Fermi National Accelerator Laboratory

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Coil Measurement Data Acquisition and Curing Press Control System for SSC Dipole Magnet Coils *

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COIL MEASUREMENT DATA ACQUISITION AND CURING PRESS CONTROL SYSTEM FOR SSC DIPOLE MAGNET COILS

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ABSTRACT

A coil matching program, similar in theory to the methods used to match Tevatron coils, is being developed at Fermilab. Modulus of elasticity and absolute coil size will be determined at 18-inch intervals along the coils while in the coil curing press immediately following the curing process. A data acquisition system is under construction to automatically acquire and manage the large quantities of data that result. Data files will be transferred to Fermilab's VAX Cluster for long term storage and actual coil matching. The data acquisition system will also provide the control algorithm for the curing press hydraulic system. A description of the SSC Curing Press Data Acquisition and Controls System will be reported.

INTRODUCTION

Members of Fermilab's Technical Support Section are now involved in the design and construction of a combined development laboratory and production facility for the SSC 17 Meter Dipole Magnet. The facility, located in Fermilab's Industrial Center Building, will include a coil winder, a curing press, a collaring press, and a yoke and skinning press. The design of production tooling for the SSC Dipole is largely being based on experience gained during magnet development and production for Fermilab's superconducting synchrotron, the Tevatron. The facility will feature automatic control and data acquisition for virtually all processes. From a control and data acquisition standpoint, the curing press process has proved to be the most complex and problematic. This paper will present and discuss the data acquisition and control solution which we have designed to operate the SSC Curing Press.

The Curing Process

The Superconducting Super Collider will require the production of 8,000 dipole magnets. (See Figures 1 and 2.) Each dipole will require two inner and two outer coils. Therefore, the SSC will require the production of approximately 32,000 superconducting coils, each 16.6 meters in length.

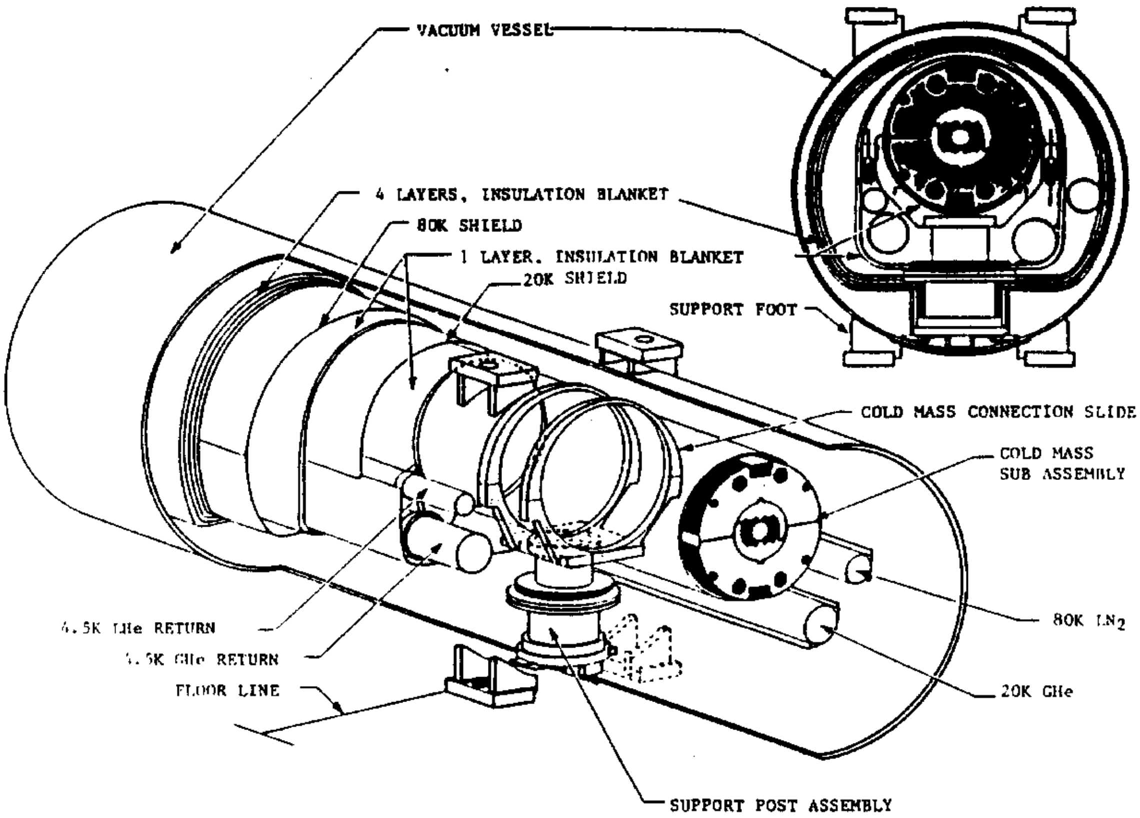


Fig. 1 SSC DIPOLE

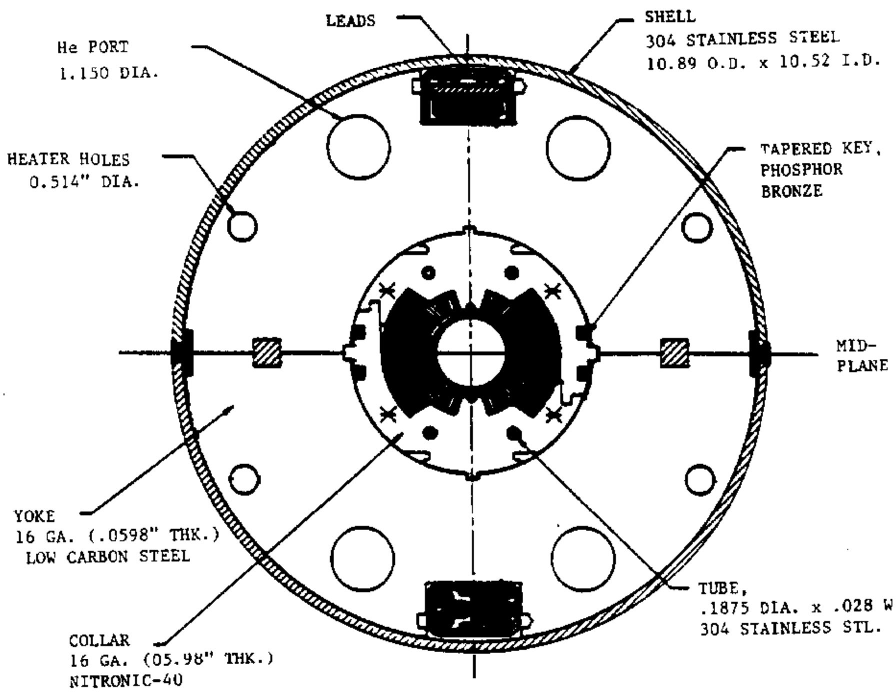


Fig. 2 SSC DIPOLE CROSS SECTION

Inner and outer dipole coils will be produced in a similar manner. Basically, the coil will be wound on a mandrel from a stock of superconducting cable. (See Figure 3.) The superconducting cable will have been previously insulated and wrapped with epoxy impregnated, thermal setting tape. After the winding process has been completed, the coil is ready to be cured.

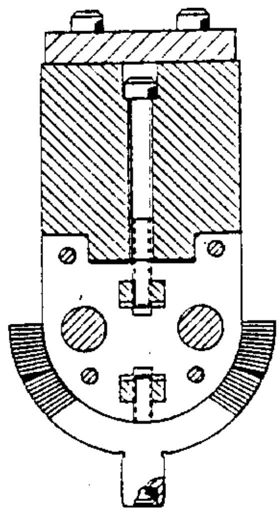


Fig. 3 COIL IS WOUND ON A MANDREL

During the curing process, the coil is confined at high pressure in a precision mold. The curing process bonds the superconducting cable wraps together and forms the coil into a unified structure. To cure the coil, the coil and mandrel will be assembled into the curing tooling. (See Figures 4 and 5.) The curing tooling assembly, which contains the coil, is placed in the curing press. (See Figure 6.) The press is brought to bear on the curing tooling which loads the coil. The tooling is heated to approximately 250 degrees farenheit causing the epoxy to polymerize. After a sufficient period of time has passed to insure that the epoxy has been thoroughly cured, the tooling is cooled. At this point, a superconducting coil has been cured and in theory is ready for the collaring process. In practice, the situation is not so simple.

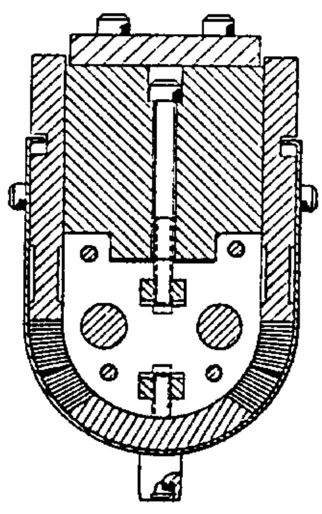


Fig. 4 COIL ASSEMBLY WITH SIZING BARS AND RETAINER

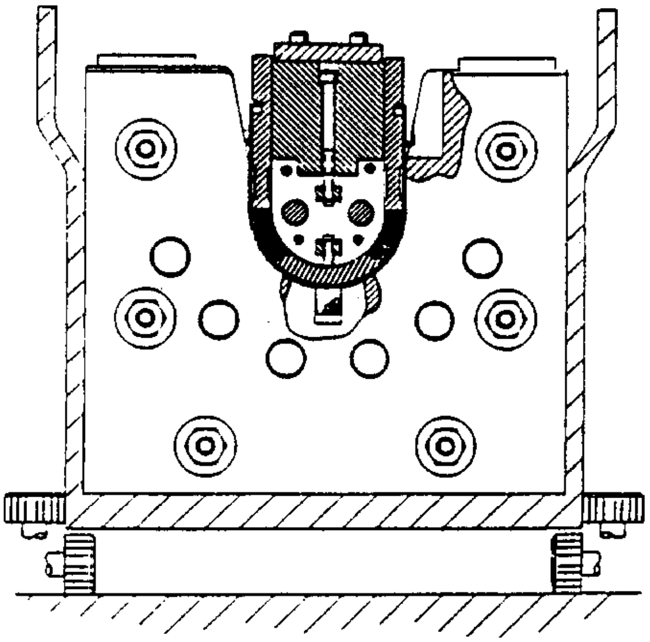


Fig. 5 COIL ASSEMBLED INTO TOOLING

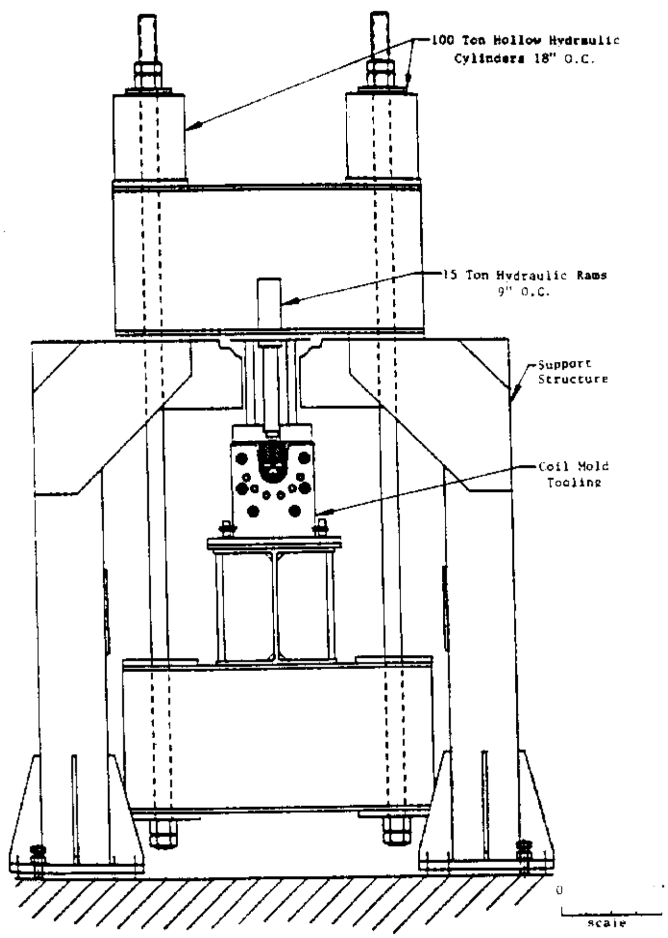


Fig. 6 THE SSC CURING PRESS

Parting Plane Offset and Coil Matching

The SSC dipole magnet will be constructed by collaring two sets of inner and outer coils together. (See Figures 7, 8 and 9.) The collaring process forces the coils together and maintains sufficient load upon the coils to help insure a stable geometry under full field excitation. Unless the two sets of coils are matched in terms of absolute size and modulus of elasticity, upon collaring, the planes of contact between the coils will part from the horizontal dividing plane of the free state. (See Figure 10.) As this "parting plane" increases, so does the harmonic energy of the magnetic field. Low harmonic energy is a figure of merit for a dipole magnet.

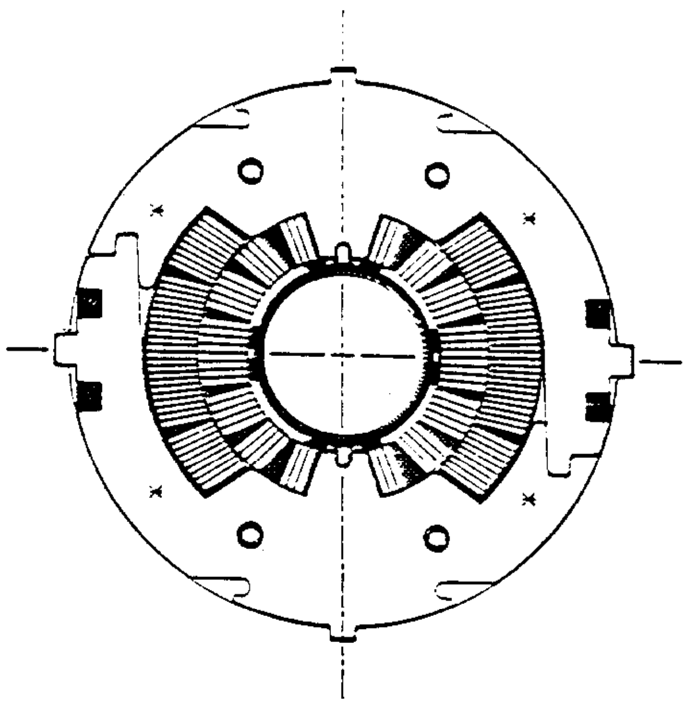


Fig. 7 COLLARED COIL ASSEMBLY

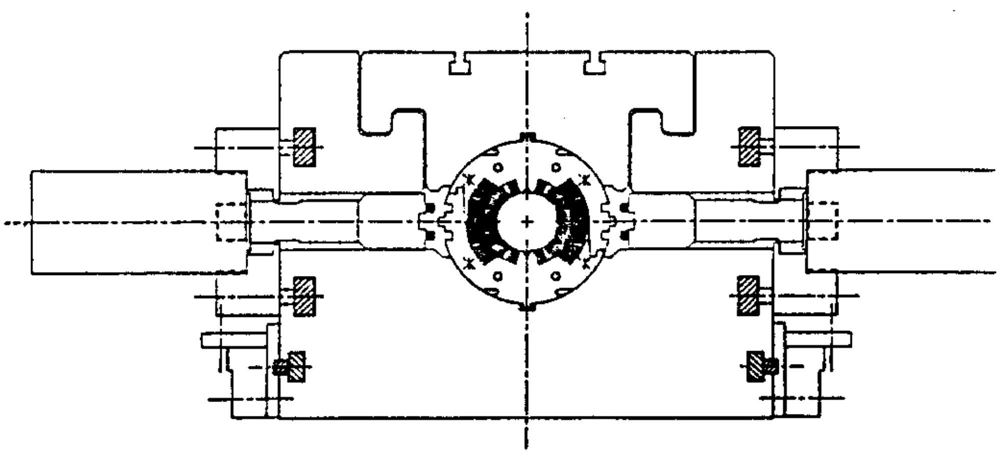


Fig. 8 COLLARING TOOLING

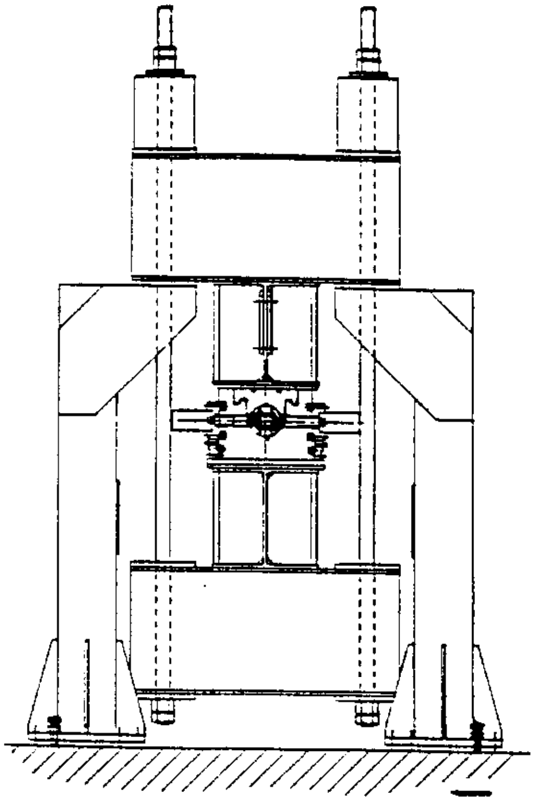


Fig. 9 COLLARING PRESS

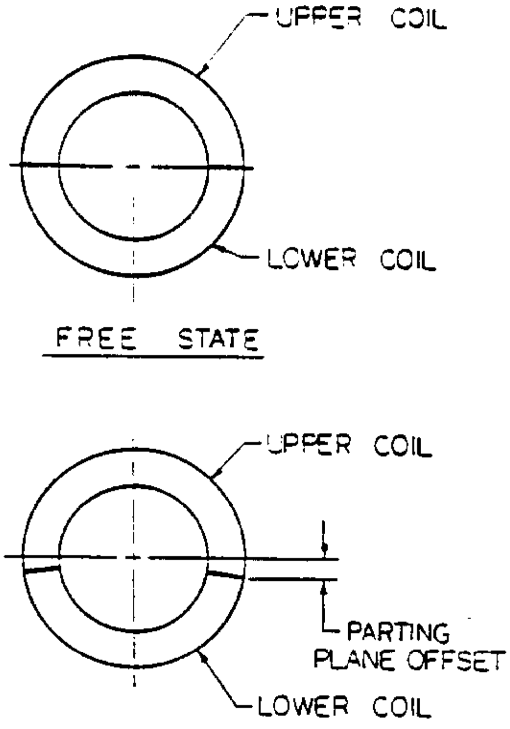


Fig. 10 PARTING PLANE ILLUSTRATION

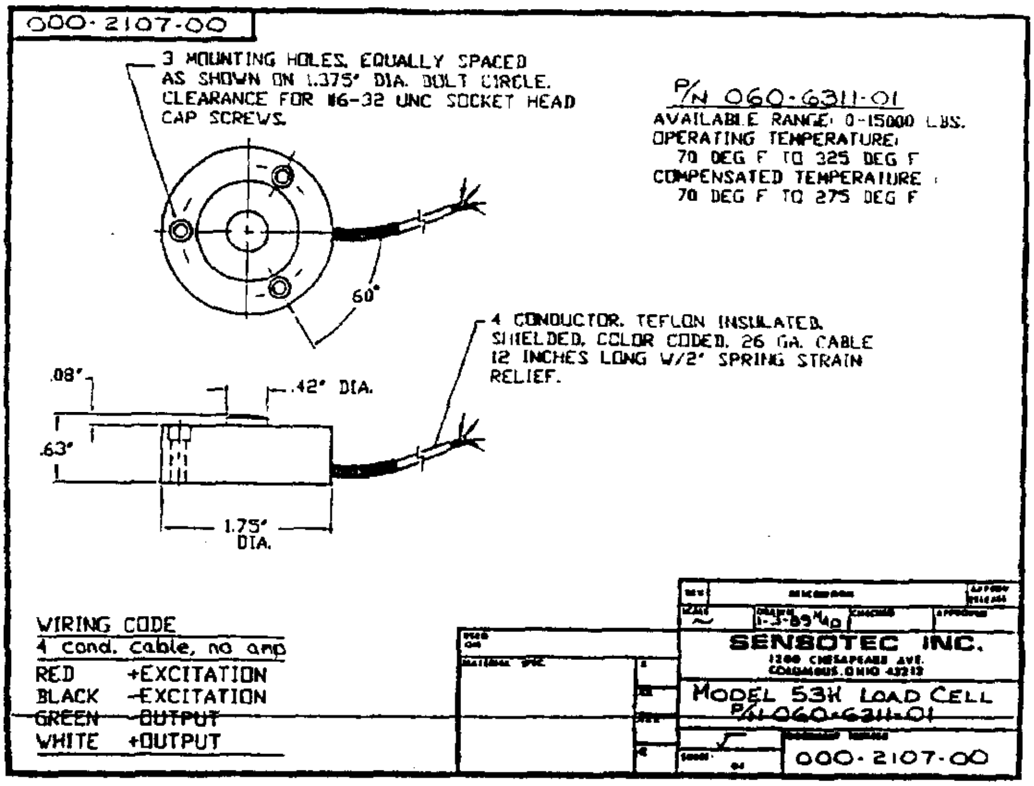
In the past there have been two successful methods used to minimize the parting plane offset. These techniques involve "matching" coils to form collaring sets. The first method involves generous amounts of "artistic ability". Basically, the absolute size and modulus of elasticity for two coils are measured. Then, using the measured data and previously acquired curing press experience, one of the coils can be recured to match the other. This technique is especially difficult since the recuring process changes both the size and modulus of the coil simultaneously. Considering the generous amounts of time and experience needed for the "artistic method", it is difficult to imagine successfully matching 32,000 coils in this manner.

The second method calls for a number of coils to be produced as uniformly as possible. Absolute size and modulus of elasticity data will be compiled for each coil. Coils will be matched into collaring sets. This method might be called the "statistical method" since it is expected that many matchable coils will be produced in a large population of sufficiently narrow distribution. As previously discussed, the SSC Dipole Project will require that a large number of coils be manufactured. In addition, Tevatron coil production experience indicates that coils can be produced in a sufficiently narrow distribution of absolute size and elastic moduli to insure that "statistical matching" will not be difficult.

CURING PRESS DATA ACQUISITION AND CONTROL

Statistical matching requires that large quantities of coil data be acquired, stored and compared. In fact, it is expected that each coil will be characterized by more than 18,000 pieces of information. Obviously, coil information should be automatically acquired, processed and stored. Traditionally, the acquisition of coil data has taken place after the coil has been cured and removed from the curing assembly. However, there are advantages to acquiring coil data immediately after the curing process while the cooled coil remains assembled into the press. First, if data acquisition takes place within the curing press, a step in the production process will be eliminated. Not only will time be saved, but the coil will not have to be handled as often. Secondly, to acquire coil data using the curing press itself will require that the curing press be fully instrumented and automatically controlled. If the curing press instrumentation and control system could be designed to work at 250 degrees farenheit, we not only have the ability to automatically acquire data from a cooled cured coil, but for the first time we also may observe and control the curing process itself. We may be able to better control the coil's size and elastic modulus. It is possible that a "smart" curing press will enable the band of coil distribution to be narrowed and thus increase the frequency of matchable coils. Therefore, we believe that performing data acquisition within the curing press will lead to more efficient production of better dipoles.

Modulus of elasticity is the relationship between applied stress and resultant strain. To obtain modulus of elasticity information with the curing press, the press instrumentation and control system must be able to apply known stresses to the coil and determine the associated resultant strains. A "load cell" is a device, usually strain gauge bridge based, which can be used to readback applied stress. Figure 11 illustrates the load cell which has been developed to provide stress readback for the curing press. This load cell is basically a standard Sensotec Model 53 which has been modified to provide temperature compensated output up to 275 degrees farenheit, easy mounting in the curing press and 15,000 lbs. of load sensing in a small package which possesses a 50% overload margin. The Sensotec Model 53H is a strain gauge transducer using a 350 ohm full bridge electrical configuration.



Strain readback will be accomplished using a device known as a "DC gage head". A DC gage head is basically an AC linear variable differential transformer (LVDT) which has been built into a hermetically sealed package and provided with a spring return indicator shaft. In addition, the DC gage head includes a hybrid circuit which provides AC excitation for the internal LVDT and signal conditioning of the LVDT secondary signals to provide a linear DC output. The hybrid eliminates much of the external circuit complexity typically associated with LVDT's. Figure 12 shows the Schaevitz Model GCD-121-250 DC gage head which has been selected for use in the curing press. The gage head system will also be used to determine the absolute size of the coils. The absolute coil size will be established by taking gage head readings at full press loading while the upper press block is in contact with the specific tooling. As the load is caused to diminish, the upper press and the specific tooling seperate. The difference between the gage head readings at full load and at zero load will determine the absolute size of the coil.

schaevitz

609/662-8000

Precision

GC/GP Series

SPECIFICATIONS BY MODEL

AC-Operated Units (2.5 kHz)

Model Number	GCA-121-050 GPA-121-050	GCA-121-125 GPA-121-125	GCA-121-250 GPA-121-250	GCA-121-500 GPA-121-500	GCA-121-1000 GPA-121-1000
Gaging Range	±0.050" (±1.27 mm)	±0.125" (±3.17 mm)	±0.250" (±6.35 mm)	±0.500" (±12.7 mm)	±1.000" (±25.4 mm)
Phase Shift (Degrees)	+6	+5	+5	+2	+1
Sensitivity (mV/0.001"/V Input)	5.0	2.4	1.7	1.1	0.9
Impedance (Ohms)					
Primary	430	1710	800	900	900
Secondary	950	1820	940	1150	2100
Pretravel (Nominal)	0.26" (6.6 mm)	0.30" (7.6 mm)	0.06" (1.5 mm)	0.18" (4.5 mm)	0.01" (0.25 mm)
Minimum Overtravel	0.15" (3.81 mm)	0.15" (3.9 mm)	0.15" (3.8 mm)	0.90" (22.8 mm)	0.10" (2.5 mm)
Spring Load Over Gaging Range	3.5 to 5.8 oz. (99 to 164g)	3.5 to 5.8 oz. (99 to 164g)	3.5 to 5.8 oz. (99 to 164g)	3.2 to 8.0 oz. (91 to 227g)	3.2 to 8.0 oz. (91 to 227g)
Dimensions					
A (±0.01"/0.25 mm)	1.70" (43.1 mm)	2.55" (64.7 mm)	3.41" (86.6 mm)	5.09" (129 mm)	7.35" (187 mm)
B (±0.03"/0.76 mm)	4.33" (109 mm)	5.14" (130 mm)	6.10" (154 mm)	10.75" (273 mm)	13.01" (330 mm)
C (±0.02"/0.50 mm)	3.27" (83 mm)	4.12" (104.6 mm)	4.99" (126 mm)	8.27" (210 mm)	10.53" (267 mm)
Weight	2.2 oz. (64g)	2.9 oz. (85g)	3.17 oz. (90g)	5.0 oz. (142g)	7.5 oz. (213g)

DC-Operated Units

Model Number	GCD-121-050 GPD-121-050	GCD-121-125 GPD-121-125	GCD-121-250 GPD-121-250	GCD-121-500 GPD-121-500	GCD-121-1000 GPD-121-1000
Gaging Range	±0.050" (±1.27 mm)	±0.125" (±3.17 mm)	±0.250" (±6.35 mm)	±0.500" (±12.7 mm)	±1.000" (±25.4 mm)
Sensitivity (mV/0.001"/V input)	200	80	40	20	10
Pretravel (Nominal)	0.30" (7.62 mm)	0.35" (8.8 mm)	0.18" (4.5 mm)	0.20" (5.08 mm)	0.10" (2.5 mm)
Minimum Overtravel	0.39" (9.4 mm)	0.14" (3.5 mm)	0.03" (0.76 mm)	1.00" (25.4 mm)	0.10" (2.5 mm)
Spring Load Over Gaging Range	3.5 to 5.8 oz. (99 to 164g	3.5 to 5.8 oz. (99 to 164g)	3.5 to 5.8 oz. (99 to 164g)	3.2 to 8.0 oz. (91 to 227g)	3.2 to 8.0 oz. (91 to 227g)
Dimensions					
A (±0.01"/0.35 mm)	2.46" (62.5 mm)	3.30" (83.8 mm)	4.17" (105.9 mm)	5.86" (148.8 mm)	8.11" (205 mm)
B (±0.03"/0.76 mm)	5.08" (129 mm)	5.90" (149.8 mm)	6.77" (171.9 mm)	11.53" (292.86 mm)	13.76" (349 mm)
C (±0.02"/0.50 mm)	4.02" (102 mm)	4.87" (123.6 mm)	5.74" (145.7 mm)	9.05" (229.8 mm)	11.29" (286 mm)
Weight	2.5 oz. (71g)	3.2 oz. (93g)	3.5 oz. (100g)	5.5 oz. (156g)	8.0 oz. (227g)

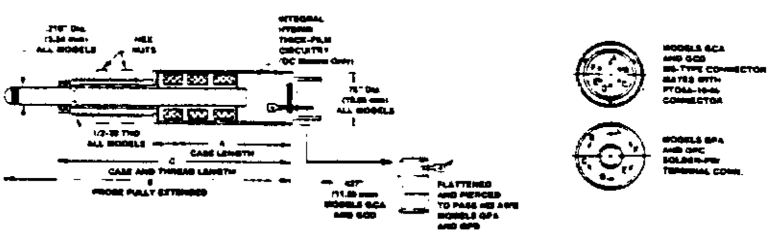


Fig. 12 SCHAEVITZ MODEL GCD-121-250 DC GAGE HEAD

Figure 13 illustrates the relative positions of the curing press gage heads and load cells. Gage heads will be located outside the tooling. A convective boundary layer flow exists along the outer tooling surfaces. This vertical flow will keep the gage heads cool. The load cells will be located in the 1.5 inch thick steel upper press block assembly and positioned to contact the sizing bars which directly load the coil. (See Figure 4.) The sizing bars will be decoupled to isolate the load cell from sizing bar side effects. (See Figure 14.) A total of 150 gage heads and 150 load cells will be distributed at 18 inch intervals along both sides of the full coil length.

The gage head system has been designed to permit automatic calibration. Gage heads will be assembled onto the press in positions which are "close" to the perfect positions. Full open and full closed position readbacks will be obtained and the computer will establish the calibration. The load cells will be calibrated using a fixture shown in Figure 15. A small hydraulic cylinder will be mounted on a base and connected to a Lebow high accuracy load cell. The cylinder will be energized and caused to load individual Sensotec load cells, installed into the upper press block, through the Lebow load cell. The outputs of both load cells will be compared by the computer and calibration will be determined. The Lebow load cell will serve as the calibration standard.

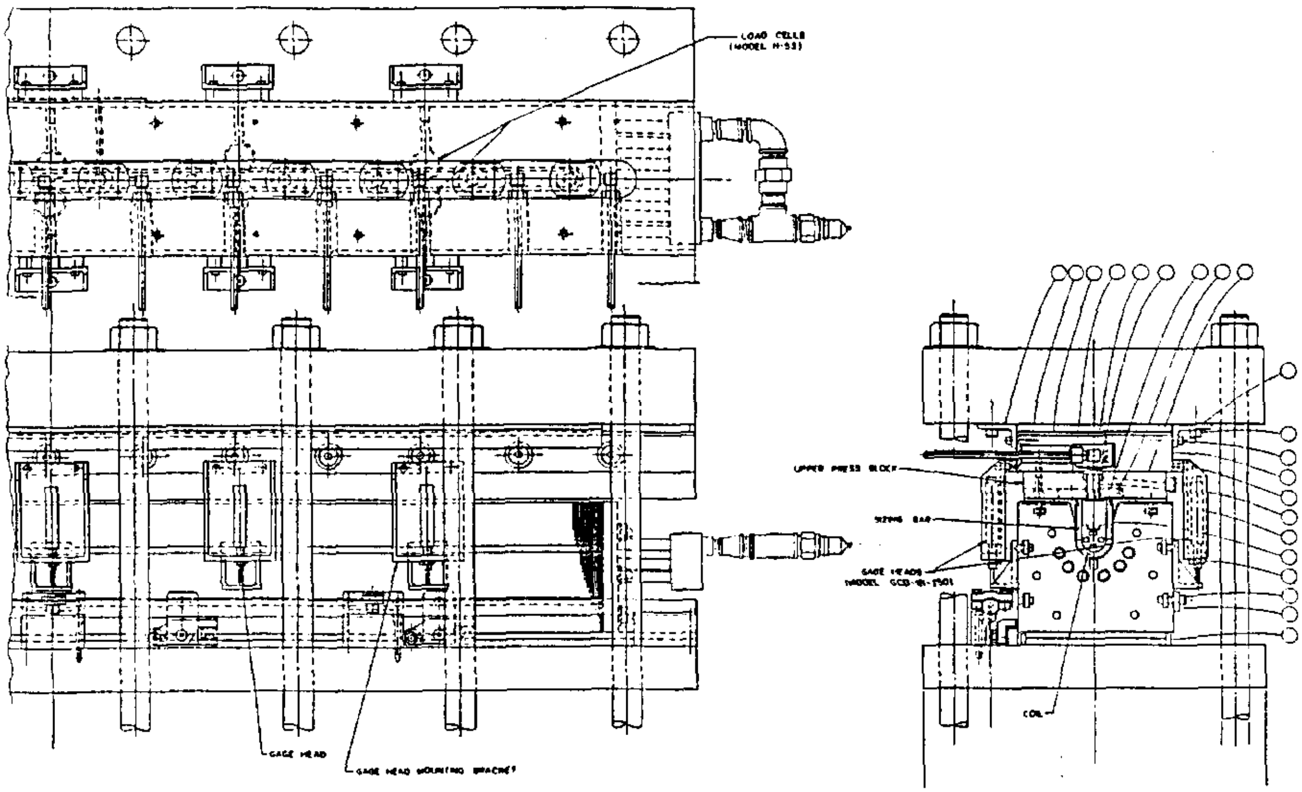


Fig. 13 GAGE HEAD AND LOAD CELL LOCATIONS

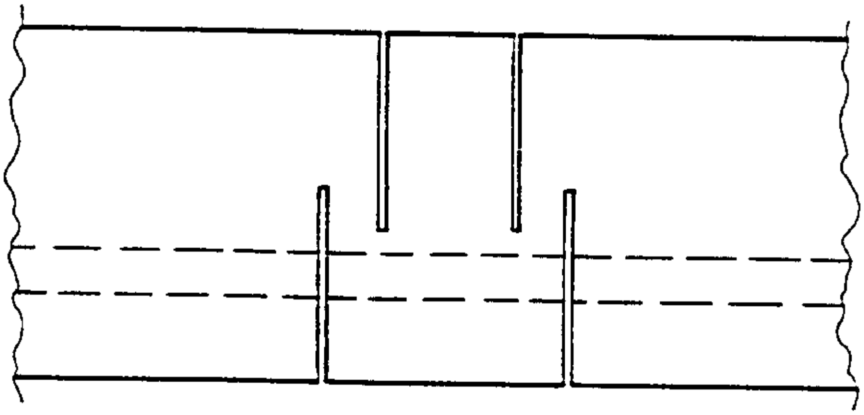


Fig. 14 DECOUPLED SIZING BAR

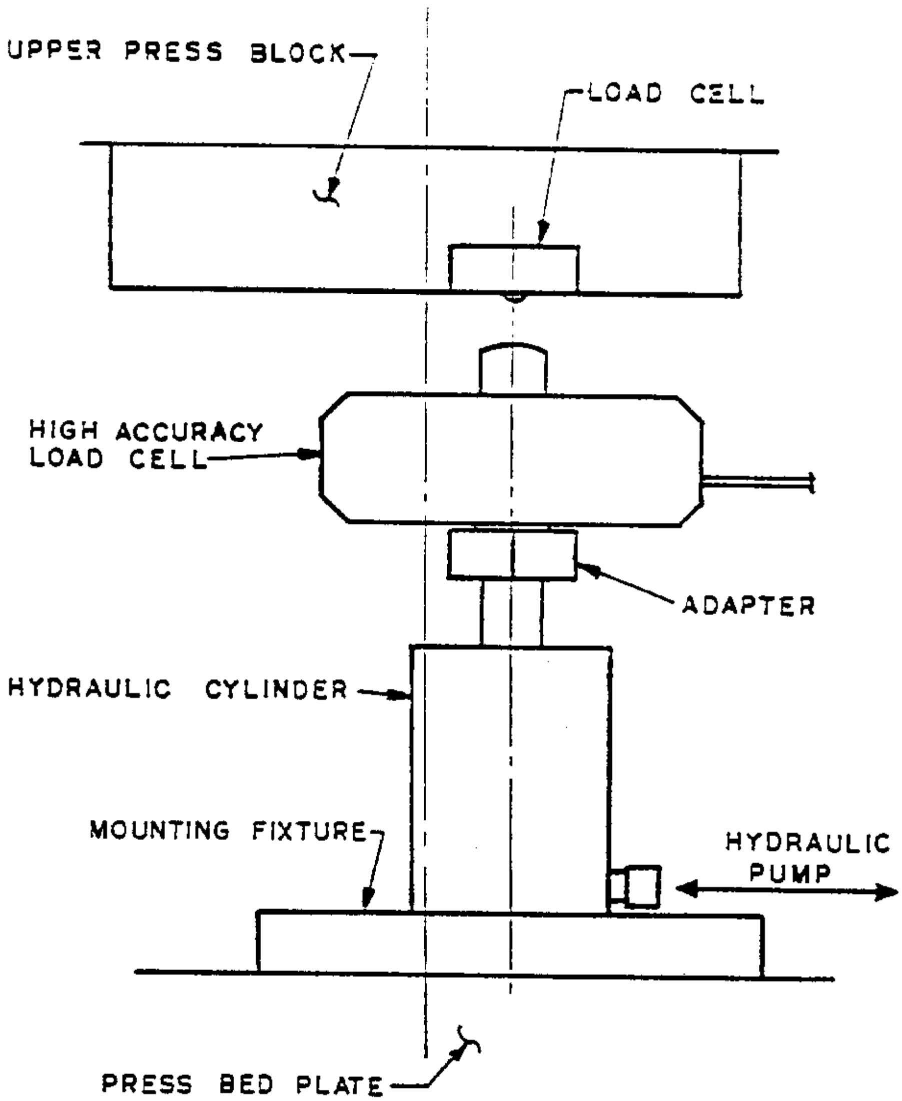


Fig. 15 LOAD CELL CALIBRATION FIXTURE

It is important to note that the instrumentation layout illustrated in Figure 13 includes no instrumentation in the specific tooling. The instrumentation will be assembled into the curing press and calibrated. Specific tooling can be moved in and out of the curing press without affecting the instrumentation. Removing the instrumentation from the production process should decrease assembly time and increase instrumentation accuracy and reliability.

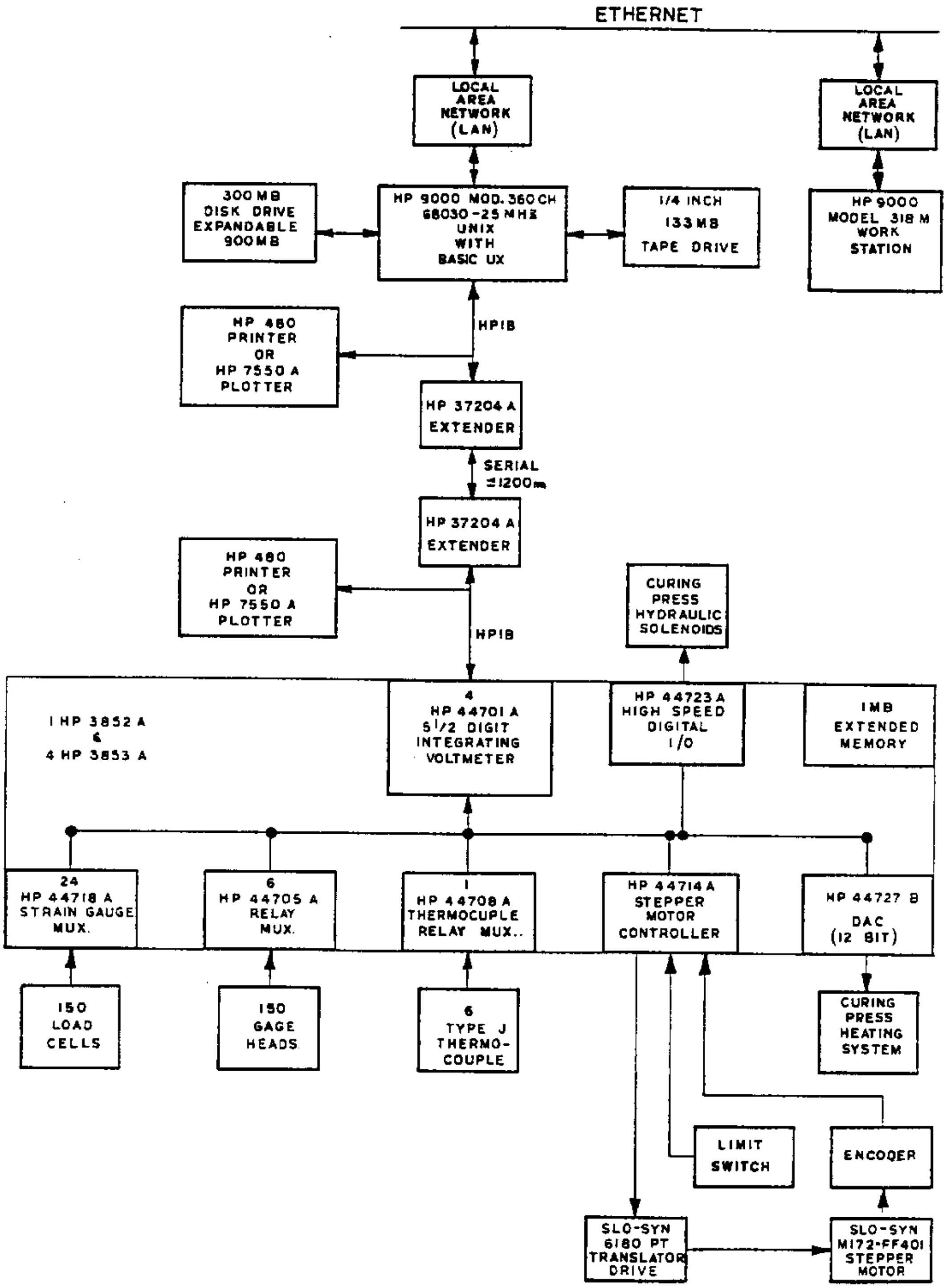
The curing press will include over 300 instrumentation transducers. Stress and strain measurements will be obtained for ten increasing and ten decreasing stresses per measurement cycle. Three measurement cycles will be performed per coil. Therefore, more than 18,000 measurements will be required to characterize each coil.

After careful consideration, the Hewlett Packard 3852A Data Acquisition and Control System was selected to control the press, perform the necessary measurements, process the data and route the information for storage in Fermilab's VAX system. The HP3852A supports modules to measure and condition the load cell strain gauges, measure gage heads, measure coil resistance during the curing process, measure and compensate thermocouples for temperature readback and control, and provide digital I/O, DAC output, and stepper motor control.

Figure 16 shows the overall data acquisition and control system for the SSC Curing Press. Basically, strain gauge, voltage, and thermocouple multiplexers reside in the HP3852A Data Acquisition and Control Mainframe or the HP3853A Extender Chassis. These multiplexers feed into HP44701A 5 1/2 digit integrating voltmeters. The HP3852A's send information over IEEE 488 (HP-IB) to HP37204A extenders. The extenders permit data to be sent up to 1200 meters to the HP360CH control computer. The computer, tape drive, disc drives, printer and plotter will be housed in a remote location which is isolated from the industrial environment. The HP360CH uses the MC68030 microprocessor running at 25MHz. Control software will be developed using HP BASIC UX. A local area network (LAN) is being established to permit communication over ETHERNET via a THINLINE. This system will permit communication with the curing press operating system from remote terminals.

The majority of controls problems that have been encountered concern control of the hydraulic system of the press. The control system must permit proper valve sequencing and hydraulic pressure regulation up to 10,000 psi. Figure 17 is a schematic layout of the curing press hydraulics. Figure 18 shows the typical control arrangement for the various hydraulic valve solenoids. Basically, common collector digital signals from a HP44723A High Speed Digital I/O Module will control solid state relays, which in turn place 115 VAC power on selected valve solenoids. (See Figure 16.)

SSC CURING PRESS
DATA ACQUISITION AND CONTROL SYSTEM



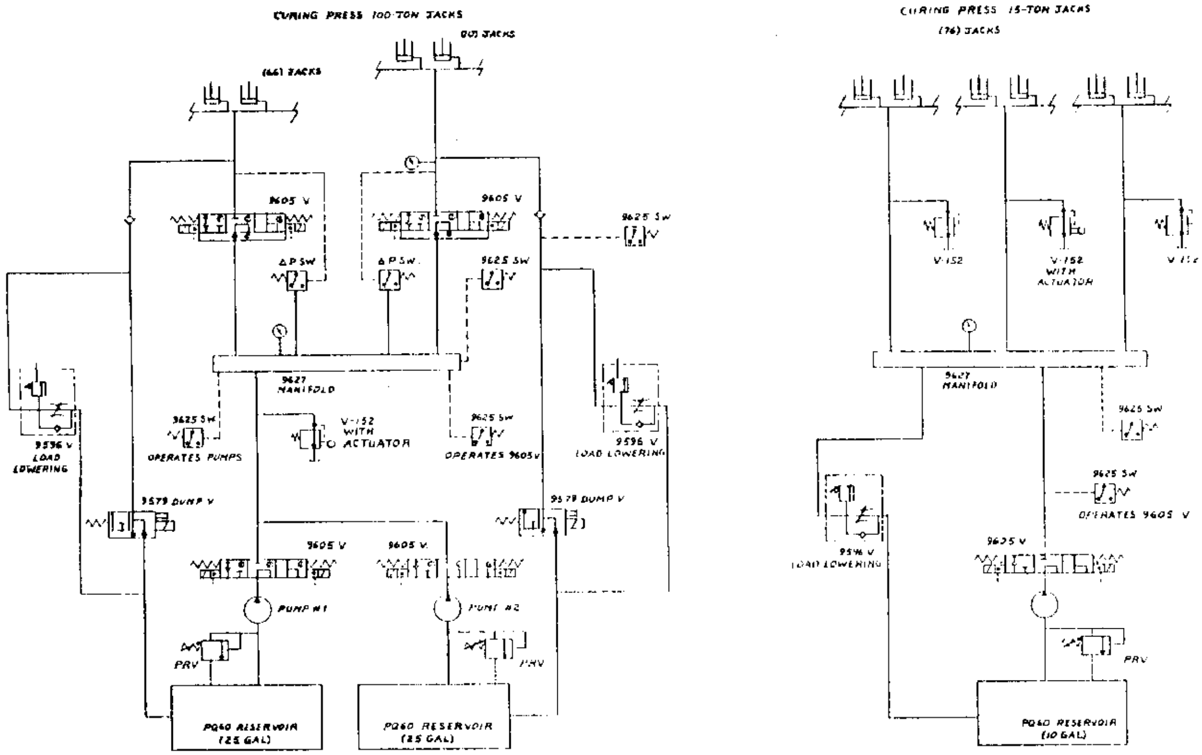


Fig. 17 SSC CURING PRESS HYDRAULICS

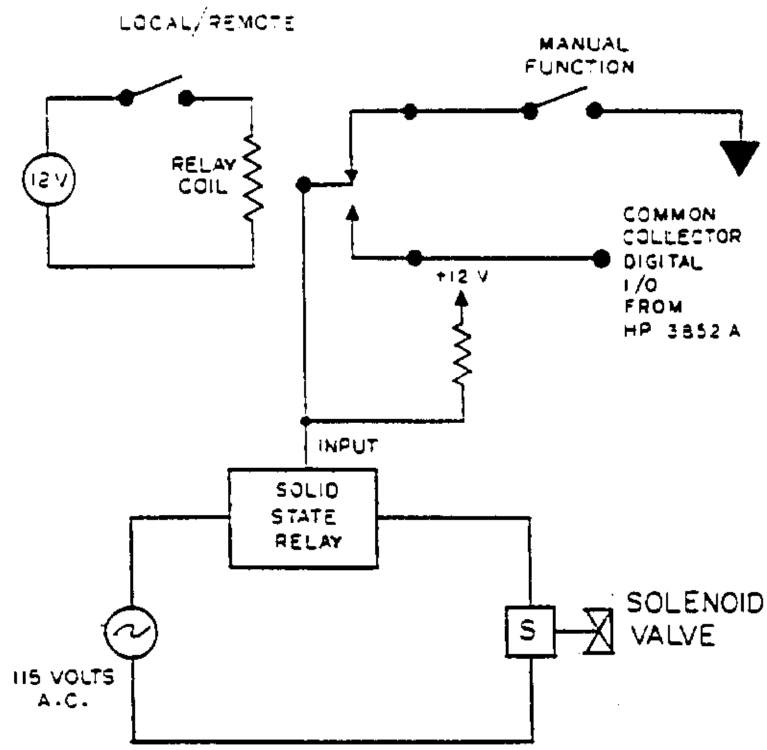


Fig. 18 TYPICAL SOLENOID CONTROL

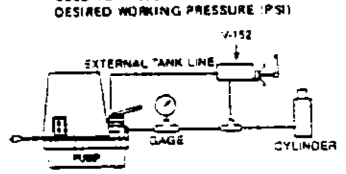
In the past, hydraulic pressure has been regulated manually using the Enerpac V-152 Pressure Control Valve. (See Figure 19.) However, for efficient data acquisition, hydraulic pressure must be automatically controlled. A number of valve/actuator systems were investigated. None of the systems could provide pressure control at 10,000 psi. Studies were performed that indicate that the Enerpac V-152 valve displays highly repeatable pressure regulation with respect to the rotational position of the valve spring loading screw. Consequently, this points to the possibility of pressure regulation by controlling the valve's position. Figure 20 is a drawing of the valve actuator which has been designed to position the pressure control valve. A high power stepping motor supplies torque to the pressure control valve. Due to the design of the valve, a spline coupling is needed to take up the linear motion of the valve's loading screw. A limit switch carriage has been incorporated into the design to electrically indicate the valve's full open limit and full closed limit. Ball bearings, recirculating ball screws and splines have been used throughout the design to insure low friction. An optical encoder is used to provide position feedback. The system will provide 4800 discrete regulation points between the full open and full closed valve positions. The actuator will be controlled using a HP44714A Stepper Motor Control Module, which will be located in the HP3852A Mainframe. The HP Stepper Motor Control Module will feed into a Superior Electric 6180-PT Translator Drive. The Translator Drive decodes the pulsed trapazoidal motion profile output of the HP44714A, amplifies the signals and directs the power pulses to the SLO-SYN M172-FF401 stepper motor. Figure 16 shows the actuator control system.

VALVE OPERATION

System pressure is applied to the piston (C). The hydraulic pressure on piston (C) will act against the two inch compression spring (B) and lift the cone off the seat so that the oil flows thru orifice (A) to tank. The oil passes thru the orifice until the oil pressure is equal to the compressive force from the bias spring. At that time the cone will move upon the seat, and the process repeats this cycle over again. Just enough oil from the system is allowed to pass thru the orifice to tank which will maintain the system pressure as set by the relief valve.

VALVE FUNCTION

V-152 RELIEF VALVE serves the purpose of limiting the pressure developed by the pump in a hydraulic circuit, thus limiting the load that may be developed or imposed upon other components. To increase setting, turn the handle clockwise.



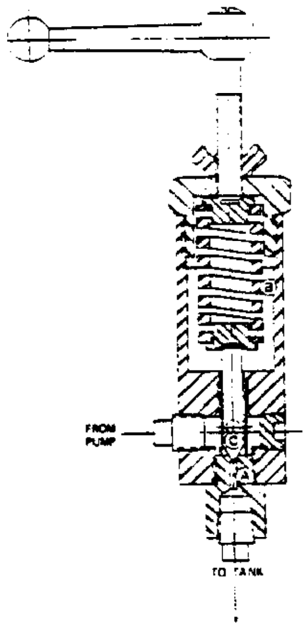


Fig. 19 ENERPAC V-152 VALVE

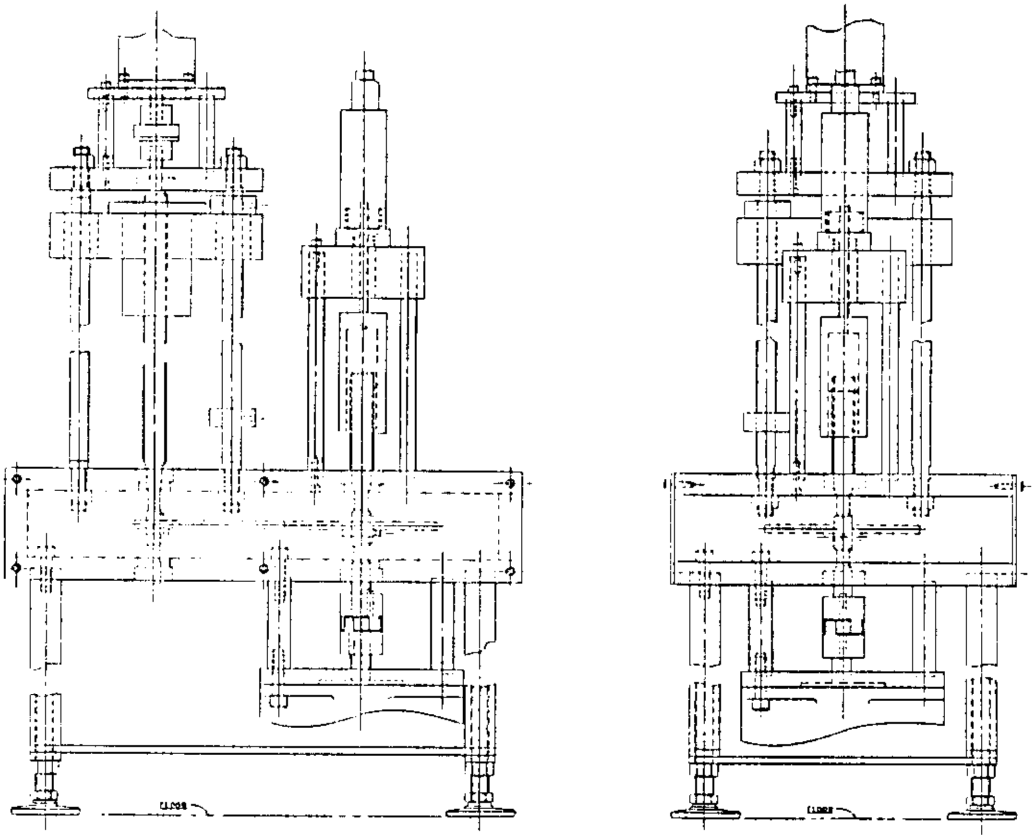


Fig. 20 HYDRAULIC SYSTEM ACTUATOR

CONCLUSION

Construction of the SSC Dipole Factory at Fermilab is well underway. Computer control and data acquisition are being designed into many of the production processes. We are enthusiastically looking forward to the development of the SSC Dipole.