ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
ANN ARBOR

Final Report

DEVELOPMENT OF A FAST RADIOMETER FOR MEASURING GLASS-PRESS TEMPERATURES

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ABSTRACT

A radiometer using a lead sulfide cell as the sensing unit was fabricated for investigation of the rapid temperature variations of the male plunger surface of a glass press used to produce the front face of television tubes. Experiments show that the radiometer and a fast recorder can produce a recording of temperature changes with a high degree of accuracy.

OBJECTIVE

The purpose of this study was to investigate the possibility of measuring the forming plunger temperature of a glass press utilizing an infrared radiometer with rapid response design features.

OPERATION OF THE GLASS PRESS

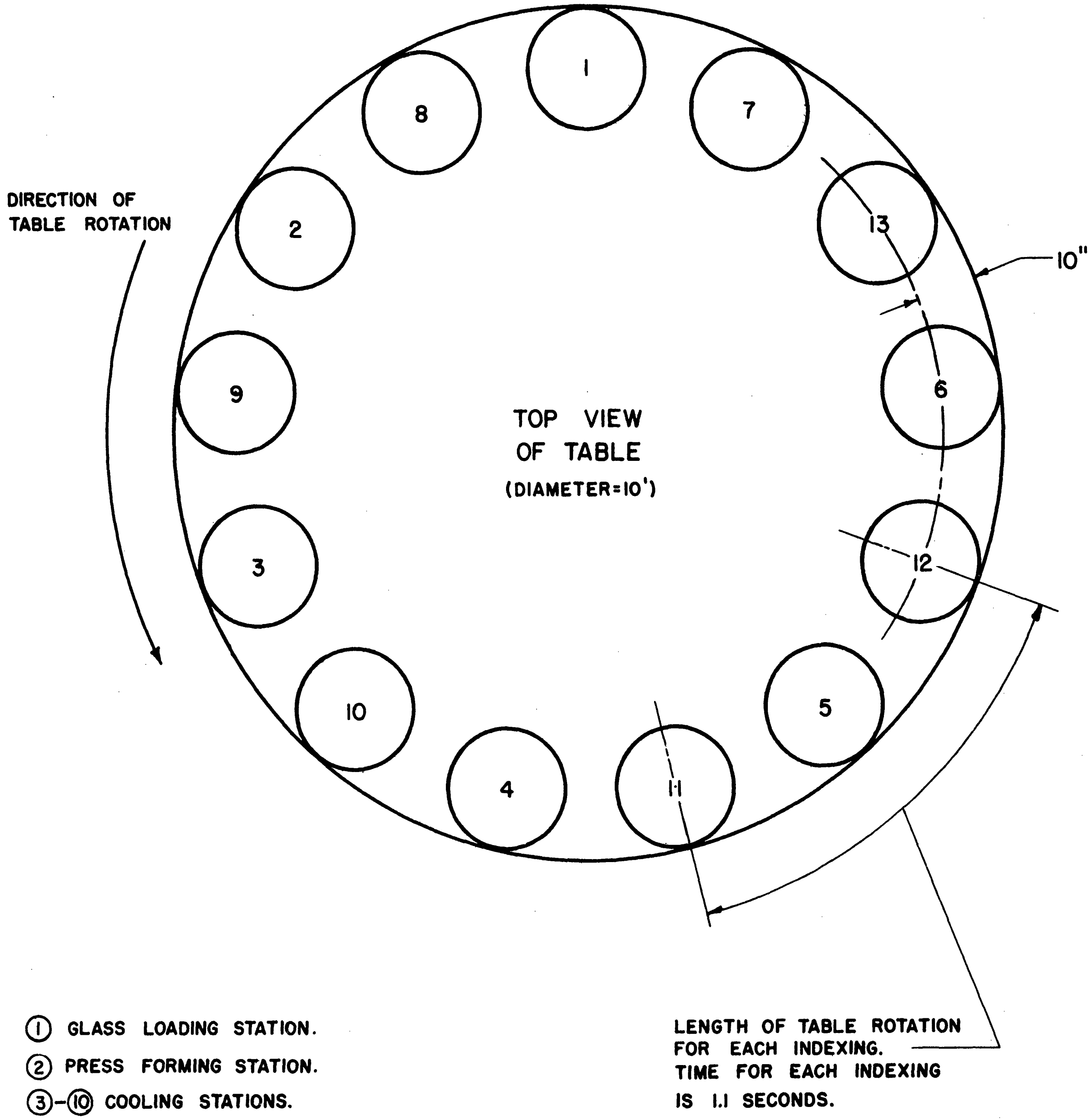
The formation of the television-tube face units is carried out using a glass press with a circular movable table. Depending on the type of product involved, the table contains an odd number of concave molds ranging from 5 to 13. The glass is formed and treated in its mold as the table indexes from station to station with each piece moving 1-1/2 revolutions of the table to complete the process.

A production cycle is as follows. A mass of molten glass is first dropped into a preheated female mold (Station 1 as indicated in Fig. 1). The mold now indexes once, skipping one station and arriving at the plunger station where the male forming-plunger presses the hot glass into the desired shape. The next indexing carries the mold two more stations, and the cooling process of the glass begins. Since the table contains an odd number of molds, and the complete cycle of the table is 1-1/2 revolutions, the formed piece indexes past the raised plunger the second time around as the cooling continues.

THE CONTROL PROBLEM

The quality of the glass product produced by the press is affected by the temperature of the forming-plunger. Because of the heat transfer from the molten glass to the plunger in the forming operation, the plunger is water-cooled. This cooling must be controlled, as an overheated plunger will cause the glass to adhere, while one that is underheated will result in striations in the glass. The present method of control entails observation of the finished product and adjustment of the water flow accordingly. However, this control method is highly unsatisfactory, first, because of the time lag between the pressing of a piece and its removal from the press for inspection, and second, because the defects cited encompass a temperature spread of about 100°F. Therefore, the operator is uncertain of the plunger temperature as long as it is within this 100°F spread.

Various temperature-measuring techniques were tested previously by Owens-Illinois engineers. Measurements with thermocouples placed inside the plunger had little meaning because of the temperature lag and the temperature differential encountered between the two sides of the thick metal die. Drilling a small blind hole and inserting a thermocouple very close to the die surface was also unsatisfactory since the local thermal variations induced left a visible mark on the finished product. Furthermore, the fast indexing and operating cycle does not permit the positioning of a contact thermocouple on the outer surface of the die.



(1) GLASS LOADING STATION.
(2) PRESS FORMING STATION.
(3)-(10) COOLING STATIONS.
(11) GLASS UNLOADING STATION.
(12)-(13) EMPTY MOLD PREHEATING STATIONS.

Fig. 1. Glass press - circular movable table.

As a result, a research project was set up with The University of Michigan to investigate the possibility of measuring the plunger temperature utilizing an infrared radiometer with rapid response design features. Such an instrument must exhibit the following characteristics for this problem:

1. It must be sensitive to the radiation emitted by a plunger in the temperature range of 700 to 1000°F. This radiation is a variant since the emissivity of the plunger metal is not known, but is thought to be in the range of 0.3 to 0.7, with possible variations depending on the length of time in service.

2. The response time of the radiometer must be fast enough to obtain a temperature measurement in 0.2 sec. The time cycle of the plunger is such that it is in contact with the glass for about 9 sec and is in its raised position for about 3.5 sec, and any measurements must be made while it is in this latter position. However, the radiation from the plunger during the 3.5 sec of the up-position time is ambiguous because during a portion of the time there is reflected radiation from one of the pieces of hot glass on the table below. Therefore, there remains only 0.2 sec when the radiation from the plunger results entirely from its own temperature.

INITIAL LABORATORY EXPERIMENTS

A study phase was carried out to determine the feasibility of measuring infrared radiation of the plunger utilizing a lead sulfide cell. Previous work with this and other detectors had shown the following to be true:

1. The lead sulfide cell is sensitive out to 2.5 μ.

2. The time constant of the cell (ca. 200 μsec) is well below the response time required.

3. Lead sulfide cells, in general, have sensitivities of the order of 10-20 v/mw/cm^2, and respond linearly to signal energies up to a level of approximately 100 μw/cm^2.

4. Other radiation detectors are available, such as vacuum thermocouples, thermistor bolometers, and other types of photoconductive cells, such as lead telluride and lead selenide. All these are sensitive to radiation of longer wavelengths than the lead sulfide cell. However, only the first two are commercially available, and their speed of response is not as good as the lead sulfide cell. They are also more susceptible to mechanical vibration and shock.

The initial experiment was carried out using a detector a 3/4- x 3/4-in. lead sulfide cell of .35 megohms dark resistance, placed in one leg of a bridge circuit. The output of the bridge was then displayed on a Sanborn Model 60-300 d-c strip-chart recorder. The radiation source was provided by a 2 x 2 x 1-1/4 in., previously oxidized steel block so placed in an oven that the square side faced the detector. To simulate the fast response characteristic, a shutter driven by a synchronous motor was used to expose the cell to radiation for 1/4 of each second. To limit the exposure area, a 1-cm-diameter aperture was so placed as to allow only the test-block radiation to impinge upon the cell. This is shown in Fig. 2.

The oven was heated to above 1100°F, turned off, and with the overall recorder sensitivity set at 40 mv per millimeter deflection, a cooling curve of temperature versus deflection was obtained.

The following results were obtained.

TABLE I. DEFLECTION VS. OVEN TEMPERATURE

Oven Temperature (°F)	Deflection (mm)
1100	40
1000	30
900	20
800	10
700	5.5
600	2.5

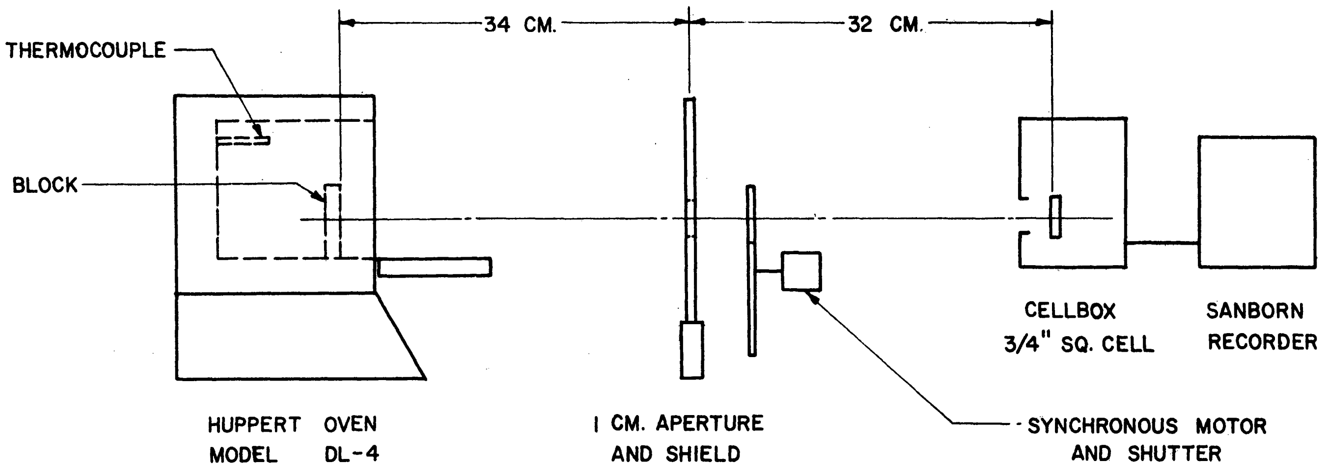
Furthermore, recorder traces taken at high tape speeds showed that the recorder was up to full deflection and steady in 0.1 sec. This speed of response is known to represent the maximum response rate of the recorder. Oscillographic displays indicate that the cell and bridge circuit respond even faster.

On the basis of the above experiment, it was decided (1) that a lead sulfide cell was satisfactory for the type of measurement desired, and (2) to fabricate a more usable working model for preliminary testing at the Owens-Illinois Columbus plant.

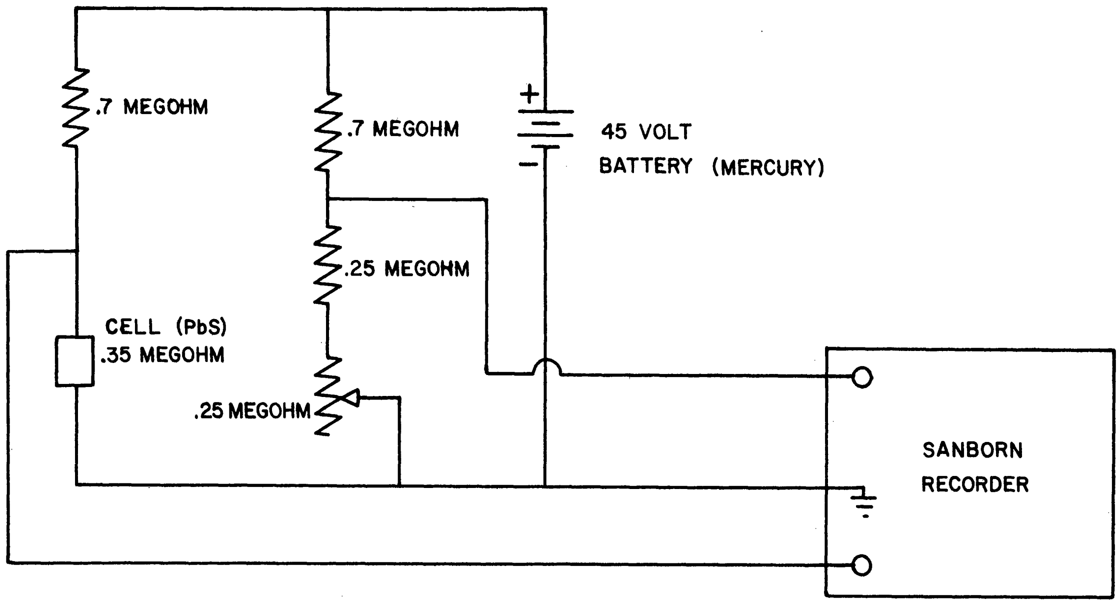
DESIGN AND TESTING OF A "BREADBOARD" MODEL

DESIGN

The components of the breadboard unit consisted of a Corning No. 2550 filter, a lens (f.l. = 6.5 in.), and the cell, all mounted into a telescopic system as shown in Fig. 3. Approximately one square inch of the plunger sur-

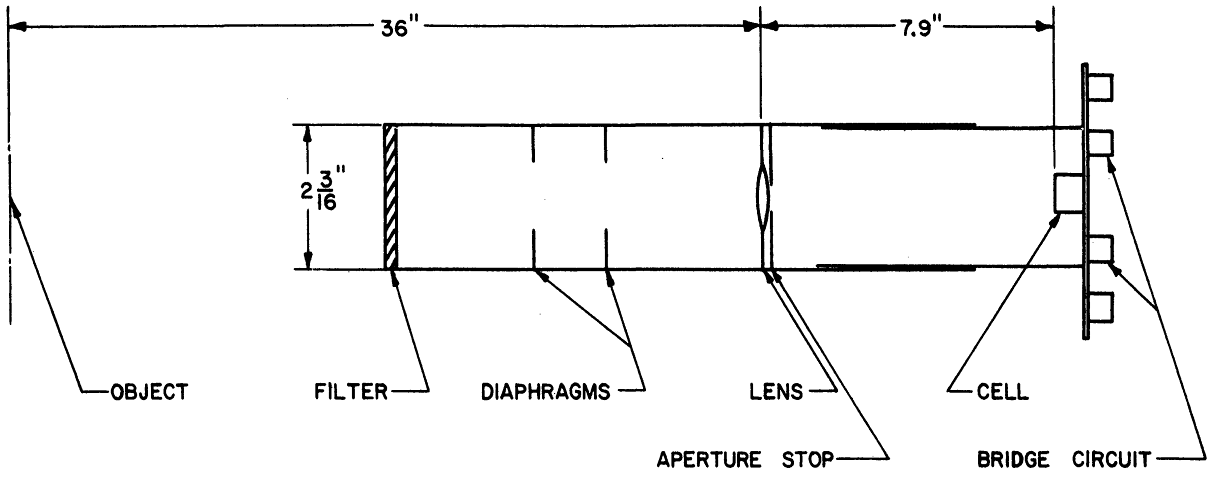


EXPERIMENTAL APPARATUS FOR MEASURING BLOCK RADIATION

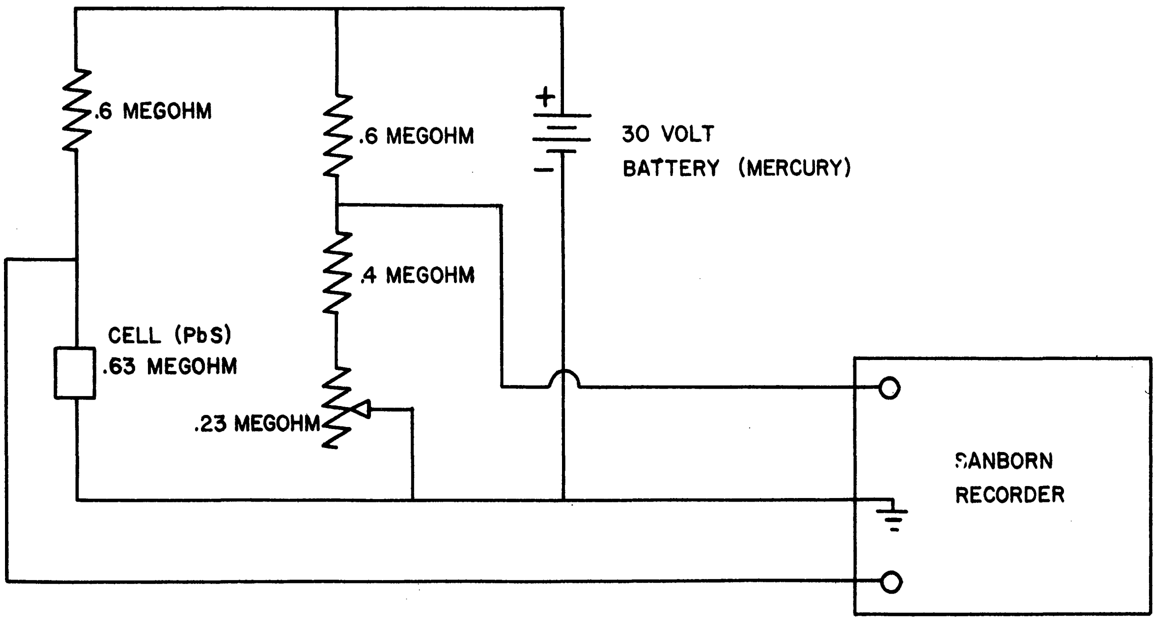


CELL BRIDGE CIRCUIT

Fig. 2. First experimental apparatus.



BREADBOARD RADIOMETER



CELL BRIDGE CIRCUIT

Fig. 3. Breadboard radiometer.

face when the radiometer was at a distance of three feet was to be viewed, and therefore a lens having a focal length of 6.5 in. was used to image the plunger surface on a 5 mm square cell. The filter was selected to make the radiometer insensitive to visible light. The bridge circuit associated with the cell was mounted directly behind the cell.

TESTS

A series of experiments was carried out to determine the proper operating conditions for the breadboard unit as dictated by the response characteristics of both the lead sulfide cell and the bridge circuit. From the initial experimental data obtained by using the full lens aperture, it was observed that the response curve showed saturation characteristics. Subsequent experiments were undertaken using apertures of 1, 1/2, and 1/4 in. The data shown in Fig. 4 were obtained using a 1/4-in. aperture. This curve is similar in shape to that which one would obtain by plotting infrared radiation for the spectral region in which the lead sulfide cell is sensitive. A thermocouple attached to the block surface provided the block temperature.

The next experiment undertaken was to determine whether changes in emissivity could be induced in the laboratory. To do this, three temperature runs were made with the same measuring technique and 1/4-in. aperture as outlined above, using as the radiant source a 2-1/2- x 3-in. section of cold-rolled steel which was plated in the same manner as the plunger surface material. Previous to the first run, the metal was maintained for one hour at 1200°F in an open air system to obtain an oxidized surface. The block was cooled and then heated to 1200°F three consecutive times; cooling-curve data were obtained each time. No variations in recorder deflection interpretable as major emissivity changes were noted in the data shown below.

TABLE II. CHANGE IN EMISSIVITY WITH TIME

Block Temperature (°F)	Recorder Deflection (mm) Run 1	Run 2	Run 3
1090	21.4	20.5	20.2
1027	15.5	15.3	15.0
901	7.5	7.4	7.6
774	3.6	3.3	3.3
644	1.4	1.7	1.3

The conclusion to be reached is that no significant changes in plunger material emissivity could be detected under present laboratory conditions.

A concluding laboratory experiment was then carried out to determine the

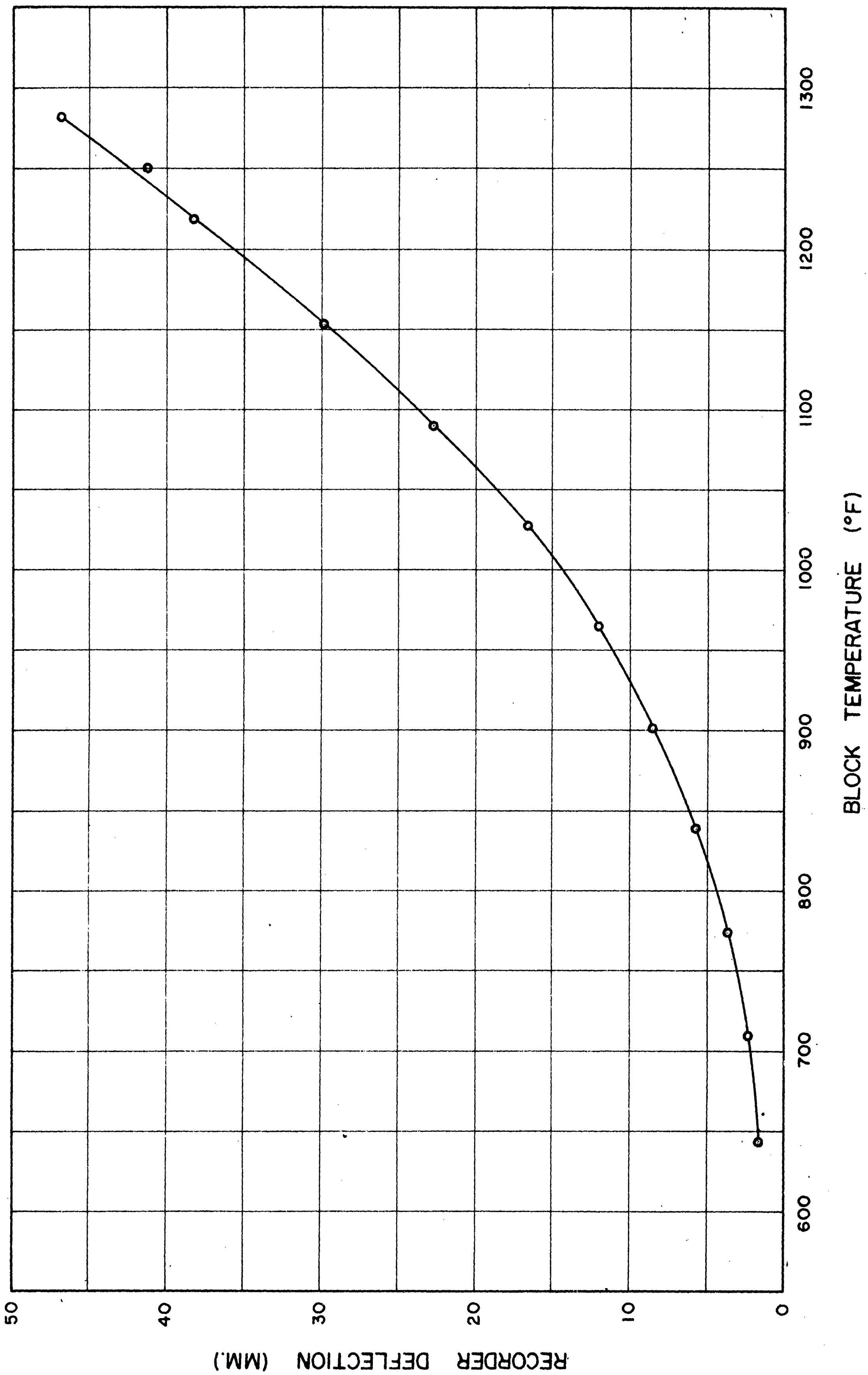


Fig. 4. Radiometer recording of source block temperature.

effect of continuous exposure to infrared radiation on the dark current and cell sensitivity. For this experiment, the block was maintained at approximately 900°F and the cell (using a 1/4-in. aperture) was exposed for 45 min. A consistent drift of dark-current deflection amounting to 10 mm at the end of the 45-min period was noted. However, the signal deflection also increased and several interim checks showed some detectable change in cell sensitivity. This is shown below.

TABLE III. CELL SENSITIVITY CHANGE WITH EXPOSURE TO 900°F SOURCE

Time Exposed (min)	Deflection (mm) (minus dark current)
0	7.3
30	8.3
45	9.6

Since no shutter was used, the exposure time of 45 min is at least equivalent to the total of the four previous runs when the shutter was used, and probably even to a much longer exposure time. Nevertheless, the exposure factor must be taken into account in final design considerations.

OWENS-ILLINOIS PLANT EXPERIMENTS

The breadboard radiometer was taken to the Owens-Illinois Columbus Plant on March 20, 1957. The purpose of this trip was essentially to cover the following points.

1. Verify the technique of rapid temperature determination by infrared radiation measurement.

2. Verify that the lead sulfide cell and associated measuring apparatus will provide the desired temperature information.

3. Verify the feasibility of the measurement system by correlating the response measurements with the cycling operation of the glass press.

4. To assay the problems involved, if Steps 1, 2, and 3 were verified, in any future radiometer designs.

The equipment taken on the trip included the radiometer, a d-c amplifier oscilloscope, and the mounting apparatus. It had been determined that the Owens-Illinois Sanborn recorder would be adequate. Unfortunately, this recorder was found to operate improperly. After checking our system by the scope presentation, the Owens-Illinois Sanborn recorder was taken apart and the faults corrected so that it would operate with a balanced-input type of circuitry. It was also suspected that the recorder preamplifier stages were improperly adjusted, but since a calibrated voltage source of proper impedance was lacking, no effort was expended toward checking and correcting this fault. Therefore, no quantitative comparisons can be made between data taken at different attenuator settings, and there is no proof that the saturation levels of either section of the bridge input were not attained.

Measurements were made with the apparatus at two general positions (as seen in Fig. 5):

1. with the unit almost at the height of the raised plunger, and viewing the plunger surface at an oblique angle; and

2. with the unit positioned upward at approximately a 50-75° angle with respect to the floor so as to be viewing the female mold, with exposure to the male plunger surface only during the indexing cycle.

The advantage of making measurements at Position 1 is that during indexing only the temperature of the plunger is observed and recorded. Therefore a simple picture is recorded. There are two main disadvantages:

1. The surface viewed comprises a large area of the plunger because of the oblique angle, thus reducing the possibility of measuring temperature variations across the die.

2. A large amount of flare light for a longer period of time is incident on the cell.

Unlike measurements taken at Position 1, those obtained at Position 2 are somewhat more complex due to the position of the radiometer. Whereas the radiometer at Position 1 views the plunger surface during the entire indexing cycle, the radiometer in Position 2 views the plunger surface only briefly at those times when the female molds do not block the view of the plunger. This by no means detracts from the validity of Position 2 measurements. Indeed, the female molds obstruct the view at just those times when the plunger surface radiation contains a large amount of reflected energy from the glass in the mold. As indicated in Fig. 5, the amount of flare light seen by the radiometer is considerably less in Position 2 than is the case in Position 1. Therefore it is expected that the more accurate measurement is obtained in Position 2. Furthermore, since a smaller and more easily controlled area of the plunger is viewed in Position 2 as compared to that viewed in Position 1, it is possible to perform more accurate temperature gradation measurements across the plunger surface using the radiometer in Position 2. Usable data were obtained on the following runs.

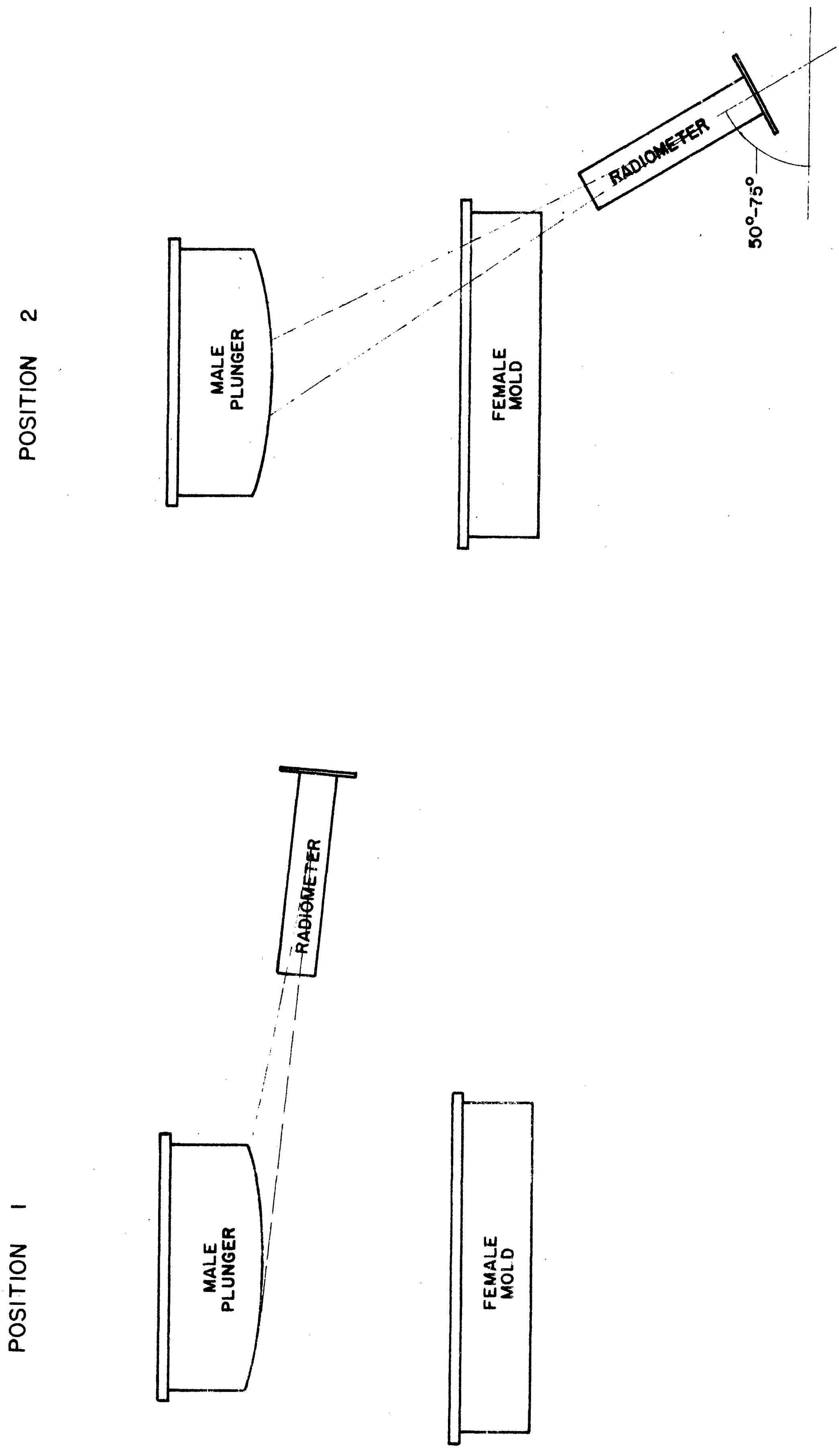


Fig. 5. Radiometer measurement positions.

A. POSITION 1. A NORMAL INDEXING CYCLE

The time for an indexing cycle, i.e., from the time the plunger starts to rise until it closes again, is approximately 3.5 sec. This may be observed in Fig. 6a where the various details of the radiometer output have been identified. Note that during a normal indexing cycle the "true" temperature of the plunger surface is measured only at Points 3 and 5. The obvious question arises: are the temperatures recorded at Points 3 and 5 influenced by reflected flare light from the passing cooled glass? If this were the case, then covering the cooled glass mold as it passed beneath the plunger should reverse the peak at Point 4, showing that Points 3 and 5 did not represent true temperatures.

B. POSITION 1. COOLED GLASS MOLD COVERED

An experiment was then performed to investigate this possible influence of reflected flare light. For several indexing cycles, the passing cooled glass mold was covered by a transit board, effectively shielding the plunger surface from the cooled glass radiation. The results are shown in Fig. 6b. Notice that no temperature gradient exists between Points 3, 4, and 5, thus proving that Points 3 and 5 are true indications of the plunger surface temperature during a normal indexing cycle.

C. POSITION 1. SKIPPED HOT GLASS MASS

To substantiate further that the flare light from the arriving hot glass mass was not contributing to the temperature indication at Point 5, the hot glass mass was diverted from the mold with the results as shown in Fig. 7a. Notice that no further drop in temperature is recorded at Point 5, indicating that flare contribution is insignificant. Point 6 on Fig. 7a indicates the plunger temperature plus the radiant contribution of the heated empty mold beneath it. Skipping one mass of glass, of course, allowed the plunger to cool considerably below its normal operating average. This initial drop in temperature followed by a gradual temperature rise was noted in the recordings obtained on subsequent cycles. After resuming normal operation, it was found that approximately 19 to 20 indexing cycles occurred before normal plunger temperatures were obtained once again. This correlates well with the 20 to 25 scrap pieces resulting from a skipped cycle as judged by usual quality-control inspection practices.

D. POSITION 1. COOLED EMPTY FEMALE MOLD

Having skipped a hot glass mass, the empty cooled mold indexed around and passed under the plunger again. Figure 7b shows the record obtained at that time. Again no variations at Points 3 and 5 were observed. This result is to

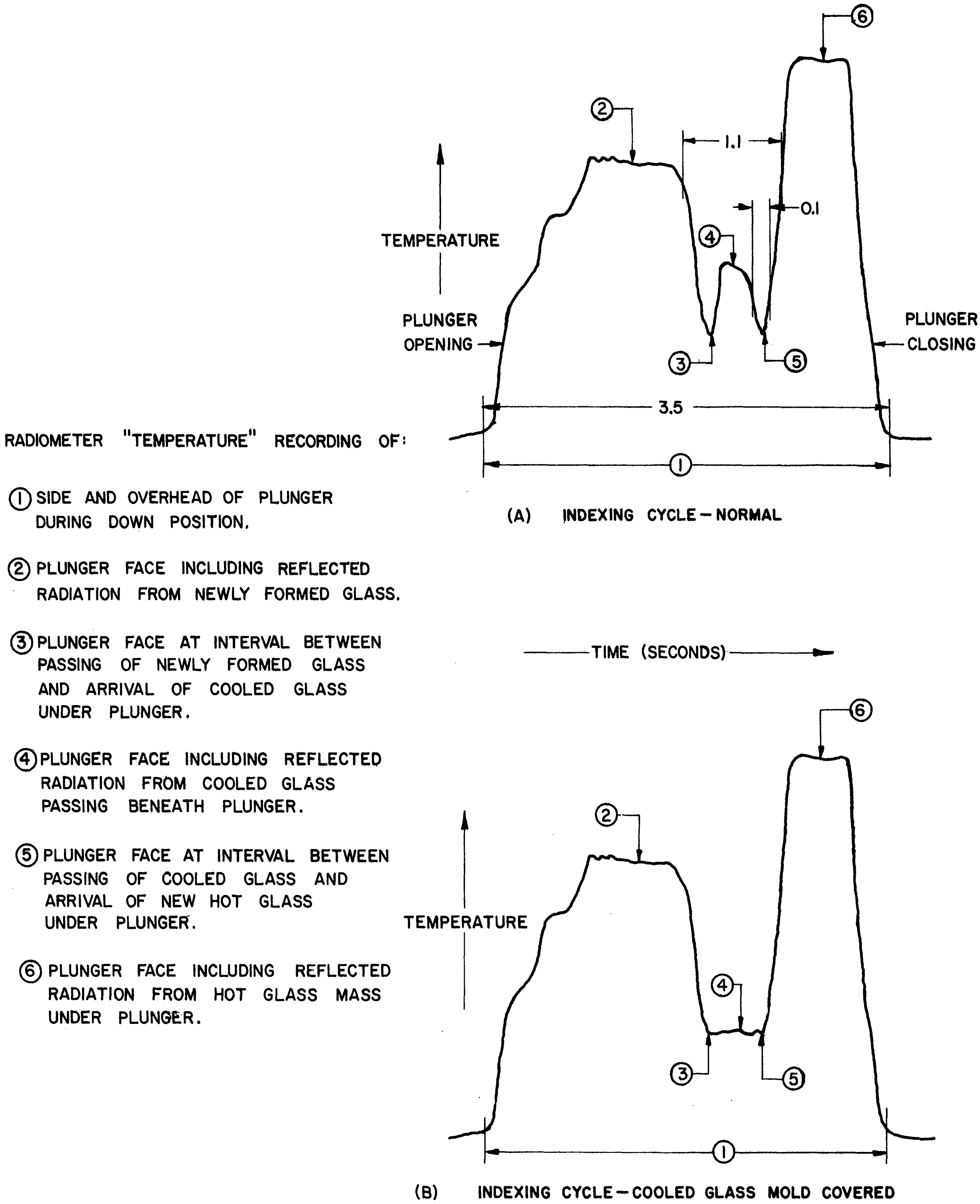


Fig. 6. Glass forming indexing cycles, Position 1, Runs A and B.

RADIOMETER "TEMPERATURE" RECORDING OF:

(1) SIDE AND OVERHEAD OF PLUNGER DURING DOWN POSITION.

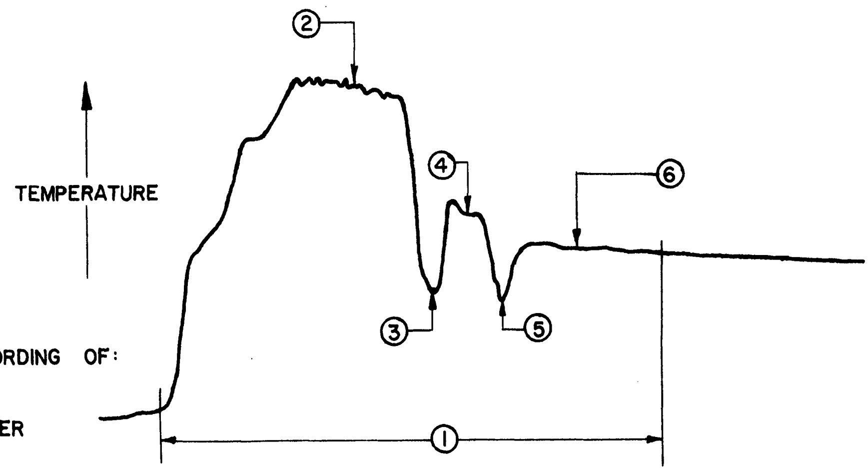
(2) PLUNGER FACE INCLUDING REFLECTED RADIATION FROM NEWLY FORMED GLASS.

(3) PLUNGER FACE AT INTERVAL BETWEEN PASSING OF NEWLY FORMED GLASS AND ARRIVAL OF COOLED GLASS UNDER PLUNGER.

(4) PLUNGER FACE INCLUDING REFLECTED RADIATION FROM COOLED GLASS PASSING BENEATH PLUNGER.

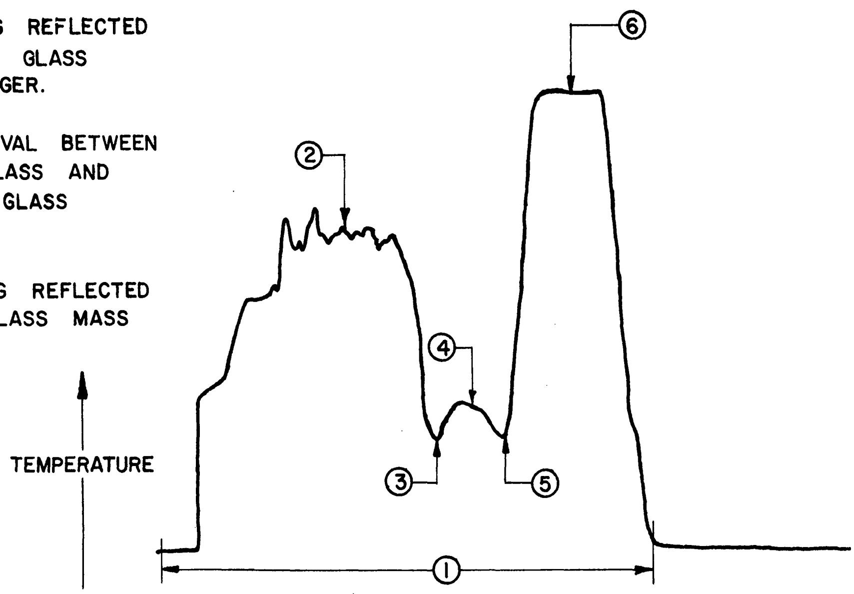
(5) PLUNGER FACE AT INTERVAL BETWEEN PASSING OF COOLED GLASS AND ARRIVAL OF NEW HOT GLASS UNDER PLUNGER.

(6) PLUNGER FACE INCLUDING REFLECTED RADIATION FROM HOT GLASS MASS UNDER PLUNGER.



(A) INDEXING CYCLE - SKIPPED HOT GLASS MASS

TIME (SECONDS) →



(B) INDEXING CYCLE - COOLED EMPTY FEMALE MOLD

Fig. 7. Glass forming indexing cycles, Position 1, Runs C and D.

be expected since the more drastic experiment represented by Fig. 6b showed no contributions from the covered cooled molds to Points 3 and 5.

E. POSITION 2. NORMAL INDEXING CYCLE

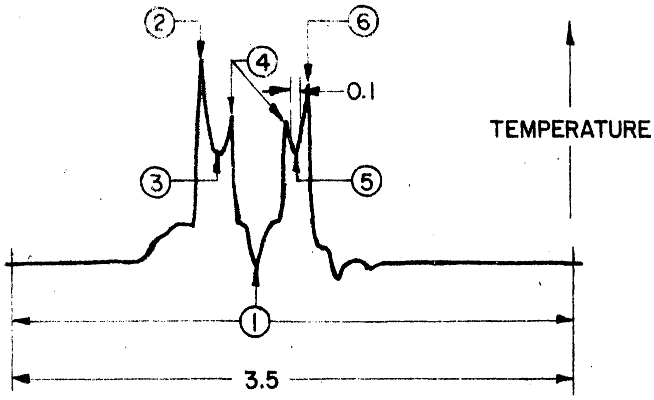
The recording of the normal indexing cycle differs appreciably from that obtained at Position 1 due to the shielding of the radiometer from the plunger radiation by the indexing female molds. The indexing cycle is still 3.5 sec. However, as may be seen from Fig. 8a, the plunger is viewed for only about 0.6 sec, while for the other 2.9 sec the plunger radiation is blocked successively by the mold containing the newly formed glass, the passing cooled glass mold, and the mold containing the hot glass mass. But as has been noted before, this positioning of the radiometer, although providing a seemingly more complex recording, in reality offers a better measurement technique because of the observing angles. Therefore Points 3 and 5 as indicated on Fig. 8 are expected to be more useful representations of the plunger's thermal behavior than those presented in Figs. 6 and 7.

F. POSITION 2. SKIPPED HOT GLASS MASS

To show that no contribution to the plunger temperature as indicated at Point 5 was made by the flare light of the arriving hot glass mass, this mass was diverted from the arriving mold with the results recorded as shown in Fig. 8b. Notice that less amplitude is indicated at Point 6 where flare light usually dominates. No change was recorded at Point 5, showing that the measurement of the true plunger temperature indicated at that point is not influenced by the flare light of the hot glass mass.

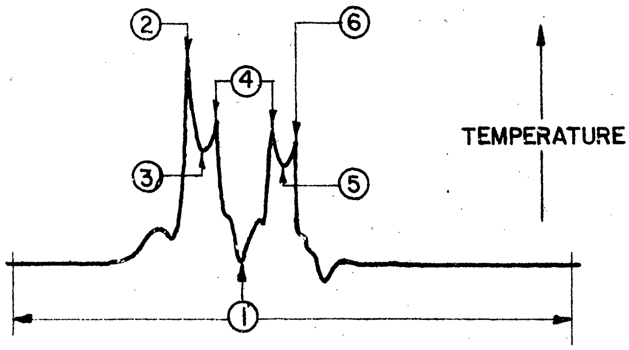
G. POSITION 2. COOLED EMPTY FEMALE MOLD

To confirm the supposition that no contribution to the plunger temperature indications at Points 3 and 5 were made by the passing cooled glass, a recording was taken of an indexing cycle in which there was no glass in the passing mold. This is shown in Fig. 8c. Note that there is no change in the recording curve at Points 3 and 5, showing no contribution to the plunger temperature indication from the passing mold. Of course the temperature indicated at Point 4 shows a decrease when compared to Point 4 of Fig. 8a, since the mold at 8c was empty and consequently cooler.



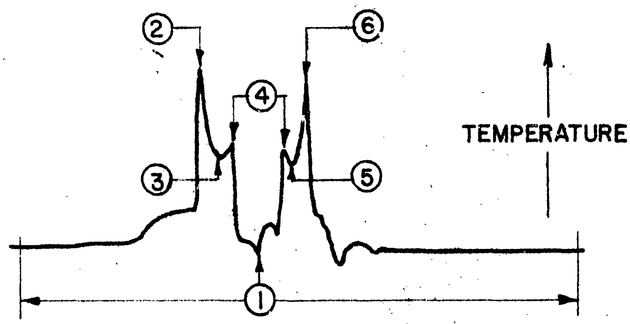
(A) INDEXING CYCLE – NORMAL

TIME (SECONDS)



(B) INDEXING CYCLE—SKIPPED HOT GLASS MASS

TIME (SECONDS)



(C) INDEXING CYCLE—COOLED EMPTY FEMALE MOLD

RADIOMETER "TEMPERATURE" RECORDING OF:

1 UNDERSIDE OF FEMALE MOLDS.

2 PLUNGER FACE INCLUDING REFLECTED RADIATION FROM NEWLY FORMED GLASS ARRIVING UNDER PLUNGER.

3 PLUNGER FACE AT INTERVAL BETWEEN PASSING OF NEWLY FORMED GLASS AND ARRIVAL OF COOLED GLASS.

4 PLUNGER FACE INCLUDING REFLECTED RADIATION FROM COOLED GLASS PASSING BENEATH PLUNGER.

5 PLUNGER FACE AT INTERVAL BETWEEN PASSING OF COOLED GLASS AND ARRIVAL OF HOT GLASS MASS.

6 PLUNGER FACE INCLUDING REFLECTED RADIATION FROM HOT GLASS MASS ARRIVING UNDER PLUNGER.

NOTE: RADIOMETER EXPOSED TO PLUNGER SURFACE RADIATION AT INTERVALS BETWEEN POINTS 2 TO 4 AND 4 TO 6.

Fig. 8. Glass forming indexing cycles, Position 2, Runs E, F, and G.

CONCLUSIONS

As a result of the plant tests and the previous laboratory experiments, the following was concluded:

1. Determination of male plunger die temperatures can be obtained using infrared measurement techniques.

2. The response of the lead sulfide cell and the associated circuitry is rapid enough to follow changes in plunger temperatures. This may be observed from an examination of Figs. 6 through 8.

3. Accurate correlation can be obtained between the response of the measurement system and cycling operation of the glass press.

4. There is some change in cell sensitivity over periods of relatively long exposure time. This variation can be minimized by utilizing a shutter system for controlling exposure time.

5. The present limited data seem to indicate that possible emissivity changes do not constitute a serious limitation for this application. However, refined instrumentation and carefully controlled experiments will be required to substantiate this.

RECOMMENDATIONS

The breadboard radiometer demonstrated that it is feasible to measure the plunger temperature using its infrared radiation. The next logical step in the program would be to design and fabricate a research-type radiometer for use by an engineer under everyday plant conditions. This will permit the measurement of plunger temperatures at various points and under varying conditions to establish the particular measurements and correlations that are necessary for proper quality control. This information is necessary before the final phase of the program, the design of a quality-control radiometer, can be undertaken.

The research-type radiometer should incorporate the following improvements lacking in the breadboard model:

1. a convenient sighting apparatus;

2. a more readily adaptable aperture-changing device;

3. a shutter arrangement to block radiation during nonmeasuring time;

4. a calibration-signal source, either an electrical or radiant signal, or both;

5. a more adequate mounting system; and

6. a suitable recorder.