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providing a window into the process

Melt Pressure Measurement: Environmental Effects

Introduction

The Need for Pressure Measurement in Extrusion

In order to maintain the dimensional stability necessary to produce extruded products that meet todays precise quality and tolerance specifications, it is necessary to keep both the output rate and the melt condition constant (1,2). Although it is not possible to measure these quantities continuously, closely related variables such as melt temperature and melt pressure can be measured or controlled. If there is a constant feed condition, uniform melt temperature and constant melt pressure at the die, the output rate can be considered constant (2).

In practice, melt pressure measurements are invaluable for a number of reasons. Small changes in head pressure have been related to dimensional variations in the extrudate. Studies have shown that a head pressure variation of 1% is equivalent to a 1-3% change in extruder output, depending on the rheological properties of the polymer melt (3). Die pressure changes have been found to follow output rate changes (surging) accurately although cannot be directly related to output due to changes in melt viscosity (4).

Melt pressure has also been related to the cellular quality of foamed extrudates. Results indicate that as the extrusion pressure increases, cell size decreases, foam density decreases and the overall quality of the foam increases (5). Extrusion head pressure measurements are also used as a diagnostic tool.

Changes in head pressure can indicate the condition of the screen pack, die or barrel heater troubles, screw/barrel wear or damage, material feed problems and start up or shut down related problems (6).

In general, accurate pressure measurements can improve production, product quality, protect personnel and equipment from damage, and can be used as a diagnostic tool. Yet, industry wide data suggest that only 50% of all extruders are equipped with melt pressure sensing equipment (7).

Pressure Sensors

Pressure is not a fundamental quantity, but is derived from force and area, which in turn are derived from mass, length and time, the fundamental quantities. The vast majority of practical pressure measurement devices are elastic transducers and use a Bourdon tube, diaphragm or bellows as their sensitive element. The gross deflection of these elements may directly actuate a pointer/scale readout through suitable linkage, or the motion may be transducer to an electrical signal by one means or another. Strain gages bonded to diaphragm actuate beams are widely used to measure local strains, that are directly related to pressure (8). Melt pressure sensors for extrusion applications must meet certain requirements. The sensors are exposed to high temperatures (up to 700°F) and high pressures (up to 30,000 psi) for long periods of time, and may operate in abrasive or corrosive environments. A brief description of the most commonly used types of melt pressure sensors is given below.

Bourdon Tube

The simplest type of melt pressure sensor is the silicone grease filled Bourdon tube gage, equipped with a grease gun fitting at the dial end of the gage for filling and cleaning obstructions. These gages should be located on the underside of the equipment to minimize contamination, since the polymer melt is in direct contact with the silicone grease (9, 10). Without proper care, these gages may become plugged with polymer. On the other hand, routine maintenance during extruder operation will result in grease contamination of the extrudate (11).Bourdon gages can monitor pressure, but cannot act as the sensing element for control systems. The Bourdon tube gage is still used to some extent, but other mechanical senors have been developed to perform a similar function, without the disadvantages associated with direct grease/ melt contact.

Mechanical Pressure Sensors Incorporating A Lower Diaphragm

These mechanical pressure sensors work on a principle similar to that of the silicone grease filled Bourdon gages, but have a solid diaphragm between the strain transfer media and the polymer melt, and thereby eliminating the contamination problems (9). The motion of the diaphragm in contact with the melt is transferred to the gage portion of the instrument using a fluid-filled capillary or a push rod. These sensors are an improvement over the grease filled Bourdon gage, and generally function as melt pressure monitors, although pneumatic types can act as the sensing element for melt pressure control systems.

Electronic Pressure Transducers

Electronic Melt Pressure sensors or transducers are accurate and versatile instruments. These sensors have a metal diaphragm flush with the extruder's die or barrel wall. The motion of this lower diaphragm is transferred to the elastic electronic displacement transducer, which is located some distance away from the process heat, by a push rod or fluid-filled capillary tube (4). The internal structure of the push rod and capillary transducer stems is shown in Figure 4.

The fluid filled capillary or push rod, mechanically deforms the upper elastic displacement transducer, and an electrical signal proportional to the melt pressure is obtained. Bonded foil-type strain gage pressure transducers are of interest here, although other electronic displacement transducers, such as piezoelectric elements are widely used (8). The electrical output pressure signals from these transducers can be displayed, recorded or fed to control systems (9).

Electronic pressure transducers using the fluid-filled capillary system to transfer lower diaphragm deflections to the electronic sensing element, have certain advantages over the push rod type. These transducers are insensitive to mounting torque, have an increased diaphragm fatigue life, often have greater accuracy (typically ±0.5 of the full-scale range as opposed to ±1.0% of the full-scale range for push rob types), and have the ability to incorporate flexible stems if necessary (12). However, the liquid mercury fill in the capillary system, approximately 0.003 cubic inches per transducer, is a concern to processors of certain products such as food packaging. Lower diaphragm rupture could result in extrudate contamination, not a problem encountered with push rob transducers. Unfortunately, push rob transducers are sensitive to mounting torque and are said to be sensitive to ambient temperature changes (12). This study was performed to determine the relative effect of ambient temperature fluctuations on the output signal of both push rod and fluid-filled capillary type transducers. Highlights of the study are presented in this paper.

Experimental

Pressure Variation Vs. Production Variation

To illustrate the importance of melt pressure measurement in extrusion, and in order to obtain a relationship between melt pressure variation, and product dimensional variation, simulated surging experiment was performed. The experimental equipment consisted of a 2½ inch, 24:1 L/D ratio, Welex Extruder, fixed with a strand die and a pressure valve. Low melt index Arco 2800 F"Dylan" LDPE was extruded through the die, with the head pressure valved to 2500 psig. A mechanical device fixed to the pressure valve caused the valve to screw in and out of the melt stream regularly, causing sinusoidal variations in the melt pressure. The frequency of oscillation (ΔP) was varied. The strand was then hauled off at a constant rate, with a draw-down ratio of 1.2:1, cooled, and the diameter measured at increments along the strand length.

Pressure Transducer Environmental Study

Run 1 "Normal" Extrusion Environment: The extruder described above, and shown schematically in Figure 3 was used for the study. An extrusion die with melt pressure transducer ports located at an equivalent length along the die, but 180° apart was used. A push rod transducer (Dynisco Model PT411-1M-6) was placed in pressure port B and fluid-filled capillary transducer (Dynisco Model PT420A-1M-6) was placed in pressure port A. Later, the positions were reversed. Both transducers had a range of 0-1000 psig and an overall accuracy rated at ±1.0% of the full-scale range. Arco 6560 "Super Dylan" HDPE was extruded and melt pressure at locations A and B were recorded. Ambient air temperatures in the vicinity of the extrusion die were also recorded.

Run 2 Stem Environmental Temperature Chamber: The environmental chamber shown schematically in Figure 7, was mounted around the extrusion die. This chamber was designed to isolate the ambient temperature conditions in which the stem portion of the pressure transducers operate. Air, at controlled temperatures was circulated through the chamber at a rate of 40 cubic feet/minute. While extruding at steady state conditions, the transducer outputs were recorded, as controlled changes in the environmental temperature were acting on the transducer stems.

Run 3 Full Transducer Environmental Chamber: In this test, the larger chamber shown in Figure 11, was mounted around the extrusion die. This chamber was used to determine how environmental temperature changes acting on the full transducer, i.e. the stem and upper strain gage housing, influence the output signals of the transducers, during steady state extrusion. The results obtained from Runs 1,2 and 3 were used to determine the relative magnitude of the ambient temperature sensitivity of the transducer components.

Results and Discussion

The results of the simulated surge experiment show that changes in melt pressure can be related to product dimensional variation. Figure 1 shows how an extruded strand diameter changes with a sinusoidal disturbance in the process. The frequency of dimensional variation correlates well with that of the disturbance. Figure 2 shows that as the amplitude of pressure fluctuation increases, the dimensional uniformity of the product decreases. Although the experiment only simulated melt pressure instability, from the results it is clear that even small changes in melt pressure cause a change in the extruder's output.

The results of the ambient temperature study, Run 1, are presented in Figure 5. The pressure output signals of both the push rod and capillary transducer are shown as a function of time. The transducers were positioned as shown as in Figure 3, and operated in the "normal" ambient temperature environment. One would expect that during steady state extrusion conditions, the melt pressure recorded at ports A and B would be equivalent. The average values obtained are equivalent, but the push rod transducer indicates a pressure fluctuation of 20 psig or 0.5% of the full-scale value. Although both transducers were operating within their overall accuracy limits, the difference in apparent melt pressure stability was worth investigating.

To get an idea of the pressure transducers operating environment, thermocouples were placed in the vicinity of the die. Figure 6 shows that the air temperature near the extrusion die is constantly changing, and can change by as much as 100°F within a few seconds.

In Run 2, the operating environmental temperature of the transducer stems was controlled using the apparatus in Figure 7. Figure 8 shows that when the environmental temperature surrounding the transducer stems is constant, both transducers show a melt pressure fluctuation only 0.5% of the capillary transducer when operating in the "natural" environment. From this data, it can be seen that the true magnitude of melt pressure fluctuation shown by the push rod transducer. The error was due to changing ambient temperature conditions, similar to those shown in Figure 6. The capillary transducer performed well in both situations.

In order to demonstrate this point further, the environmental temperature around the transducer stems was changed in a controlled manner. Figure 9 shows that a gradual ramp changes in the operating environment, about 1°F/minute had no influence on either transducers output. However, a large step change in temperature, from 175°F to 80°F had a significant temporary influence on the output of the push rod transducer, 7.5% of the full-scale range, and little or no change in the output of the capillary transducers. This result is shown in Figure 10. Independent measurement of melt pressure and temperature indicated that the melt pressure itself remained constant. This large change in the push rod transducer's output was due only to environmental effects, i.e. changes in the air temperature around the transducer's stem. One can explain the result qualitatively by reasoning that the thermal expansion or contraction of the push rod lags behind that of the stem to some extent. A decrease in the ambient temperature will cause a decrease in the stem length, causing the relatively longer push rod to exert a strain on the sensing element, indicating a higher pressure. If given enough time, the push rod should contract. This trend can be seen in Figure 10. For fluid-filled transducers, it is the nature of the semi-flexible capillary system and the small volume of fluid contained within that account for the temperature stability. Although large steady state step changes in temperature of this type are not likely to occur, large pulse changes in the ambient operating temperature are common producing the result observed in Figure 5. A problem of this type would be of particular concern if the push rod transducer was to act as the sensing element in a closed loop melt pressure control system. In attempting to remove the "apparent" melt pressure fluctuation, the control system would actually be destabilizing the melt pressure.

In Run 3, ambient temperature changes on the full transducer (stem and upper strain gage housing) were simulated using the apparatus shown in Figure 11. It was found that changes in the upper strain gage housing environmental temperature had no significant effect on the output signal for either type of transducer.

Results have also shown that overall performance of the push rod transducer could be improved by applying a wrap of thermal insulation around the stem of the transducer.

Conclusion

Changes in extrusion melt pressure can be related to dimension changes in the extruded product.

The operating environment of melt pressure transducers may be subject to rapid pulse type changes in temperature, with magnitude as large as 100°F.

The stem portions of the push rod electronic strain gage pressure transducers evaluated are sensitive to thermal shock. Changes in the ambient operating temperature influence the output signals of these transducers, indicating melt pressure instability, when in fact, the melt pressure may be stable.

The Fluid-Filled Capillary Strain Gage Pressure Transducer evaluated are not affected by ambient temperature fluctuations to any significant degree.

Thermal insulation placed around the stem portion of push rod strain gage pressure transducers can somewhat reduce undesirable ambient temperature effects.

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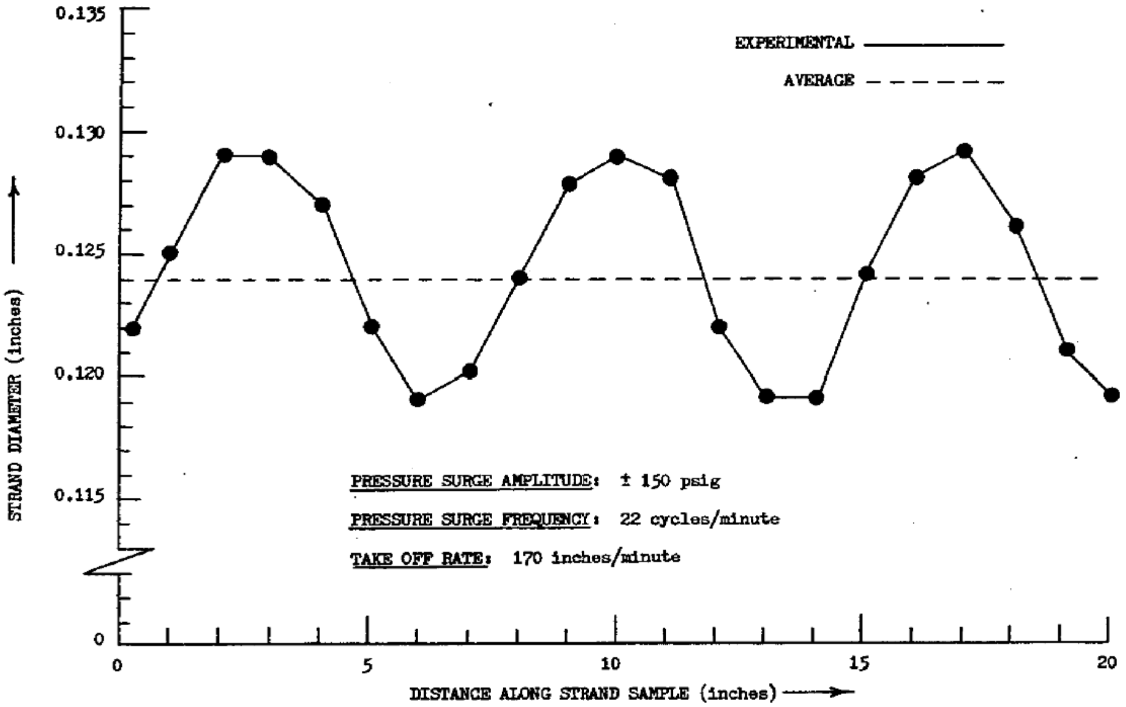

PRESSURE SURGE AMPLITUDE: ± 150 psig

PRESSURE SURGE FREQUENCY: 22 cycles/minute

TAKE OFF RATE: 170 inches/minute

FIGURE 1. STRAND DIAMETER vs. STRAND LENGTH; SIMULATED MELT PRESSURE SURGE EXPERIMENT.

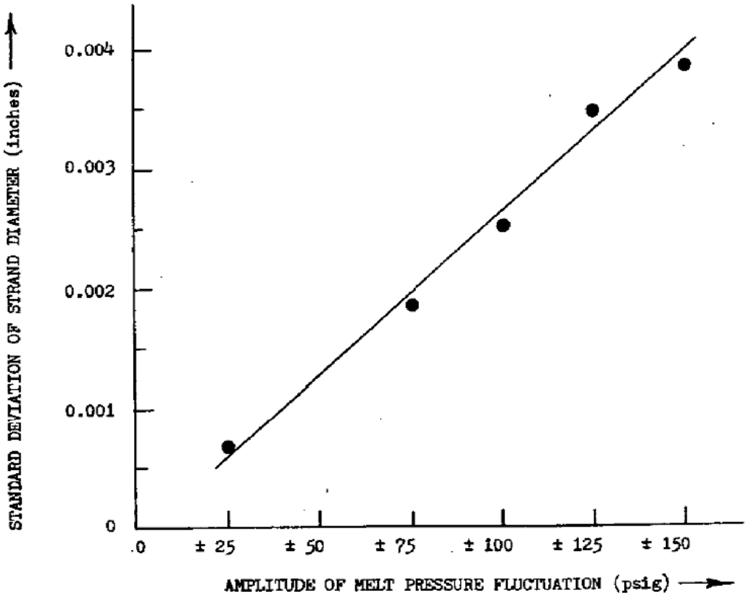

FIGURE 2. EXTRUDATE VARIATION vs. MELT PRESSURE VARIATION; SIMULATED SURGE EXPERIMENT.

SURGE FREQUENCY: 22 cycles/minute
AVERAGE STRAND DIAMETER: 0.124 inches
AVERAGE MELT PRESSURE: 2500 psig
EXTRUDATE DRAWDOWN RATIO: 1.2:1

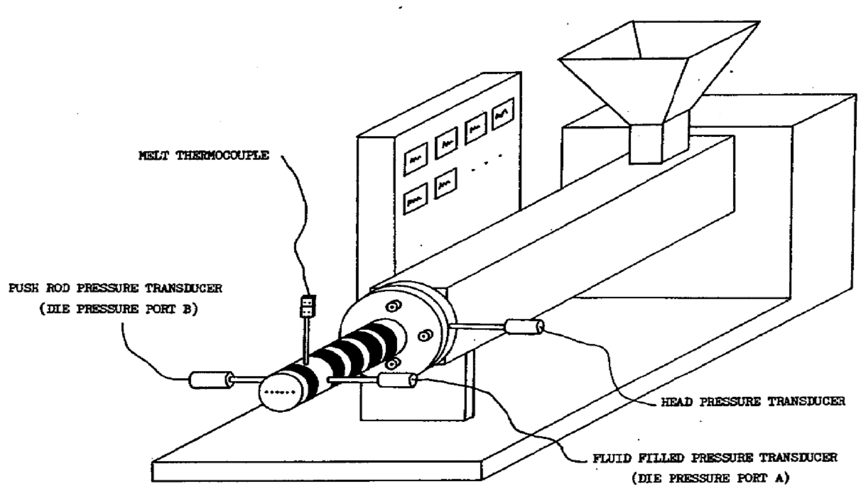

FIGURE 3. PUSH ROD AND FLUID FILLED PRESSURE TRANSDUCER LOCATIONS.

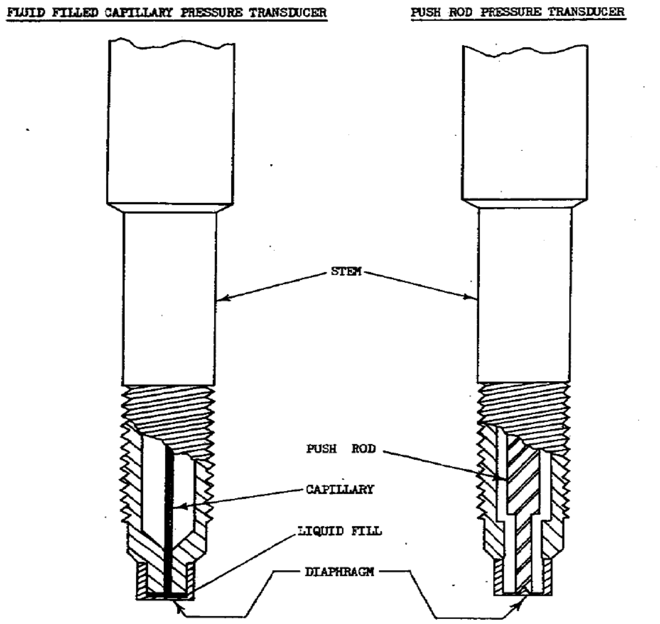

FIGURE 4. INTERNAL STEM CONSTRUCTION; PUSH ROD AND FLUID FILLED PRESSURE TRANSDUCERS.

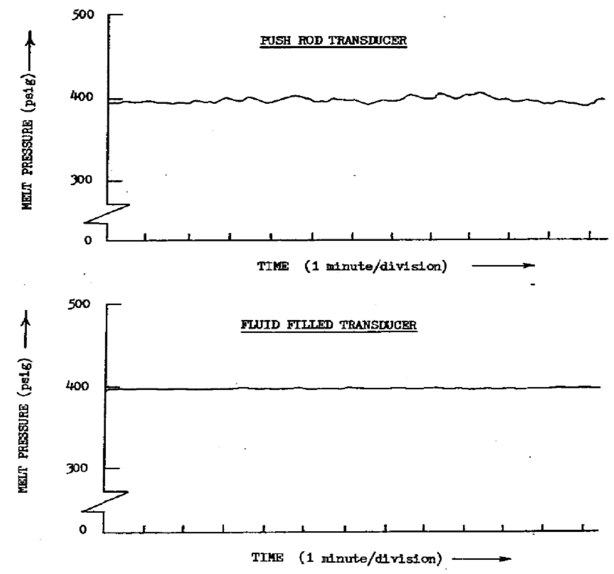

FIGURE 5. TRANSDUCER OUTPUTS vs. TIME; STEADY STATE EXTRUSION, NATURAL ENVIRONMENT.

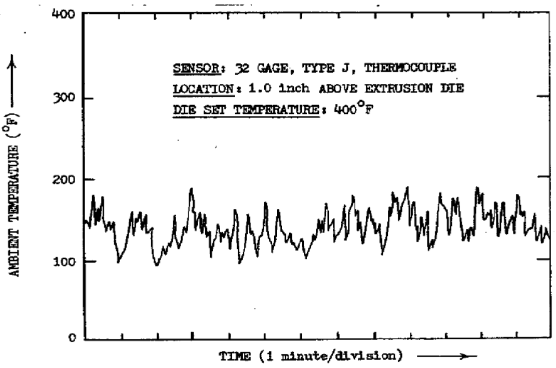

FIGURE 6. AMBIENT TEMPERATURE NEAR AN EXTRUSION DIE vs. TIME, DURING STEADY STATE EXTRUSION.

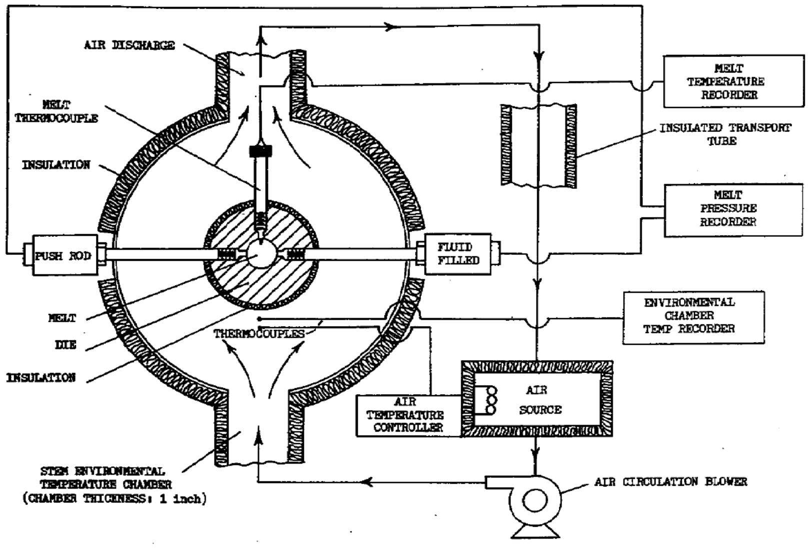

FIGURE 7. DIE MOUNTED, PRESSURE TRANSDUCER STEM ENVIRONMENTAL TEMPERATURE CONTROL APPARATUS.

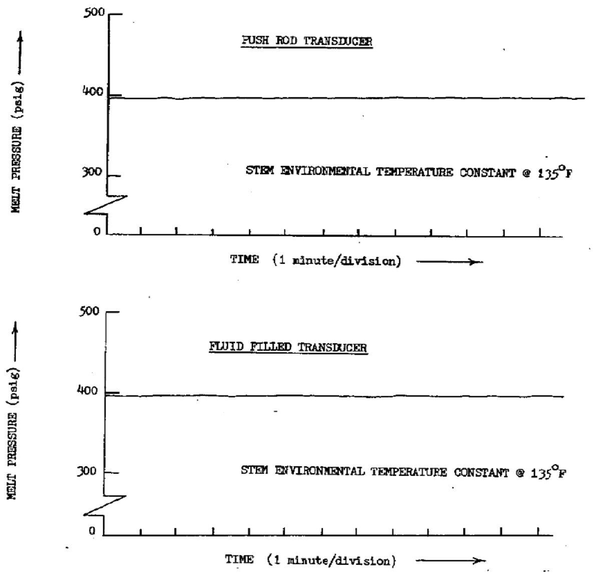

FIGURE 8. TRANSDUCER OUTPUTS vs. TIME; STEADY STATE EXTRUSION, WITH TRANSDUCER STEMS EXPOSED TO A CONSTANT ENVIRONMENTAL TEMPERATURE.

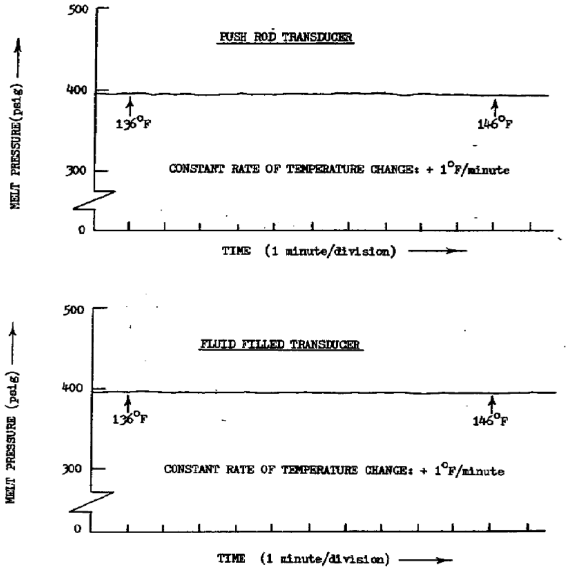

FIGURE 9. TRANSDUCER OUTPUT RESPONSES TO A SLOW RAMP INCREASE IN THE STEM ENVIRONMENTAL TEMPERATURE DURING STEADY STATE EXTRUSION.

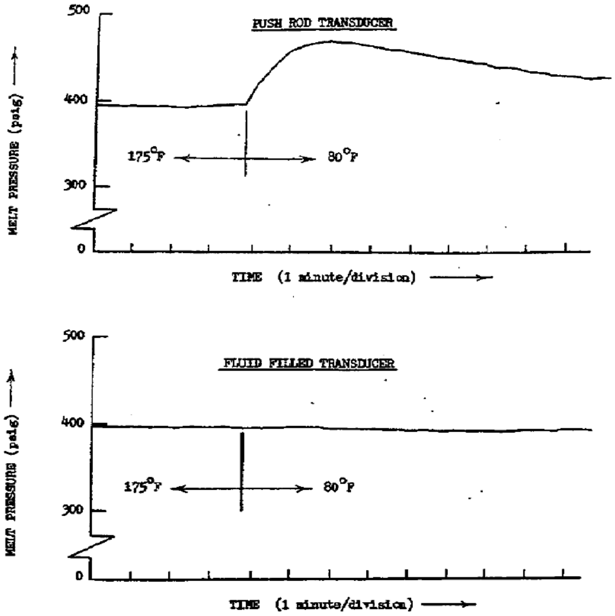

FIGURE 10. TRANSDUCER OUTPUT RESPONSES TO A STEP DECREASE IN THE STEM ENVIRONMENTAL TEMPERATURE DURING STEADY STATE EXTRUSION.

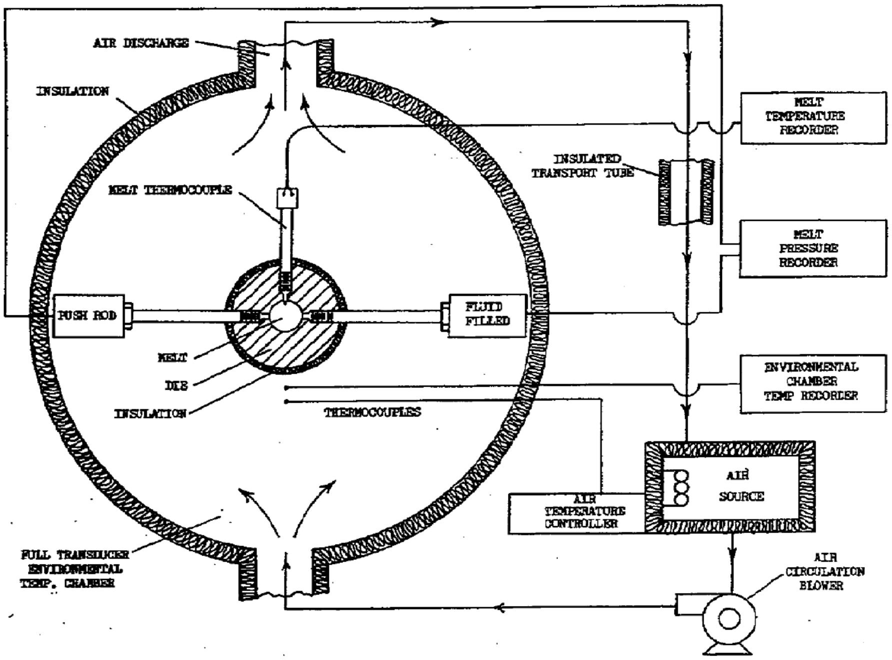

FIGURE 11. DIE MOUNTED, FULL PRESSURE TRANSDUCER ENVIRONMENTAL TEMPERATURE CONTROL APPARATUS.

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