MICROPROCESSORS IN FLUID POWER ENGINEERING

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CONTENTS

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A review of the application of microprocessors to electrohydraulic control systems

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SYNOPSIS

Microprocessors have been successfully applied to servohydraulics at various levels of complexity at a number of levels of control authority. The paper categorises the different microprocessor control techniques witnessed by the authors into six main divisions: sequence control, closed loop control, pre-loop and peripheral processing, adaptive control, smart redundancy, time optimal control. Each category is explored and illustrated by reference to a working system. Brief details are also provided about the limited number of devices currently available which modulate hydraulic flow and pressure in response to an electrical command signal.

1. INTRODUCTION

A paper presented by Maskrey (1) in 1978 divided electro-hydraulic microprocessor techniques into five categories:

* Closed loop servocontrol - where microprocessors are used to replace conventional analogue loop closure electronics.
* Pre-loop or peripheral processing - where information is processed, both ahead of and subsequent to a conventional closed loop servo
* Adaptive control - using intelligence to modify the basic closed loop control process
* 'Smart' redundancy - improving a redundant hydraulic system with the capability of higher level thinking
* Improved time-optimal control - enhancing bang-bang control

Although principally defined in relation to closed loop servocontrols these categories can be used in a wider context to discuss a general range of open loop or closed loop hydraulic control systems employing microprocessors. For completeness however, it is necessary to add:

* Sequence controllers - microprocessor control of an hydraulic system involving sequential operations

These six categories are discussed in more detail later. It is important to note, however, that whatever technique is used there are only a limited number of devices available which modulate hydraulic pressure and flow in response to an electrical command signal.

2. TYPES OF ELECTROHYDRAULIC CONTROL

2.1 On/Off Control

On/off valves in the form of solenoid valves are commonly used devices and their operation is well understood. There are just two states, on and off, that correspond to an open or closed hydraulic path. The input requirements are either AC or DC voltage of a specified value at a specified current level. The flow characteristics are usually defined by an effective orifice size or valve coefficient, C_V. Specification of pressure and environmental considerations are straightforward.

In a typical control system accuracy is proportional to the product of valve response time and slew rate (velocity). Therefore, large valves selected to provide fast machine movement result in poor position accuracy. Increased accuracy requires faster valve operation or slower slew rate.

2.2 Modulated Control

Positional accuracy of on/off control can be improved by variable slew rates obtained with the use of modulation control. Modulation control is the continuous cyclic operation of on/off devices at variable on times to achieve a desired average speed. This is also called pulse-width modulation control and has led to a new family of devices sometimes known as 'switching valves' (2,3).

A typical system uses two valves, one for each direction of movement. For an average zero speed, both valves would be cycled with equal open and closed times. The result in a position servo is a modulation about a fixed position. Desired slew rate is achieved by adjustment of the on-and-off times of each valve. With one valve full on and the other full off maximum speed is obtained in one direction. The limitation of this approach is similar to on/off control. The frequency of the modulation is limited by the speed of the valves. Since large valves are slower than small valves, modulation at low frequencies produces unacceptable vibration and noise in equipment.

2.3 Proportional Control

Proportional control is achieved using electro-hydraulic devices which modulate flow or pressure in response to a continuously variable input voltage or input current. Two commonly available devices are proportional valves, (fig. 1a) and servovalves (fig. 1b).

Proportional valves use relatively high power switching electronics (typically 50 watts) to drive proportional solenoids. By using the position feedback transducer shown in fig 1a to close a control loop around the valve, the electronics are used to accurately regulate the position of the spool and hence the flow through the valve.

The servovalve shown in fig 1b uses an internal mechanical feedback system, which in conjunction with a low power (typically 0.15 watts) current driven force motor and hydraulic amplifier, accurately regulates the position of the spool. Servovalves do not require any external electronics to close the position loop on the spool. More information on the operation of servovalves can be found in ref 4.

Proportional valves typically respond to a control signal in the range ±10 volts. Servovalves typically require a control signal conditioned in the range ±100 mA. The flow rating of the valves shown in fig. 1 will be around 60 l/min at 70 bar pressure drop. Electrohydraulic valves capable of controlling flows from as little as 1 l/min up to 1000 l/min at 70 bar are widely available.

For the types of valve shown in fig. 1, whilst there is little to choose in terms of static accuracy the major difference in performance relates to the frequency response. The relatively high mass of the solenoid cores and spool in a proportional valve limits the 90° phase lag point to around 20Hz. Standard industrial servovalves normally have a 90° phase lag point in excess of 100 Hz and there is little practical difficulty in taking this above 200 Hz if necessary.

In installation terms, the necessity to generate high currents to directly drive the spool and the high inductance of the solenoids means that proportional valves are difficult to make intrinsically safe. Unlike servovalves, the proportional valve shown in fig. 1a cannot be readily used in flammable atmospheres.

There are many variants of proportional valves available today. Some dispense with the feedback position transducer and use springs to position the spool against the force from the solenoids. This together with other design simplifications can reduce the cost of proportional valves relative to servovalves though often at the expense of static performance. Clearly the most appropriate valve is one which provides adequate performance at an economical cost.

3. OPEN Vs CLOSED LOOP CONTROL

In an open loop system the desired end result of the control system, whether it be position, force, pressure, velocity or acceleration, is not compared with the output of an appropriate transducer. In other words there is no feedback loop, as illustrated in fig. 2a. This makes open loop systems susceptible to external disturbances.

As an example consider the situation where the output of a microprocessor controller electrically modulates a pressure control valve to produce a certain force output from an hydraulic actuator. The actual force output of the actuator will be dependent on certain effects (disturbances) not apparent to the controller, namely variations in seal friction and changes in inertia loading with changes in acceleration.

The addition of a feedback path capable of providing the controller with information about the actual output (such as a load cell) results in the closed-loop control system illustrated in fig. 2b.

Whilst it is clear that a closed loop system has the potential of being more accurate than an open loop system there are a number of other considerations that must be taken into account when assessing system capability (4). To cover all the points is beyond the scope of this paper; suffice it to note that the repeatability or resolution of a position control system will be influenced by:

- load breakout friction and seal friction
- electrohydraulic valve threshold
- electrohydraulic valve hysteresis
- electrohydraulic valve null shift
- electrohydraulic valve pressure & flow gains
- mechanical backlash
- transducer resolution
- transducer linearity
- control electronics resolution (12 bit versus 16 bit)

A well designed closed loop system maximises the electronic and transducer gains. This minimises the influences of electrohydraulic valve inaccuracies. This is most easily done by careful selection of the control valve size. Use of a valve with excessive flow capacity results in a more inaccurate system.

4. SEQUENCE CONTROL

Machines that go through a fixed series of operations in a repetitive cycle conventionally use a number of strategically placed sensors connected into a hard wired relay cabinet. The sensors detect completion of one motion and instruct the relay cabinet to commence the next operation. In a typical hydraulically powered machine, it is usual to employ on/off solenoid valves to control the linear actuators and rotary drives and a number of trip switches to sense when an axis has reached the required position.

Hard wired relay cabinets tend to be expensive to manufacture and pose serious limitations if it is found necessary to change the machine sequence. For both these reasons there is now increasing use of reprogrammable microprocessor based controllers.

In essence a programmable controller is a device which uses a programme to link together a number of input and output devices to produce a desired sequence of operations. It cannot replace the sensors or the on/off solenoid valves but it allows them to be connected together in increasingly complex configurations without the high wiring costs associated with hard wired logic.

A typical programmable controller will not only handle all the usual relay functions but will also have in-built functions such as up/down counters, timers and a power fail reset capability. Controllers are also appearing which can monitor analogue input signals, make certain decisions based on comparator logic, then issue a fixed analogue output signal. This leaves the way open for use of proportional valves discussed in section 2.3, albeit in an open loop manner.

5. CLOSED LOOP CONTROL

The use of a microprocessor as a closed loop controller appears to have many attractions as complex linear or non-linear functions can easily be introduced into the control loop. The microprocessor in this role acts as the summing point for the command and feedback signals (fig. 2b), and conditions the error providing the information to drive the electrohydraulic components.

In general, the accuracy and response of a practical servohydraulic control system is determined by the open loop gain. Ideally, the gain would be set high enough so that the system accuracy becomes dependent on the accuracy of the transducer itself. In practice however, the gain, limited by stability considerations, is determined by the system component with the lowest bandpass and so in order to make sense as a closed loop controller the microprocessor must be capable of handling information at a rate consistent with, or faster than, the bandpass of the electrohydraulic components.

If a typical microprocessor, such as the Intel 8085A operating with an internal clock frequency of 5.0 megahertz, is considered then the update time of a microprocessor controller can be determined. The function to be resolved is one that is often, and successfully, performed using conventional analogue methods and is described as follows: The command and feedback signals are to be sampled and summed to determine the error. The error is then to be conditioned by a first order differential equation with an adjustable gain of 16:1 and output to the servohydraulic components.

A simple programme written to perform this task, using 16 bits of data (giving a servo resolution of 1 part in 65536), will have an update time of approximately 10 milliseconds. If, as is often done with servohydraulic components, we define the bandpass as the frequency for 90° of phase shift, then the controller will have a bandpass of 50 Hertz. As a comparison, using analogue electronics a controller with a bandpass of 1.5 KHz can be easily obtained.

Most practical systems require the signal processing device to be 5 to 10 times quicker than the hydraulic power control elements in the loop. This is especially true where error signal frequency shaping is done, or if minor loops are present. This rule of thumb means that if the microprocessor controller is not to restrict the system performance then the bandpass of the power control elements must be less than 10 to 20 Hertz. A spectrum of typical applications for servohydraulics is given is fig. 3. It can easily be seen that the majority of applications require servovalves that have bandpasses above 20 Hertz thus it would be difficult to employ a microprocessor as a closed loop controller in these situations.

It is worth emphasising that in the above example the microprocessor was dedicated to the controller task and the update time will of course increase if the microprocessor has to perform other tasks. There are techniques by which the update time can be reduced, such as multiprocessors or dedicated logic circuits, but this becomes rather specialised and the development time, as well as the hardware costs increase.

The important conclusion to be drawn from this argument is that if closing the loop with a microprocessor is just a matter of convenience then we are contributing nothing to, and may be in fact reducing, the overall system performance capability.

There may of course be other reasons for using a microprocessor to close the loop, for example where there is complex interaction of two variables or where a non linear operation must be performed. These tasks are not easy to achieve using analogue techniques but are however simple to implement in the form of mathematical functions or 'look up tables' by a microprocessor controller. It is in these areas where closed loop control by microprocessors is of advantage to the system.

6. PRE-LOOP PROCESSING AND PERIPHERAL PROCESSING

Using a microprocessor as a pre-loop processor whilst maintaining analogue loop closure, combines the flexibility and sophistication of a microprocessor with the speed of an analogue controller. The microprocessor can be used to interface to a wide range of devices, for example keyboards, other computers and data storage devices, from which the processor can take raw data and convert it into a form intelligible to the system.

The use of a microprocessor as a preloop processor is very popular and as such there are many examples of their uses in this role.

One such example is where a microprocessor is used as a command generator for two axes of position control. In this application three parameters are used to establish the command signal to each axis: axis co-ordinate, velocity, and dwell time at each co-ordinate. The microprocessor uses these parameters to interpolate between successive co-ordinates causing both axes to arrive at the next co-ordinate at the same time, with the required velocity and remain there for the time specified by the dwell period. To achieve this the command signal to each axis is incremented or decremented by the microprocessor at a rate calculated during the dwell period. This means that the majority of the processing work is done during the dwell period leaving the microprocessor free to update the command signals at a high frequency thus giving the impression of a smooth transition between co-ordinates.

There are many ways in which the raw data the microprocessor requires can be entered. In the above example the machine was required to repeat a fixed sequence of points, and so, the co-ordinates were pre-programmed and stored in permanent memory. The natural extension to this application is to allow the machine to be taught a new sequence by moving each axis to the required position, using a joystick to input a command voltage, measuring each new position with the microprocessor and storing these positions as co-ordinates for the next sequence.

Another popular area where microprocessors are used in a pre-loop and peripheral processing role is test equipment, where careful control over information is required both before and after each test. Often, because of the accuracies and speeds required it is not unusual to use a high performance electro-hydraulic servo to perform the tests which may include materials testing or failure mode examination. In many of these cases re-running a test is expensive so there is a requirement to maximise data usage. The microprocessor can be used to establish the conditions for tests, monitor the tests and manipulate the data presenting it to the operator in the most useful form. It is usual in these cases to interface the microprocessor with a terminal, keyboard and printer to allow the operator to participate in the tests. Using a microprocessor to condition the data allows results to be checked against limits and tests to be re-run to check unexpected results.

The combination of a microprocessor, analogue servos, and a human operator provides a high degree of test sophistication, repeatability and reliability.

7. ADAPTIVE CONTROL

A system with adaptive control has the ability to provide optimal or consistent control in the presence of identifiable changes. In the past, adaptive control has been achieved by using analogue or hard wired logic controllers and the consequent expense has limited its application. The advent of lower cost microprocessors has made it realistic to use adaptive techniques on a far wider range of applications.

On a closed loop system, adaptive control may be used either internal or external to the loop. In the latter case, adaptive control is generally accomplished by measuring the actual outputs of the system, comparing these with the desired outputs and making changes to correct for the difference.

7.1 Internal Loop Adaptive Control

Internal loop adaptive control is used to compensate for either changes in load or changes in gain with amplitude. Examples of the former are when load inertia changes during reel winding and unwinding or when the inertia changes due to effects outside the loop being controlled. Such an example is the robot arm shown in fig. 4.

Major changes in the inertia seen by axis 1 occur with changes in the position of axis 2. In a conventional loop, the gain of axis 1 is set for the worst case, i.e. when axis 2 is in a position to cause the highest inertia to be seen by axis 1. With axis 2 retracted, the gain of axis 1 is unnecessarily low and accuracy is compromised. Adaptive control is used to alter the gain of axis 1 as axis 2 changes, and thereby maintain maximum possible accuracy in all cases. The microprocessor monitors the position of axis 2 and uses this value to alter the digital input to the multiplying D to A convertor used within the axis 1 loop as shown on fig. 5. The output from the D to A convertor is the input voltage multiplied by the value of the digital input. Therefore the forward signal gain is digitally controlled. Apart from this, the loop is conventional. Note that the inherent speed of the analogue electronics is not compromised by using the D to A convertor. Therefore, this technique combines all the advantages of analogue electronics with the versatility of the microprocessor.

7.2 External Loop Adaptive Control

External loop adaptive control is typically used where constant performance is desired in spite of:

1. Long term changes where the element being controlled experiences changes due to time or temperature.
2. Change occurs in the power availability such as changes in supply pressure.

One example of the former is to use an historical technique. This is particularly suitable to repetitive processes but may be applied to unrepetitive processes by the addition of an artificial repetitive calibration cycle.

The historical technique measures the difference in desired and actual outputs at one or more points and uses this to offset the system. This offset will ensure that the desired and actual outputs are equal. If these two outputs differ with time, the offset is adjusted. The system therefore updates the offset on each cycle. The offset may be added or subtracted to the digital command signal.

The historical technique enables greater accuracy to be attained or allows cheaper, lower performance components to be used.

An example of adaptive control allowing for power availability changes is on intermittent sequence control. In such cases, major savings in component and running costs can be made by using a small fixed displacement pump, accumulator and unloading valve rather than a large pressure compensated pump. Ideally, the accumulator is fixed to provide peak demands and the pump sized to provide the average flow. However, under certain conditions, the peak demand may tend to deplete the accumulator. This will result in loss of flow and the output will not follow the command signal.

In this system, pressure switches are used to monitor the state of the accumulator. Should the pressure fall to the lower limit, the microprocessor will interrupt the command sequence and allow the accumulator to be recharged. When the upper limit of pressure is reached, the microprocessor will allow the sequence to continue either from the point at which it stopped or from another start point.

8. "SMART" REDUNDANCY

It is possible to conceive of systems in which additional control devices are added to enable a system to continue to operate after one or more component failures. In other words the system has in-built redundancy.

Redundant hydraulic controls are frequently used on manned space vehicles and aircraft. Industrial systems also use redundancy if the potential failure of a component or system could create a disruption that is uneconomic compared with the cost of redundancy, or when human safety is in jeopardy.

Depending on the type of failure and the action that must be taken these systems can become very complex (5). Fig. 6 shows the schematic of a servoactuator used in the F-111 flight control system. The actuator receives three electrical command signals and two hydraulic supplies. All the mechanisation necessary to produce an actuator displacement proportional to the input command signals, and after-failure detection of any inputs or internal component, is contained within the package.

Whilst the schematic looks complex it basically contains two active hydraulic control channels to driving a common actuator, with a third model channel and some failure detection and switching devices for disabling the failed channel.

The important point about the example is not the elegance of the design nor the method of operation but the overall complexity that has had to be adopted to ensure reliable operation of the system.

The designer has had to anticipate all the causes of failure and then assume the worst case, which in the case of the example has meant that an entire control channel has had to be disabled. A follow on failure in the other control channel would result in mission abort. To be able to tolerate multiple failures even more complex triple and quadruple redundant systems are required (5).

It is not difficult to conceive that much of the hydro-mechanical logic used in fig. 6 could be replaced by a number of strategically placed electronic monitors, such as pressure switches and position transducers. By continuously monitoring vital points in the system, when a failure occurs it should be possible to decide not only what has failed, but also how serious is the failure and take the appropriate steps. Furthermore, by having knowledge about the actual capability required from the system it may be possible to continue to use part of the failed system even at reduced levels of performance.

The advantage of such a "smart" system is that it can increase the useful on-time of the system. Minor failures do not cause complete shut down and failures are interpreted on the basis of system need, not on a conservative, predetermined scale.

The availability of low cost and large capacity microprocessors has meant that control schemes which require a high level thinking capability are now becoming quite practical. One caveat that must be applied, however, is that such schemes will also need to anticipate the failure of the microprocessor control system itself.

9. TIME OPTIMAL CONTROL

There may be certain hydraulic systems where because of the need for simplicity, expense or questionable reliability, the use of proportional electrohydraulic valves is inappropriate and an ON/OFF solenoid valve is used. System requirements dictate however that a control strategy must be adopted which is able to position a variable load with a high degree of repeatability.

Consider the simplified example shown in fig. 7a where a controller switches open a solenoid valve to admit hydraulic oil to an actuator to drive a load. Although the position of the load is being monitored, the controller must decide exactly when the solenoid valve should be switched off to ensure that the load comes to rest at the required position. If the controller waits until the load reaches the required position then dwells in operation of the solenoid valve and the inertia of the load will cause an overshoot.

An alternative is to design the controller to monitor the error signal so that a comparator triggers the solenoid valve off when the error has fallen to a certain preset value. Whilst this method now anticipates the approach to the required position it is still a function of many variables not being monitored by the controller, namely:

1. Approach velocity at switch off (this itself is a function of available flow-rate, hydraulic pressure, temperature and loading.
2. Solenoid dwell time
3. Load inertia
4. Actuator and load friction

There is generally little practical difficulty in designing the controller to monitor item 1 of this list, approach velocity as well as position so that the comparator trigger point can be adjusted according to some pre-ordained regulation scheme.

The other items pose a greater problem in terms of an optimisation strategy. Especially so when all three will probably vary in time as components wear. For an analogue control system there is probably very little more that can be done without a great deal of cost and complexity. A microprocessor on the other hand has sufficient 'thinking' capability to provide correcting information to the switch point on a cycle to cycle basis learning from and factoring the conditions of the previous cycle. In other words the more you use the control system, the better it gets.

10. SUMMARY

The microprocessor will never be capable of doing the work of a fluid power system, but as many of the foregoing examples show there is now an unrivalled opportunity to extend the capability and improve the utilisation of hydraulic control systems. The challenge is in trying to analyse all of these apparent opportunities to properly assess the benefits and liabilities. The new techniques must clearly contribute to an improvement in performance or a reduction in cost.

The control engineer is presently in the enviable position of being able to build on traditional control techniques and explore new theories and control strategies that would have been unthinkable a few years ago. In so far that any new technology needs a structure this paper has attempted to identify six categories of electrohydraulic control technology that are using microprocessors. It will be interesting to reflect how relevant these categories are in ten years time.

ACKNOWLEDGEMENTS

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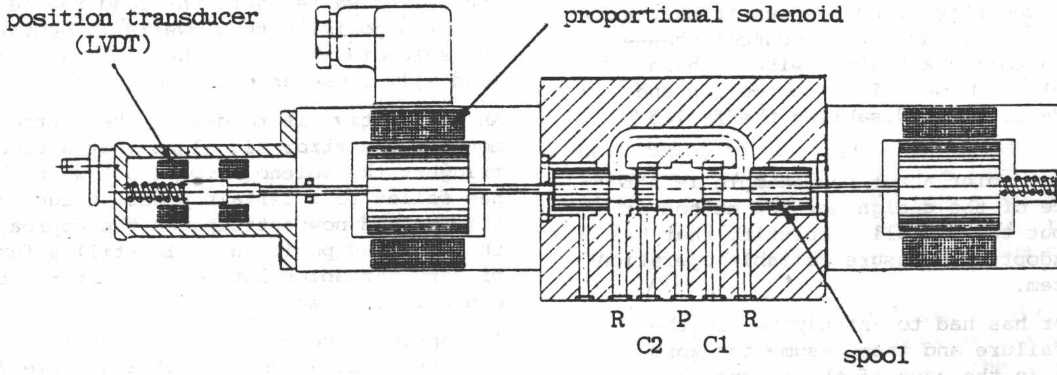


Fig 1a Proportional valve

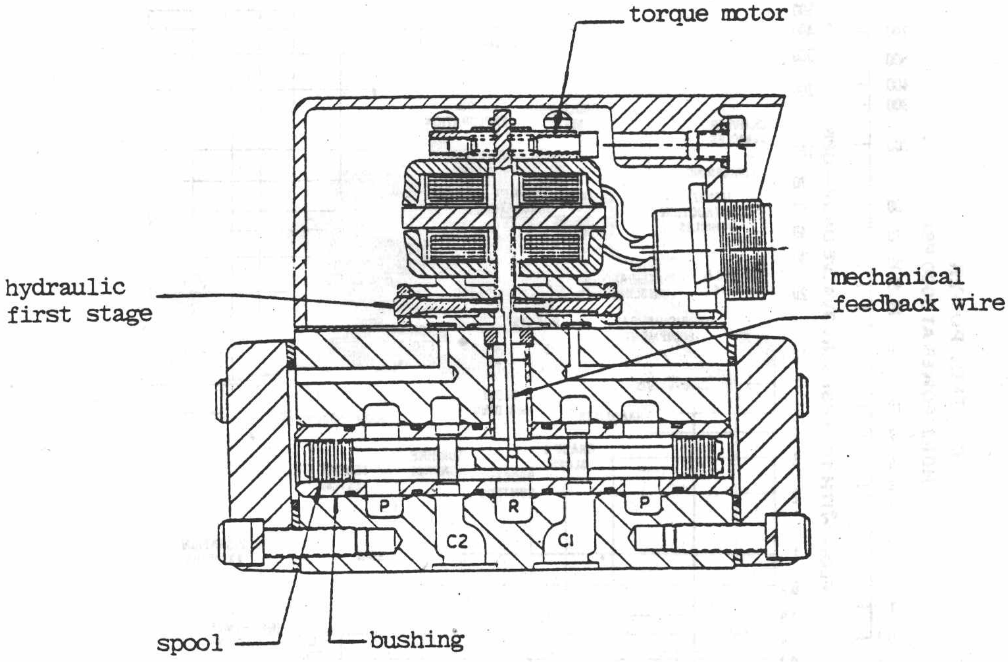


Fig 1b Servovalve

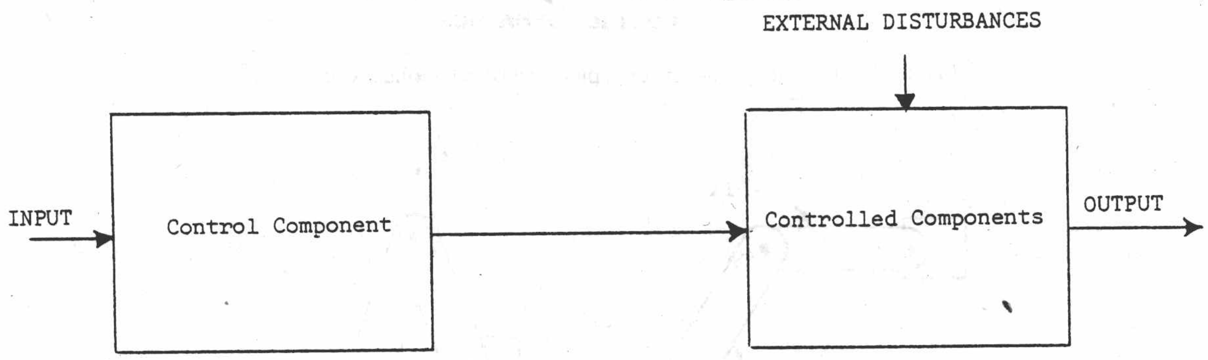


Fig 2a Open loop control

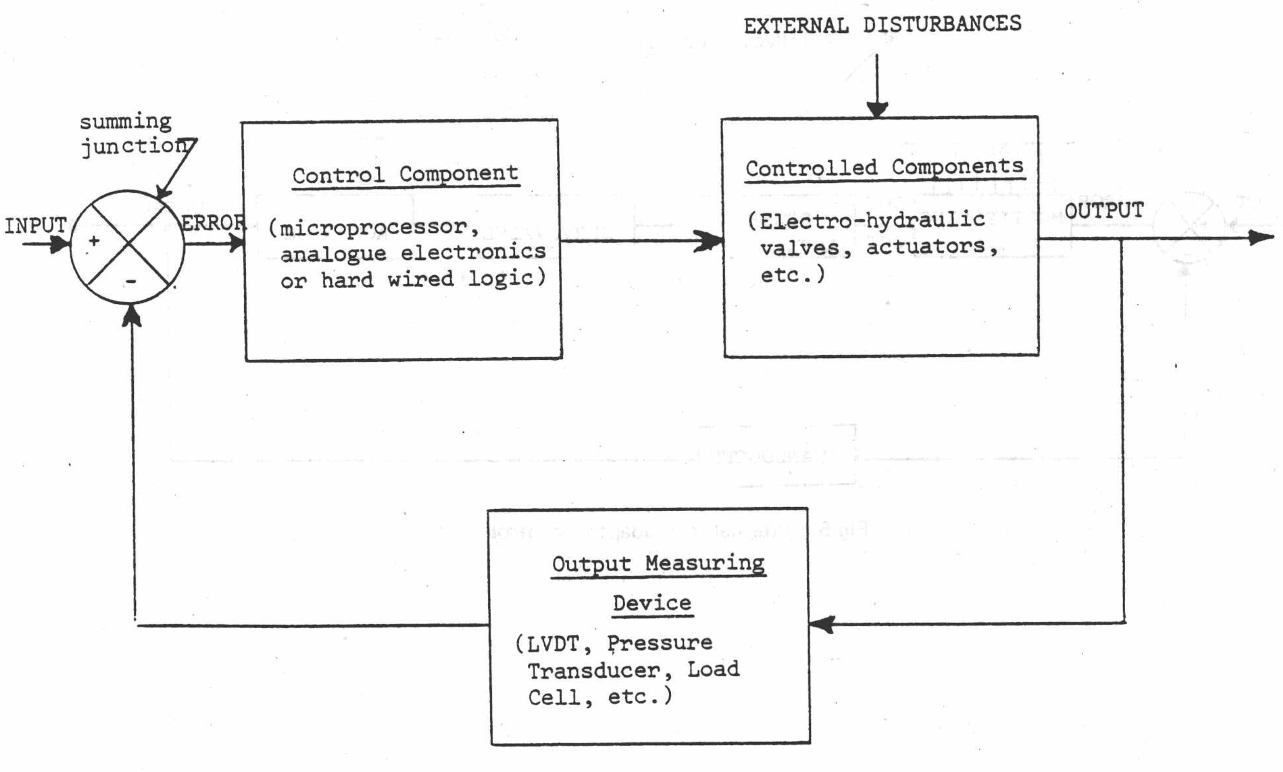


Fig 2b Closed loop control

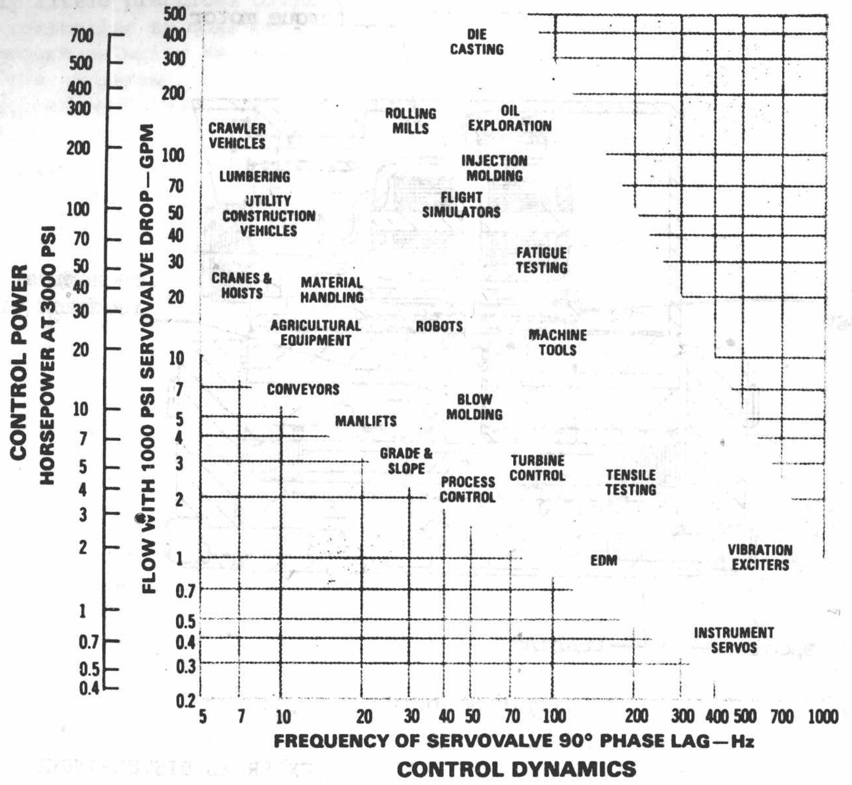


Fig 3 Control requirements for typical industrial applications

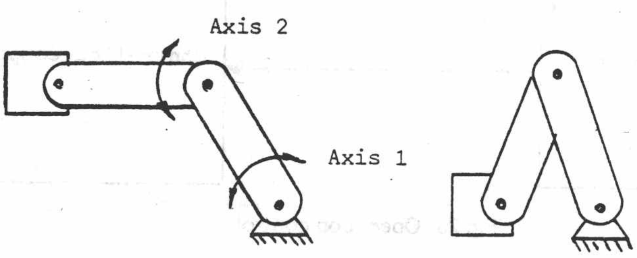


Fig 4 Reflected inertia change on robot arm

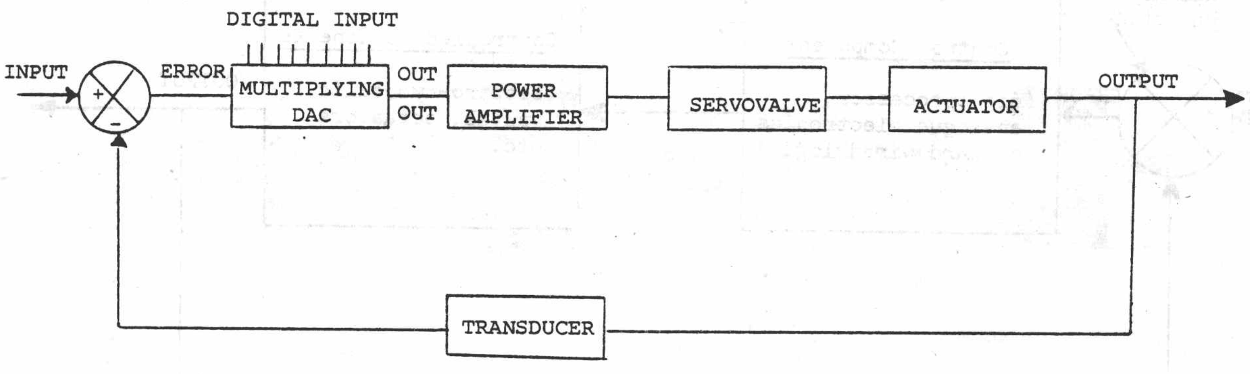
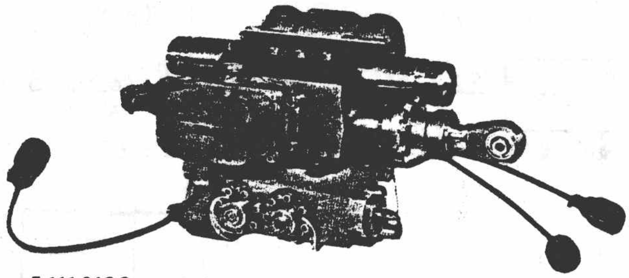


Fig 5 Internal loop adaptive control



F-111 SAS Servoactuator

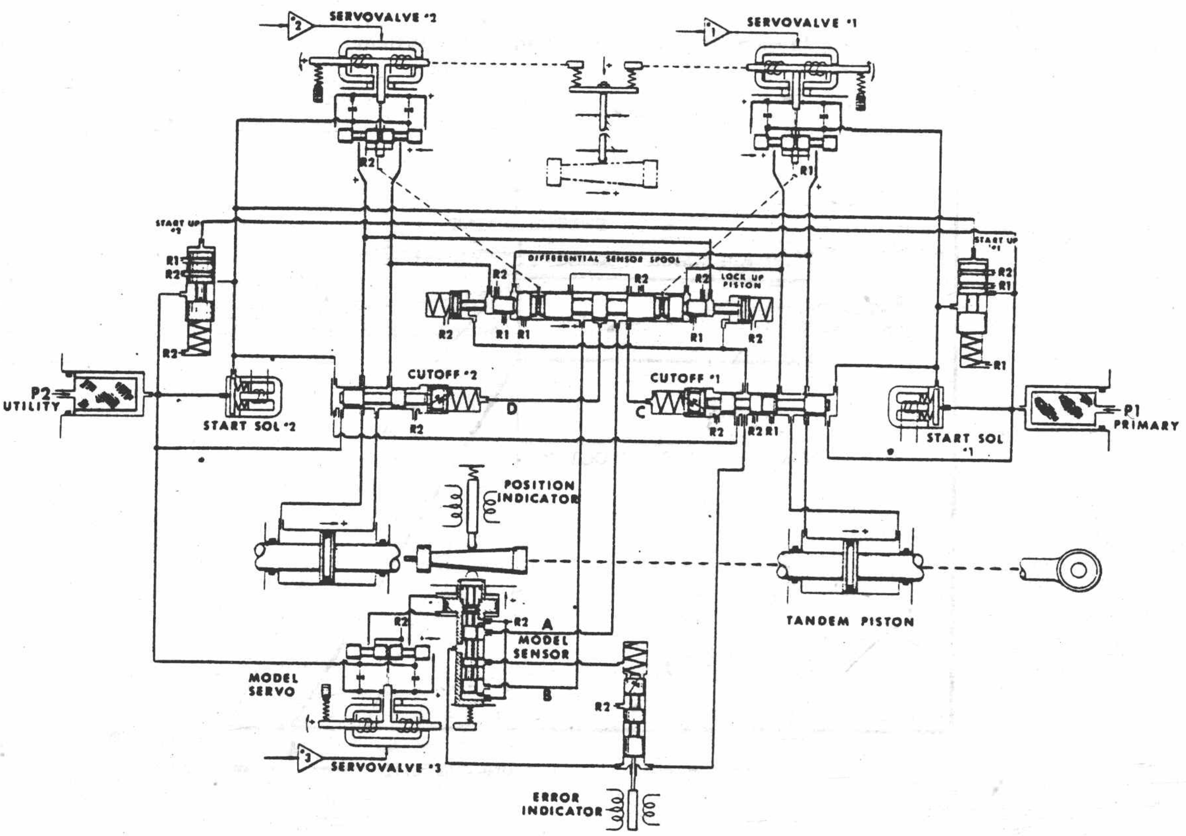


Fig 6 F-111 servoactuator schematic

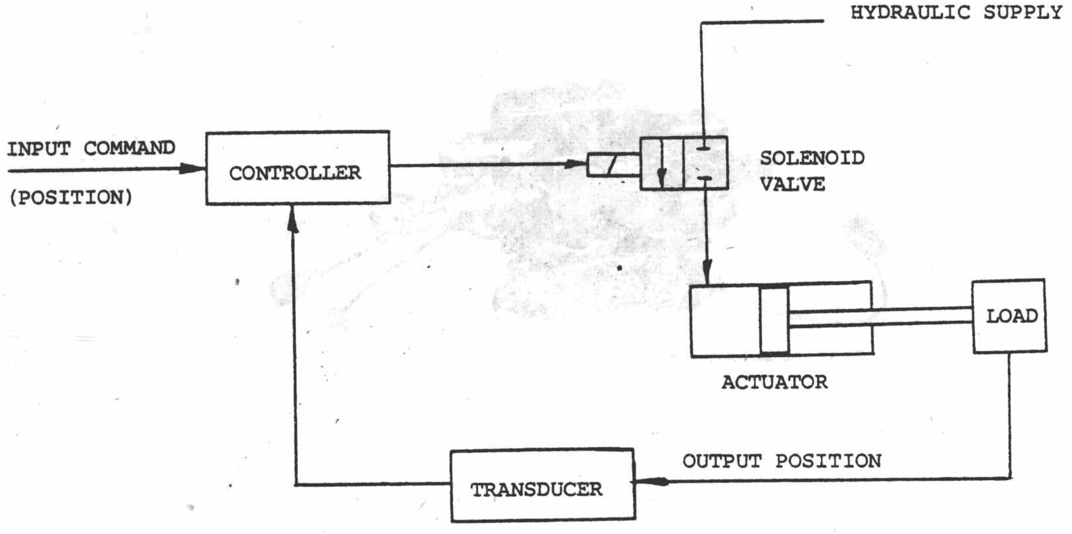


Fig 7a Simplified time optimised control system

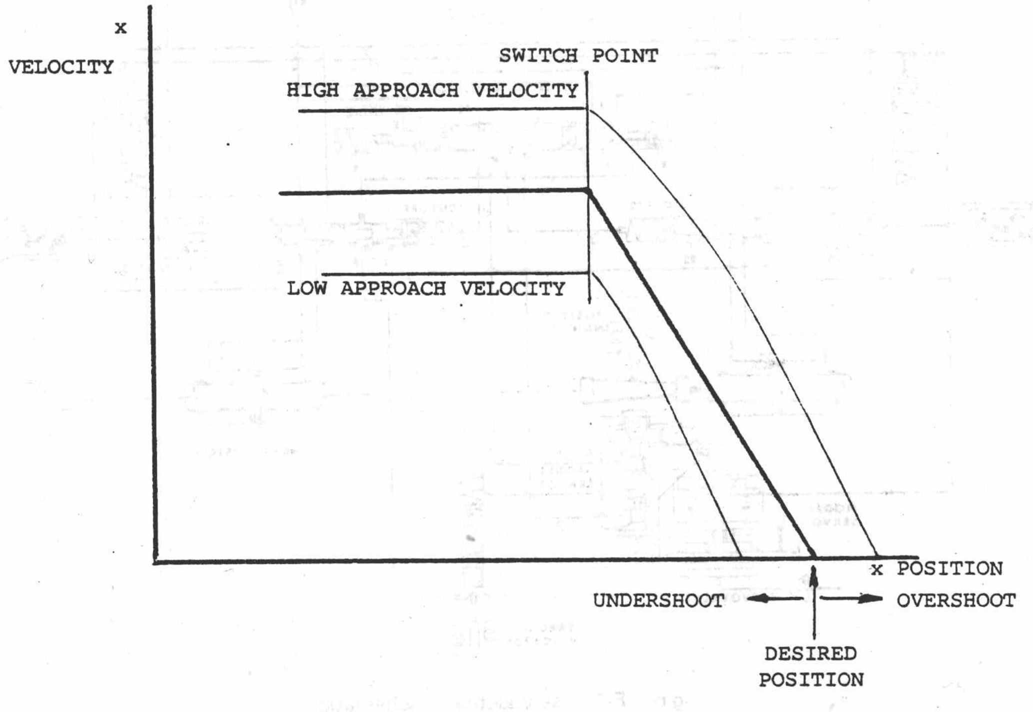


Fig 7b Possible settling point trajectories with variation in approach velocity

C225/84

The up-grading of a triple-acting hydraulic press from manual control to microprocessor control in order to perform hydro-mechanical forming

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SYNOPSIS Described is a means of controlling hydro-mechanical forming done by a hydraulic press. Proportional valves with microprocessor control are used. The complete hydraulic control system discussed in this project is typical of many.

1 INTRODUCTION

There already existed at Leeds Polytechnic a triple-acting hydraulic-press for research purposes. The controls were manual without feedback facilities and accurate control was not possible. Fig.1.

The aim of this enhancement was to produce a press that is capable of performing various types of forming especially hydro-mechanical forming of small components. This was done by replacing the manual controls with hydro-electrical devices and a micro-computer.

The paper describes the system and the hydraulic circuits, using high technology valves, and the transducers necessary to provide the accuracy of control demanded by the hydro-mechanical forming process. It covers the interface elements and the microcomputer system necessary as well as the accompanying software. A brief insight into hydro-mechanical forming is also given.

2 HYDRO-MECHANICAL FORMING

Deep drawing is one of the most important processes in the production of sheet metal components ranging from items for the motor car industry to cooking utensils.

Factors which limit the speed of the operation of the process and the geometrical variety of products are:-

i) the quality of properties of materials
ii) the tools and their geometry
iii) lubrication between the touching surfaces of punch, workpiece and the die

To eliminate these shortcomings hydro-mechanical deep drawing was introduced. This process, although commercially available, is still in its infancy. The principle of the operation is similar to that of conventional deep drawing except the die is replaced by an oil-filled pressure chamber and an intensifier.

The principle is illustrated in Fig.2.

Fig.2.a. The workpiece (metal disc) is placed over the pressure chamber and the pressure plate and former is lowered.
Fig.2.b. There is initial hydro-static reverse forming and this is shown.
Fig.2.c. The punch is lowered, drawing the workpiece into the pressure chamber, as far as the height of the component permits.
Fig.2.d. While the former is stationary the pressure in the pressure chamber is increased to the region of 700 bar. At this pressure the sheet metal is formed around the profile of the former.

When the forming is completed the pressure is lowered to a safe level and the former is withdrawn and the component removed.

By the same token, reverse-forming using a hollow former is possible. Without hydro-mechanical forming two stages of operation would be required. The complete shape can be formed in one operation, with the pressure of the oil in the pressure chamber forcing the material into the cavity in the core of the former.

3 THE TRIPLE-ACTING PRESS

See Fig.3.

Key to Fig.3.

1 Main ram
2 Pressure plate cylinders
3 Ejector/Cushion
4 Pressure control valve
5 Check valve
6 Pressure cylinders
7 Intensifier/pressure chamber
8 & 10 Proportional directional valves
9 Proportional pressure valve
10 Check valve
11 Pressure transducer

The press has three distinct hydraulic actions which control the following:-

3.1 Pressure Plate

This uses two 75 mm diameter single acting rams. This plate is independently lowered. The pressure plate's rams are powered by an independent single pump system.

3.2 Cushion/Ejector'

This utilises a ram of 90 mm diameter. The cushion is raised independently but the return is by the action of the main ram and gravity.

3.3 Main Ram

This is a double acting cylinder of 150 mm bore. The cushion/ejector and the main ram are powered by a twin pump system.

Originally the valves to control these movements were manually operated. The pressure relief valve for the pressure plate was motorised.

4 DESIGN CONSIDERATIONS

The requirement to do hydro-mechanical forming needs variable pressures and speeds from all of the three actions simultaneously.

The forming process demands a constant hydro-static force of up to 700 bar on the workpiece blank. The requirement is to maintain this pressure as the forming progresses.

To provide accurate control, feedback from pressure and position transducers is necessary.

This project could be regarded as requiring a slow-speed, servo-control system but, by integrating a microprocessor, the variable-gain control of a typical servo is dispensed with. Instead of using servo valves, with their inherent drawbacks of high cost, and being easily damaged by impurities in the oil, proportional solenoid valves are used at half the cost and with less dependency on oil cleanliness.

The press was designed and built over 10 years ago with manual control valves for direction of operation and an electrically modulated relief valve controlled through a stepping motor and gear box.

A special interface board is shown for connecting the shaft encoder to a port. This was done because of the micro-computer system available. A better solution would have been to use a CTC (counter timer) which can be an integral part of a Z80 based microcomputer. One of its functions is to record pulses.

6 HYDRAULIC CIRCUIT

Ref. Fig.3.

With the pumps running, the proportional relief valves are unloaded and vent the pump flows to the tank.

The operator loads the workpiece, closes the guard and initiates the start. The relief valve 9a is energised to the desired pressure and the proportional solenoid 'a' of the directional control valve 8a is energised with a set value. This lowers the pressure plate 'A' onto the workpiece.

The proportional relief valve 9a is set to the new desired value and the main cylinder 'B' is lowered to touch the workpiece. The proportional relief valve 9b is set to the desired value and the proportional solenoid 'a' of the directional control valve 8b is set to the desired value and pressure is then created in the underside of the workpiece. This pressure is slowly increased by changing the value of the relief valve 9b.

The drawing operation now starts by setting the value of 8a, solenoid 'a' and 8b, solenoid 'b', so that they both flow at the same speed. When the workpiece is drawn to almost the major dimension the hydrostatic back pressure is reduced.

Final drawing is performed at very low pressures.

7 DISCUSSION

This paper describes the elements involved in developing a typical hydraulic system controlled by microcomputer. The approach has been to employ proportional valves rather than servo valves because of the lower cost and less susceptibility to failure by unclean oil.

The software for the microcomputer allows infinite flexibility for research to be done on hydro-mechanical forming.

It is expected that experiments at Leeds Polytechnic will be able to be carried out fully controlled to pre-set conditions which until now have not been possible.

REFERENCES

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