branch of machines where efficiency of power use connected with weight, size and resistance to environmental condition is more important than movement precision.
Excavator belong to this group of machines. High precision movement of manipulators like scoop enables save time and money. A earthwork can be done more effective. The place of digging and shape of excavation can be controlled with higher accuracy.
This remote controlled machines can be used as manipulators in special works like mines removing. In this situation not only accuracy of positioning is important, but smooth movement with stable speed as well.

3. Conception of rotation drive machinery

Based on above analysis , the challenge of building hydraulic drive with high positioning accuracy and low stable speed was taken.
The task is to build this machinery basing on typical fluid power element but with new controller and sensors. The aim is to rich higher speed rate and stable slow movement with smooth stopping in required position with high accuracy.
A simplified schema of built machinery is shown in Fig. 2

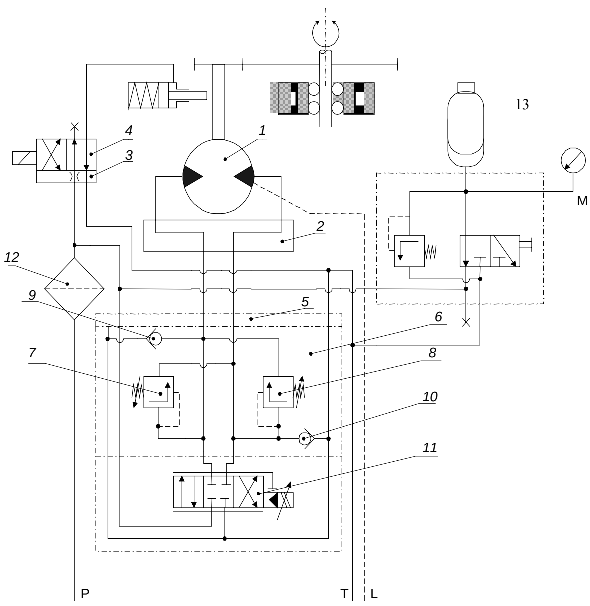

Fig. 2 Simplified hydraulic diagram of rotary platform drive system

1 low speed hydraulic motor with brake,2 subplate, 3 subplate, 4 directional control valve, 5 subplate, 6 sandwich mounting for valves, ***7*** direct relief valve, 8 direct relief valve, 9 non return valve, 10 non return valve, 11 stage directional servo valve with mechanical feedback, 12 pressure filter.

In realised hydraulic drive the speed control is executed by servo valve, whose solenoid current is controlled by regulators. It means that electronic unit doesn't control hydraulic motor indirectly but via electro-hydraulic servo valve.
This is nonlinear and has hysteresis. So the same solenoid current cause different flew and motor rotation.
This situation make hydraulic drive difficult to control.
There are same efforts taken to remove unreliability of valve behaviour.
One of those effort is supplying solenoids with oscillating current to keep valve control spool oscillating by mean position. This method minimises static friction effect. But it causes vibration as well.
Another method of reducing valve problems is control spool position. For using this methods a special valves with spool position sensors are needed. In this case one more feedback loop of spool position is added to control system.
Using this valves with spool position sensor we know spool position, but problem of static friction and flow regulation resolution is still present.

This problem is reduced in new kind of valve spool drive. The spool is driven by screw which is propelled by small electric motor [4]. It enables set valve slid very precisely and change its position with high resolution.
These methods are effective but aren't very popular in typical excavators yet.
For this reason we decided to limit our activity to find such control methods and introduce such sensors which allow us to rich our aim.

4. The problems connected with measuring parameter of manipulator motion.

High accurate positioning demands controllable very low speed. This speed is decreased to zero in destination place.
To keep speed in narrow bands the device must react very quickly for its changes. It would be better to control acceleration and keep it on required level. To big acceleration changes (called jerk) effect in changes of construction tensions and can caused oscillations.
So controlling these three movement parameters (position, speed, acceleration) is the best way to rich settled aim.
This parameters are in close relation shown in Fig. 3 and Fig. 4

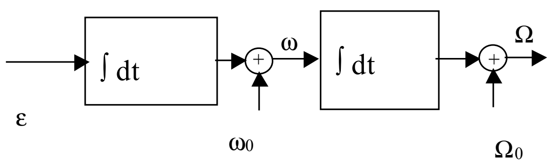

Fig. 3 Relation between acceleration, speed and position

or

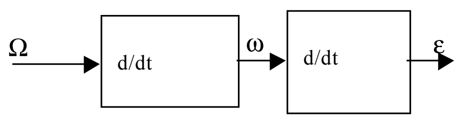

Fig. 4 Relation between position, speed and acceleration.

We can see that having one parameter it is possible to calculate others.
But it isn't so easy. We need choose proper sensor and set it on the machine.

4.1 Acceleration measurement

If we measure acceleration and take as start condition known position and speed equal zero, we will be able calculate actual speed and position by integration of acceleration.
The accelerometers can be used as sensor of rotary acceleration. To reduce influences of different movements we need to use at least two sensors settled on rotating platform as it shown in Fig. 5.

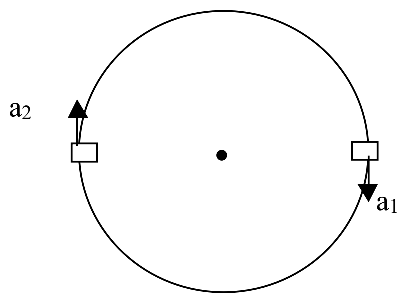

Fig. 5.Setting acceleration sensor to rotary acceleration measurement .

Sensors are situated in opposite side of rotary axis but at the same distance. The sensors active axes are turn in the opposite direction tangentially to vector of translation speed.
The rotary acceleration is equal:

$$\varepsilon = k_{\varepsilon} \bullet (a_1 + a_2) \quad \text{(eq. 1)}$$

This sensors are easy to settle. But if they are taken for whole range of acceleration, because of signal noise they could be inaccurate working in range of very low speed and acceleration. So they shouldn't be source for speed and position integration.

4.2 Speed measurement

Using speed sensors seems to be more difficult problem.
Typical speed sensors like rate generators needs to be coupled directly or through multiplying gear with rotary axis. In low speed range noise of signal is relatively to high. Another speed sensor is optical gyros.

It is possible to control rotary speed with accelerometers.
The example of setting accelerometer as rotary speed sensor is shown at. Fig. 6

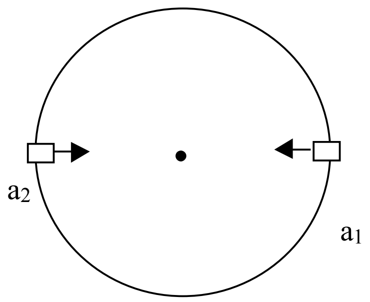

Fig. 6 Setting acceleration sensor to rotary speed measurement

The sensor measures centripetal acceleration. To avoid influence another acceleration it is necessary to use at least two sensors settled in opposite side of rotary centre with active axis turn in opposite direction. The absolute value rotary speed is equal:

$$|\omega| = k_{\omega} \bullet (a_1 + a_2) \quad \text{(eq. 2)}$$

This method is easy to realisation but it doesn't differ speed direction.

4.3 Position measurement

Position measurement seems to be the most accurate way of counting speed and acceleration by differentiation In this method the error of measurement is differentiated
There are many position sensor converting position to analogue and digital signal. There are absolute and incremental sensors. The first one give information about real position the second about way which sensor has passed. Absolute sensor should be coupled with rotating axis with 1:1 rate. Examples of absolute sensors are: resolvers, synchros, encoders, potentiometers, and Hall effect potentiometers.
The incremental sensors are couplet with different ratio. The incremental sensors encoders, multipole resolvers, inductosyns , inductive sensors uses to measure gear tooth position.

4.4 Speed deriving based on position measurement

Speed counting based on position difference take same difficulties. The value taken from subtraction of position value at successive sampling moments is proportional to average speed in sampling period. To close up to real speed value the sampling period should be as short as possible. According to Shannon criteria [5]of render real value of variable is sampling time less than:

$$T_S \leq \frac{\tau \cdot \pi}{100} \quad \text{(eq. 3)}$$

Where T_S –sampling time, -time constant.
In real machinery the sampling time is about $\tau/50$.
If position sensor is used as source for speed counting with required accuracy $\Delta\omega$, the sensor resolution $\delta\Omega$ should be small enough to find error.

$$\delta\Omega = \Delta\omega \cdot T_p \quad \text{(eq. 4)}$$

So when small $\Delta\omega$ is allowed and T_P is short the resolution of position sensor should be very small.
A bit number sensor resolution n is given by equation:

$$n = \log_2 \frac{\Omega_{zak}}{\Delta\Omega} \quad \text{(eq. 5)}$$

Where Ω_{zak} is fullrange of movement.

But sometimes the value of real speed isn't necessary. Because of inertia of driven machinery, the rotation speed doesn't change immediately. Regulator reaction for this changes takes same time. So knowing real speed isn't necessary.
Every speed trajectory can be approximate with broken line made of segment with finitely slope.

For small time period all movement can be represent by sum of periods uniformly accelerated (retarded) motions.

Based on this assumption read position change divided by sampling period gives real speed in middle of sampling period. It is easy to calculate real speed in moment ω_n by follow equation:

$$\omega_n = \omega_{n-1} + 2(\frac{\Delta\Omega_n}{T_P} - \omega_{n-1}) \qquad \text{(eq. 6)}$$

where: ω_{n-1} previous speed, T_P –sampling period, $\Delta\Omega_n$ position increase in n sampling period.

The accuracy of calculation real speed depend on:

- T_P –sampling period,
- inertia of machinery,
- variation of load torque.

The load torque changes in unpredictable way, and have feature of disturbance. The source of this disturbance can be internal or external for regarded machinery. One of internal reason of load changes is changes of friction during rotation connected with used up elements. In this case the higher friction force last on same part of path.

When this torque disturbances appear immediately they effect more to stability of low speed than higher speed on the same distance s.

The speed losses on s-distance where torque of friction rose by ΔM_T is equal:

$$\Delta\omega = \omega \pm \sqrt{\omega^2 - \frac{2 \cdot \Delta M_T \cdot s}{J}} \qquad \text{(eq. 7)}$$

or

$$\frac{\Delta\omega}{\omega} = 1 \pm \sqrt{1 - \frac{2 \cdot \Delta M_T \cdot s}{J\omega^2}} \qquad \text{(eq. 8)}$$

But speed changes in the time period ΔT_P is the same for the same ΔM_T .

The speed changes depended on time ΔT_r reaction is given by very well known equation:

$$\Delta\omega = \frac{\Delta M_T}{J} \Delta T_r \qquad \text{(eq. 9)}$$

If acceptable speed error is $\Delta\omega_a$ the reaction time should be shorter than:

$$\Delta T_r = \frac{J \cdot \Delta\omega_a}{\Sigma \Delta M_D} \qquad \text{(eq. 10)}$$

where: ΣM_D is a sum of all maximum value of disturbance turning moments.

Reaction time consist of T_P measurement time, T_V valve solenoid current regulation time , T_F flew stabilisation time. Diagram of those time period is shown in Fig. 7

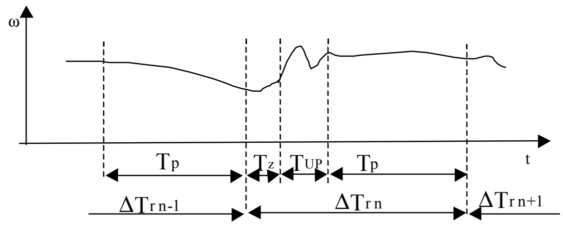

Fig. 7 Diagram of reaction time periods

Based on this measurement time T_P is equal:

$$T_P = \Delta T_r - T_V - T_F \qquad \text{(eq. 11)}$$

In this time the speed should be stable or changing relatively slowly. Its changes are caused only by changes of load torque, not by change of control signal.

In hydraulic drive with high speed rate which moves with low speed the huge spare driving torque is much greater than expected movement resist. So time of speed changes cased by driving torque is much shorter than changes caused by changes of load. The preparation of control signal time by digital processor is negligible short. Reaction time of servo valve depend on his construction. The servo valves with mechanical feedback has this time relatively short , but it isn't negligible. In range of low speed and low level of control signal, more difficult problem is its insensibility. This insensibility causes that small control signal doesn't change flew rate, so doesn't change the speed. To shorten the reaction time it is possible to include transition time into sampling time. So red average speed in Tp period consist transition speed changes. It cause same counting errors but in the dynamic process the errors are compensated during next steps.

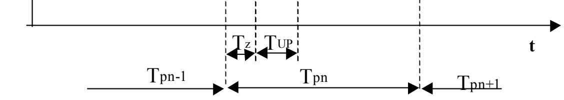

Fig. 8 Sampling period including transition times.

4.5 Acceleration deriving based on position measurement.

Acceleration counting is sensible only with reconstruction of real speed what needs position sensor with high resolution and short sampling time. The calculation of acceleration using above method leads to too big error.
Because of measurement delay time combined with insensitiveness and time constant of valves, the acceleration control is very difficult by using only position sensor.

5 Control system

The simplified diagram of hydraulic drive system with position sensor for position and speed control is shown in Fig. 9

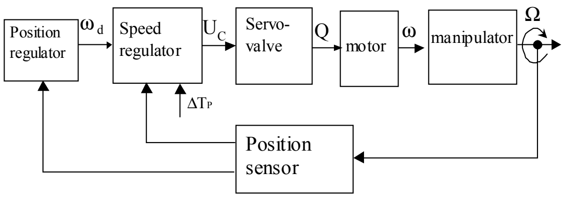

Fig. 9 Block diagram of hydraulic drive control system with position sensor for position and speed feedback.

The Up- voltage of valve solenoid quantum should be work out with resolution no greater than flew rate given:

$$\Delta q = \frac{\Delta \omega_{pom}}{k} \qquad \text{(eq. 12)}$$

where k is motor capacity.

Based on above analyses the laboratory station was designed and build. The control algorithm and computer program was made.[6], [7]

6 Conclusion

Computer control technique with digital control elements combined with typical elements significantly improve hydraulic drive property.
It widen speed range. Based on acceptable speed error a lower sampling frequency and lower position sensor can be used to position and sped control.
The laboratory stand which was built enable investigation influence of sensor resolution and sampling period to speed and position accuracy.

7 References

1 A. Garbacik K. Szewczyk.:
„NEW ASPECTS OF MEDELING OF FLUID POWER CONTROL”
Wrocław-Warszawa-Kraków. Ossolineum 1995.
2 Andrzej Garbacik & Jacek Stecki :
“DEVELOPMENTS IN FLUID POWER CONTROL OF MACHINARY”. Cracow 2000.
3 Churn P. M. Schofield N. Maxwell C. J. Howe D. and Powell D.J.:
INNOVATIVE ELECTRO-HYDRAULIC ACTUATION OF PRIMARY FUTURE PASSANGER AIRCRAFT.
PCIM Conference Numburg 1999
4 A. Ławniczak, a. Milecki:
„ELECTROHYDRAULIC LINEAR DRIVE UNITS WITH STEPPING MOTOR AND ELECTRICAL FEEDBACK LINKAGE”
Drittes Deutsch-Polnisches Seminar „Innovation und Fortschritt in der Fluidtechnik”;
Zakopane, Polen 16-17 September 1999.
5 Philippe de Larminat, Yves Thomas
AUTOMATIQUE DES SYSTEMS LINEARES
6 T. Mirosław, J. Szlagowski, Z.Żebrowski
„POSITION CONTROL-ALGORUTHM OF HYDRAULICDRIVE OF WORKING MACHINE”
2-nd International Scientific Forum „Developments in Fluid Power Control of Machinery and Manipulators” Cracow, Poland 28.06-2.07.2000
7 T. Mirosław, J. Szlagowski, Z.Żebrowski
„CONTROL AND POSITION CONTROL-OF ROTARY DRIVE IN THE WORKING MACHINE”
Drittes Deutsch-Polnisches Seminar „Innovation und Fortschritt in der Fluidtechnik”;
Zakopane, Polen 16-17 September 1999