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Development of an Automated Probe Positioner for Measurements in Fire-Generated Plumes and Ceiling Jets

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ABSTRACT

This report describes the development of an automated probe positioner. This system has been used for extensive measurements of temperatures at a large number of positions within a laboratory-scale fire-flow experimental apparatus. In its present configuration, the device is designed to operate within a 1.22 m diameter cylindrical enclosure and can position a probe anywhere within this enclosure. The apparatus has horizontal, vertical, and rotational motion capabilities. A single microcomputer is used to control probe positioning, perform data-taking, and evaluate statistical results. These statistical results are used by the system to determine the number of data points to record at a given position. Large numbers of points may be taken at positions showing large fluctuations while small numbers of points are recorded in more quiescent flow regions. Results of several experiments, used to check positioning accuracy and system performance during actual tests, are presented. An analysis of the heat transfer to the test enclosure ceiling, based on data obtained using the automated probe positioning system, is included in the presentation of results.

Keywords: computers; experiments; fire measurements; gas burners; measuring instruments; temperature measurements; velocity measurements.

1. INTRODUCTION

Several laboratory-scale fire experiments [1] [1] have been conducted at the National Bureau of Standards (NBS) Center for Fire Research (CFR) using a cylindrical test enclosure (figure 1). In these experiments, the cylindrical space involved an "enclosure" built over a circular plywood floor, 1.22 m (4.0 ft) in diameter. A 1.22 m (4.0 ft) diameter marinite board, 12.7 mm (0.5 in) thick, is used as the ceiling of the enclosure. The ceiling is supported 1.83 m (6.0 ft) above the floor by two threaded steel rods, 12.7 mm (0.5 in) nominal diameter, and several U-shaped steel bars. The ceiling is surrounded by a 3.17 mm (1/8 in) thick PMMA (polymethylmethacrylate) curtain which extends down from the ceiling .305 m (1.0 ft). This piece forms the "wall" of the enclosure. During experiments where a gas burner is placed at some location below the center of the ceiling, this configuration provides a means for developing a steady axisymmetric flow within the enclosure.

An automated probe positioner for use in this enclosure has been developed at the CFR. This device is capable of recording a virtually unlimited number of velocity or temperature measurements within the cylindrical space. The device moves to selected locations within the space and records a specified number of measurements at each location. The functioning of the positioner is controlled by a microcomputer which allows the system to run almost independent of human intervention.

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1 Numbers in brackets refer to literature references at the end of this report.

2. SYSTEM DESIGN REQUIREMENTS

The probe positioning system must be able to position a probe anywhere within and below the area encircled by the hollow PMMA cylinder. This requires that the positioner move horizontally, vertically, and rotate. It needs a horizontal travel distance capability of 1.22 m (4.0 ft) and a vertical travel distance capability of about 0.305 m (1.0 ft). The entire system must be able to rotate 360 degrees about a central vertical axis. The positioning system will have to support relatively light loads (less than 0.454 kg), so the controlling static structural design criterion for each component will be its capability to support other components mounted on it. It will be necessary to support the system on a plywood sheet. Therefore, the total system's mass should not produce noticeable bending of the plywood sheet when supported at four points along its outer edge.

While accurate positioning dictates the need for precision motors, the motor velocities cannot be unduly slow. It should not take more than a minute to traverse the longest dimension of the enclosure.

The positioner system should be computer controllable. A controller must be available which interfaces to a computer and connects to the motors with a minimum of wiring difficulties. The controller must either be programmable itself or respond to simple commands from a host computer. Finally, the equipment should be compatible with existing computer and data acquisition systems already available within CFR.

3. SYSTEM COMPONENTS

3.1 Horizontal Motion Assembly

A motor driven slide assembly was chosen to provide horizontal motion capability (figure 2). While slides are available in a wide range of sizes, the one with a 0.838 m (2.75 ft) base length was selected due to the enclosure constraints. This base length allows the system to just clear the ceiling support struts. The slider has a length of 102 mm (4 in) and a width of 51 mm (2 in). This provides a 0.734 m (2.42 ft) travel distance.

A screw, driven by a factory installed stepping motor, provides the force to move the slide. The screw is a 3/8 in - 20 double start Acme which advances 2.54 mm (0.1 in) for each revolution. The motor takes 200 steps to turn the screw one revolution. For every step of the motor, the slide moves 0.0127 mm (0.0005 in) in the appropriate direction. The maximum motor speed is 3000 steps per second. At a motor speed of 1600 steps per second, the slide can be moved the entire width of the enclosure in one minute. This is an acceptable velocity capability.

The motor and slide assembly was received preassembled and prewired. Two connectors are provided on the assembly. One is used to control the motor speed and direction while the other monitors the slide limit switches to prevent overrunning of the motor.

The slide assembly has a maximum load capacity of 45.36 kg (100 lb_m), and it has a mass of 8.39 kg (18.5 lb_m).

3.2 Vertical Motion Assembly

For vertical motion, another stepper-motor driven slide was selected (figure 3). This slide provides approximately 0.406 m (1.33 ft) of travel distance with a 63.5 mm (2.5 in) long slide. This size slide was chosen because it provided the most travel distance while producing a minimum torque on the slide to which it is mounted.

The same precision screw and stepping motor were selected for this slide. The motor and slide were received pre-assembled and pre-wired.

This slide and motor assembly has a maximum load capacity of 13.6 kg (30 lb_m) and a mass of 4.54 kg (10 lb_m).

3.3 Rotary Motion Assembly

In order to provide a rotary motion capability, a rotary table was purchased (figure 4). This table has an 18:1 gear ratio and produces a rotation of 0.1 degrees per 200 steps of the driving motor. Another stepping motor is used to drive the rotary table. As per the manufacturer's recommendation, all of the stepping motors were of the same current rating. The table, with the motor, has a load rating of 90.7 kg (200 lb_m). The motor and table were received ready for use.

3.4 Motor Control

A commercial stepping motor controller/driver designed for use with the slides and rotary table was selected to control the three stepping motors. This controller is fully programmable, in BASIC, using a full duplex RS-232C computer interface. The unit also contains the stepping motor drivers (motor resistors and power supplies) which are required to operate the motors. The unit was received fully assembled and tested. It was pre-wired for three motors.

Commands and data received from a host computer or terminal over the RS-232 interface are interpreted by a BASIC language interpreter contained in 8K of ROM (read only memory). The controller also contains 12K of firmware in ROM which is dedicated to interactive motor control. The 20K of ROM along with

4K of RAM (random access memory) are contained on a 6502 based microprocessor [2].

To move a motor, the motion parameters are set equal to analogous BASIC variables, followed by a "GOSUB" command. The "GOSUB" command calls the appropriate system firmware which produces the motor motion. A sequence of commands can be stored in RAM. This allows the controller to be dedicated to motor motion while the host computer performs other tasks. Using the BASIC language capability, the controller may be programmed to do conditional branches, looping, transmission of status and data, self prompts, unit conversions, and other complex computing and processing.

3.5 Assembly of the System

All of the system components were received pre-drilled and ready for assembly. X-Y and X-Z adapters were purchased separately to complete the assembly. The rotary table was mounted on a plywood sheet (figure 4). The X-Z adapter plate was then used to attach the horizontal slide to the rotary table. The vertical slide assembly was secured to the horizontal slide using the X-Y adapter bracket. Figure 5 shows the vertical slide attached to the horizontal slide using the adapter bracket. The burner is visible on the right of the photograph. Figures 6, 7, and 8 are photographs of the assembled system installed in the test enclosure.

The motors and slide assemblies were connected to the controller/driver using the wiring and connectors provided. The controller's RS-232 port was connected to a corresponding port on a microcomputer. The computer was programmed in BASIC and controlled data recording and probe movement.

The computer was connected to a 6 1/2 - digit digital voltmeter and a scanner. These devices are used to select and read the appropriate thermocouple(s) during the experiments.

Because of the layout of the system, at least two probes are required to enable the system to reach all locations in the enclosure. For the experiments described in section 5, a T-shaped support (figure 9) was designed and mounted on the vertical slide. The T was constructed of three ceramic insulators which were held together using an aluminum block and set screws. Type-K thermocouples, 0.254 mm (0.01 in) diameter, were threaded through the insulators and joined to provide a junction on each side of the T cross-bar. The T was mounted so that its cross-bar ran parallel to the direction of travel of the horizontal slide (figure 7). (If velocity measurements are desired, a new support would have to be designed and built.)

4. SOFTWARE FOR SYSTEM CONTROL AND DATA ACQUISITION

A computer program was written, in BASIC [3], to provide motion control of the positioning system and to record data (see Appendix). The program has so far been tested only for thermocouple data. However, the system should work equally well for velocity measurements.

The positions to be probed are entered as input data or stored as DATA statements within a version of the control program. The choice will depend on user needs. Two coordinate systems have been developed. One is used by the experimenter to select probe locations. The other is used by the positioner to determine where to move the probe to correspond to a user specified location. The user coordinate system assumes the center of the ceiling to be the 0,0 position. All other locations are determined relative to this position.

The turntable is marked in one degree increments and the horizontal slide is positioned at the 240 degree mark at the start of each test. When the controller is turned on, this sets the starting position of the rotary table.

At system start-up, the program sets the zero positions of the two slides automatically. This is accomplished by sending the horizontal and vertical slides to positions which force the motor limit switches to activate and stop the motors. Each slide is then moved 0.0254 mm (0.001 in) in the opposite direction, and the zero position is set. By using the limit switches on the two slides to set zero positions, a repeatability of 0.0254 mm (0.001 in) is obtained. The program internally adjusts the user´s input location(s) to conform to its coordinate system and proceeds to move to the selected locations and record data measurements.

Specifically, the program operates by sending move commands to the probe positioner system. After the move is completed, it monitors the appropriate probe for the specified number of readings. It calculates the mean reading ($\bar{r}$), the standard deviation (r_{sd}), and the percent error (i.e. $|1-r/\bar{r}| \times 100$) for the set of readings. If the percent error is within user specified, acceptable limits, the probe is moved to the next location. If not, another series of readings is taken. If after three attempts, readings within the allowable percent error have not been obtained, this fact is noted in the test record and the probe is moved to the next location. The average reading, the standard deviation, the percent error, the time, and the position are recorded on tape or disk as selected by the user.

As can be seen in figures 1 through 8, the test configuration presents many obstructions to probe movement. These obstructions include the burner, the burner support, the ceiling, the PMMA curtain "wall", and the wall and ceiling support members. If the probe were to accidentally hit one of these obstructions, it and/or the probe positioning system could be damaged. The probe positioning system must be "smart" enough to know where the obstructions are and how to avoid them. The positioning system control software makes it a "smart" system.

The burner supporting structure is probably the most obvious obstruction to probe movement. Its position relative to the starting position of the system is always the same. The positioning system, through the control software, "knows" how close it can get to the burner support. If the user specifies positions closer to the support than are allowed, they will be modified so that they come as close as possible without damaging the equipment. Any modifications to user specified probe locations are noted in the test record.

In addition, the positioning system must not direct the probe to rotate through the burner support. This is accomplished by changing rotation direction. The control program determines the necessary motor direction by comparing its present location to the next desired location. If forward movement would cause the system to pass through the burner support, it reverses direction and reaches the position from the other side.

Before the probe moves in a lateral direction, it checks its proximity to the ceiling. If its present specified position is closer than 6.35 mm (0.25 in), it moves down 12 mm (0.47 in) before moving in a lateral direction. When the probe is too close to the ceiling and attempts a lateral movement, it may scrape the ceiling and be damaged.

The probe is prevented from attempting to push itself through the ceiling in two ways. First, the limit switch is set so that the sensing parts of the probe T can just touch the ceiling. If a position above the ceiling is specified, the limit switch will stop the motor when the probe tip reaches the ceiling. Second, even if the limit switch fails, the control program "knows" the maximum allowable vertical height. A position higher than the ceiling is assumed to be an error and will not be accepted.

During system operation, the software prevents the probe from being pushed through the "wall". The program "knows" when a given position would be beyond the side wall and will not accept it.

The position of each wall supporting member is specified in the control program. The system checks each position to determine whether it is within the specified "danger zone" around these supports. If a position would place the probe too close to a support, the position is modified so that the probe remains outside the software specified "danger zone". This fact is noted in the test record.

Finally, the system must be careful not to rotate the probe when it is too close to the wall. If the system attempts to rotate when the probe is near the wall, it may collide with one of the wall supports and break. Before each rotation, the system checks its position relative to the wall. If it is too close, the system moves the probe in towards the center of the enclosure. The amount of inward movement is varied depending on the length of the outward pointing part of the probe T.

5. CHECKOUT EXPERIMENTS

5.1 Positioning Accuracy Tests

As stated earlier, the positioning system operates using two coordinate systems. One is used by the experimenter for entering locations to be probe. The control software converts these coordinates into ones appropriate for controlling the movement of the slides. In order to accomplish these conversions, the distance from the ceiling to a point on the vertical slide, the distance from the burner centerline to the enclosure "wall", the vertical length of the probe T, and the lengths of each horizontal part of the T (measured from the T centerline) must be known. The first two measurements are stored in the program while the others are left as input data. This allows the experimenter to use different size T probes depending on where in the enclosure data is desired.

The first series of tests were designed to check the positioning accuracy and the coordinate conversion routine. All of the tests in this section were performed without a burner flame. The length measurements discussed in this section were determined using various measuring devices with minimum incremental markings of 1 mm (.039 in).

To check the relationship of the user and system coordinate systems, the probe was moved to selected locations within the enclosure. The distance from the enclosure 0,0 point to the probe location was measured. The difference between where the probe was positioned and where it should have been was noted. The system could position the probe at a specified location with an accuracy of ± 0.25 mm (0.01 in) vertically and ± 0.25 mm (0.01 in) horizontally.

The second set of tests checked the positioning accuracy of the system by examining its ability to return to a specified location. In these experiments, the system was moved through a series of locations within the enclosure and finally told to return to its starting position. This position was measured, relative to the adopted user coordinate system, before the motions were executed and again after the series of motions was completed. Again, results of these tests indicated that the system could return to a specified location to within an accuracy of ± 0.25 mm (0.01 in) vertically and ± 0.25 mm (0.01 in) horizontally.

The accuracy with which the probe may be positioned is directly related to the accuracy of the input measurements. The accuracy of these input measurements is influenced by irregularities in the construction of the enclosure and the experimenter's measuring ability. One construction related feature which influences positioning accuracy is deflection of the ceiling. Deflection of the ceiling may be caused by imperfect construction and/or the weight of the ceiling. The other construction feature which influences accuracy is irregularities in the PMMA wall. It is not symmetric. Special instructions in the software have been used to compensate for some of these construction problems. As for the experimenter's measuring ability, many measurements have already been made and included in the software. Slots have been provided on the probe T connecting blocks and marks have been placed on pieces of the positioning system to aid in making the required measurements.

However, despite all of these problems, the positioning accuracy obtained in these checkout tests is acceptable (for now) and better than that obtained using most other methods of thermocouple positioning.

5.2 Experiments Using the System

When a fire occurs in a room, buoyancy forces drive the high temperature products of combustion upward toward the ceiling. In this way a plume of upward moving elevated-temperature gases is formed above the fire. All along the edge of the plume, relatively quiescent and cool ambient air is laterally entrained and mixed with the plume gases as they continue their ascent to the ceiling. As a result of this entrainment, the total mass flow rate in the plume continuously increases, and the average temperature and average concentration of products of combustion in the plume continuously decreases with increasing height.

When the plume gases impinge on the ceiling, they spread across it forming a ceiling jet. As the plume flow continues, an upper gas layer develops, confined by the enclosed ceiling boundary, and grows in depth. The relatively sharp interface between it and the cool ambient air layer below continuously drops [4].

The test enclosure discussed in this report is used to model the fire flow in a fixed depth, upper gas layer. A methane gas burner simulates the burning object, and the PMMA curtain is used to develop the fixed depth, upper gas layer. Temperature and/or velocity measurements in the plume, ceiling jet, and/or upper gas layer are recorded for use in validating various parts of computer fire models.

This series of tests was designed to check system performance during actual fire tests. For these tests, the gas flow rate was adjusted to provide a constant heat release rate of 1 kW (0.95 BTU/s). The burner was located 0.72 m (2.36 ft) below the center of the ceiling.

The probe positioner system was used to measure the temperature profile of the ceiling jet in the enclosure during steady state conditions. Data were taken at the following radial distances from the burner: 50.8 mm (2 in), 152.4 mm (6 in), 305 mm (12 in), and 508 mm (20 in). At each radial location, the probe was moved in various increments from the ceiling to a position outside the confined hot gas layer. The probe was allowed to move to within 0.8 mm (1/32 in) of the ceiling level of the enclosure.

Figures 10 through 13 present the results of these tests. In a thin, near-surface region, the data, taken at the radii of 305 mm (12 in) (figure 12), and 508 mm (20 in) (figure 13), show a drop in gas temperature as the ceiling is approached. This temperature drop is a result of an energy balance at the ceiling surface between steady state radiation, conduction into the ceiling material, and convective heating of the surface from a somewhat elevated temperature, near-surface region of the ceiling jet flowing below the ceiling surface. The data at the 50.8 mm (2 in) radius (figure 10) and the 152.4 mm (6 in) radius (figure 11) indicate that the nature of this energy balance in this region (radius less than 152.4 mm) is more complex, with radial conduction possibly playing a significant role. Further experiments are needed to refine the analysis of ceiling heat transfer in this region. The automated probe positioning system would be very useful in this regard.

At each radius and below the thin near-surface region, the temperature is seen to decrease as the probe is lowered from the ceiling level. In the case of each of the three outer radii, the temperature decreases towards ambient (about 27 degrees C) at a distance of about 304.8 mm (1 ft) from the ceiling. This is the point at which the probe begins to move out of the hot gas layer contained within the PMMA curtain. It is interesting to note that once the probe has moved outside the ceiling jet the temperature in the hot layer is almost constant. Even at the 50.8 mm (2 in) radius (figure 10) where the probe is positioned very close to the plume, the temperature within the hot layer is reasonably constant. This observation lends further proof that the two-zone concept used in many fire models is a practical one.

The probe positioner system allows fire researchers to record numerous data points in areas with steep temperature gradients while recording only a few points in areas with small temperature changes. In addition, researchers can record detailed measurements in specific areas of interest while skipping other areas. Currently, the computerized probe positioner is being used in a series of small scale fire tests designed to record detailed temperature measurements in the region of plume penetration at the interface between the hot gas and ambient air layers [5].

6. CONCLUSIONS AND FUTURE DIRECTIONS

The use of this automated positioning system has many advantages. Since this system can operate without supervision, a virtually unlimited number of readings may be taken during any experiment. In addition, experiments can be run overnight. This allows the laboratory space to be used for other experiments during the day. These types of small scale experiments are very sensitive to ambient air currents. Running at night and without people in the laboratory area minimizes air movement providing more accurate measurements.

The positioning apparatus may be moved in increments of 0.0127 mm (0.0005 in) [manufacturer´s specification]. Measurements may be recorded at smaller intervals than are possible using other methods of probe positioning. The probe is rigidly supported using a ceramic insulator, and only the sensing element is exposed.

The system has only been evaluated for performance during steady state, confined experiments. While this is an important problem in fire research, it is not the only one. Future efforts will also be directed toward using the system in studies of unsteady phenomena and unconfined fires.

7. ACKNOWLEDGEMENTS

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APPENDIX

Positioning and Data Acquisition Computer Program

```
1 INIT
2 SET KEY
3 GO TO 100
4 Z9=1
5 GO TO 2380
100 PAGE
110 F$="0"
120 POLL A,B;22
130 GO TO 100
140 REM
150 REM KEY 1 - TO TERMINATE DATA COLLECTION:
160 REM         PRESS USER DEFINABLE KEY NUMBER 1
170 REM
180 DIM I$(1),J$(1),F$(1),H$(1),V$(1)
190 V$="Y"
200 PRINT " THIS IS A PROGRAM FOR TAKING TEMPERATURE "
210 PRINT "   PROFILES NEAR 1/4 SCALE CEILINGS "
220 PRINT " USING HP/TEK SYSTEM AND AUTOMATED PROBE. "
230 CALL "WAIT",30
240 A$=CHR(10)
250 CALL "MARGIN",0,0,0
260 CALL "RATE",1200,3,2
270 CALL "RCRLF",3,2,0
280 CALL "RSTRING"," ",A$,"9999"
290 PRINT @40:"E"
300 PRINT @40:"R1=1:R2=1:R3=1"
310 PRINT @40:"C1=0.0005:C2=0.0005:C3=0.1"
320 PRINT @40:"V1=700:V2=700:V3=200"
330 PAGE
340 PRINT " CONTROLLER READY"
350 PRINT "   "
360 PRINT "   "
370 REM DATA INPUT
380 REM READ IN LOCATIONS OF VERTICAL CEILING SUPPORTS
390 DIM L1(100),L2(100),L3(100),P1(100),P2(100),P3(100)
400 DIM T9(20),T8(20),T7(20)
410 K1=0
420 DIM V(14)
430 FOR J=1 TO 14
440 READ V(J)
450 DATA 38,42,78,82,98,102,158,162,218,222,278,282,338,342
460 NEXT J
470 PRINT " GGGGG"
480 PRINT " YELLOW AND GREEN LIGHTS ON CONTROLLER "
490 PRINT " SHOULD BE ON. "
500 PRINT "    "
510 PRINT " ENTER THE X1 (OUTWARD), X2 (INWARD),  "
520 PRINT " AND Y (VERTICAL) LENGTHS OF THE PROBE T."
530 PRINT "     ALL UNITS IN INCHES."
540 INPUT X1,X2,Y
550 PRINT "    "
560 PRINT " ENTER INTERIOR THERMOCOUPLE NUMBER (1 OR 2)."
```

```
570 INPUT A$
580 PRINT " ENTER EXTERIOR THERMOCOUPLE NUMBER (1 OR 2)."
590 INPUT B$
600 IF B$<>A$ THEN 640
610 PRINT " GGGG SAME THERMOCOUPLE NUMBER WAS ENTERED."
620 PRINT " RE-ENTER THERMOCOUPLE NUMBERS."
630 GO TO 560
640 PRINT " ENTER THE X,Y LOCATION OF THE BURNER IN INCHES."
650 INPUT B1,B2
660 PAGE
670 PRINT " ENTER THE NUMBER OF POSITIONS TO BE PROBED."
680 INPUT N2
690 PRINT " ARE THE LOCATIONS TO BE PROBED STORED"
700 PRINT "        AS DATA STATEMENTS (Y/N)? "
710 INPUT H$
720 IF H$<>"N" THEN 820
730 PRINT "    "
740 PRINT " ENTER THE PROBE LOCATIONS. "
750 PRINT " DATA SHOULD BE GROUPED AS X,Y,THETA SETS."
760 PRINT "   THE CENTER OF THE CEILING IS 0,0.      "
770 PRINT " X AND Y ARE IN INCHES AND THETA IS IN DEGREES."
780 FOR I=1 TO N2
790 INPUT L1(I),L2(I),L3(I)
800 NEXT I
810 GO TO 1040
820 FOR I=1 TO 20
830 READ T7(I)
840 NEXT I
850 FOR I=1 TO 1
860 READ T8(I)
870 NEXT I
880 FOR I=1 TO 1
890 READ T9(I)
900 NEXT I
910 FOR I=1 TO 1
920 FOR J=1 TO 1
930 FOR K=1 TO 20
940 K1=K1+1
950 L1(K1)=T8(J)
960 L2(K1)=T7(K)
970 L3(K1)=T9(I)
980 NEXT K
990 NEXT J
1000 NEXT I
1010 REM T7, K = Y     INDICIES.
1020 REM T8, J = X     INDICIES.
1030 REM T9, I = THETA INDICES.
1040 FOR I=1 TO N2
1050 P3(I)=L3(I)
1060 NEXT I
1070 A$="0"&A$
1080 B$="0"&B$
```

```
1090 REM
1100 GOSUB 3060
1110 REM SET ZERO POSITION OF CONTROLLER.
1120 PRINT "    "
1130 PAGE
1140 05=6
1150 04=4.25
1160 REM CHECK X2 LENGTH.
1170 IF X2>04 THEN 1270
1180 V4=04-X2
1190 V$="N"
1200 PRINT " GGGG X2 LENGTH TOO SHORT GGGG "
1210 PRINT "  BURNER CENTERLINE CANNOT BE PROBED."
1220 PRINT "  CLOSEST APPROACH TO BURNER WILL BE "
1230 PRINT "       ",V4," INCHES AWAY.          "
1240 PRINT "  MINIMUM X2 LENGTH IS ",04," INCHES."
1250 PRINT " (RETURN) TO CONTINUE.                "
1260 INPUT Q$
1270 REM
1280 PRINT @40:"A2=-18:@"
1290 W=18/(700*5.0E-4)
1300 W=W+0.5*W
1310 CALL "WAIT",W
1320 PRINT @40:"A1=36:@"
1330 W=36/(700*5.0E-4)
1340 W=W+0.5*W
1350 CALL "WAIT",W
1360 PRINT @40:"I1=-0.001:I2=0.001:@"
1370 CALL "WAIT",10
1380 PRINT @40:"P1=0:P2=0:P3=0"
1390 PRINT @40:"V1=200:V2=200:V3=25"
1400 CALL "WAIT",10
1410 V1=200
1420 V2=200
1430 V3=25
1440 REM
1450 PRINT " STORE DATA ON TAPE (Y/N)?";
1460 INPUT I$
1470 IF I$<>"Y" THEN 1700
1480 PRINT " "
1490 PRINT " ENTER FILE NO. (GREATER THAN 5) WHERE DATA"
1500 PRINT "    WILL BE STORED.        ";
1510 INPUT F
1520 IF F<=5 THEN 1490
1530 PRINT " INSERT DATA STORAGE TAPE GGGGG"
1540 PRINT " IF OTHER THAN PROGRAM TAPE.   "
1550 PRINT " TYPE A CARRIAGE RETURN TO CONTINUE.";
1560 INPUT L$
1570 FIND F
1580 PRINT "    "
1590 PRINT " INPUT FIRST OF TWO LINES OF TEST DESCRIPTION."
1600 PRINT "    "
```

```
1610 PRINT "    ",
1620 INPUT C$
1630 PRINT "    "
1640 PRINT " INPUT LAST  OF TWO LINES OF TEST DESCRIPTION."
1650 PRINT "    "
1660 PRINT "    ";
1670 INPUT D$
1680 PRINT @33:C$
1690 PRINT @33:D$
1700 PRINT "    "
1710 REM
1720 PRINT " TO TERMINATE DATA COLLECTION, PRESS USER KEY 1."
1730 Z9=0
1740 REM ROUTINE TO CHECK FOR TEMP. REF. COMP. ACTIVATION.
1750 PRINT @9:"C"
1760 PRINT @9:"00"
1770 PRINT @22:"T3"
1780 PRINT @22:"T3"
1790 INPUT @22:R8
1800 IF 24587*R8<=40 THEN 1820
1810 GO TO 1830
1820 IF 24587*R8>10 THEN 1870
1830 PRINT "GGGGGG IS TEMP. REFERENCE TURNED ON ?  TEST TERMIN"
1840 PRINT " TO CONTINUE, PRESS RETURN."
1850 INPUT Q$
1860 GO TO 1740
1870 REM DATA TAKING
1880 DIM R1(4000)
1890 PRINT "G"
1900 PRINT " TO START TEST, PRESS RETURN.","GGG"
1910 INPUT Q$
1920 PAGE
1930 REM
1940 FOR I=1 TO N2
1950 K=1
1960 R=0
1970 GOSUB 2440
1980 X=H-L1(I)
1990 IF L1(I)>7.25 THEN 2020
2000 P$=A$
2010 GO TO 2030
2020 P$=B$
2030 REM
2040 FOR J=1 TO 4000
2050 PRINT @9:"00"
2060 PRINT @22:"T3"
2070 INPUT @22:R0
2080 PRINT @9:P$
2090 PRINT @22:"T3"
2100 INPUT @22:R2
2110 R1(J)=24587*(R2+R0)
2120 R=R+R1(J)
```

```
2130 NEXT J
2140 R=R/4000
2150 REM CALCULATE THE STANDARD DEVIATION.
2160 S1=0
2170 FOR J=1 TO 4000
2180 S1=S1+(R1(J)-R)^2
2190 NEXT J
2200 E=S1/4000
2210 REM ROUTINE TO PRINT DATA ON TAPE.
2220 D0=24587*R0
2230 D=R
2240 REM
2250 PAGE
2260 T=0
2270 IF I$<>"Y" THEN 2310
2280 PRINT @33:"REF    ";D0;" DEGS C"
2290 PRINT @33:T,L1(I),L2(I),L3(I),D,E
2300 REM
2310 REM
2320 PRINT "     "
2330 PRINT "REF         ";D0;" DEGS C"
2340 PRINT T,L1(I),L2(I),L3(I),D,E
2350 NEXT I
2360 PRINT "     "
2370 IF Z9=1 THEN 2380
2380 PRINT " DONE GGGGG"
2390 PRINT " TURN OFF REFERENCE JUNCTION GGGGGG"
2400 PRINT @40:"&"
2410 IF I$<>"Y" THEN 2420
2420 CLOSE
2430 END
2440 REM POSITIONING SUBROUTINE
2450 IF I-1>0 THEN 2520
2460 IF L3(I)-180<=0 THEN 2480
2470 IF L3(I)-180>0  THEN 2500
2480 I3=L3(I)
2490 GO TO 2620
2500 I3=L3(I)-360
2510 GO TO 2620
2520 S3=L3(I)-L3(I-1)
2530 IF L3(I)>180 AND L3(I-1)>180 THEN 2570
2540 IF L3(I)<180 AND L3(I-1)<180 THEN 2570
2550 IF S3>0 THEN 2590
2560 IF S3<0 THEN 2610
2570 I3=S3
2580 GO TO 2620
2590 I3=S3-360
2600 GO TO 2620
2610 I3=360+S3
2620 U$=STR(I3)
2630 U$="I3="&U$
2640 U$=U$&":@"
```

```
2650 PRINT @40:U$
2670 W=I3/(0.1*V3)
2680 W=ABS(W+0.3*W)
2690 CALL "WAIT",W
2700 REM CHECK FOR VERTICAL CEILING SUPPORTS.
2710 FOR J=1 TO 12 STEP 2
2720 IF P3(I)<V(J) THEN 2760
2730 IF P3(I)>V(J+1) THEN 2760
2740 P3(I)=P3(I)+1.75
2750 GO TO 2770
2760 NEXT J
2780 REM CHECK FOR BURNER LOCATION
2780 IF V$="Y" THEN 2810
2790 IF P1(I)>V4 THEN 2810
2800 P1(I)=V4
2810 REM
2820 X$=STR(P1(I))
2830 Y$=STR(P2(I))
2840 Z$=STR(P3(I))
2850 CALL "WAIT",10
2860 U$="A1=-"&X$
2870 U$=U$&":A2="
2880 U$=U$&Y$
2890 U$=U$&":@"
2900 PRINT @40:U$
2910 IF I=1 THEN 2960
2920 D1=P1(I)-P1(I-1)
2930 D2=P2(I)-P2(I-1)
2940 D3=P3(I)-P3(I-1)
2950 GO TO 2990
2960 D1=P1(I)
2970 D2=P2(I)
2980 D3=P3(I)
2990 W1=ABS(D1/(V1*5.0E-4))
3000 W2=ABS(D2/(V2*5.0E-4))
3010 W3=ABS(D3/(V3*0.1))
3020 W=W1+W2+W3
3030 W=W+0.3*W
3040 CALL "WAIT",W
3050 RETURN
3060 REM ROUTINE TO CONVERT INPUT LOCATIONS TO
3070 REM       CONTROLLER COORDINATES.
3080 REM H = RADIAL DISTANCE TO PROBE CENTERLINE.
3090 H=14.75
3100 REM V = VERTICAL DISTANCE FROM SLIDE TO CEILING.
3110 V5=46
3120 REM VERTICAL COORDINATE CONVERSION.
3130 FOR I=1 TO N2
3140 P2(I)=V5-(Y+L2(I))
3150 REM P2(I)=P2(I)+ADJUSTMENT
3160 NEXT I
3170 REM HORIZONTAL COORDINATE CONVERSION.
```

```
3180 FOR I=1 TO N2
3190 X=H-L1(I)
3200 IF L1(I)>7.25 THEN 3230
3210 P1(I)=X-X2
3220 GO TO 3240
3230 P1(I)=X+X1
3240 NEXT I
3250 RETURN
3260 REM Y DATA (HEIGHT) NEXT
3270 DATA 0,0.05,0.1,0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.5,0.6,0.8,1,2,3
3280 DATA 5,8,10,12
3290 REM X DATA (RADIUS) NEXT
3300 DATA 11
3310 REM THETA DATA NEXT
3320 DATA 0
```

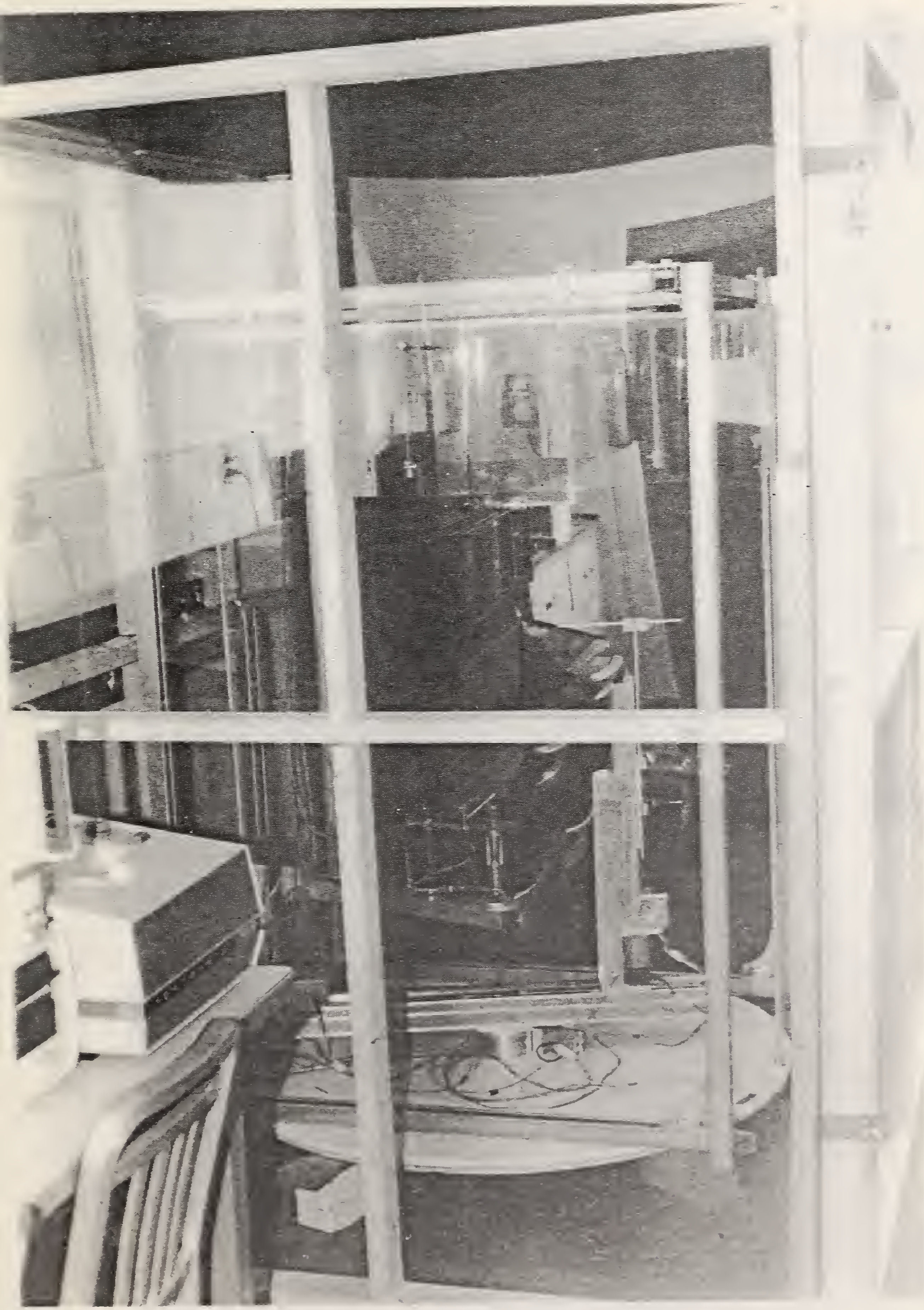

Figure 1. Photograph of Test Enclosure

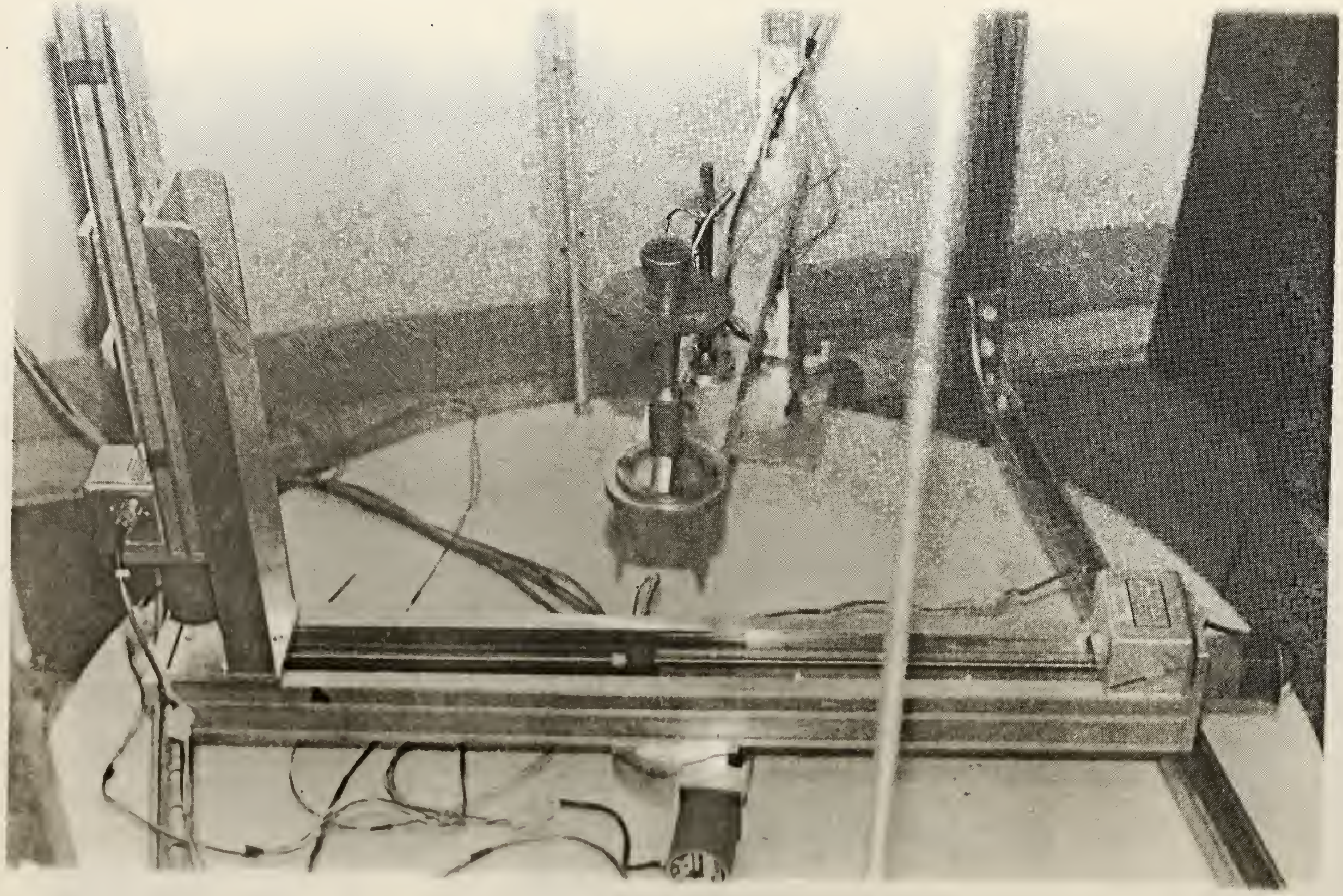

Figure 2. Photograph of Horizontal Motion Assembly

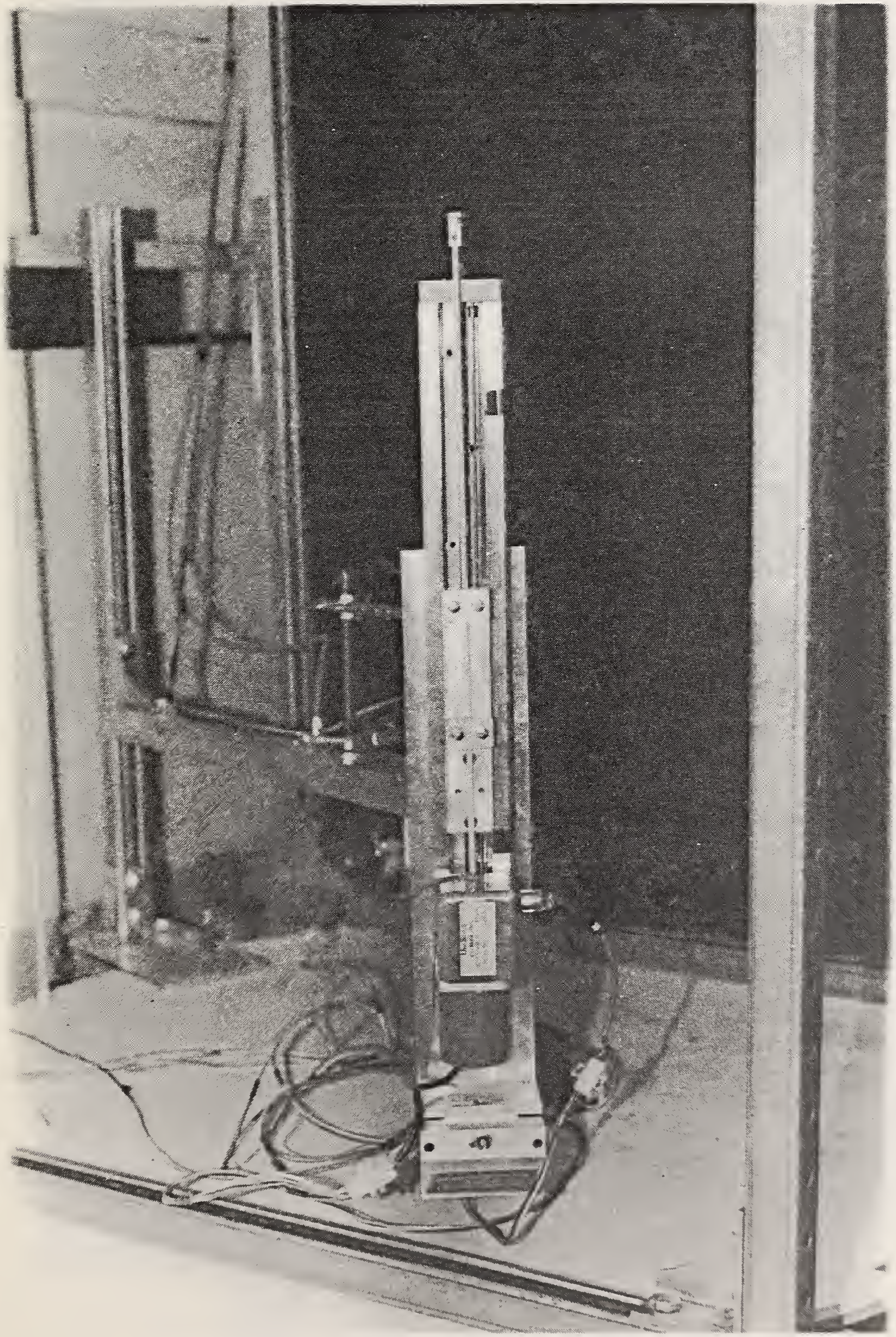

Figure 3. Photograph of Vertical Motion Assembly

Figure 4. Photograph of Rotary Motion Assembly

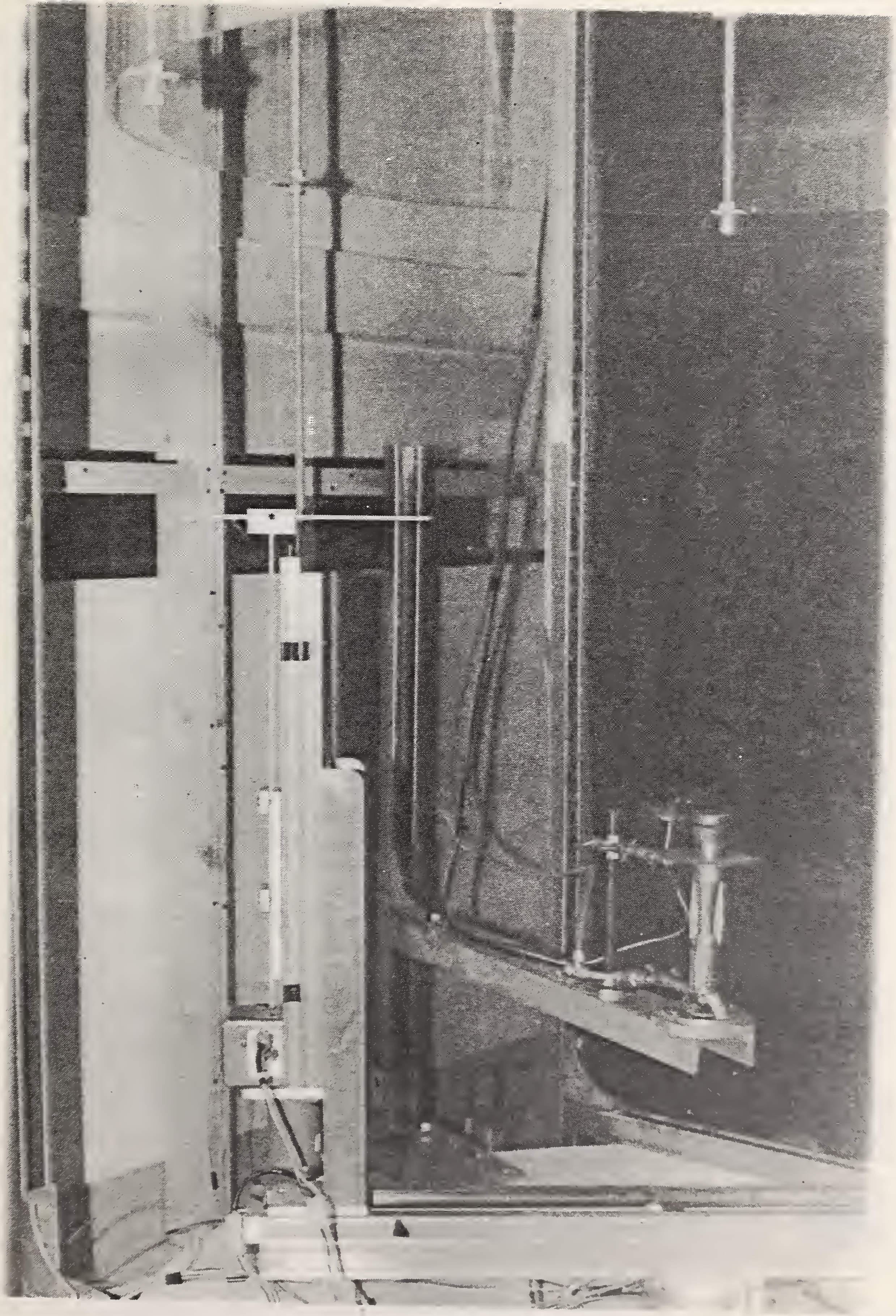

Figure 5. Photograph of Vertical Slide Attached to Horizontal Slide

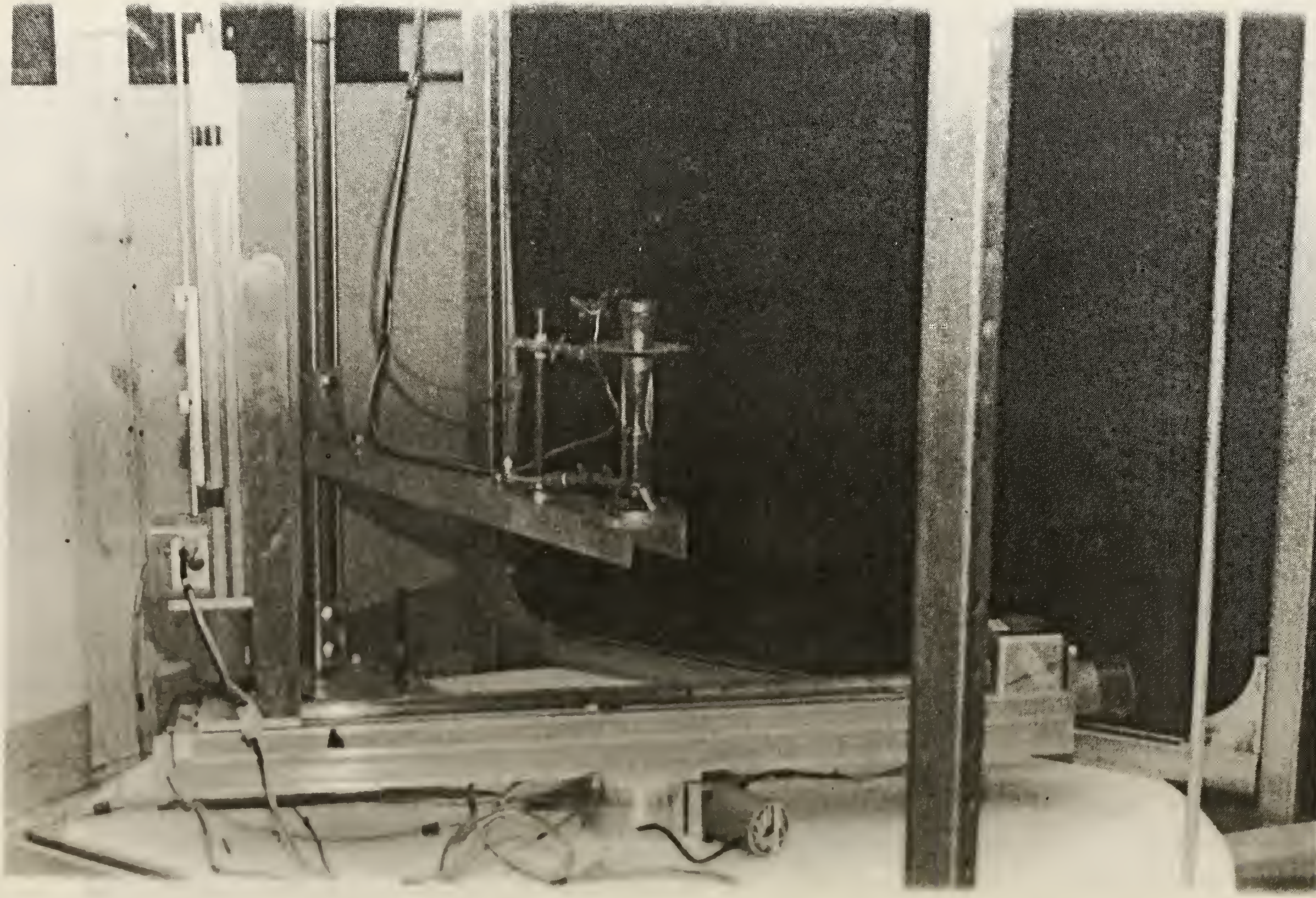

Figure 6. Photograph of Assembled Positioner System
(Side View)

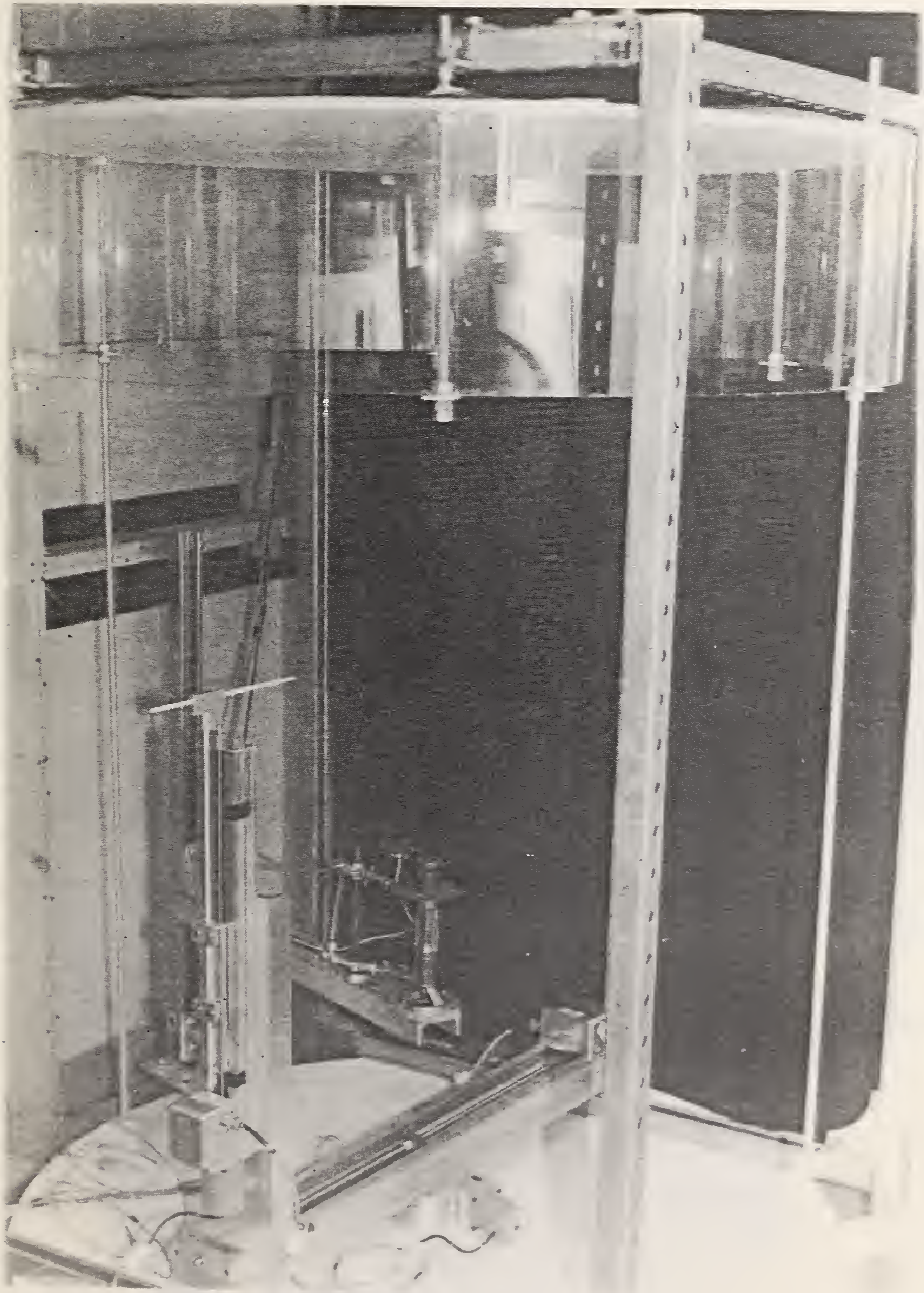

Figure 7. Photograph of Assembled Positioner System
(End View, looking from above)

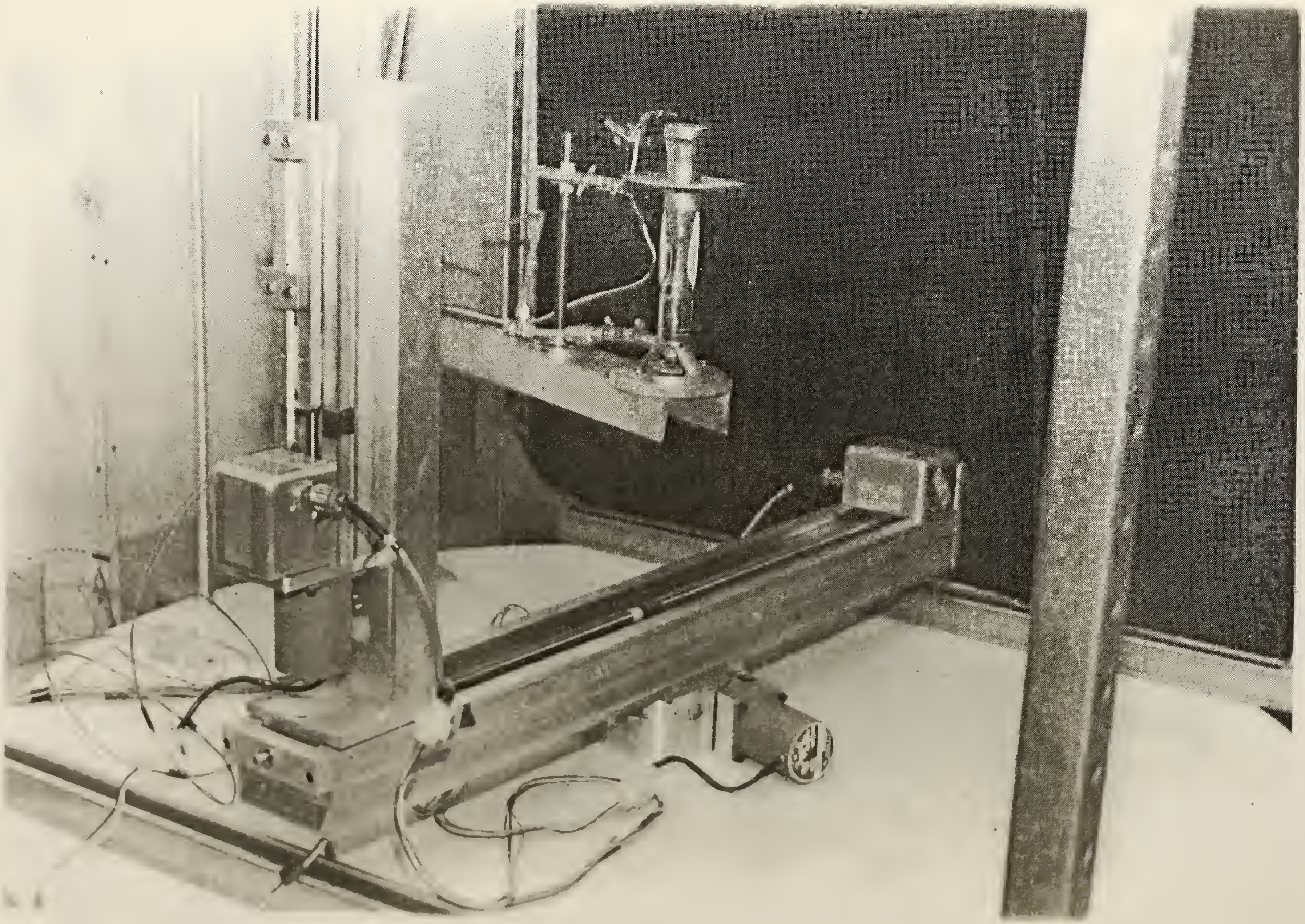

Figure 8. Photograph of Assembled Positioner System
(End View, looking from below)

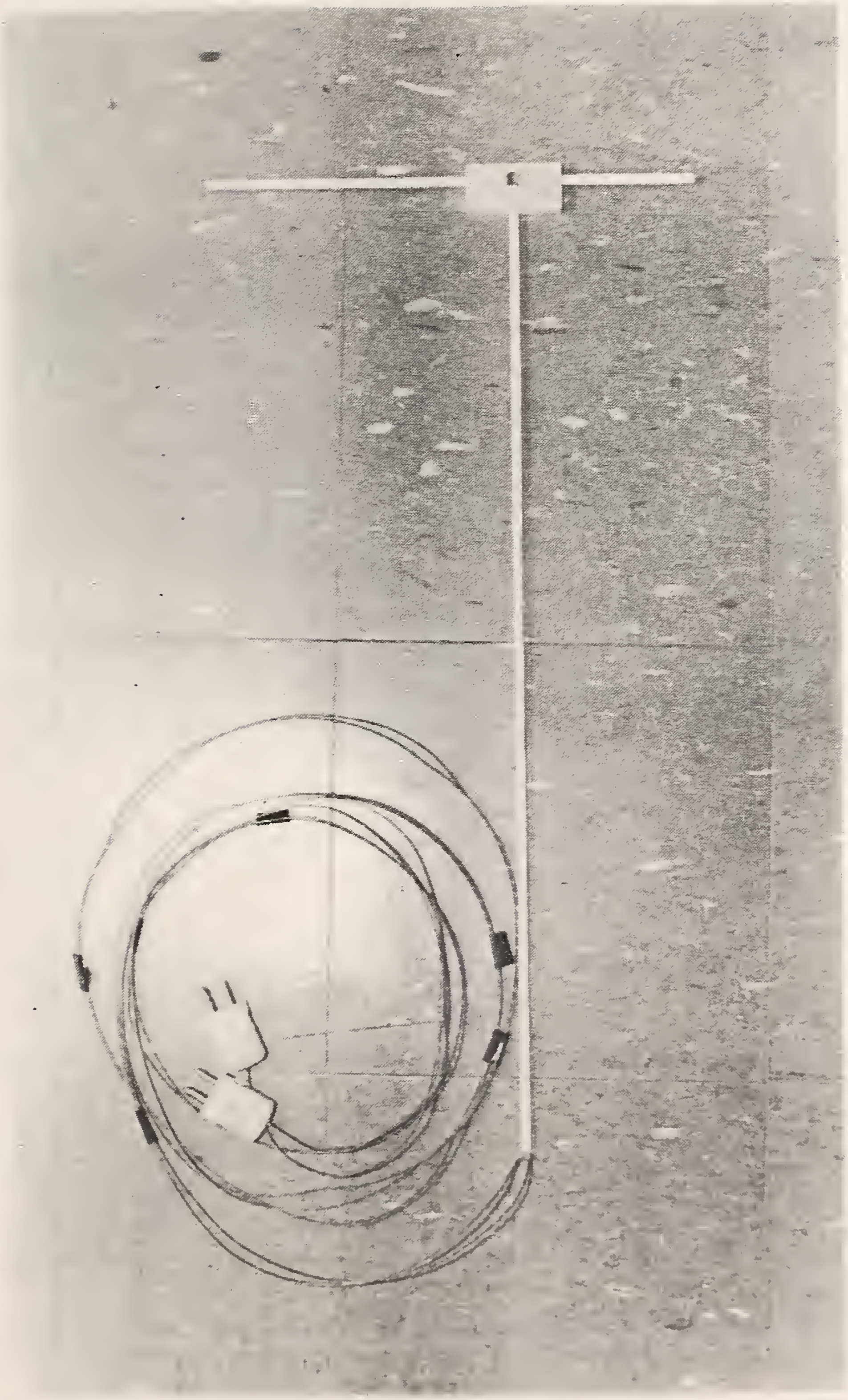

Figure 9. Photograph of Probe Support

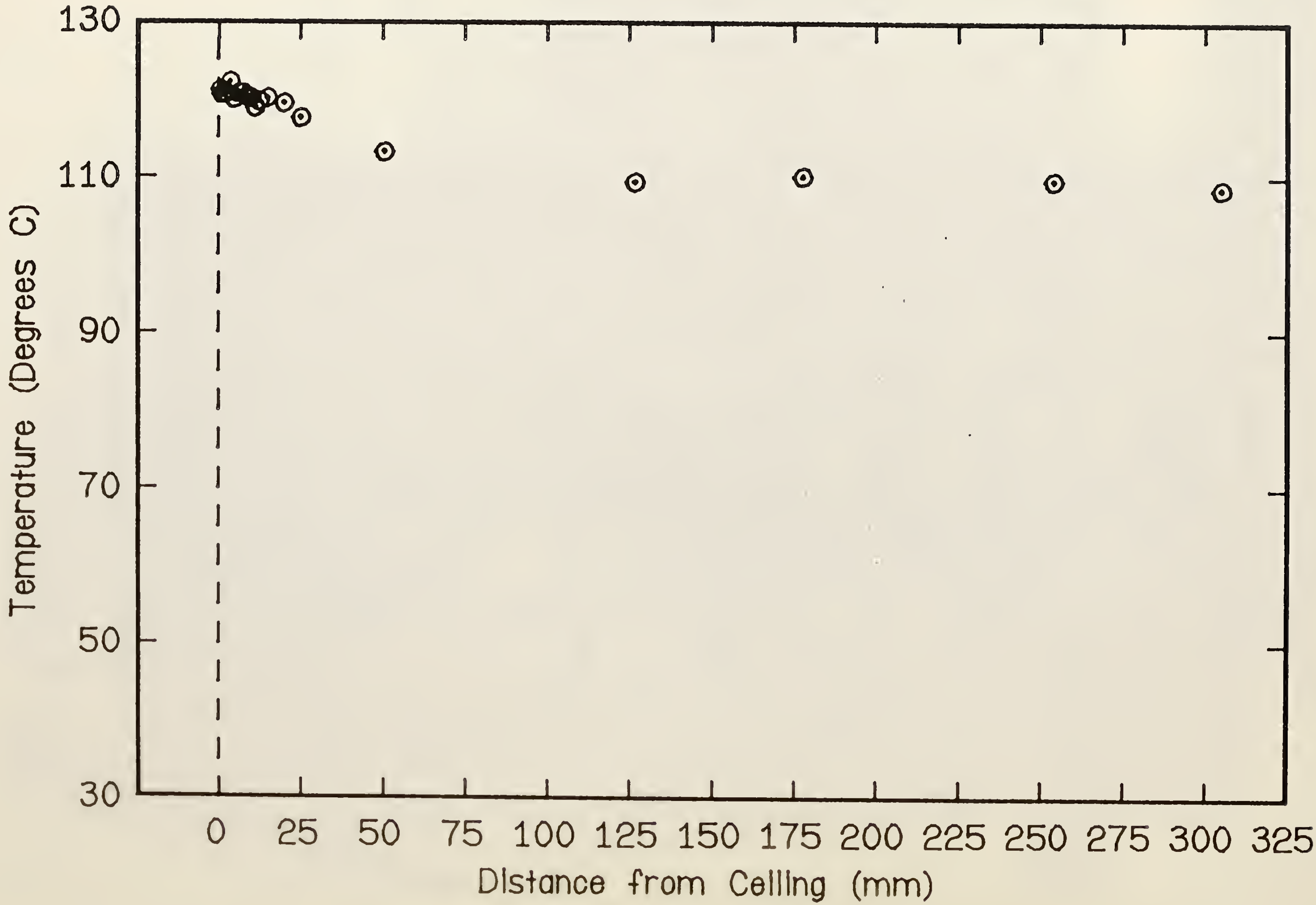

Figure 10. Plot of Gas Temperature vs. Distance from Ceiling for 50.8 mm from Burner Centerline

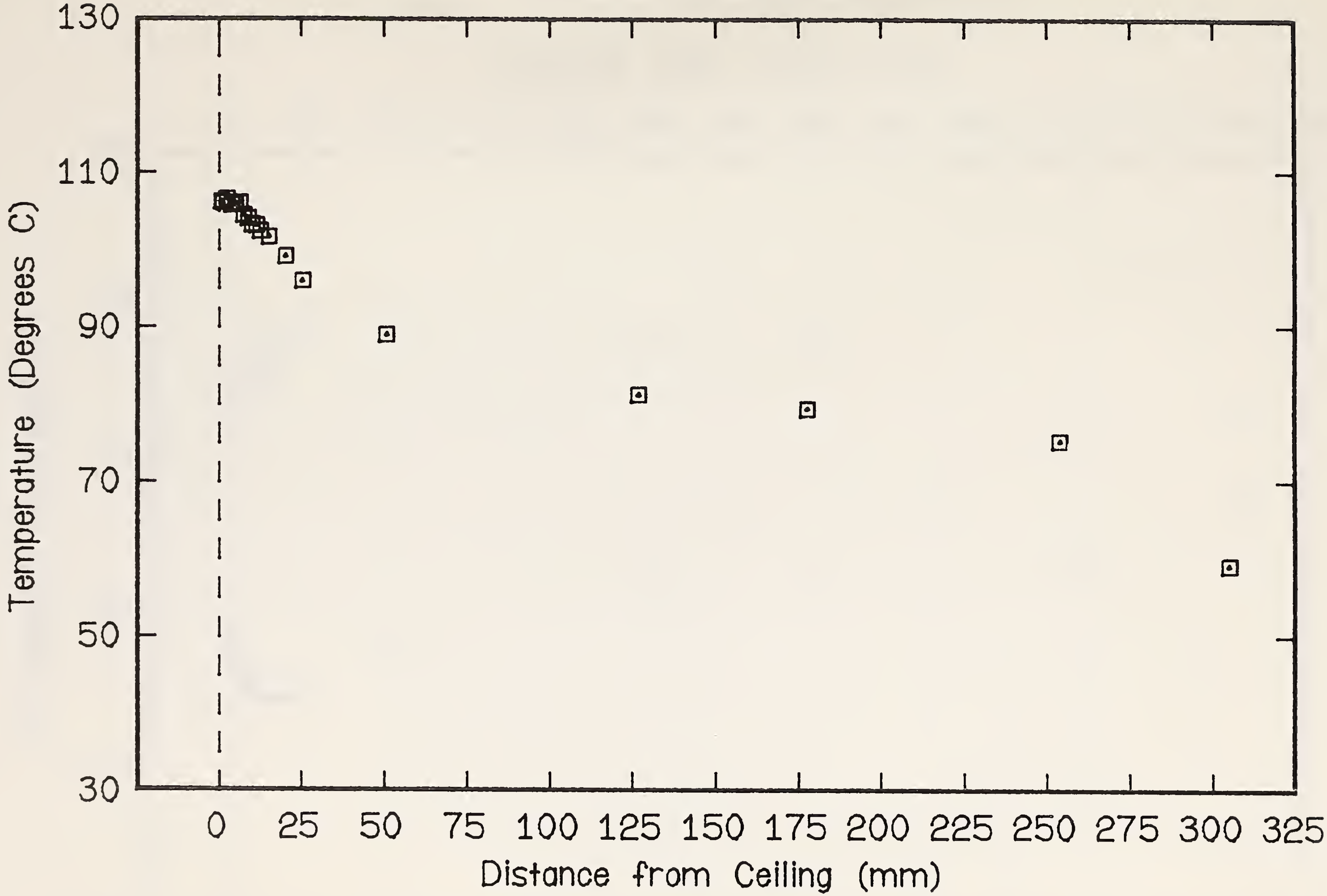

Figure 11. Plot of Gas Temperature vs. Distance from Ceiling for 152.4 mm from Burner Centerline

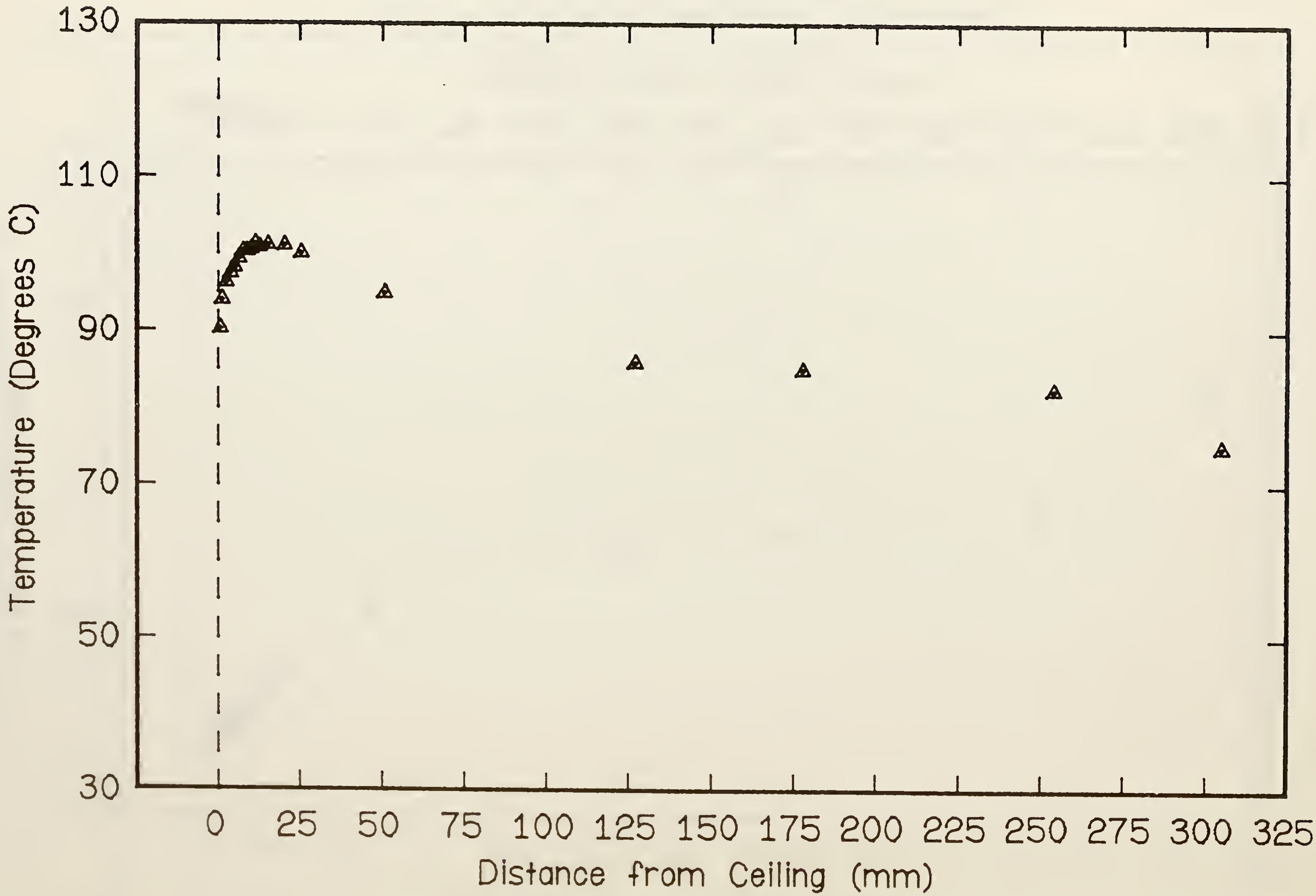

Figure 12. Plot of Gas Temperature vs. Distance from Ceiling for 305 mm from Burner Centerline

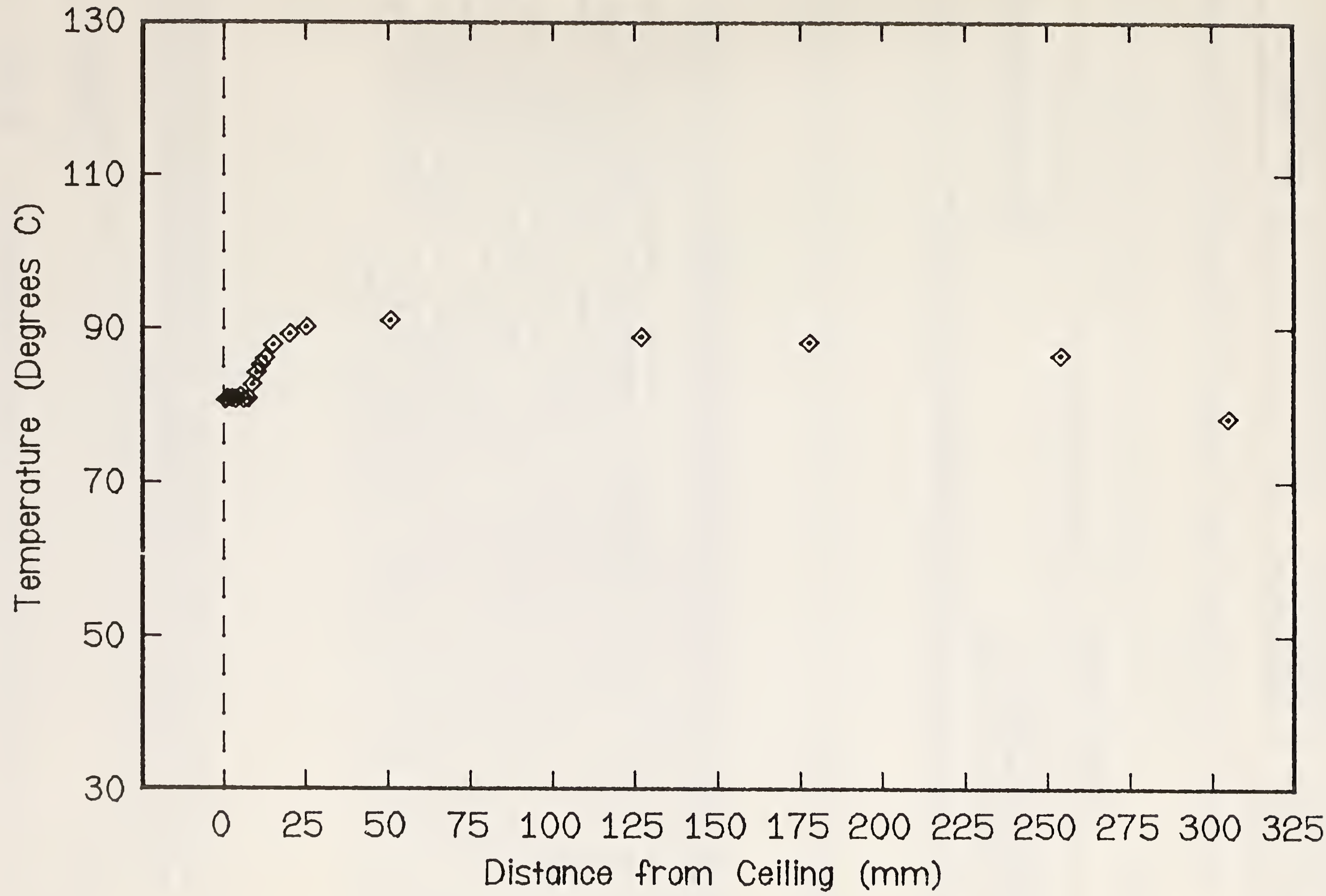

Figure 13. Plot of Gas Temperature vs. Distance from Ceiling for 508 mm from Burner Centerline

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This report describes the development of an automated probe positioner. This system has been used for extensive measurements of temperatures at a large number of positions within a laboratory-scale fire-flow experimental apparatus. In its present configuration, the device is designed to operate within a 1.22 m diameter cylindrical enclosure. The apparatus has horizontal, vertical, and rotational motion capabilities. A single microcomputer is used to control probe positioning, perform data-taking, and evaluate statistical results. These statistical results are used by the system to determine the number of data points to record at a given position. Large numbers of points may be taken at positions showing large fluctuations while small numbers of points are recorded in more quiescent flow regions. Results of several experiments, used to check positioning accuracy and system performance during actual tests, are presented. An analysis of the heat transfer to the test enclosure ceiling is included in the presentation of results.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

computers; experiments; fire measurements; gas burners; measuring instruments; temperature measurements; velocity measurements

13. AVAILABILITY

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