Microprocessor controlled hydraulic load unit

by Mohammad Taghi Karami

A thesis submitted in partial fulfillment of the requirement for the degree of MASTER OF SCIENCE in AGRICULTURAL ENGINEERING
Montana State University

Abstract:
The purpose of this research project was to develop a microprocessor control unit for a hydraulic load system and to determine the accuracy of control. This was a laboratory oriented fluid power system that would use a microprocessor to simulate the loads involved in a cable conveyor system for conveying logs out of the woods. The laboratory system would duplicate the simulated loads on the hydraulic, system.

The designed system included a variable displacement hydraulic pump and motor. A tractor engine was used to power the hydraulic pump and a water brake dynamometer was used to load the hydraulic motor. The torque on the dynamometer was monitored by a strain gauge pressure transducer in parrallel with the dynamometer torque arm pressure gauge. This transducer transmitted data to a strip chart recorder which recorded the loads as a function of time. In addition a voltage output from the recorder proportional to the torque was input to the microprocessor through an A/D converter. The digital data from the A/D input was used by the control software to determine the control response needed. A computer controlled stepping motor was used to move the variable displacement arm on the hydraulic pump as required to obtain the desired load.

Test results were recorded as a series of curves on a strip chart recorder. These curves represented the actual response of the load system to the computer control system.

The objectives of this research project were accomplished as follows: a) A microprocessor control unit for a hydrostatic transmission load system was developed that could duplicate desired loads; and b) A control program was developed that could accurately duplicate a predetermined series of forces that changed as a function of real time.

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APPROVAL

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Mohammad Taghi Karami

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

3/27/86 — W. E. Larsen

Date — Chairperson, Graduate Committee

Approved for the Major Department

3/27/86 — W. E. Larsen

Date — Head, Major Department

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TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

The purpose of this research project was to develop a microprocessor control unit for a hydraulic load system and to determine the accuracy of control. This was a laboratory oriented fluid power system that would use a microprocessor to simulate the loads involved in a cable conveyor system for conveying logs out of the woods. The laboratory system would duplicate the simulated loads on the hydraulic system.

The designed system included a variable displacement hydraulic pump and motor. A tractor engine was used to power the hydraulic pump and a water brake dynamometer was used to load the hydraulic motor. The torque on the dynamometer was monitored by a strain gauge pressure transducer in parrallel with the dynamometer torque arm pressure gauge. This transducer transmitted data to a strip chart recorder which recorded the loads as a function of time. In addition a voltage output from the recorder proportional to the torque was input to the microprocessor through an A/D converter. The digital data from the A/D input was used by the control software to determine the control response needed. A computer controlled stepping motor was used to move the variable displacement arm on the hydraulic pump as required to obtain the desired load.

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Chapter 1

INTRODUCTION

Computer controls for real time systems are becoming more and more common. The ability to monitor variables, collect data, and control the real time systems in an accurate and fast manner, are some of the reasons the application of microprocessors and computers in research and industry have become popular.

Expansion of computer technology to agriculture has introduced an exciting area where electronic controls, computers, and microprocessors are assisting with various forms of farm tasks. Microprocessor systems are versatile and in most cases very economical tools. They are being adapted to a variety of agricultural applications which require rapid and precise control or data acquisition. These electronic devices are useful in agricultural research as well as in commercial applications. When used for research, a microprocessor system can provide the following advantages: (a) fast collection of data during complex tests; (b) precise timing and triggering of simultaneous or sequential events; (c) automatic control of numerous devices or operations; (d) versatility of operation through software control; and (e) ease of interfacing to a variety of computer terminals and digital recording systems.

Microprocessors also provide the ability to change the control strategy with a software application which may be quite desirable in any system in order to maximize the efficiency in data collection or control. Conventional electromechanical or solid state controls can be designed to handle many different control problems but anything more than a minor change in the control strategy will probably require hardware changes in wiring, components, and circuit boards. A microprocessor or microcomputer-based control system, on the other hand, would allow many complex control strategies to be implemented simply by changes in software (program). Once the inputs (from sensors, switches, and transducers) and outputs (to lights, solid state relays, valves, and stepping motors) are connected to the microcomputer, the control strategy is dependent only on the software modification.

More and more farmers are investing in personal computers for record keeping, planning market strategies, and other management related farm tasks as software becomes available. "AGNET" is an interstate computer network available to farmers through the Montana Cooperative Extension Service. It consists of 78 different computer programs that can help farmers plan or manage their particular operation. Furthermore, microprocessors are being used to monitor and control equipment operations on various on-farm systems. Some of these on-farm systems include dairy equipment, feeding equipment, and some agricultural machinery.

Agricultural operations have been highly mechanized but they still require interfacing with the operator for proper control. Engineering design has improved many of these machines and microprocessors and monitors have helped the operator make the proper decision for their operation. Some of these design improvements have come through the application of microprocessor and microcomputer technology. In addition to the existing microprocessor applications in agriculture, there are a considerable number of research projects that involve the application of microprocessors and microcomputers. Recent publications from the American Society of Agricultural Engineers (ASAE) show frequent applications for microprocessors and computer controls. Some of the typical research examples being conducted by agricultural engineers include areas such as: Agricultural Environment Controls, Food Processing (4, 15, and 25), Tractor Engine Performance and Endurance Testing (5, 14, and 17), Irrigation Scheduling and Control (10 and 22), Control and Monitoring of Solar Collectors (7), etc.

The rate at which microprocessors are being applied to agricultural problems is increasing rapidly due to the low cost of computer chips and the accuracy of data acquisition and control which can be obtained with microprocessors and digital computers. Clearly, computers will continue to take over decision making processes and the control of agricultural equipment due to their speed and accuracy. Computer scientists and computer engineers have stated that robotics and artificial intelligence (AI) will not only take over most of the manual or mechanical work of systems, but they will also take over the decision making parts of systems where humans are still the main active part. The truth in their prediction is becoming apparent in many different projects in agricultural engineering.

Statement of The Problem

The purpose of this research project was to develop a microcomputer control unit for a hydraulic load system (real system), and to determine the accuracy of control. This was a laboratory oriented fluid power system that would use a microcomputer to simulate the loads involved in a Cable Conveyor System for conveying logs out of the woods. The laboratory system would duplicate the simulated loads on the hydraulic system. Results from this study could then be used to determine the efficiency, speed of operations, and significance of computer control on a Cable Conveyor System.

Background

The Cable Conveyor System is being developed to overcome many of the current problems in logging systems. In recent decades, timber harvesting in the Rocky Mountain area has gradually progressed from the better growing sites on gentle terrain at lower elevations to steeper, more rugged terrain at higher elevations . Early logging (during the 1950's and 60's) in steep terrain employed much of the same equipment that was used in gentle terrain, principally crawler tractors. In addition cable yarders were added in some locations. All of these methods depend on a relatively dense network of roads.

A consequence of a dense network of relatively inexpensive roads in steep terrain, coupled with relatively large clearcuts, was soil erosion and widespread public antagonism. Visual impacts coupled with erosion and stream sedimentation in various locations resulted in many constraints on these harvesting methods. Road densities were reduced and road construction standards increased, requiring that cable yarding distances be increased. More partial cuts were implemented to avoid the objections to clearcutting. The consequence was costlier roads and harvesting, to the point that balloon and helicopter logging became competitive in some circumstances.

The USDA, Intermountain Forest and Range Experiment Station and Montana State University entered into a cooperative research agreement to explore ways by which timber in many mountainous areas could be harvested without having to build an extensive road network. It was proposed to design and built a microprocessor controlled zig-zag cable conveyor system which would transport logs from high elevations down to locations where they can be loaded on trucks. The proposed design includes many different components that each have to be developed. One of the main components in the system is a set of sheaves used with transducers to monitor and control the forces (loads) on the cable system by microprocessors. This thesis project was designed to develop a laboratory oriented system which would use a microcomputer to simulate the forces involved in the cable conveyor system and try to simulate the loads that would be applied to the real system.

Cable Pull Simulation Design Criteria

A system was needed to simulate the pull on a cable that would be introduced by a log being conveyed between two support towers. The system requirements for this simulation are:

A hydraulic power supply with a variable displacement pump and a motor. This hydraulic system required an external source of power and a load absorption unit. A tractor engine was used to power the hydraulic pump and a water brake dynamometer was used to load the hydraulic motor. The torque on the dynamometer was monitored by a pressure transducer in parallel with the dynamometer torque arm pressure gauge. This transducer transmitted data to a strip chart recorder which recorded the loads as a function of time. In addition a voltage output from the recorder was proportional to the torque. This voltage was input to a microprocessor through an A/D converter. Torque loads on the dynamometer are proportional to the amount of water in the dynamometer case and the square of the dynamometer RPM. Therefore, changing the dynamometer speed would result in a change in the torque on the dynamometer. Speed control for the hydraulic motor was obtained by moving the control arm on the variable displacement hydraulic pump. A computer controlled stepping motor was used to move the variable displacement arm on the hydraulic pump. The computer also monitored the torque from the dynamometer and controlled the stepping motor to obtain the desired torque.

Chapter 2

REVIEW OF SELECTED LITERATURE

Flexibility is a key element in increasing productivity and energy efficiency in mechanical and process systems. Today microprocessors and microcomputers have provided the built-in intelligence that engineering systems should have in order to respond to diverse and changing demands with maximum speed and efficiency. Computers are becoming the most cost-effective alternatives for achieving functional flexibility since they are inherently flexible. Microprocessors and computers could be reprogrammed to perform different tasks without making any physical changes in the system. This provides modifications and upgrading of engineering systems at minimum cost.

To understand the design of real-time control systems, one should be aware of the methods by which a computer can be interfaced to external equipment, the types of program instructions, and microelectronics that are required for this interaction.

Microprocessors in a Control System

The words "microprocessor", "microcomputer" and "computer" will be used throughout this chapter interchangeably. The word "Microprocessor" describes a single computer chip which contains the logic of a central processing unit (CPU), plus various amounts of the "depository and conduit" logic that surrounds the CPU (16). Central Processing Unit (CPU) itself includes Arithmetic and Logic Unit (ALU) and Control unit. The microprocessor unit (MPU) is the basic processing unit of the microcomputer system but not much is possible from using a microprocessor alone. Thus the MPU is connected to input/output (I/O) and memory devices as shown in Figure 1.

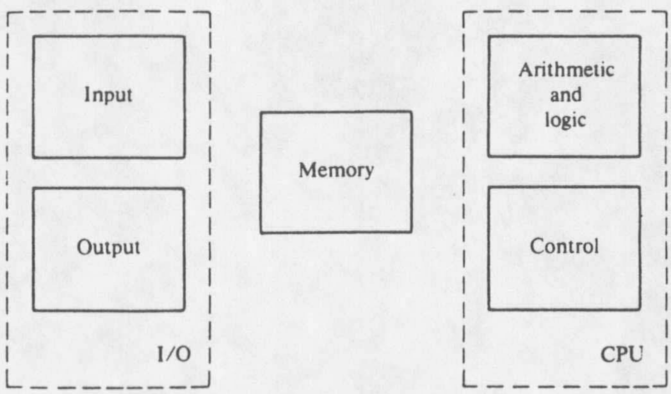


Figure 1: Basic functional units of a computer

The memory unit might consist of several devices such as read/write or random-access memory (RAM) and read-only memory (ROM). Memories store necessary programs (software) for the particular application of the microprocessor. The primary connection to external devices such as CRTs (Cathode Ray Tubes), Keyboards, or Teletypes is accomplished through an input/output (I/O) unit. This interfacing unit of the microcomputer system is implemented with one or more special chips which are provided by the microcomputer manufacturers (2). The signals going out of and coming into a microprocessor chip are seldom directly sent to interfaces and memory. Instead, additional logic is used to form a standardized communication device called "bus" to which peripherals and memory would be interfaced (3). The microprocessor system transmits information through three buses or communication lines: the data bus, address bus, and control bus.

The word "Microcomputer" describes a product that contains all of the functions found in a computer. The word microprocessor has come to describe a special type of electronic logic and its package. This electronic logic must contain the equivalent of a central processing unit (CPU) and the package should be a single chip. In contrast, the word microcomputer has come to describe special electronic logic including a variety of different packages, ranging from a single DIP to a box full of electronics.

Instructions and Programs (software)

A group of instructions that a specific microprocessor can execute is called it's "instruction set". MPU instruction sets might have as few as 8 or as many as 200 or more instructions. Several of these instructions could make a program statement and a group of statements would make a program. All the tasks done by computers require program writing or software development. A program written using the instruction codes of a microprocessor is called assembly language programming. Thus the process of developing assembly level programs is based on writing statements containing labels, instruction mnemonics such as operating codes (Op-codes) or operators and operands as variables. The assembly language follows the structure of the machine language closely. In the assembly process, each statement written in symbolic form is translated into its equivalent binary form (1s and 0s), consisting of instruction code and memory location. This kind of language is referred to as a low level language. Universal programming languages, originally designed for second and third generation computers, are application oriented and include words and phrases used in English. Of these programming languages, FORTRAN and ALGOL are designed for scientific users, COBOL for business systems, and BASIC for instructional time sharing or general problem solving. The above programming languages are called high level languages. Once a program is written in a high level language, a special program called a "compiler" converts the program to binary object code, which is consequently run on the machine. Note that the compile process or "compilation" follows essentially the same line as assemblers, in assembling the source code into machine readable object code. An interpreter, unlike a compiler, translates the instructions of the source program and also executes them immediately.

Hardware Interfacing

Interfacing is defined as the mating of one component on a system to another to form a totally operational unit. Today microcomputers are being used in areas such as information processing, data acquisition and control, robotics and CAD/CAM (computer aided design/computer aided manufacturing). To understand the design of real time data acquisition and control systems using microcomputers, one must know the way by which a computer can be interfaced to external equipment, and the kinds of program instructions that effect this interaction. Digital computers can only understand digital signals. Therefore, all the signals that are input to or output from the computer have to be in digital format. This is the reason for having A/D/A (Analog to Digital to Analog) converters.

Analog to Digital Converters (A/D)

The process of taking analog signals from the real world, processing and converting them into digital data, and finally bringing the results into a computers memory is defined as "data acquisition". For data acquisition, one must first convert voltage levels, current flows, pressure, fluid flow, or any other physical parameter measured by a transducer (transducers will be discussed in a later section of this chapter). If the transducer does not generate a high enough signal for the processing circuitry, an amplifier is used to amplify the signal. Filters can also be used to remove unwanted high and low frequency signals. The A/D unit then converts the filtered voltage level to a digital value that corresponds to the input analog voltage. The digital data is then put through some interface components and transmitted to a microprocessor. The microprocessor uses this data to either make decisions in software (program) or simply stores the data in memory for future analysis. The following parameters should be considered for selecting an A/D converter (3).

1. **Resolution** - This is the number of bits of output code and the percentage of the range covered in a certain A/D converter (the size of voltage step).

2. **Range** - This is the difference in input voltages that can be read by an A/D converter. An A/D converter that can operate between voltages of -5 and +5 volts, would have a range of 10 volts.

3. **Linearity** - This is defined as the maximum difference between the voltage steps. Theoretically, voltage steps must be exactly the same size.

4. **Relative accuracy** - This parameter is defined as the output voltage error for any two input voltages across the entire range.

5. **Absolute accuracy** - This is the output voltage error for full scale input voltage.

6. **Monotonicity** - This is the property of having an increasing output for an increasing input over the A/D converter's entire range.

7. **Missing codes** - The property or ability of an A/D converter to skip a code due to nonlinearity.

8. **Quantizing error** - This is the maximum voltage error due to A/D converters non-infinite resolution.

9. **Offset error** - This is the numerical value of an A/D converter output when a zero volt input is applied.

Digital to Analog Converters (D/A)

Conversion of a digital word or signal to a proportional analog value is an important task in the parallel type of A/D converters and is useful for generating analog control signals. A Digital to Analog (D/A) converter would be used to perform this task. The hardware for this device provides an electric current proportional to its binary weight to a common line. The sum of currents from all the bits in the input word are finally fed to an amplifier and converted to a voltage. This voltage is then used as an analog control signal or is amplified to a higher voltage level and used to activate some electrical device. The following features need to be considered before purchasing a D/A converter (3):

1. **Resolution** - The number of bits converted.
2. **Accuracy** - Percentage error in voltage output.
3. **Settling time** - This is the time taken for the digital input to be converted to an analog output.
4. **Linearity** - Maximum error of conversion between two input codes.
5. **Output range** - Difference in voltage between minimum and maximum output voltage.
6. **Input coding** - This is the format of input code - binary or BCD (Binary Coded Decimal) format.

Transducers

A transducer is defined as a device that converts electrical energy to mechanical energy (Output Transducers) or mechanical to electrical energy (Input Transducers). When used with microprocessors, these are devices that allow a system to sense and control real world events (3).

The signal from an **input transducer** is either a voltage or a current level. Interfacing a transducer to a microcomputer requires amplifying the input signals into a readable analog voltage. The analog voltage level is then converted to a digital form using an A/D converter or, in the case of a switch, counting the resulting digital waveform. Application notes are usually provided for commercially available transducers which give the exact types of outputs to be expected from a specific transducer and appropriate filter components for their use. Some of the different types of input transducers include: Motion-Sensing, Pressure Sensing, Flow-Rate sensing, and Smoke Detector transducers. The application of some of these transducers is shown in Figures 2, 3, and 4.

Motion-Sensing Transducers: The process of converting mechanical motion to an electrical signal is the function of a motion-sensing transducer.

Pressure-Sensing Transducers: The function of this device is to detect pressure using capacitive sensors.

Flow-Rate Transducers: Inline flow transducer utilizes fluid flow to spin a turbine at a flow-proportional rate. Turbine rotation is then monitored by an external coil to measure the flow rate.

Strain Gauges: Sensing forces and deformations on structures

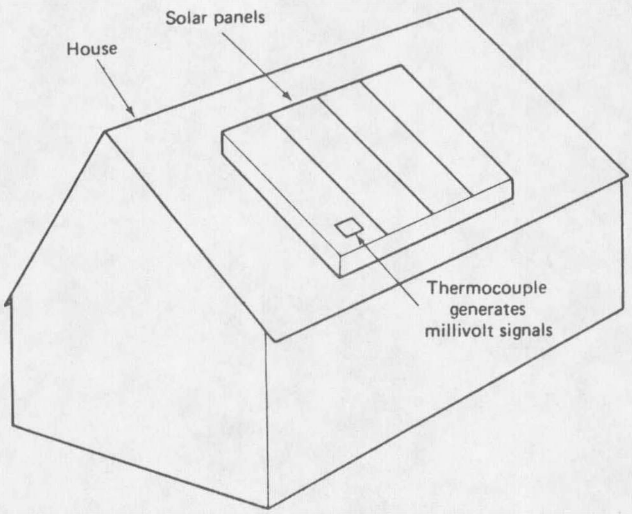


Figure 2: Measurement of temperature

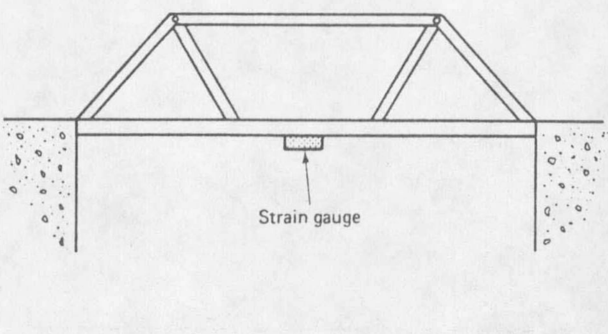


Figure 3: Indirect measurement of deformation

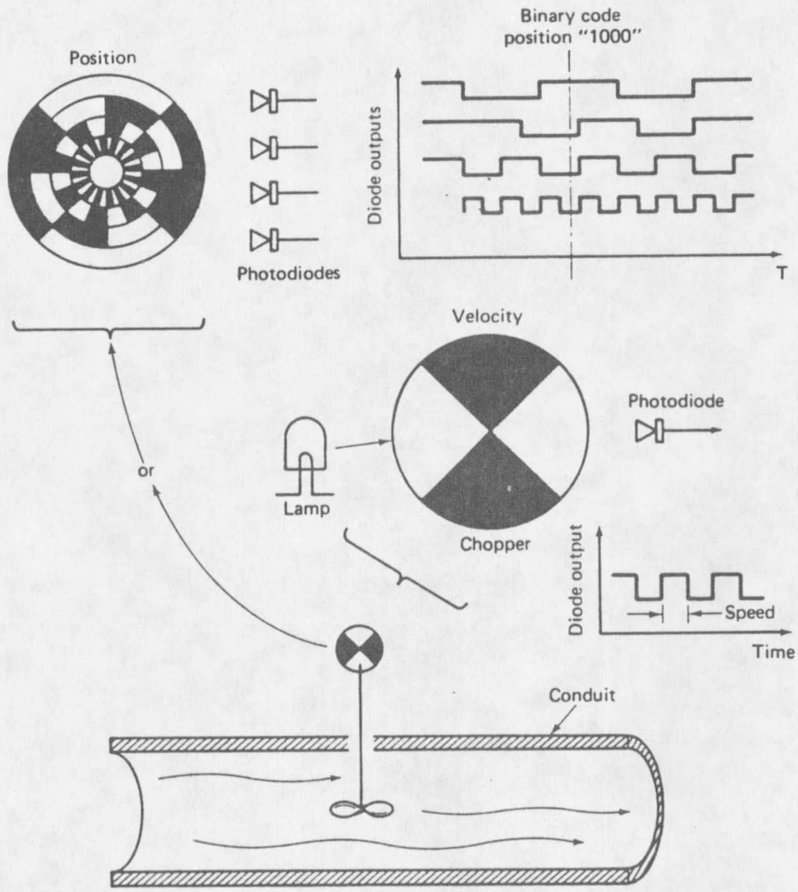


Figure 4: Measuring position, flow rate, or velocity

and mechanical components is the function of strain gauges. They are also used on some pressure sensing transducers.

Thermocouples: This device consists of a junction of two dissimilar metals or alloys. This junction is small and can monitor temperature changes rapidly and will come to an equilibrium condition quickly. A temperature difference between two thermocouple junctions creates a small voltage that is proportional to the temperature difference.

Smoke Detectors: These devices can sense the presence of smoke. Smoke detectors measure the resistance changes, current changes or optical smoke changes which are three methods of smoke detection.

The function of an **output transducer** is to convert electrical energy from the controller into mechanical energy. These transducers require either a switched current to actuate stepping motors and solenoids or an accurately controlled voltage/current to drive a motor or any other electric device. Power switching circuits such as a SCR (Silicon Controlled Rectifier), Transistor, and VMOS (V-shaped Metal Oxide Semiconductor) are utilized for switching. D/A converters and servoamplifiers are utilized for accurate voltage control. Some of the different types of output transducers include: Solenoids, Servomechanisms, and Stepping Motors.

Solenoids: This is a transducer that converts current into linear motion. A Solenoid is an electromagnet that causes a metal plunger to move.

Servomechanisms: A Servo converts electrical signals into controllable linear or rotary motion. Servos also have motion sensing transducers that provide motion information to the controlling logic. These sensors act as a feedback system for precise positioning (3).

Stepping Motors: This device is a precisely controllable rotating source that can be used for various mechanical control systems. Stepping motors consist of a gear-like inner rotor surrounded by three or more gear-like stators. The rotor aligns itself with the stator that is actuated with the magnetic induction of an electromagnet. Switching current sequentially between the stator magnets, activates the rotor to cause it to move in a back-and-forth or rotary motion. Figure 5 shows a microprocessor/VMOS/stepping motor system and Figure 6 shows a 4-phase, permanent magnet stepping motor (3).

A/D/A (Analog to Digital to Analog) converters could, therefore, provide monitoring of real world data using "input transducers" and control of real world systems using "output transducers". Typical voltage ranges that an A/D converter could tolerate or a D/A converter could generate is in the range of -5 to +5 volts. Furthermore, typical values of current used or generated by an A/D/A converter is in the order of a few milliamps. Amplifiers are used to increase current/voltage values of an A/D/A converter when needed. A/D/A converters of various capabilities are

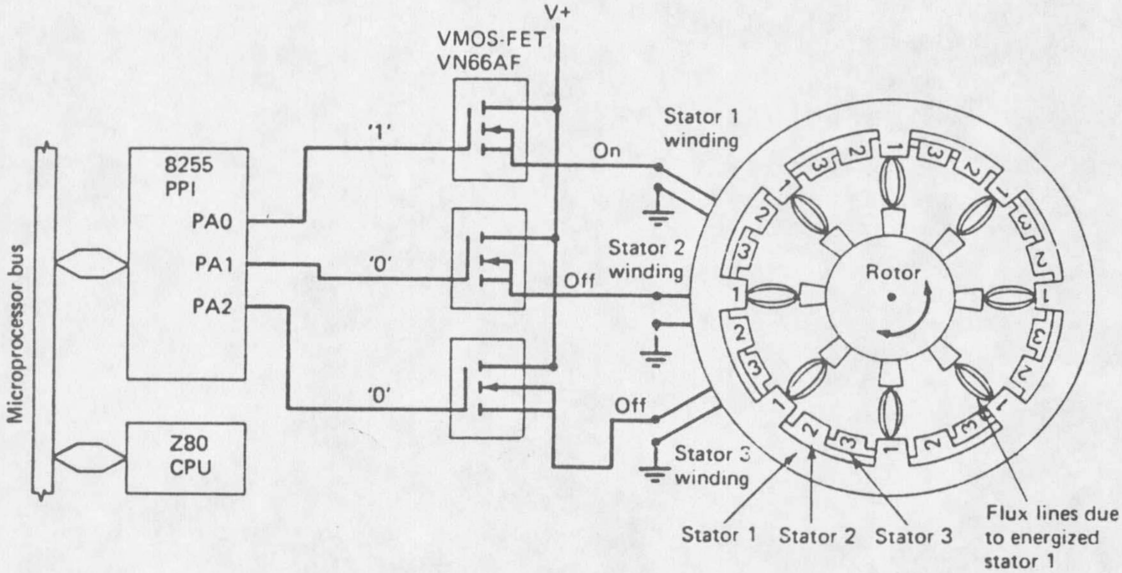
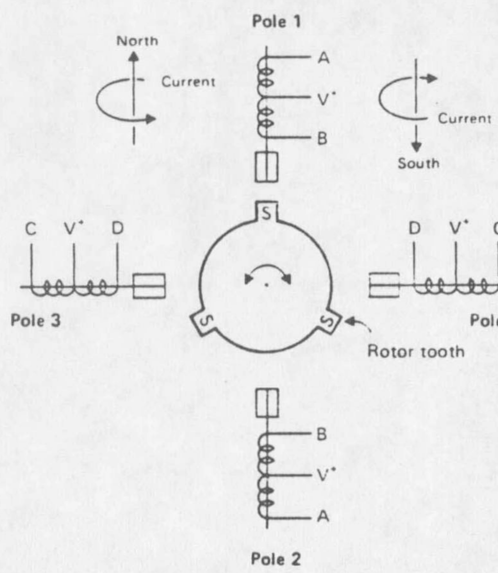


Figure 5: Microprocessor/VMOS/stepping-motor system



Coil A	Coil B	Coil C	Coil D	Pole 1	Pole 2	Pole 3	Pole 4
On	Off	On	Off	S	N	S	N
On	Off	Off	On	S	N	N	S
Off	On	Off	On	N	S	N	S
Off	On	On	Off	N	S	S	N

Counterclockwise ↓ / Clockwise ↑

Figure 6: 4-Phase, perminent magnet stepping motor and its full step actuation sequence

available from several manufacturers. A/D/A converters usually come in the form of micro-boards that are compatible with various microcomputers. When selecting this hardware, one should consider the following guidlines:

a) Decide if an A/D/A, A/D, or D/A board is needed. The purpose is to prevent purchasing of extra hardware for more cost.

b) Determine the maximum number of input/output channels that might be needed for a specific project.

c) Determine the minimum number of bits of resolution required for a particular application.

d) Determine the maximum speed of signal conversion required for a certain task.

e) Investigate the compatibility and size of the board to make sure that it would fit into an empty slot inside the computer box.

f) Investigate the language used for development of A/D/A board software if any.

Monitoring Data by Microprocessors

The real world seldom permits us to directly interface naturally observed signals with a microprocessor. In fact, most of the real world signals are incompatible with any machine measurement. Thus a "system" that can either measure signals or control the activity of some process is necessary. This "system" is illustrated in Figure 7 and includes three elements a) a controller, b) a process that needs to be observed and/or controlled, and c) the measuring device.

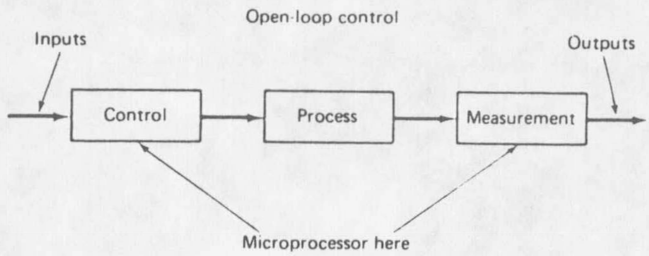


Figure 7: The System

The above system (Figure 7) is considered to be an open loop system since the input, which could come from either the process block or the measurement block, feeds the control. If closed loop control is desired, however, the measured output is generally linearly combined with the input to serve as a primary signal for the control. Note that the microprocessor plays a primary role in both the measurement block and the control block of Figure 7. Furthermore, in most systems, the measurement block could be combined with the control block.

Signal Types

In the previous section, it was mentioned that, in the real world, natural signals are not directly compatible with microprocessors. Therefore, one needs to know what are commonly encountered signals that one should expect to see in measurement and control? Some typical physical signals are temperature, pressure, humidity, proximity, force, or displacement. These measured signals are seldom directly compatible with the microprocessor interface since they are not electrical signals. Some other "measured" signals are physiochemical signals that give properties for chemical analysis such as: electrical conductivity, thermal conductivity, mass spectrum, and diffusion coefficients (chromatography) (2). Physical and physiochemical signals are not the only signals that one may encounter, even though they are the most common. It is possible that one may need to monitor physical properties, such as density, viscosity, mass, and vibrational frequency. These properties, however, are usually observed indirectly using the physical signals that were mentioned above.

These incompatible signals are translated into compatible signals using a transforming device called a transducer that was discussed earlier in this chapter. Thus, a transducer is an integral part of the input circuit for the process control system that was described. Transducers could be found in either the control block, the measurement block or both of these blocks shown in Figure 7.

Signal Conditioning

The output signal from the transducer itself is not necessarily useful until it is further modified. Generally, the output signal, which is an electrical quantity, needs to be amplified, attenuated, filtered or translated. Microprocessors are interfaced with TTL (Transistor-Transistor Logic), which recognizes voltages of 0 or +5 volts. In this logic, the 0 represents a Boolean value of 0 and +5 volts represents a Boolean value of 1. Most transducers can not generate such large voltages and the signal needs to be modified. This modification is referred to as "signal conditioning". Signal conditioning may be performed either by the microprocessor itself or by analog devices prior to interfacing with a microprocessor. Generally, signal conditioning would include: a) Amplification, b) Filtering, c) Input Protection, d) Isolation, e) Common Mode Rejection, f) Cold Junction Compensation, and g) Transient Excitation (2).

When signals are conditioned, they would usually be in the form of small voltages (between -5 to +5 volts) and can be transmitted to an A/D converter. The A/D converter would then change this analog signal to its equivalent digital format and supply it to the microprocessor. The data in the digital format could then be displayed on a CRT terminal or be used in a computer program.

Controlling Mechanical Systems With Microprocessors

Different mechanical systems have different characteristics which have a direct relationship with the simplicity or complexity of interfacing the mechanical system to computers. To control any mechanical system, the computer should be able to move a mechanical device in a certain direction or turn certain switches on and off and other similar control tasks. Special equipment such as stepping motors, electronic relays, and so on are available for interfacing with a computer. These devices enable computers to accomplish the expected tasks. These devices recognize digital signals or binary code and behave or respond accordingly. To activate any of these devices, several logical switches might be needed to be in "high" or "low" state. Furthermore, computers can only recognize binary code (0s and 1s) in which "0" is a low/off signal and "1" is a high/on signal. Thus, to activate a device, the proper binary code could be sent to the device through either parallel or serial ports from a computer. This is not the only way to send codes to outside devices. Other means such as input/output (I/O) channels in certain computer boards (A/D/A) and others) could also be utilized for transmitting binary codes. Computer Aided Manufacturing (CAM) and Robotics are highly advanced mechanical systems that are controlled by microprocessors and are being utilized in most manufacturing companies.

Computer Interfacing With Hydraulic Systems

In recent years, hydraulic systems have undergone a dramatic change in that many fluid power applications are demanding the control of force and velocity as well as position, using electronics. A new area of control is now possible due to the development of the new generation microcomputers. The hydraulic system supplies "power" and the combination of electronics and microprocessors supply the "control and decision making". This is the most effective method for utilizing the benefits of fluid power systems (18). The dramatic potential for controlling mechanical components in such complex applications as robotics and flexible manufacturing systems (FMS), in addition to small everyday applications such as a tractor pulling implements, indicate the range of applications possible for the combination of hydraulic systems and microelectronics.

A hydraulic system can be divided into the following elements or components (18):

The Energy supply component provides a hydraulic fluid under pressure which is utilized to provide force and movement. An example of an energy supply element is a hydraulic pump or an air compressor.

The system for **Controlling** hydraulic systems should be safe and effective. Microprocessors are powerful and inexpensive and can act on information given to them more rapidly and more accurately than can other methods of control. Microprocessors can be considered one of the most suitable means of control for fluid power systems of any complexity.

Motion and power are obtained from hydraulic motors and cylinders. Various types of valves are used to provide direction, speed, and load control. Many of these controls regulate the flow of the hydraulic fluid.

A **Feedback** signal is a signal that is returned from the components that are providing the system performance. These signals would then verify the correct execution of input commands. Today's electronic feedback components that are used with microcomputers provide a very high degree of accuracy and resolution.

Advantages of a Microprocessor Controlled Hydraulic System

The rate of transmission of data between microprocessors and electronic devices is very high. This characteristic enables the hydraulic system to be controlled very accurately. This is accomplished by the ability of computers to cause hydraulic components to move accurately and their ability to monitor response such as pressures in high pressure lines of a fluid power system. Precision and accuracy in controls, such as small incremental variations in force and speed of a hydraulic system, is only possible with computer controls. Once the hydraulic system is operational, it could be modified further to do other tasks by simple software modifications which requires no changes in mechanical components of the system. This enables the hydraulic system to be much more flexible than might be obtained otherwise. There are a great number of interface devices such as stepping motors, limit switches, solid state relays, solenoids and other components available that can be used to achieve the desired response from a particular system.

Disadvantages of Microprocessor Controlled Hydraulic System

One of the problems often associated with hydraulic systems is fluid leakage. Hydraulic fluids that leak into any microelectronic devices could easily cause permanent damage and a variety of malfunctions in the electronic system. The usual environment for the operation of hydraulic systems is considered hostile to microprocessors. Dust and temperature variations can have some unpredictable negative side effects and one should consider these effects in interface design. Electronic devices may need to be encapsulated for protection against contamination. The response time of a fluid power system is very slow compared to the rate of transmission of data between microcomputers and electronic devices. This may create problems in software development. An example is the movement of the variable displacement arm on a hydraulic pump which causes a flow change in the outlet port of pump. The resultant flow change shows as a pressure change required to accelerate or decelerate the motor. The time delay due to the mechanical system to move the pump control lever arm could take as much as a couple of seconds. When this time is compared to the execution time of a computer program statement, which is in the order of nano or microseconds, one could see the difference clearly. This difference requires the microprocessor to wait for a signal from the hydraulic system.

The increase or decrease of force, pressure or torque by a fluid power system would usually be achieved by hydraulic valves or by changing the displacement of a variable displacement pump. A stepping motor could be used to actuate mechanical or hydraulic controls under computer control. Some knowledge of stepping motors, therefore, would be required for interfacing of stepping motors between hydraulic and computer systems.

Chapter 3

LOAD SIMULATOR COMPONENT DESIGN

The load simulator has five main components or subsystems. Each subsystem is designed as an independent unit and then they are combined for the load simulator system. The five components are:

1) Computer Control Subsystem
2) Hydraulic Load Subsystem
3) Power Source Subsystem
4) Load Absorption Subsystem
5) System Software Subsystem

The Computer control subsystem provides the data acquisition and control capability for the entire load simulator system. The computer monitors the required variables (in this case, the force on the dynamometer) by using pressure transducers on the load absorption unit. The control subsystem calculates a desired load as a function of time and then causes the system to adjust to this load as closely as possible. The main purpose of this project was to find out how accurately the behavior of the actual system matches the pre-simulated data. The control consisted of an AT&T 6300 computer, an A/D (Analog to Digital) converter board, a stepping motor with its controller chip, a 12-volts power supply, a strain gauge pressure transducer and a multi-channel strip chart recorder. A description of each of these components follows below.

Computer: The computer used was an AT&T 6300 microcomputer with 640 K of memory. This machine has an 8086 intel processor. The RS-232 serial port could be used as an output port for control purposes but was not used in this system.

A/D (Analog to Digital) Converter Board: The variables that might be monitored are dynamometer speed, force on the dynamometer and fluid pressure on the hydraulic motor. The force (load) on the dynamometer is the only variable that needed to be monitored in this experiment. The load on the dynamometer, as a function of time, should be directly proportional to the pre-simulated force as determined by the computer. This pre-simulated data consists of curves of load verses time. The monitoring of the dynamometer was done through the A/D converter. Movement of the variable displacement control arm on the hydraulic pump was the only control variable that needed to be changed to adjust the force on the dynamometer. The dynamometer force is a function of the amount of water in the dynamometer and the square of the speed of the dynamometer. For a given amount of water in the dynamometer, the load can be varied by changing the dynamometer speed. This was achieved by changing the oil flow rate to the hydraulic motor using a stepping motor to move the variable displacement arm on the hydraulic pump. The digital outputs on the A/D board were used to send signals to the stepping motor. Typically, the A/D board might use several A/D channels for monitoring several variables (only one variable was required for this project). An A/D converter board from MetraByte was used in this project. This board was selected on the basis of: 1) the cost and compatibility of the A/D board and 2) the requirements of the system.

Stepping Motor, Controller Chip and Power Supply: The stepping motor was a linear displacement stepping motor with a threaded shaft which had seven threads per centimeter. The threaded shaft was connected to the variable displacement arm on the hydraulic pump. The stepping motor received control commands from the AT&T computer to control the variable displacement pump. A Hurst Manufacturing corporation, linear actuator, model LAS stepping motor was used for this control. This stepping motor was supplied with its particular controller chip and has the following four operational modes:

a) RUN Mode: This mode results in continuous rotary motion of the stepping motor. This results in a continuous linear change of the hydraulic pump displacement.

b) JOG Mode: This mode results in a single step rotary motion for the stepping motor (48 steps per revolution). The JOG control has no effect if the RUN control is activated.

c) CW/CCW Mode: This mode provides clockwise or counter clockwise rotation of the stepping motor.

d) DISABLE Mode: This mode deactivates all previously activated modes and stops motor rotation.

The step angle for this stepping motor could be either 7.5 or 15 degrees per step (48 or 24 steps per revolution).

Specifications for this motor are shown in appendix A. A small power supply that would provide 12-volts DC to the stepping motor was also required. A mounting fixture for the stepping motor held it in a fixed position relative to the hydraulic pump. A connecting link from the variable displacement lever on the hydraulic pump was then connected to the shaft on the stepping motor for pump displacement control.

Pressure Transducer: The dynamometer force was sensed by a strain gage pressure transducer. This BLH ELECTRONICS INC., model GP-CG low pressure transducer operated in a pressure range of 15 to 100 PSI (100 to 700 KPa). The pressure transducer was attached to the hydraulic line from the dynamometer. This pressure was directly proportional to dynamometer torque. A Hewlett Packard four channel strip chart recorder was used to provide the power for the strain gage bridge and to record the strain gage signal as a function of time. Signal conditioning and amplification was therefore provided by the recorder. An analog signal equivalent to the displacement of the recorder pen was fed into the computer through an A/D converter board. This then became the monitored load used by the computer for comparison with the desired load.

Strip Chart Recorder and Preamplifier (Transducer and Computer Interface): This interface was a four channel strip chart recorder and preamplifier. This unit was able to condition, measure, and record four input signals as a function of time (Appendix A provides the specifications for this device). The strip chart recorder would process and record the electrical signal output from the strain gage transducer. The preamplifier supplies excitation voltage to the transducer bridge, and receives the returning transducer output. It, then, amplifies this signal, compares it with a synchronous detector, filters and passes it to the recorder for chart display.

A "PREAMP OUTPUT" from each channel of the strip chart recorder is available for remote recording or display devices. The preamp output at the terminal strip is ±5 dc volts for full scale deflection of the recording pen. The voltage will be either plus or minus 5 volts depending on the side of the chart used as the zero reference.

Hydraulic Load Subsystem: The hydraulic load subsystem consists of a variable displacement hydraulic pump and motor, an oil reservoir and connecting hydraulic lines. The hydraulic pump is powered by an internal combustion engine, and the pump supplies hydraulic power for the hydraulic motor. The hydraulic motor is directly connected to the dynamometer. The torque and speed of the motor are directly proportional to the torque and speed of the dynamometer. The dynamometer load was the only variable monitored by the computer. The description of the components for this subsystem follow:

Variable displacement hydraulic pump and motor: A VICKERS variable displacement pump and motor, model TA(3)-15, was used for the hydrostatic drive to the dynamometer. The pump has a maximum pressure rating of 4500 psi and maximum operating speed of 3000 rpm. The displacement of 2.01 cubic inches per revolution gives a flow of 15 GPM at 3000 rpm. The pump requires 21 HP at 1800 rpm and 3000 psi pressure. The motor is identical to the pump but was used in a fixed displacement mode.

Power Source: The Hydraulic Load Unit was powered by an INTERNATIONAL 504 tractor. The internal combustion engine was directly connected to the hydraulic pump by a double B-section V-belt drive. The pump and engine configuration as part of the total system is shown in Figure 8.

The Load Absorption Subsystem: The Load absorption unit was a "Taylor True Test" dynamometer. This unit absorbed the load output from the hydraulic motor and indicated the torque (or force on the dynamometer case) delivered by the hydraulic motor. This force was monitored by the AT&T computer using the output from a pressure transducer. The dynamometer was directly connected to the hydraulic motor unit as shown in Figure 8. The dynamometer was selected for the load absorption unit, as it could absorb forces in the same load range as that predicted for the real life system. The average load absorption levels for a given dynamometer

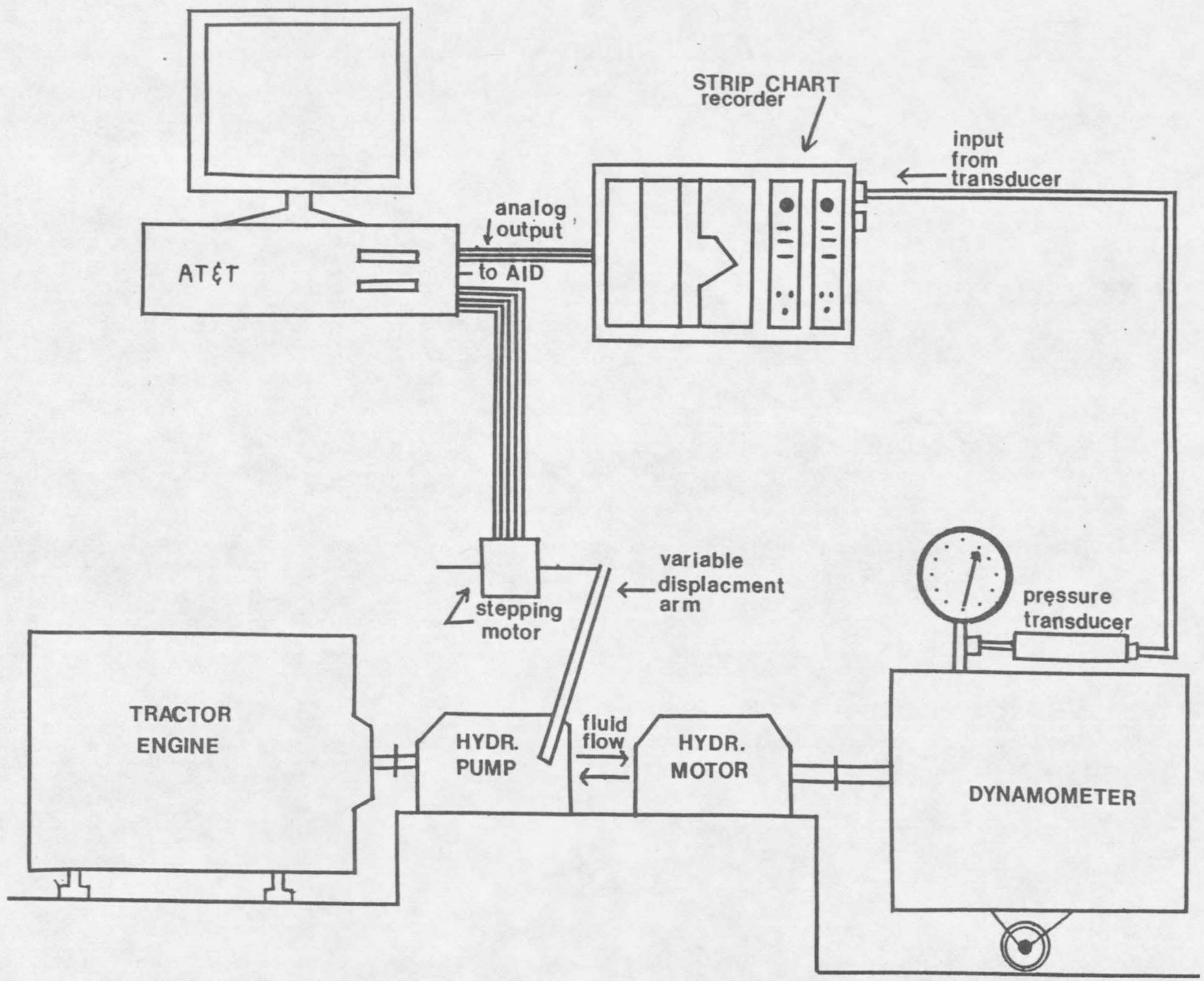


Figure 8: Hardware for microprocessor controlled hydraulic load unit

speed were determined by changing the volume of water inside the dynamometer case. The load change was then a function of the square of the dynamometer speed and could therefore be changed by changing the dynamometer speed.

System Software: The software program for the computer was developed in BASIC programming language. This program monitored and controlled the appropriate variable (force). The monitored force was compared to a calculated force which was determined simultaneously from Pre-simulated data. BASIC was chosen for the software language due to its flexibility for I/O purposes and the ease of programming. The software provided for the DASH8 A/D board was also in BASIC. The components for this subsystem are described as follows:

GW-BASIC Compiler: The AT&T 6300 microcomputer used in this study was equipped with GW-BASIC software. The program required for control was written in BASIC to utilize this software. The BASIC program was written with a minimum number of statements in the decision making control loop to minimize the time to complete the monitor and control loop. By measuring the cycle time for the control loop, it was found that there was a time limit of about 0.25 seconds for the decision making control loop. The response would overshoot the desired load when the time for this loop became much over 0.25 seconds. The complete program with its control subroutines is provided in the appendix B. Comment statements are provided within the program for clarification and documentation.

Pre-simulated Data (Curves): An equation was developed that simulates the pulling force on the cable caused by a load as it passes between two supports on a cable conveyor system. This equation determines the pulling force on the cable as a function of cable speed and time. The forces change as the load moves from one support tower to the other. The equations for these forces as a function of time were used in conjunction with the internal clock of the microcomputer to simulate forces with respect to time. The software could then calculate the desired force, read the actual force from the dynamometer and compare the information to make control decisions. In this manner the software could duplicate the pre-simulated data by adjusting the hydraulic system.

Chapter 4

PROCEDURE

A hydrostatic transmission using the Vickers pump and motor was fabricated and mounted on the tractor and dynamometer. The system was tested using manual controls for the hydrostatic drive. Minor modifications of the belt drive were required. The hydrostatic drive was then determined to be satisfactory as it could transfer all of the engine power to the dynamometer. The dynamometer force could be readily changed by changing the pump displacement.

The computer was interfaced with the hydrostatic transmission by a stepping motor connected to the displacement control arm of the hydrostatic pump. When the stepping motor was added to the system, a small routine was written to test the stepping motor for its proper operation (This program is provided in Appendix B). Tests without the engine running showed that the stepping motor could change the pump displacement over its entire range of adjustment. Tests under load, however, showed that the force required to operate the torque arm was too great for the stepping motor. The engine and pump vibrations also caused the torque motor to lose its holding ability. The force required to move and hold the displacement control arm was reduced by increasing the length of the torque arm approximately three times. The vibrations on the stepping motor were also reduced by moving the stepping motor to the rear frame of the tractor. It was then connected to the new motor displacement shaft with a low mass control rod. Tests showed that the stepping motor was now able to adjust the pump displacement over the needed portion of the pump displacement control while the hydrostatic transmission was operating under light and heavy loads. In these studies the operator would input control signals to the computer to see that the stepping motor and the hydrostatic transmission responded in the desired manner.

Preliminary testing showed that a system had been developed that would permit the computer to control the hydrostatic transmission over the desired operating range. The next step was to develop a software (program) that could monitor the actual load, calculate the desired load and use the differences to actuate the control system. The sequence of the required operations in the development of the software is listed below:

1. Input the primary variables that are required for the evaluation of the pre-simulated data (force) which includes:

    a) Cable velocity
    b) Cable span
    c) Cable slope
    d) Cable tension
    e) Number of load cycles with their particular load

2. Determine the required Recorder Attenuator Dial Setting with respect to the above input primary variables.

3. Start the control loop of the test sequence in the following manner:

    a) Simulate load as a function of time

b) Monitor force from the real system (dynamometer)
c) Compare forces and evaluate Error
d) Evaluate a Control Signal (feedback signal) based on the Error
e) Make decision based on the Control Signal to activate the stepping motor to adjust the load on the real system
f) Repeat steps (a) through (e) until the end of the cycle/s
g) Return control to the operator

Computer Control System

An automatic system to perform a test sequence was required. This system would control the test process by starting and testing the system and would also indicate problems and changes required in the system. The following would be required for the automatic system:

1. Input the desired test sequence so that the computer could determine the force needed as a function of time.

2. Calibrate equipment such as the pressure transducer.

3. Evaluate a feedback signal which would provide the computer the ability to sense the monitored data (force) and prevent overshooting. The feedback signal is a rate of change that permits the computer to sense when the error signal is approaching zero to start the change before the error signal changes.

To perform the above test sequence, an IBM compatible AT&T microcomputer was used as the main controller. An A/D (Analog to Digital) converter was used to monitor data and transmit signals to the stepping motor for control purposes. A pressure transducer was attached to the hydraulic line from the dynamometer. The pressure transducer was calibrated before being used so that it would read the same as the dynamometer gage. Signals from the transducer were then fed to a strip chart recorder that would plot the absorbed loads of the dynamometer. This recorder then provided an analog signal in the range of -5 to +5 volts that was fed into the A/D converter through a ribbon cable. The A/D converter provided a digital reading of the force signal to the microcomputer when requested. Using BASIC software, the microcomputer translated the signal into its equivalent load and used it for comparison with the simulated load. The difference between these two values was an error or control signal with a positive error telling the system to increase the pump displacement and a negative error to decrease the pump displacement. The stepping motor was activated to correct this error. To operate the stepping motor, digital output ports of the same A/D board were used to transmit a binary signal to the stepping motor. This binary code activated the stepping motor to run in CW/CCW directions depending on the sign of the control signal determined by the computer. Movement of the stepping motor in a certain direction continued until a new error signal directed the stepping motor to either change the direction of movement or disable the stepping motor. A feedback signal proportional to the rate of change of the error signal was evaluated and added to the software. This feedback signal helped the computer to sense the increase or decrease of the load as the stepping motor moved the variable displacement arm. This control signal helped to prevent overshooting of the desired load to a great extent and was evaluated as follows:

The Control Signal was an Error Signal minus Feedback Signal. The time required for the software to simulate the load, monitor the load through the A/D board, compare the simulated load with the actual load, and finally to make a decision was a limiting factor in determining the accuracy of the control system. About four decisions were made in the control loop every second, which appeared to be satisfactory. The software written to do the above test sequence for the control system is provided in Appendix B.

The mechanical system was tested under manual control after it was built to make sure that all mechanical components were operating properly. The recorder was used to test the performance of the dynamometer when the pressure transducer was added to the system. The software was written in BASIC language since the software for the A/D converter board was also in BASIC. The time required to run through one loop of the control was reduced to about 0.25 seconds without changing the programming language. However, if a shorter time had been required it would have been necessary to use a BASIC compiler to change the program to assembly or machine language to reduce the time further. Another solution would have been to write the same program in a low level language which would achieve the same task as BASIC compiler.

Chapter 5

RESULTS AND DISCUSSION

The main purpose for this project was to interface a microcomputer to a hydrostatic transmission so that the system could duplicate the pulling or braking forces that would be obtained when a cable conveyor system moved a load between two support towers. The test for this system was to determine how accurately the system was able to duplicate the desired loads. The desired load had been determined to be a uniform load plus a step increase and decrease. The load between the two step functions was a linear ramp decreasing as shown in Figure 9. The time between the two step functions was equal to the distance between the two cable supports divided by the cable velocity.

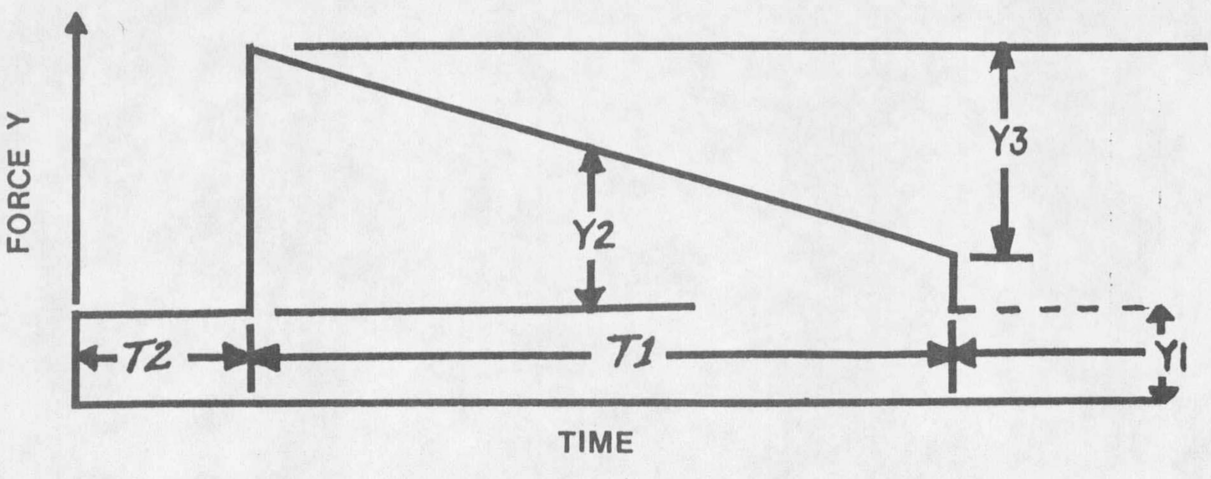


Figure 9: Typical loading pattern for a load simulation device as the load moves between two support towers.

A series of equations were derived to simulate the forces shown in Figure 9. These equations determine the braking or pulling force on the cable and are a function of cable size, cable tension, span chord length, slope and the size of the load. The variables shown in Figure 9 are:

Y = the braking or pulling force that must be applied to the cable to duplicate or simulate field conditions. This is the force desired from the test system.

Y1 = the braking or pulling force due to the weight of the cable alone.

Y2 = the mean value of the additional braking or pulling force that is due to the addition of a load on the cable. This mean value occurs at the mid point of span because of the linear change between the supports.

Y3 = the change in braking or pulling forces as the load moves from the uphill tower to the downhill tower.

The total cycle time between loads is (T1 + T2). This time is a function of the length of the cable segments and cable velocity, therefore:

T1 + T2 = 500 x 60 / Vel.

T1 and T2 are in seconds and the velocity (Vel.) is in feet per minute. The length of the cable segment is shown as 500 feet. T1 is the time in seconds required for the load to pass between two support towers. The distance is measured as the chord distance between the towers so that the time can be calculated directly as a function of span and the cable velocity.

T1 = Span x 60 / Vel.

The force applied to the cable is called Y and can be determined by the equation:

$$Y = Y1 + Y2 + Y3/2 - (Y3 \times T)/T1$$

T is the elapsed time in seconds with T=0 at the first step function and T=T1 at the second step function. Y1, Y2 and Y3 are functions of the cable conveyor system. They are shown for a 3/8 inch cable conveyor system as follows (11).

$$Y1 = 0.259 \times SPAN \times (SLOPE^2 / (SLOPE^2 + 100^2))^{0.5}$$

$$Y2 = LOAD \times (SLOPE^2 / (SLOPE^2 + 100^2))^{0.5}$$

$$Y3 = 10 \times \left[61.16 \times \frac{((0.285 \times SLOPE^2) + 100^2)}{(SLOPE^2 + 100^2)} - \frac{(500 - SPAN)}{40} \right] \times \frac{LOAD}{TENSION}$$

These equations were used in the software program to simulate the appropriate loads at each interval of elapsed time. These loads were compared to the actual real world system loads (dynamometer loads) monitored by a pressure transducer. A "Control Signal" was then determined based on the differences between an "Error Signal" and a "Feedback Signal". This "Control Signal" was derived in the following manner:

a) The "Error Signal" is defined as:

Error Signal = Desired Force - Actual Force

b) The "Feedback Signal" is defined as:

Feedback Signal=(Current Force-Previous Force)/Time per loop

Where: The values inside the parentheses are "Current Actual Force" and "Previous Actual Force" or the force change during the time for one loop and is therefore the rate of change of the force.

c) By using the "Error Signal" and the "Feedback Signal", the "Control Signal" would be derived as:

Control Signal=Error Signal - (Constant x Feedback Signal)

The actual time per loop was not measured but was a constant for all measurements. "Constant" in the above equation was a gain constant that could be adjusted to change the magnitude of the feedback signal.

Based on the value of "Control Signal", the following decisions were made by the microcomputer in order to duplicate the simulated loads on the real system:

1. If the "Control Signal" is positive (+), increase displacement
2. If the "Control Signal" is negative (-), decrease displacement
3. If the "Control Signal" is zero (0 ± 0.1), stop or no change

Software Testing

Initial trials with the system software written in BASIC showed that the system response time was too slow. The system did change with time as desired but overshooting of the desired load was very severe. The software program first monitored the actual load from the real system and then compared the monitored load with the pre-simulated load. The difference, called the error signal, was used to decide to increase or decrease the load on the real system. The stepping motor was then activated to move the variable displacement arm on the pump in the direction required to correct the error. The cycle was then repeated (as a loop in the software) and another decision made. The time for this cycle to repeat itself was about one second. This time plus the lack of feedback signal to tell when the load was approaching the desired load resulted in considerable overshooting of the desired load.

The overshooting problem was solved by starting the time cycle for determining the "Error Signal" and subtracting the "Feedback Signal" to determine the "Control Signal". The cycle time was reduced to about 1/4 second by revision and modification of the software program. All unnecessary "PRINT" and "IF" statements were eliminated from the software enabling the computer to run the control routine without any output to the screen or printer. The results of these modifications satisfied our demand for a system that could duplicate the design loads. If these modifications had not reduced the software run time to a satisfactory level, then it would have been necessary to use a BASIC compiler or Assembly level program to increase the speed of execution and control.

Test Results

Test results were recorded as a series of curves on a strip chart recorder. These curves represented the actual response of the load system to the computer control system. A typical example of a satisfactorily generated curve is shown in Figure 10.

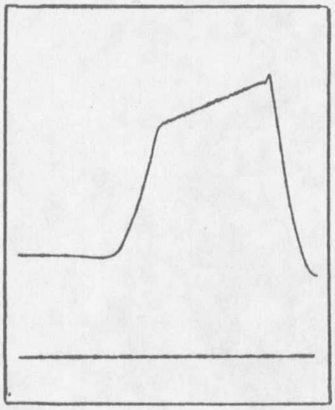


Figure 10: Actual loading pattern for a load simulation device as load moves between two support towers.

The step increases and decreases were not as rapid as desired due to the time required to accelerate and deccelerate the dynamometer. The ramp function very accurately duplicated the desired load between the two step functions. The size of the step functions, curve slope and time could all be preprogramed as parameters of the cable conveyor system.

Control Loop

The task of the control loop was to a) monitor the actual force from the real system, b) calculate the desired force for the real system, c) calculate a control signal to either increase or decrease the force and d) to initiate a control command to activate the control system. To monitor the force on system, the signal from the strain gage pressure transducer was converted to a force value and then translated to a load value. This was achieved by a subroutine that contained an A/D conversion of the transducer signal. The measured force was then compared with the desired force to determine an error signal. A positive error required the force to be increased and a negative error required the force to be decreased. The control signal was the error minus a feedback signal. A small error with a large feedback would tell the system that it was approaching the desired value and should stop the change to reduce or prevent overshooting the desired load. This was achieved by two subroutines in which one commanded the stepping motor to increase the load and the other commanded the stepping motor to decrease the load.

The final control loop performed satisfactorily and contained a single A/D conversion with no input or output statements such as "print" or "input". The initial control loop did not perform satisfactorily and resulted in considerable overshooting. In the initial program, 100 A/D conversions were taken and the average value of these readings was used for decision making. Figure 11 shows the improvement in control as software modifications were made in the program. A single A/D conversion was adequate for determining the actual force in this study since the force signal had already been filtered by the recorder. In many control applications it may be necessary to take several readings and average the values to obtain an accurate A/D reading.

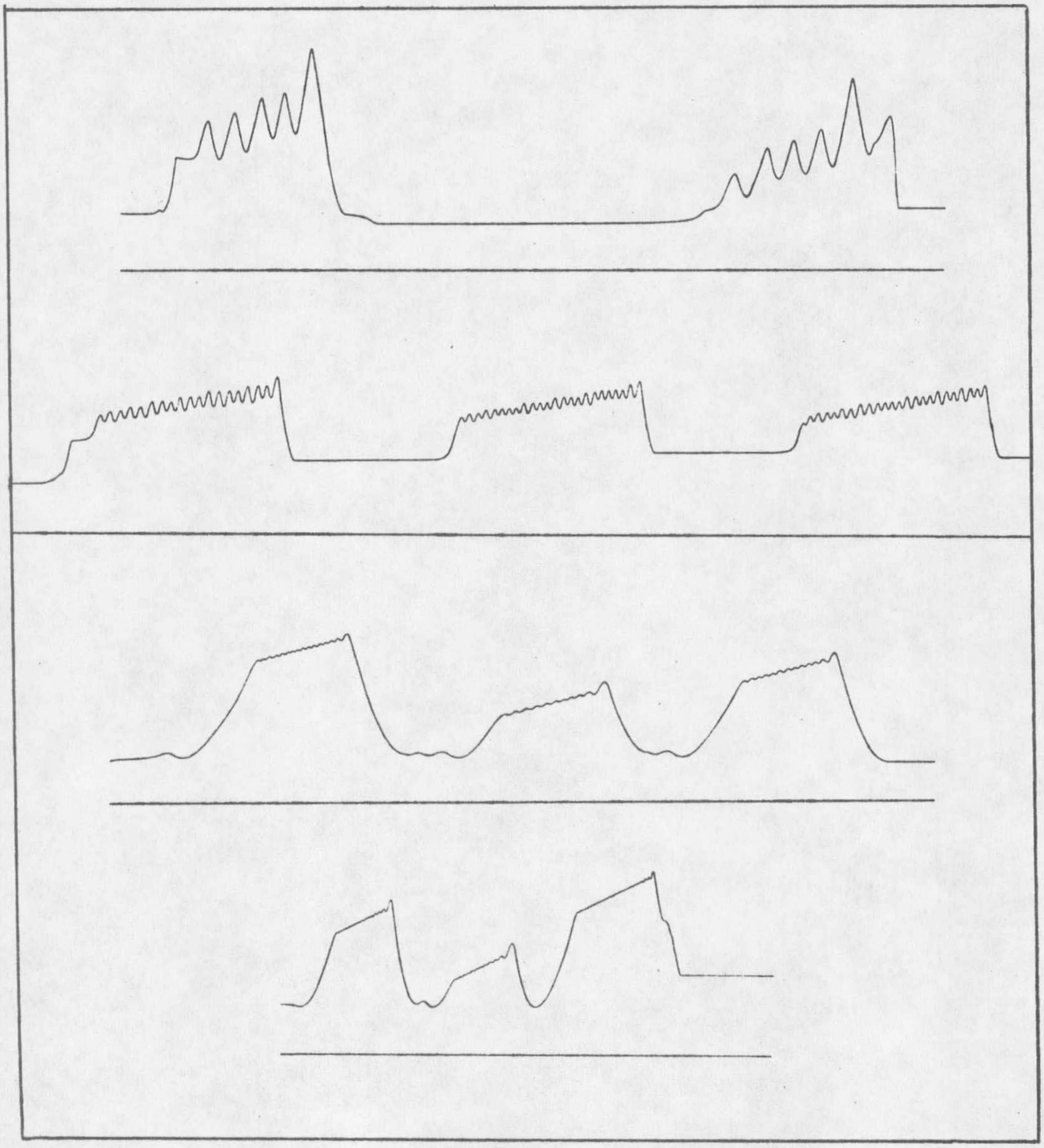


Figure 11: Improvements in the degree of control from the control loop as software modifications were made in the program.
a) Control loop containing 100 A/D conversions, no feedback signal and same output statements.
b) Control loop with a single A/D conversion, feedback signal and same output statements.
c & d) Control loop with a single A/D conversion, feedback signal and no output statements.

Chapter 6

SUMMARY AND CONCLUSIONS

Summary

A system was needed to simulate the pulling or braking force on a cable that would be introduced by a log being conveyed between two support towers. The system requirements for this simulation use a hydrostatic transmission with a variable displacement pump and motor. The hydrostatic transmission was interfaced between an external source of power and a load absorption unit. A tractor engine was used to power the hydraulic pump and a water brake dynamometer was used to load the hydraulic motor. A pressure transducer monitored the torque on the dynamometer and transmitted data to a strip chart recorder which recorded the dynamometer force as a function of time. The recorder also provided a voltage output that was proportional to the dynamometer force. This voltage output was input to a microcomputer through an A/D converter. A computer controlled stepping motor was used to move the variable displacement arm on the hydraulic pump. Furthermore, the computer monitored the torque from the dynamometer, simulated the expected loads, and activated the stepping motor to duplicate the simulated loads on the real system. Simulation of the expected loads was accomplished by software using a pre-determined equation.

Conclusions

The objectives for this research project were accomplished and are described as follows:

1. A microcomputer control unit for a hydrostatic transmission load system was developed that could duplicate desired loads.

2. A control program was developed that could accurately duplicate a predetermined series of forces that changed as a function of real time.

The accuracy of the control system was satisfactory as it could nearly duplicate the forces needed to simulate the pull on a cable that would be introduced by a log being conveyed between two support towers of a cable conveyor system. A pre-determined equation in the software was used to determine the desired forces as a function of cable conveyor parameters. This equation could be modified or replaced by other equation/s that represents the load behavior of any real life system. The computer, therefore, would accept any equation/s of any real system and would simulate the expected loads of the system accordingly. This provides a great deal of flexibility for the hydrostatic drive.

Recommendations for Future Work

There are three main recommendations for future work on this project (Cable Conveyor System):

In the actual Cable Conveyor System there would be a number of support towers with a cable running over a sheave at each tower (11). In addition to monitoring the forces involved in the system, there would be a need to monitor variables such as the amount of cable wrap around the sheave (position sensing) and the velocity of cable movement (speed sensing). Thus the first recommendation regarding future work on this project would be **to develope a system that can monitor multiple strain gage devices, position sensors and speed sensors.**

In addition to controlling the forces involved in the real system, there might also be a need to control several variables. One of these variables could include the amount of cable wrap around the sheave to create more friction and prevent slippage when braking forces are applied to the system. Therefore, the second recommendation would be **to develope a system that can control a number of different actuators such as stepping motors.**

Microprocessor units (single board computers) would be used to monitor and control the variables for the actual Cable Conveyor System. These microprocessors would need to monitor and control the variables of one or several towers. All microprocessors would be required to not only communicate with each other but also transmit data to a master computer when requested. Thus the final recommendation for this project would be **to develop a system that can be synchronized with other microprocessors.**

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APPENDICES

APPENDIX A: EQUIPMENT SPECIFICATIONS

I. Computer Control Subsystem:

a) Microcomputer (AT&T 6300):

- 8086 Microprocessor (8MHz clock speed)
- 640 K Hard disk memory
- 1 RS-232 Serial port
- 1 Centronics parallel port
- 1 360 K Double sided/double density drive
- 1 Video display
- 6 Expansion slots

b) A/D (Analog to Digital) converter board (8 Channel high speed A/D converter and timer counter interface, Model DASH-8):

- 8 A/D channels with 12 bit resolution
- 4000 samples/s A/D throughput with supplied software
- Hardware supports 30000 samples/s in assembly language
- Programable scan rate
- Foreground/Background operation
- 7 bits of digital I/O (4 outputs, 3 inputs)
- Interrupt handling
- Event, period, pulse width, and frequency counting
- Software included (graphics, calibration, installation, linearization, I/O driver)
- Precision 10 volts reference output
- +/-12 and +5 volt power from IBM PC/XT
- Accessories-screw terminal and expansion to 128

channels

c) Stepping Motor (Hurst Four Phase Stepping Motor):

- Linear actuator with a threaded shaft (7 threads per centimeter and 48 steps per revolution)

- Step angle of 7.5 and 15 degrees

d) Stepping Motor Controller Chip (Hurst "Stepping Motor Controller):

- Supply voltage,
  $+V_{in}$ (Terminal 18) to COMMON (Terminal 17): 6-24V

- Logic supply,
  V_1(in circuit regulator): +5 VDC

- Operating temperature range 0-70 C

- Phase driver, open collector transistors (Terminals 7,8,9 and 10)
  I_c max 500 ma
  V_{CEO} max 80 V

- RUN, JOG, CW/CCW, and DISABLE inputs (Terminals 4,5,6 and 10)
  Input voltage range -.5 to +5.5 V
  Max. current sinking required for logic 0: 0.5 ma
  Min. input pulse width 1.0 µsec

- PULSE IN input (Terminal 16)
  Input voltage range -.5 to 5.5 V
  Min. input pulse width 1.0 µsec

- PULSE OUT and <u>PULSE</u> <u>OUT</u> (Terminals 19 & 20)
  Min. sink or source current 0.36 ma
  Typical sink or source current @ 25 C 1.0 ma

- Timing components:
  Internal timing resistor (Terminal 2) 10 KΩ
  External timing resistor
    Min. value 0 Ω
    Max. value 1 MΩ

- External timing capacitor (non-polarized, low leakage type recommended)
  Min. value 1000 pf

- Typical pulse period with external R and C
  RUN mode 4.40 RC sec

JOG mode 2.48 RC sec

- Also see next page stepping motor and controller chip Block diagram and switching sequence.

e) Pressure Transducer (Figure 12):

- BLH general purpose pressure cell (GP and GP-H models) for measurement of fluid pressures.

- Pressure range of 15-100 psi

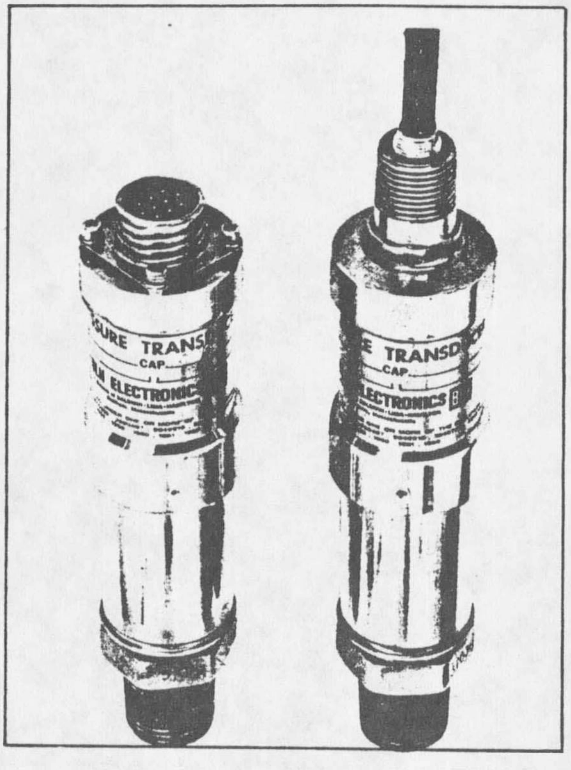

Figure 12: GP, GP-H Pressure Cells

f) Strip Chart Recorder (HP 7404A Oscillographic Recorder):

- Number of channels - Four analog channels. Four event markers, one with timer (All event markers are standard).

- Chart description - 40 mm wide channels with 50 divisions full scale. Time lines every 1 mm.