AEDC-TDR-62-96

A PRESSURE DATA SYSTEM FOR A 50-IN. CONTINUOUS MACH 8 WIND TUNNEL

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May 1962

ARO Project No. 633036

ABSTRACT

This report is a description of a pressure data system designed and built for use with a 50-inch, continuous, Mach 8 wind tunnel. The system is basically a nine-channel system, with a capacity for 99 model pressure ports. Three ranges and seven reference pressure levels are employed to provide an extended pressure level coverage, while maintaining low-level sensitivity.

Control circuits are employed to automatically select the proper range and reference level for each pressure measurement, and to simplify calibration procedures.

A description of the measuring and control systems components is included, along with a section on the operation of the control system.

The report is concluded with an evaluation of the pressure data system, based on a two-year period of operation.

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ILLUSTRATIONS

1.0 INTRODUCTION

Wind tunnel tests to determine the aerodynamic characteristics of a particular model configuration usually require the measurement of pressures at many points on the surface of the model. Moreover, these pressure measurements must be repeated for various attitudes of flight. There are a number of approaches to problems of obtaining accurate pressure data from wind tunnel models. This report describes a pressure data system that has been in use with a 50-inch, continuous, Mach 8 wind tunnel at the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), for the past two years.

1.1 PERFORMANCE REQUIREMENTS

The requirements of a general purpose pressure data system for a continuous hypersonic wind tunnel are somewhat rigorous. First, capacity for measuring a multitude of model pressures for any one test entry is one basic requirement. Second, the system must be capable of operating over a comparatively wide range of absolute measurements, with accuracies consistent with the present state of the art. For example, a particular test may require readings ranging from 0.05 psia to 15 psia, with accuracies on the order of 0.2 percent of reading. Some model entries may require measurements greater than 15 psia. Third, the pressure readings must be acceptable as inputs to an electronic computer.

The first requirement can be met in either one of two ways. A separate channel can be provided for each model pressure port to be measured or a channel can be time-shared with a number of model ports. For obvious reasons, if the system capacity is to be large, the first approach is not practical. Therefore, the second approach was chosen for this system. Nine identical channels are employed, each equipped with a twelve-position pressure scanning valve. One position of each pressure scanner is reserved for transducer calibration purposes. Therefore, each channel is capable of sequentially monitoring eleven model pressures, and the total capacity of the system is 99 model pressures.

The second basic requirement can also be approached in more than one way. One approach would be a dual installation; that is,

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Manuscript released by author April 1962.

having one system for measurement of low pressures and a second parallel system for measurement of higher pressures. However, it was desirable in this instance to utilize a single system for all measurements. This has been accomplished by employing a moderate range differential pressure transducer with de-ranging capabilities. The pressure on the reference side of the transducer is varied in semi-fixed increments to greatly extend the overall range of the transducer. How this is accomplished is explained in Section 2.0.

All readings are performed by servopotentiometer instruments. Rotational-to-binary converters are installed on these instruments to provide digital readouts to the computer in straight binary form.

1.2 DESIGN CONSIDERATIONS

In view of the inherent number of operational steps required of a system of this nature, it was more or less mandatory that operation of the system be made as automatic as possible. Several benefits were to be realized by incorporating automatic control of the pressure system. One of prime importance was the significant reduction of operator functions. In addition to a substantial reduction in spurious data due to operator error, the training requirements for operators have been reduced significantly.

Another benefit gained from the automatic control system is a reduction of time required for transducer calibrations. Since this must be accomplished at the beginning of each test run, more time is therefore available for test data acquisition. In designing the pressure system, it was desirable for economic reasons to take advantage of existing equipment wherever possible. Therefore it was decided to start with the components then in use for pressure measurement in this wind tunnel. In some instances, this approach has contributed to the complexity of the system, but with no apparent sacrifice in reliability.

2.0 THE MEASURING SYSTEM

Basically, the measuring system consists of nine identical channels, each capable of reading sequentially eleven model pressures through a Datex model SP-101 12-position pressure scanning valve. The remaining position is used for transducer calibration. The reference side of the tunnel transducer is connected to one of seven reference pressure levels through a second Datex pressure scanning valve. This is a model SP-107 unit and differs from the model SP-101 unit in that it is capable of bi-directional operation. The seven reference pressure levels are connected to similar positions on all nine reference pressure scanning valves through manifolds.

The reference pressures are measured with CEC Electromanometer equipment. These readings are digitized and scanned along with the tunnel transducers. Therefore, the absolute pressure measurement is the sum of the tunnel transducer and the appropriate reference transducer readings.

2.1 SYSTEM BLOCK DIAGRAM

Figure 1 is a simplified block diagram of the measuring system. The first (upper) port of the model pressure scanning valve is used for transducer calibration. As shown in the diagram, full-scale and zero readings can be obtained during calibration by operation of the three-way solenoid valve. A CEC type 6-201 Primary Pressure Standard (air dead weight tester) is used to establish the calibration pressure. This unit has a specified accuracy of 0.015 percent of range and provides a simple means of repeating calibration levels closely. The dead weight tester loading is applied to the computer scanner as a manual input. This input, along with zero and full-scale readings of the nine transducers are scanned by the computer to provide rapid scale factor calculations at the beginning of each test run.

Although not shown in the simplified diagram, means are provided for connecting the air dead weight tester to the reference system to check the scale factor of each reference transducer. This is normally accomplished as part of the calibration procedure.

The solenoid valve is shown in the de-energized position. This configuration permits the use of the calibration port of the pressure scanning valve to check the tunnel transducer zeroes after each pressure scan. The effect of a zero shift that may result from a change in reference pressure level can therefore be nullified.

The nine model pressure scanners are stepped together from a master switch. Each time this switch is advanced, nine new pressures are connected to the tunnel transducers. The appropriate reference level, for each channel is automatically selected by the control system and is applied to the reference side of the transducers through the SP-107 reference pressure scanners. These are special units, capable of bi-directional operation. The reference pressures are connected to these scanners in ascending order. Therefore, a scanner operates in the forward direction to increase the reference pressure on a transducer, and in a reverse direction to decrease the reference pressure.

The computer scanner is operated for each position of the model pressure scanners. The tunnel transducer readings and the reference transducer readings are scanned, along with range and reference indications for each channel as furnished by the control system. This latter information is, of course, necessary for the computation of absolute pressure data.

2.2 SYSTEM COMPONENTS

Each pressure measurement is the sum of two pressure measurements; a differential value and an absolute value. The tunnel transducer measures the difference between the model pressure and the reference level, while the reference transducer measures the absolute values of the reference pressure. A brief description of the components used to obtain the two readings follows.

2.2.1 Model Pressure Measurement

Wiancko type P1701, differential pressure transducers are used for model measurements. These are variable reluctance units and are ideally suited for this application. Their internal volume is low (0.06 cu in.); which is a necessary requirement for minimum equalization times at low pressures. They exhibit excellent de-ranging characteristics and are equipped with overload stops. For normal conditions, ±5 psid units are used and are calibrated for three ranges: 0 to 0.3 psi, 0 to 0.6 psi, and 0 to 1.2 psi full scale. For special tests requiring the measurement of higher than normal pressures, these units are temporarily replaced with ±15 psid transducers.

Since the new pressure must be applied to the transducer before the control system can sense the need for a new reference level, the transducers can experience a momentary overload at times. However a differential pressure of 417 percent of the highest range (1.2 psid) can be applied without exceeding the range of the transducer (5 psid). The transducer overload stops are set at 7.5 psid. By selectively grouping pressure ports in respect to pressure magnitudes, excessive overloads on the transducers can be avoided.

The carrier frequency for these transducers is 3 kc. The transducer output is demodulated to derive a d-c signal. This signal is connected to a Leeds and Northrup Model D indicating servopotentiometer through an external range switching voltage divider. Regardless of the full-scale calibration established by the demodulator sensitivity controls, this voltage divider holds the medium range at one-half the sensitivity of the low range and the high range at one-fourth that of the low range. These fixed ratios are essential for proper operation of the automatic ranging circuitry.

A Coleman Engineering Company rotational-to-binary converter driven by the L and N indicator servomotor provides a 10-bit binary readout to the computer.

2.2.2 Reference Pressure Measurement

Each of the seven reference pressure systems includes a volume tank, solenoid valves for controlling the pressure level, and a CEC type 1-124 Electromanometer for precise pressure readout. The purpose of the volume tank is to reduce reference level upsets resulting from the operation of the reference scanning valves.

Each reference pressure is contained by a sealed system. Therefore, as the reference scanning valves operate, air can be either removed or added to a reference system. For example, a transducer switching to a lower reference will exhaust pressure trapped in its reference chamber into the lower reference system, raising the pressure of this system. The volume tank keeps these pressure variations within acceptable limits.

Since the reference levels must ascend going from reference No. 1 to reference No. 7, several pressure head ranges are employed. A tabulation of ranges appears in the following table.

Reference Instrumentation Ranges and Levels

Reference No.	Pressure Head Range psid	Normal Operating Level psia
1	1	0.1
2	5	2.4
3	5	4.7
4	15	7.0
5	15	9.3
6	15	11.6
7	30	13.9

Reference system No. 1 is quite sensitive to pressure upsets as tunnel transducers are stepped to this reference from reference No. 2. A closed loop control is employed on this reference, utilizing the analog output of the CEC servoamplifier and an auxiliary control amplifier, to maintain this level within acceptable limits. Figure 2 shows how this is accomplished. This control was not necessary on the remaining six reference systems since they are to a large extent self-regulating.

The quoted accuracy of the CEC Electromanometer system is ±0.1 percent linearity and ±0.1 percent hysteresis. Since each reference transducer is operated around one particular pressure level, errors due to non-linearity are insignificant. This equipment also exhibits excellent long-term stability characteristics.

Figure 3 is a photograph of the monitoring equipment associated with this system. The first and third racks contain the L and N servo-potentiometers. The second rack contains the master control unit, Wiancko demodulators, the power supply, and the carrier oscillator. Five of the CEC Electromanometer amplifiers are shown in the fourth rack. The remaining two CEC amplifiers are not shown.

3.0 THE CONTROL SYSTEM

3.1 GENERAL DESCRIPTION

The primary function of the control system is to automatically select the optimum reference pressure and transducer range for each of the nine channels as the pressure scanning valves are advanced from port to port. Since seven reference levels and three ranges are involved, there are 21 possible range-reference combinations. Bi-directional stepping switches, manufactured by General Electric Company, Ltd., Coventry, England, are used for this switching operation. These are 25-point, 8-level switches. In addition to switching the range divider taps and the reference level scanner ports, these switches provide range and reference indications, both to the computer scanner and to the operator.

Figure 4 is a block diagram of the control system. Cam-operated switches in the L and N Model D indicator provide indications for a full scale condition and for readings below 45 percent of full scale. The indicator input circuitry is arranged to provide an upscale reading for both positive and negative readings. A relay contact closure furnishes a negative pressure indication. This signal and the two switch closures mentioned above are used by the master control unit to advance the stepping switch to the proper point. As shown in Fig. 4, there are two feedback loops, one to the range divider network, and one to the reference scanning valve (through its control unit).

Each time the stepping switch is advanced from one point to the next, the range is switched. A change in reference pressure occurs on every third point. Reference pressure levels and ranges are increased as the stepping switch advances in the positive direction, and decreased in the negative direction. If the full scale limit switch in the indicator is closed, a pulsed current is applied to the positive stepping switch coil, causing the channel to advance to a higher range. If the limit switch remains closed on the highest range and the pressure is positive, the stepping switch will advance to the next reference level.

In the above example, had the pressure been negative and full scale on the highest range, the stepping switch would have reversed and stepped back to a lower reference pressure.

If the indicator is reading on one of the upper two ranges and the reading drops below 45 percent of scale, a low limit switch closes, causing the stepping switch to step to a lower range. This insures that the pressures are read on the most sensitive range applicable. In other words, the scale factor most accurate for the particular pressure level is always applied. Of course, no down-switching occurs on the lowest range.

3.2 CONTROL SYSTEM COMPONENTS

3.2.1 Power Supply - Pulse Generator

This unit, in addition to supplying the required a-c and d-c voltages, includes a transistor pulse generator. This generator supplies two pulse outputs, with a repetition rate of 75 per minute. These pulses are separated in time by one-half of the pulse period. For convenience, these pulses are identified as pulse "A" and pulse "B". To minimize the peak load on the stepping switch power supply, the odd-numbered channels are stepped with pulse "A", and the even-number channels are stepped with pulse "B".

The alternate of the stepping pulse to each channel is utilized to set up the reversing action required when the indicator reaches negative full scale on the high range. This action therefore occurs halfway between stepping pulses, eliminating conflicting signals to the stepping switch. Figure 5 shows the power supply chassis.

3.2.2 Master Control Unit

Figure 6 is a photograph of the master control unit panel. This unit provides local indication of ranges and reference levels for each channel. The five position function switch includes automatic and manual modes, plus positions for switching all channels to each of the three ranges. These latter positions are used for calibration purposes.

One function of the reset pushbutton is to place all channels on the lowest range and the lowest reference pressure when the function switch is in the "low" position. The control system is designed to prevent continuous cycling should a failure occur causing the L and N indicator to remain in a full-scale condition. If a stepping switch should advance one point beyond the 21 active points in either direction, an overscale lock-up occurs, suspending further switching action. This condition is cleared (after removal of the cause) by switching from automatic to manual operation and depressing the reset pushbutton.

3.2.3 Stepping Switch Assemblies

Ten plug-in stepping switch assemblies were fabricated as shown in Fig. 7. The extra assembly is a spare to minimize lost time should a switch failure occur during a tunnel test. However, this tenth unit now appears to have been unnecessary, as only one stepping switch malfunction has occurred in the two years that the system has been in use. The nine switch assemblies are plugged into a frame mounted on the rear equipment rack door. This reduces the front panel space requirements and, at the same time, permits accessibility for maintenance.

The stepping switch coils are pulsed through a 2N375 transistor as shown in Fig. 8. Pulses of 50 milliseconds duration are applied through R1 to the base of the transistor. During the interval between pulses, the transistor is reverse-biased by +4 v. dc applied to the base through R2. The switching pulse is present at the base of the transistor at all times, but switching occurs only when an external contact is closed, supplying -50 volts to one of the stepping switch coils.

4.0 OPERATION OF THE SYSTEM

4.1 CALIBRATION

At the beginning of each tunnel run, the tunnel transducers and reference transducers are calibrated. The calibration of the tunnel transducers is described first.

The calibration plumbing is arranged so that reference system number two can be used to supply the calibration pressure to the measuring side of the transducers (see Fig. 9). The CEC air dead weight tester is connected to this reference system at this time. Reference system number one is vented to atmosphere, which vents the reference side of all transducers.

The low range is calibrated first, by placing 0.3 psid in the number two reference tank and adjusting the zero and sensitivity controls on the demodulator. Full scale on the L and N indicator is set at approximately 90 percent of scale. A manual input is used to feed the calibration pressure value to the computer. After the previously mentioned adjustments have been completed, the channel zeroes and full-scale readings are scanned by the computer for low range scale factor computation.

Then the calibration pressure is doubled (0.6 psid), and the function switch is placed in the medium range position. Since a fixed ratio voltage divider is used for range switching, no further demodulator adjustments are required, once the low range is calibrated. Therefore, the medium range end points are scanned for scale factor computation, and then all channels are advanced to the high range. The calibration pressure is again doubled and the procedure is repeated.

After the tunnel transducers are calibrated, the scale factors of the reference transducers are scanned in a similar manner. This is merely a calibration check, since no adjustments of the CEC equipment are normally required. The reference systems are maintained near specific levels during a test run; therefore scale factors for each system are obtained between zero and the various operating points to eliminate possible linearity errors.

4.2 DATA ACQUISITION

After the calibration is completed, the pressure system is readied for data acquisition by connecting the reference transducers to the vacuum pump, establishing the proper reference pressure in each volume tank, and placing the function in the automatic position. The model pressure scanners are on port number one and the reference transducers are equalized for the first data loop. When the "Take Data" pushbutton is depressed, the scanner reads all transducer zeroes at the reduced reference levels (a few microns Hg for the reference transducers and 0. 1 psia for the tunnel transducers). These zero readings compensate for any transducer zero shift between the calibration reference (atmosphere) and the operating reference.

The indicators are automatically latched by a control function of the computer scanner. A second control function advances the model pressure scanners to the first active port. Thus, while the indicators are being scanned, the first set of model pressures are connected to the transducers and equalization begins. At the end of the scan cycle, the indicators are unlatched and respond to the new signal.

The automatic switching circuitry switches the ranges and references as required for those indicators going full scale after the unlatch operation. After all the indicators have balanced, the operator again depresses the "Take Data" pushbutton, and the cycle is repeated. This continues until all active ports have been measured and the model pressure scanners are again on the zero port. It should be noted that the reference pressure last used during the data scan remains applied to both ports of each model transducer at this time.

Figure 10 is a graphical representation of typical pressure ranges and reference levels and can be used to illustrate how the control system operates. Only the first four reference levels are shown in Fig. 10. The shaded areas on the graph show the portion of each range actually used. This is the entire low range and the upper 55 percent of the medium and high ranges. A slight overlap is maintained between reference levels to allow for some variation of the reference pressures.

Assume that a particular channel is on the low range and reference 1 and a pressure of 2. 8 psia is applied. The indicator will drive full scale, initiating the stepping switch, which will advance through the medium and high ranges to reference 2. Since the low range is active at this point, the indicator remains at full scale, and the channel will advance to the medium range on the next pulse. Full scale for this range on reference 2 is 3. 0 psia; thus the indicator will balance, ending the switching action.

If the next pressure is slightly lower, e. g. 2. 6 psia, the indicator will drop below 45 percent of scale, causing the channel to step back to the low range.

Now consider the case when a negative pressure is applied to the transducer. Assume that the transducer reference is connected to reference 2 and a pressure of 1 psia is applied to the measuring port. Since the reference level is 2.4 psia, a differential of minus 1.4 psi is applied to the transducer. As mentioned previously, the indicator will read upscale for either a positive or negative pressure, with a data bit going to the computer to indicate negative pressures. Therefore, the stepping switch will first advance in a positive direction to the high range. Had the negative differential pressure been less than 1.2 psia, the indicator would have balanced at this point. However, since a full-scale condition is still present, the control system will reverse the stepping switch direction, acting on the negative indicate signal, and step back to reference 1 and the high range, where the indicator will balance with a positive differential of 0.9 psi applied to the transducer.

5.0 EVALUATION OF THE PRESSURE SYSTEM

5.1 GENERAL ADVANTAGES

The system as described in this report has been in operation for approximately two years. This is a sufficient length of time for a rather thorough evaluation. The control system has proved to be quite reliable, as there have been only three minor failures during this period. One was the stepping switch malfunction mentioned previously, and this was corrected by mechanical adjustment of the switch mechanism. A transistor failure in the pulse generator circuit and an open resistor in the power supply were the other two failures occurring within this period.

A very substantial reduction in calibration time has been realized. Before the installation of the automatic system, calibration of nine channels of tunnel instrumentation on three ranges with two reference systems required about an hour. Now an experienced operator can complete the same tunnel transducer calibration and seven reference calibrations in about 15 minutes.

Of course, another significant advantage is the wide range of pressure measurements that can be made, as compared to the previous system, which used only two manually switched reference levels.

5.2 ACCURACY OF MEASUREMENT

Two transducers are required for each pressure measurement, hence two sources of error are present. Tests have shown that the CEC reference pressure equipment can repeat pressure readings well within the manufacturer's ±0. 1 percent specification. At the higher pressures, the major portion of the total pressure is read by the reference transducer, since the tunnel transducer reads only the difference between the reference level and the model absolute pressure. Therefore, accuracies of higher pressure readings can be expected to fall between 0. 1 and 0. 2 percent.

At the lower pressure levels, the Wiancko transducer measure a major portion of the total pressure. The specified linearity and hysteresis figures for these units are ±0. 5 and ±0. 1 percent of span (±5 psi), respectively. However, by de-ranging these transducers, an improvement in the linearity figure is achieved. At the 0. 1-psia level, accuracies are usually within ±0. 5 percent of reading. Of course, lower readings become less accurate, but indications are that useable data can be obtained down to about 500 microns Hg.

5.3 POSSIBLE IMPROVEMENTS

One disadvantage of this system is the possibility of pressure overloads on the tunnel transducers. By arranging the model pressure tube connections to group pressures according to relative magnitudes, these overloads can be minimized. However, this is not always possible. Ideally, the pressure levels should be sensed and the proper reference level applied before a differential is applied to the transducer. However, this involves a sensing device and additional plumbing between the common port of the pressure scanning valve and the tunnel transducer, with a corresponding increase in lag time at low pressures. Up to this time, overloads from this cause have resulted only in zero shifts which are automatically compensated for by the computer program. A later pressure system designed for another hypersonic wind tunnel does include the feature of sensing pressures before connecting the transducer to the model pressure. However, this system has not been in operation long enought for complete evaluation.

Another possible improvement would be the elimination of the reference transducer at the lowest pressure levels with a vacuum reference connected to the tunnel transducer directly. One of the problems here is the time required to obtain accurate zero readings at a high vacuum level. Work is presently under way to overcome these problems and to include a vacuum reference along with the present seven reference levels. An improvement of data accuracy at extremely low pressures would result by the elimination of the second (reference) transducer.

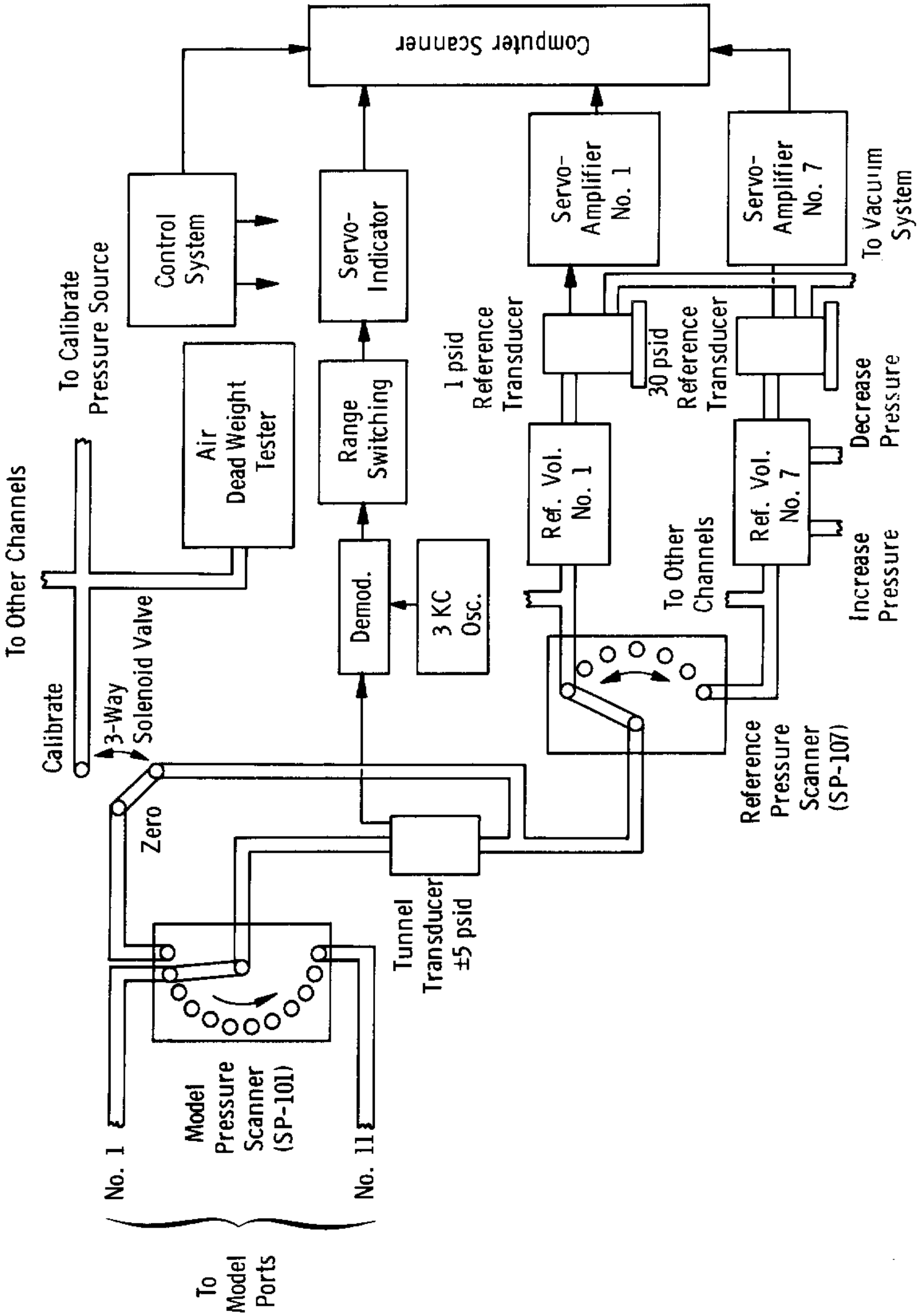

Fig. 1 Measuring System (One of Nine Channels)

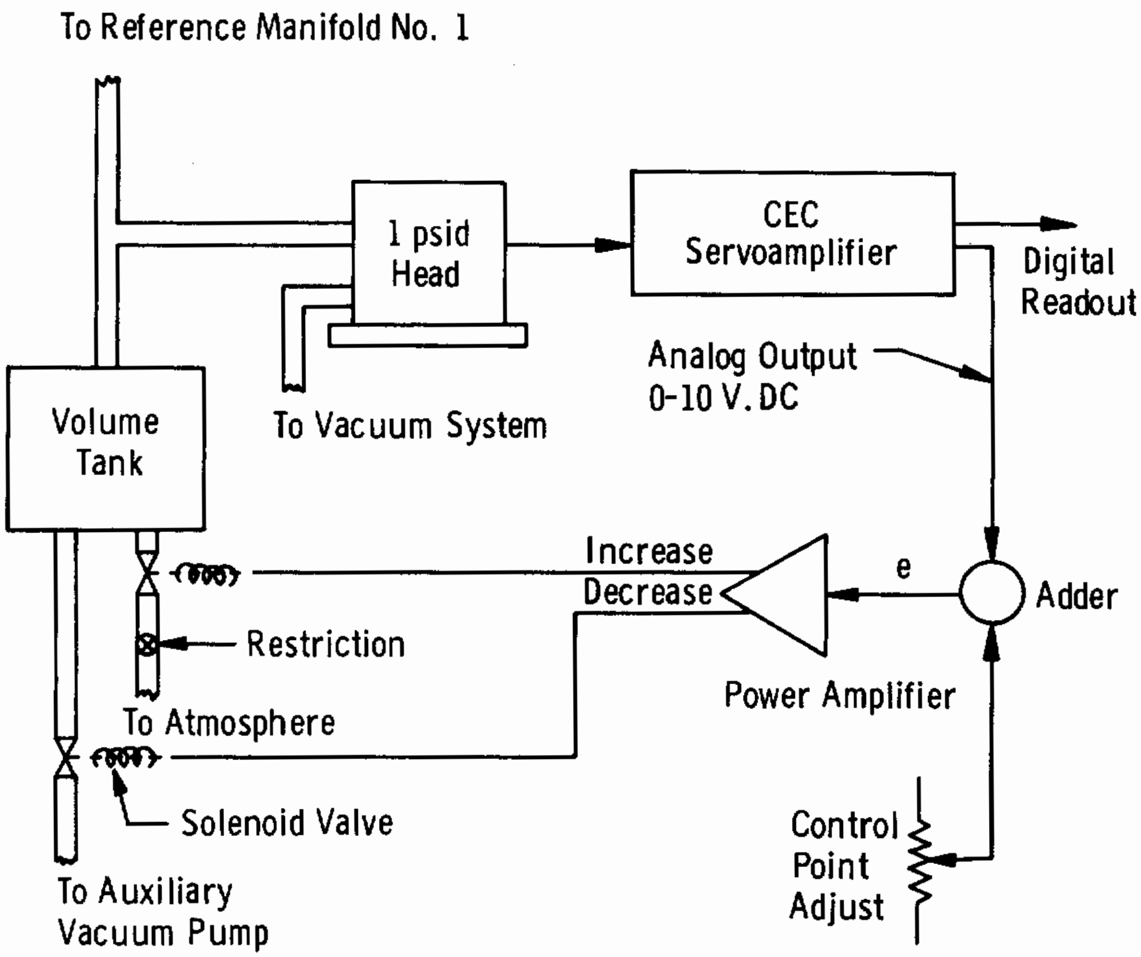

Fig. 2 Reference No. 1 Control Loop

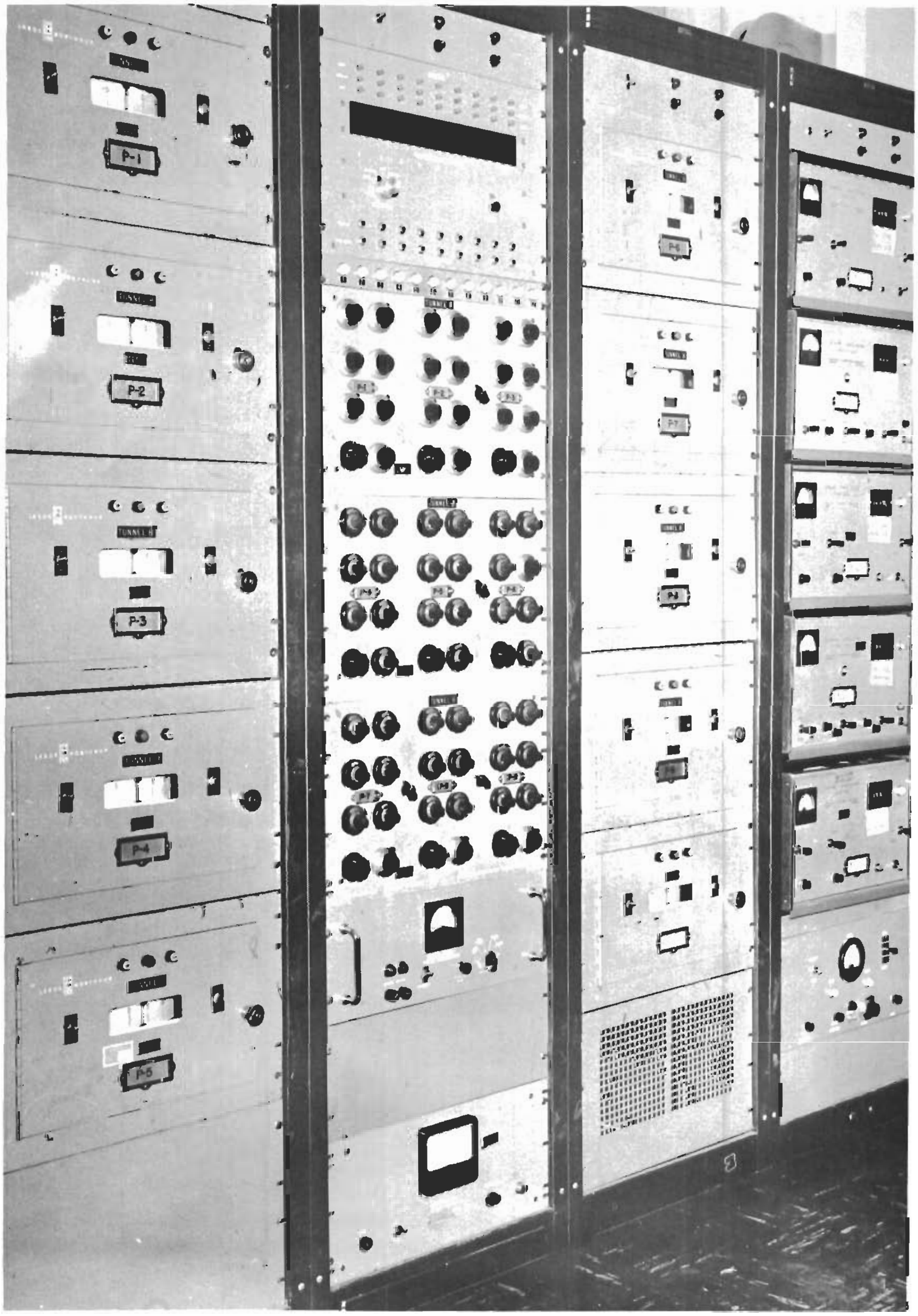

Fig. 3 Pressure System Monitoring Equipment

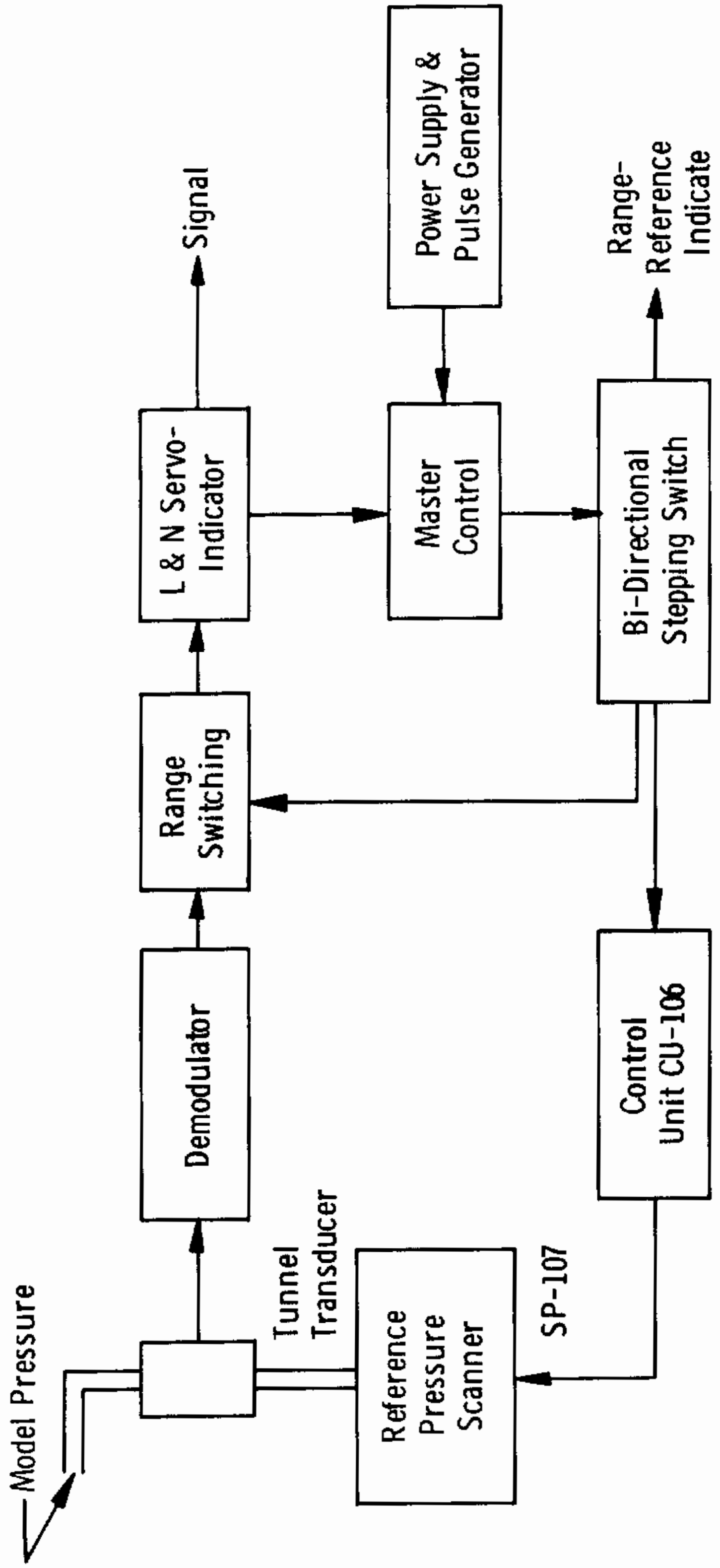

Fig. 4 Control System

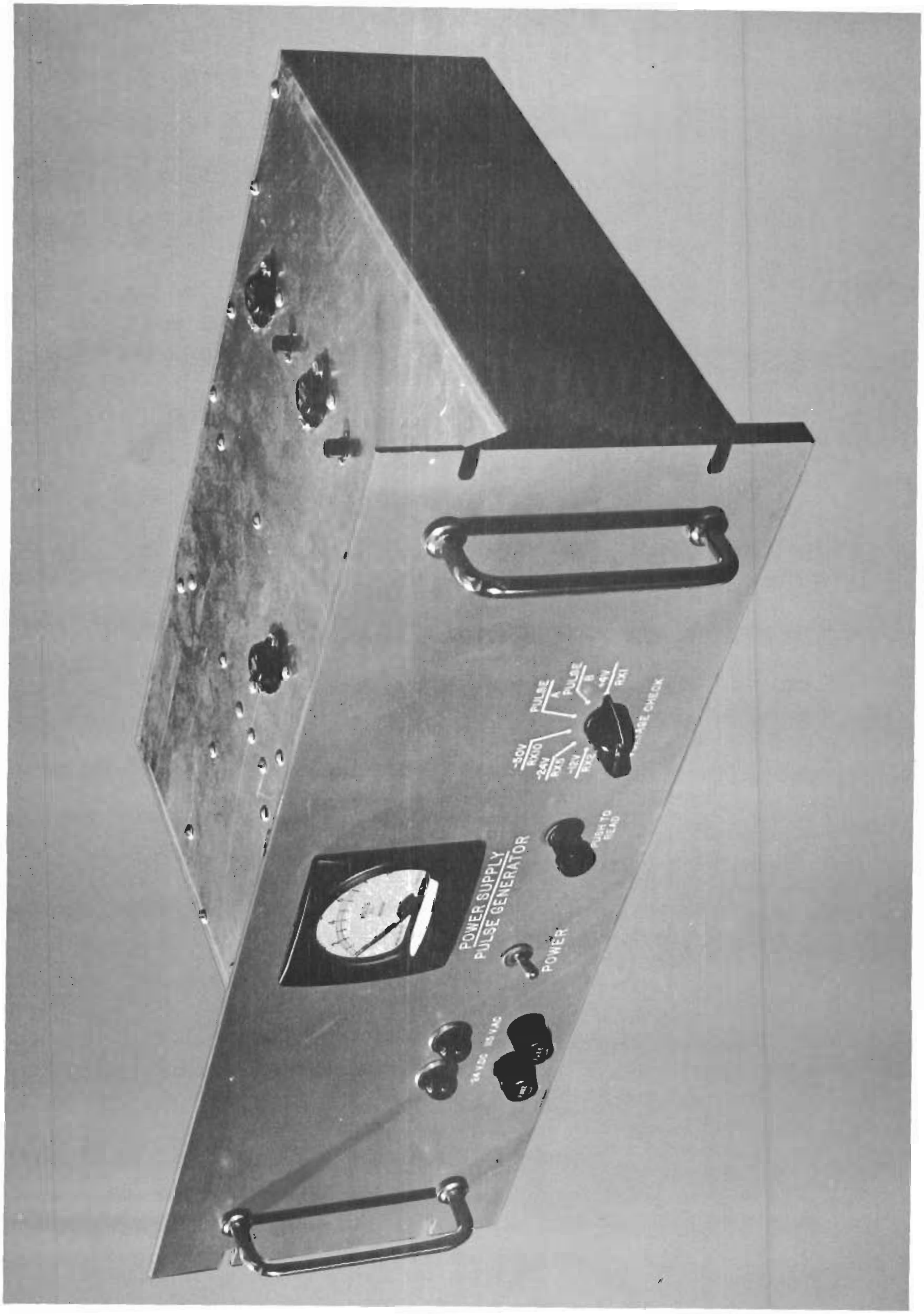

Fig. 5 Power Supply - Pulse Generator

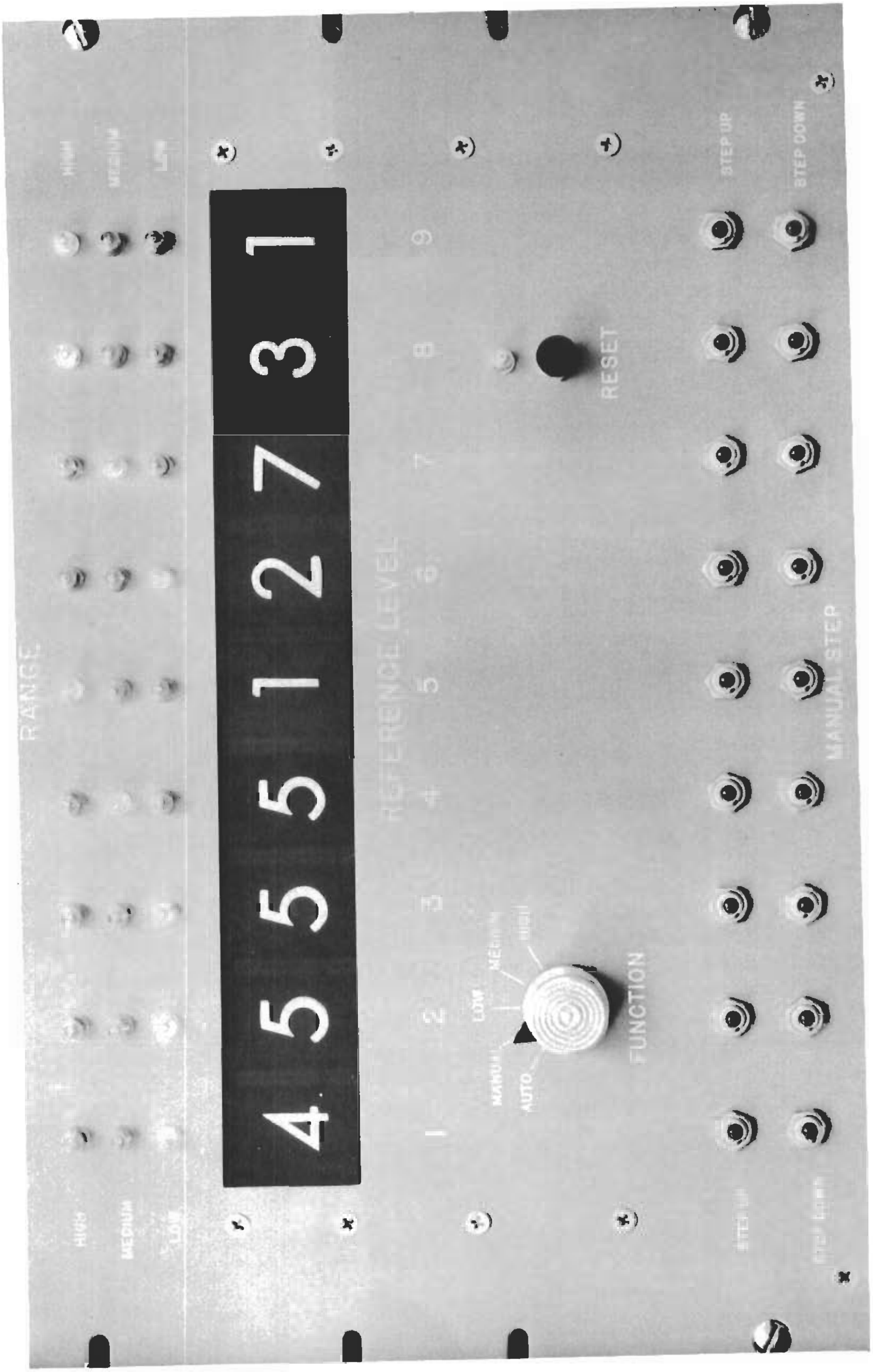

Fig. 6 Master Control Unit

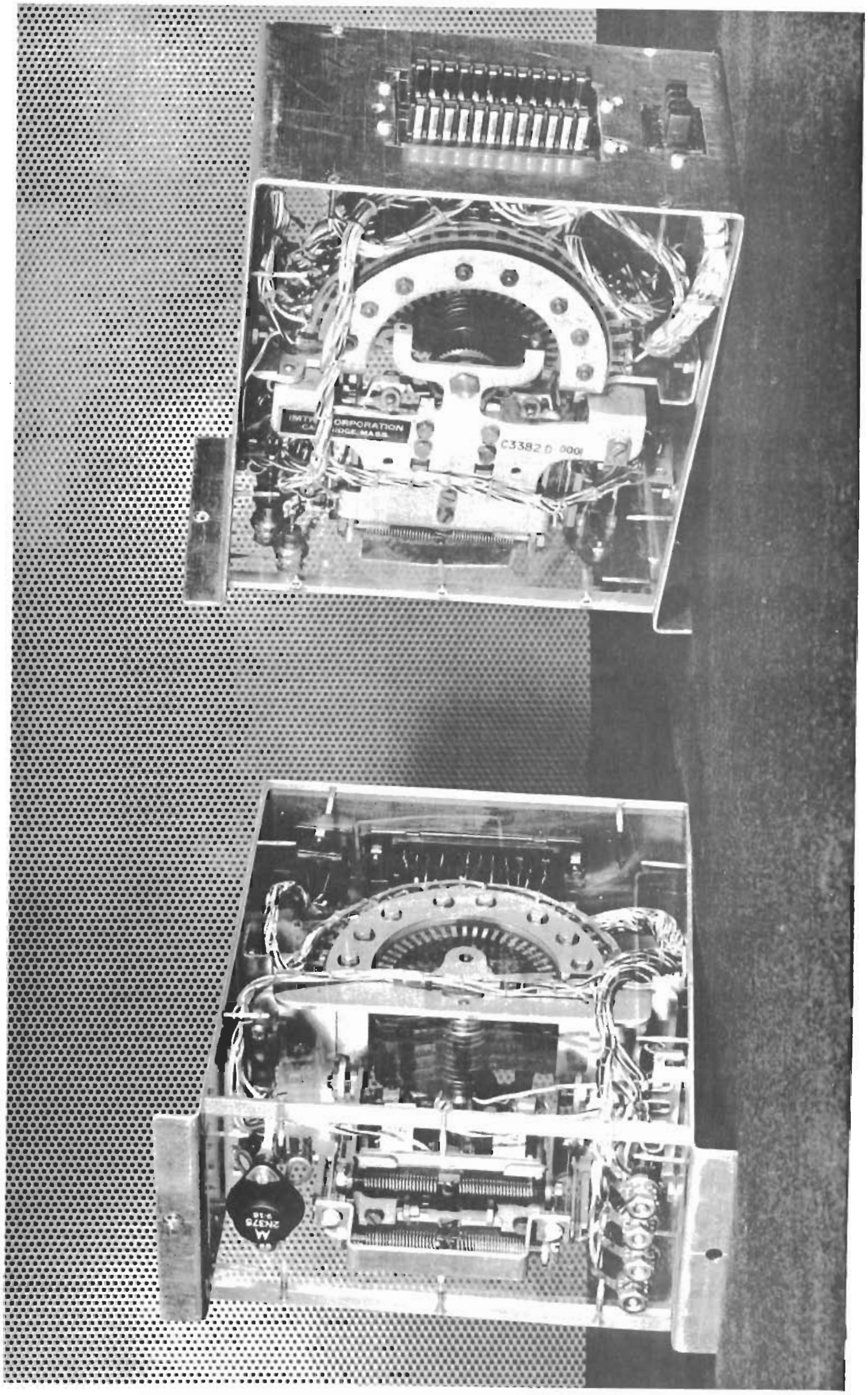

Fig. 7 Stepping Switch Assembly

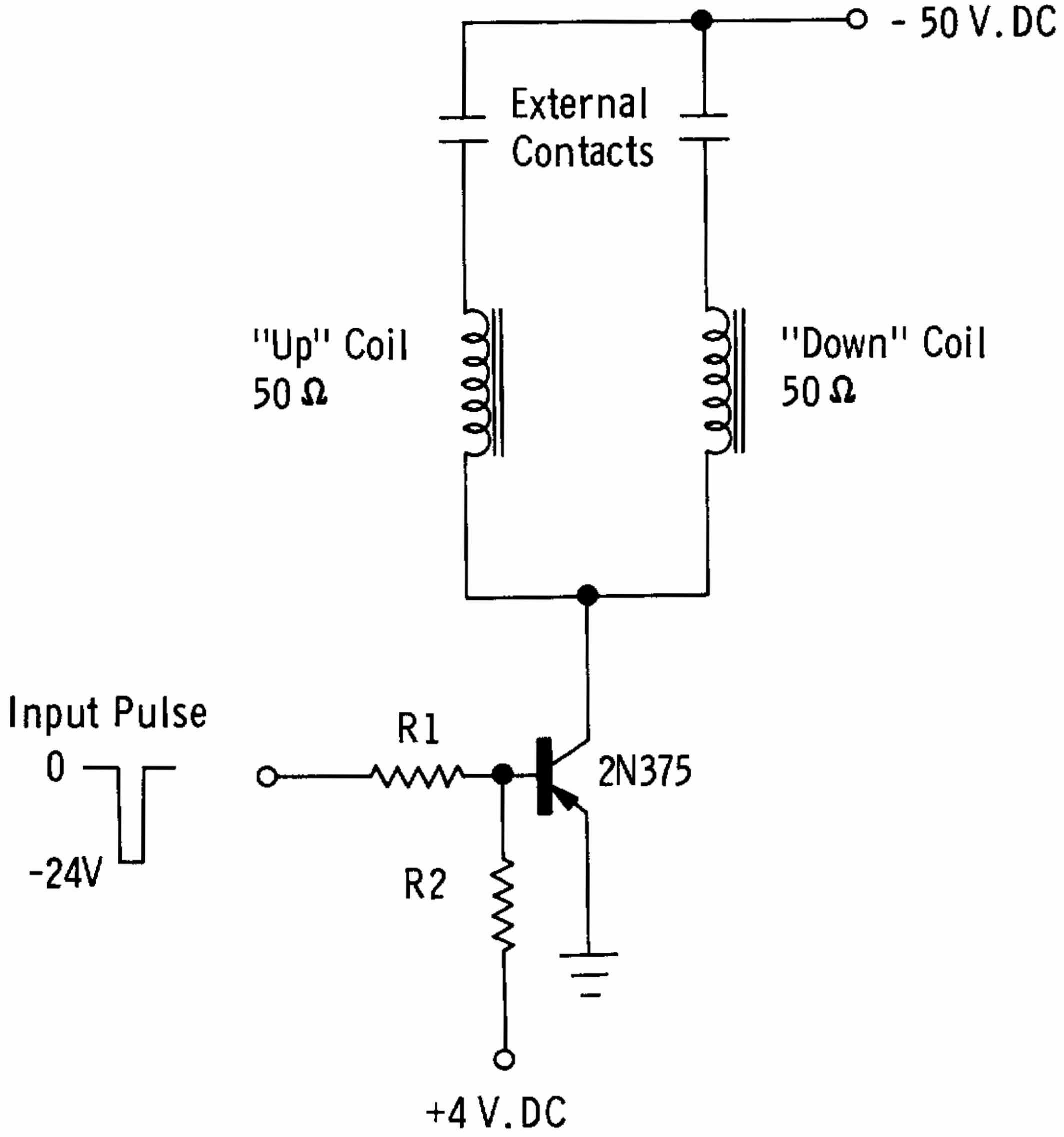

Fig. 8 Simplified Stepping Circuit

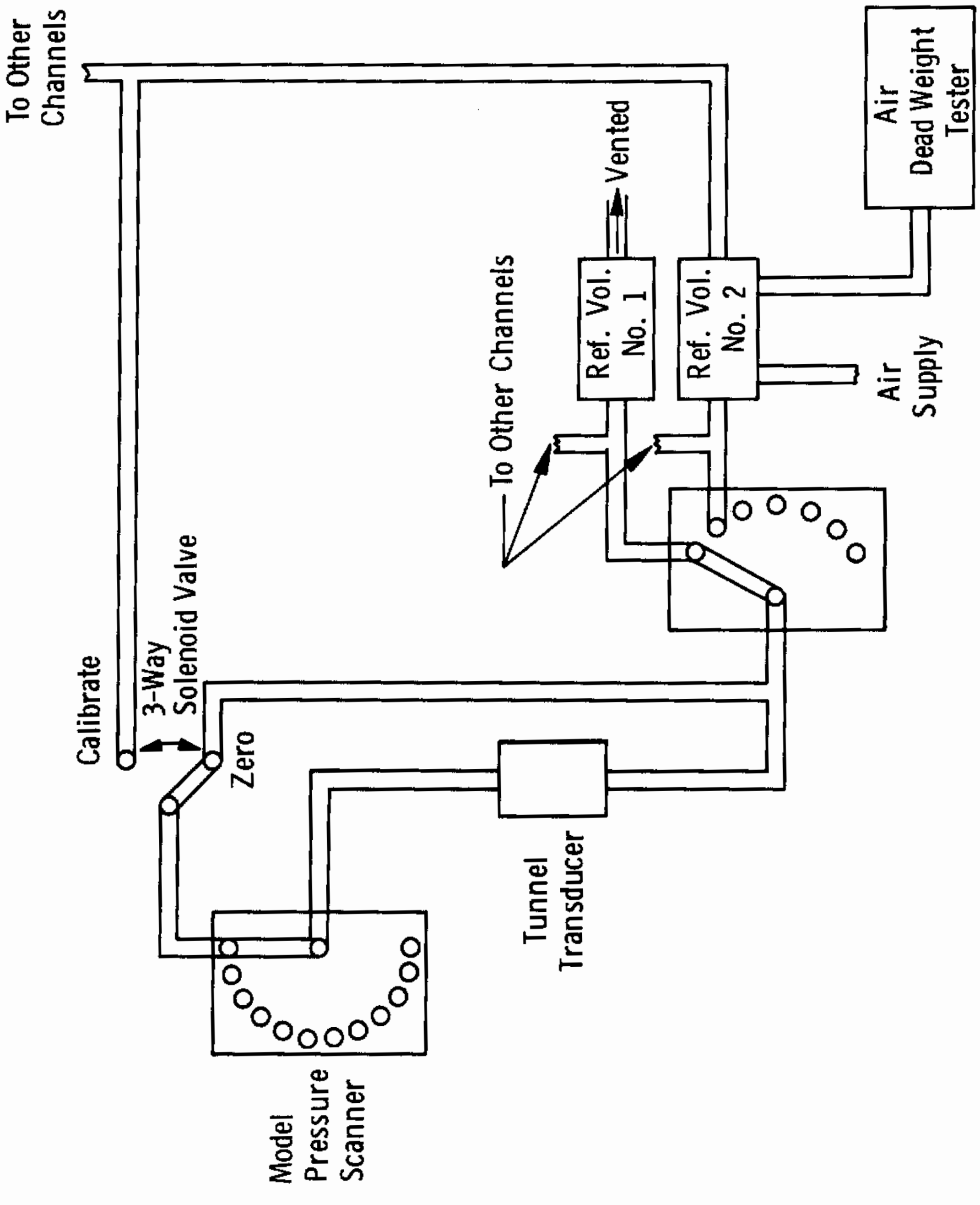

Fig. 9 Simplified Plumbing Arrangement for Transducer Calibration

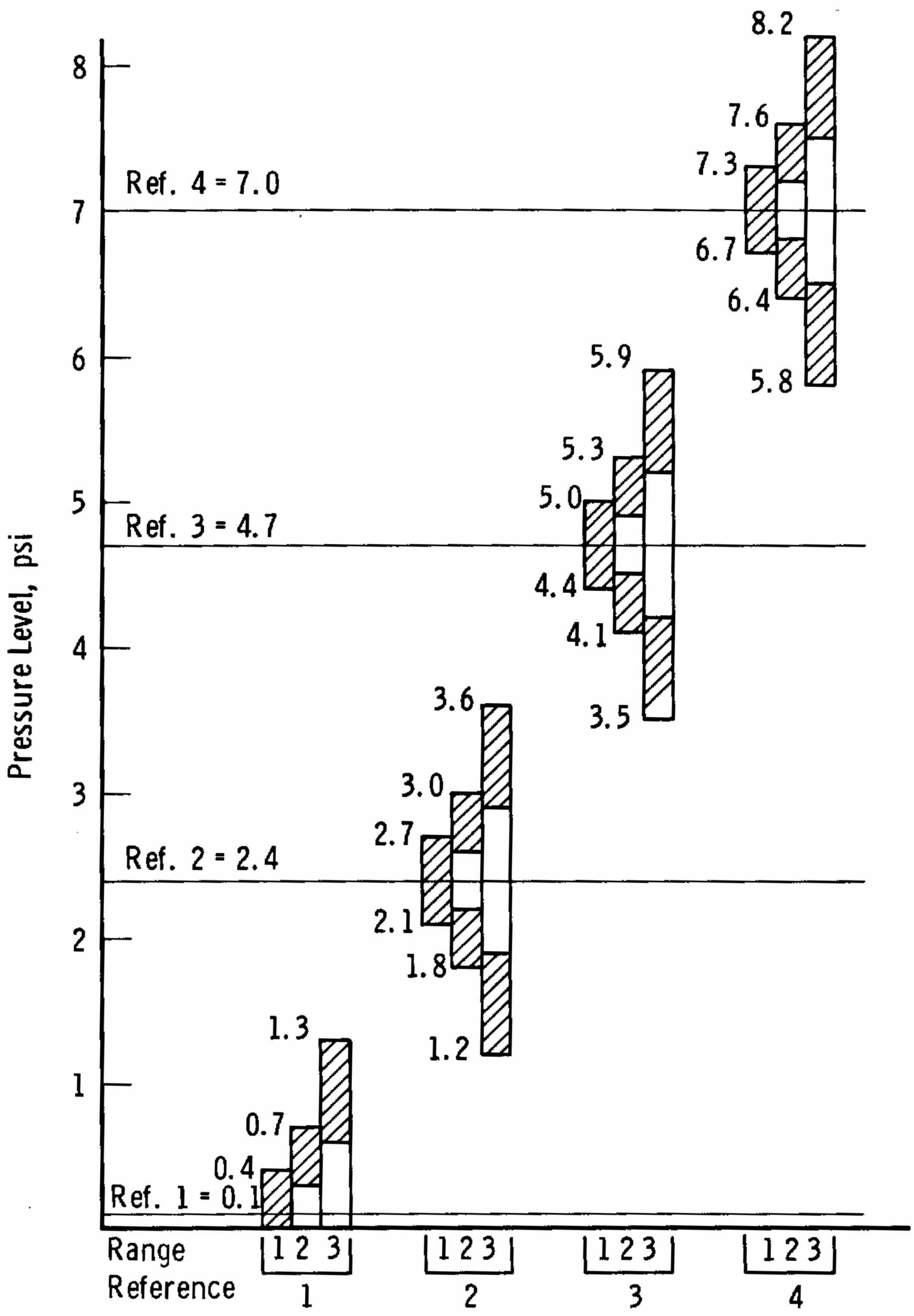

Fig. 10 Typical Range and Reference Spans