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A SHORT TUTORIAL ON CAVITY PRESSURE TRANSDUCER USAGE

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This document is intended to assist the novice user of cavity pressure sensors in their new endeavor

PURPOSE OF PRESSURE SENSING

Pressure sensing can be broken into two main purposes. First, cavity sensing can be used to provide a quality index of the injection molded part. Secondly, the pressure signal can be used to improve control of the injection molding process.

When used as a means to detect part quality, sensors can be used to determine whether the cavity pressure curve is repeatable from shot to shot. Two attributes of the pressure curve are very important. The first is peak cavity pressure. Peak cavity pressure directly correlates to part weight and density. Part weight and density are highly correlated to final part size. The second main attribute is the rate of rise of the pressure curve. The rate of pressure rise correlates to injection velocity which in turn determines the degree of molecular orientation within the part. Excessive molecular orientation can cause significant internal stress which may cause part warpage or premature failure Excessive velocity can also cause jetting and extreme shearing of the material which may cause burning and other forms of degradation.

A third attribute of the pressure curve has been receiving increased attention over the last several years. This attribute is the rate of pressure *drop* after reaching peak cavity pressure. The rate of this drop is a function of the rate of cooling of the part. Cooling rate variations will cause different rates of shrinkage and alter the degree of crystal growth within crystalline materials. After having determined the optimum cooling time, the goal should be to maintain a consistent cooling rate. The rate of fall of the cavity pressure curve can be used as an indicator of this function.

When molding multiple parts in a mold, individual part quality is best determined through the use of sensors placed in each cavity. For identical parts, the cavity pressure sensors should be placed in identical positions within each cavity. This allows the molder or mold builder to determine cavity and runner balance and make necessary changes to the tool or process to achieve optimum balance. With very large parts multiple sensors may be placed at various locations within the cavity, usually in areas which are the most difficult to fill.

When improving process control is the goal, the usage strategy changes. For example, regardless of the number of cavities, there is only one injection valve and pump system on the injection molding press. All parts must be made simultaneously, unless valve gating is utilized. This suggests that the mold must first be properly balanced and capable of running plural parts to some degree of success before process control improvements can be applied. The most common application of cavity pressure process control is to use the cavity pressure signal in lieu of the first stage timer or screw position to trigger "booster cutout" or the transfer from high volume to low volume injection. In practice, this method controls the length of time the high volume first stage pump is applied. It does not vary the actual hydraulic pressure or flow. Some therefore argue that this method is not true "closed loop cavity pressure control" because hydraulic pressure is not modulated but rather the length of time it is applied.

Regardless whether cavity pressure is used for control or monitoring, the inherent benefits are the same: cavity pressure is a result of all of the process inputs upstream from the cavity. For example, should variations in mold temp, melt temp, material viscosity, hydraulic pressure or flow occur it will cause variations in the cavity pressure curve. These variations will show as changes in the peak pressure value and/or the rate of change of pressure.

There are four major variables that have been long identified in the molding process:

1. Mold Temperature.
2. Melt Temperature.
3. Fill Time (or injection velocity).
4. Peak cavity pressure.

Assuming that mold and melt temperature control devices are adequate, variations in the final two parameters will be a result of consistency of the material and the injection flow and pressure controls. Closed loop cavity pressure control will take care of the fourth, most important parameter. Fill time can usually be adequately controlled by a good velocity profiling package built into modern day molding machine. However, using the previously described method of pressure control will vary fill time, by definition.

The four major variables also interrelate to define other important parameters. For example, the combination of mold and melt temperature will define the rate of cooling of the molded part. Variations in this combination will also affect fill time (or injection velocity)

INSTALLING CAVITY PRESSURE SENSORS

An important element in implementing process controls or monitors is the proper placement of pressure sensors. The industry has sought out a clearly defined description for a long time. When someone asks "where should I place the sensor?", the proper answer is unfortunately- "it depends!". This situation has historically been confusing to the customer because different suppliers will often make different recommendations. Some times any one of several recommendations may work. Other times we at DME have found that this is clearly not the case. When left to a mold builder, the placement decision could become a matter of where it is easiest to install. This is not a good basis for placement.

There are some very basic guidelines for placement that can be followed. The guidelines for control and monitoring are significantly different, however. For monitoring quality, the best placement is usually close to the end of flow. This can be determined by intentionally shorting the shot. If the most difficult part of the mold to fill can be filled to the same pressure on a repeatable basis, the rest of the part will usually be consistent as well. Large parts with multiple flow paths and resultant problem areas may require multiple sensors.

For process control this changes significantly. A sensor usually cannot be placed at the end of flow for accurate control of booster cutout. The sensing of pressure rise will come to late and the result will normally be an over packed cavity and potential flashing of parts. The sensor must be placed further upstream so that it can sense the impending shift from filling to packing of the part. This is where different manufacturers guidelines are known to vary. We have found that placement of the sensor somewhere between one-quarter to two-thirds the distance from the gate to the end of flow gives the best results. One manufacturer that I am aware of has had customers place sensors even closer to the gate. I generally do not recommend this because of potential problems with the sensing of jetting (i.e., by using a sucker pin across from the gate) and pressure rise to due to processing of extremely viscous resins. For control of a multi-cavity mold, sensors are sometimes placed in a conventional runner so that the effects of all cavities can be monitored and controlled. This sidesteps the possibility of having a sensor in a cavity that can freeze off which can cause the other cavities to be flashed.

There are also some very good guidelines for where not to place sensor for <u>control purposes:</u>

First, do not place a sensor in a confined area of the mold such as a boss or other trap where plastic will begin to freeze off before the part is fully filled. This will prevent accurate sensing of the entire injection phase.

Secondly do not place a sensor under a sucker pin. While there are differing opinions in this area, the undercut of the sucker pin will (as mentioned above) trap material that can possibly begin to freeze off and dampen the sensing of pressure before the part is filled. Also if the sucker pin is directly opposite the gate, the inrush of material may cause false sensing of high pressure due to the jetting of material onto the pin face. Neither of these situations are desirable. While some have successfully used this for placement, it is usually a matter of trial and error.

Thirdly, we do not recommend the use of a "static" pin, a pin that does not stroke with injection. These pins will work initially but performance will degrade over time as outgassing or flashing of material between the pin and sleeve occurs. When retrofitting a mold without ejector pins, this has often been the only course of action.

Additional points on placement:

All of DME's present cavity pressure sensors are intended for use under an ejector pin. The pressure from the cavity causes a resultant load on the face of the pin which is transferred down into the ejector housing where the pressure sensor (which is more accurately called a "load cell") resides. The ejector pin offers the sensor thermal isolation from the high temperature of the molten material. While DME sensors are rated to 450 degrees Fahrenheit, some others are only rated to 250 degrees and are even more susceptible to temperature related damage. This may become an issue in mold bases which run at elevated temperatures for use with engineering resins or thermoset materials.

Obviously, the best time to install a properly placed pin is when the tool is being initially designed and built. We realize that this is often not the case. The typical case is that an existing mold needs to be retrofitted with sensors. Water lines and other design features may prevent placing a new pin in the preferred position. The typical scenario is to analyze all existing pin positions and select the one(s) that seem the best. This often requires a compromise. If there are a couple/several positions that seem like good candidates, it isn't a bad idea to prepare all locations for receiving a sensor. Blanks can be inserted when a sensor position is not being used. It is often difficult to take a mold off line to reslot another position for a sensor once the mold is back into production. DME suggests that a newcomer to this technology employ the use of DME or other experienced supplier to review mold prints and parts and make recommendations while implementing sensors the first couple of times. We are happy to help in this endeavor.

SELECTING: THE CORRECT PRESSURE SENSOR TO INSTALL

DME sells two basic styles of sensors (button and slide) in two load ranges (500 and 2000 pound). For almost all thermoplastic molding applications, the 500 pound load range should be used with pin sizes up to 3/16 th inch diameter. For larger pin sizes the 2000 pound load cell should be used. For low pressure molding applications (including foam molding), the 500 pound load cell can be used on much larger pin sizes. It is important to realize that the 500 pound load cell could be easily damaged if accidentally used on an excessively large pin size.

Please refer to the DME catalog pages to see the basic styles. Both styles serve the same purpose but they do it in different ways. DME highly recommends using the button wherever possible for longevity reasons. While the slide sensor is more easily removed from one tool and installed into another, it has a major drawback. The drawback of the slide is the integral extension cable that extends from the mold to the monitor or control equipment. This cable historically represents the single highest area of repair in DME's sensor line. While it has not been a problem in laboratory environments, it has been a major problem in production environments: people have a tendency to forget to unplug, remove and protect the sensor when removing the tool. The end result is that the cable becomes torn out of the sensing head and causes unrepairable damage to the sensor. For this reason alone, the button sensor should be the first choice for most companies.

The button sensor becomes a permanent part of the tool because it is safely trapped inside the ejector housing. To remove the sensor, it is necessary to disassemble the ejector assembly. This suggests that a button sensor must be installed in every tool as opposed to moving a single slide sensor from one tool to the next Although this is a true statement, one must remember the high cost of replacing damaged slide sensors. When installing a button sensor, the sensor cable terminates at the side of the mold, preferably in a sub flush pocket so that the sensor connector does not become damaged when moving the tool. An inexpensive extension cable is then used to connect from the mold to the equipment. Should the extension cable become damaged it is easily repaired and much cheaper to replace than a slide sensor.

With years of history behind us, we can easily say that the damage to the sensors has been the biggest stumbling block in implementing process control programs at various companies. The cost of sensor replacements that could have been otherwise avoided has been the single biggest reason why pressure sensor programs have been canceled. All too often people are attracted to the initial cost savings of a minimal number of slide sensors that can be moved around between tools only to find the savings to be false economics. Over the long haul, most everyone finds that the button sensors eliminate the damage problems. Slide sensors are great but they are not for everyone. The customer must decide whether their setup personnel will take the needed care when installing and removing tools, else damage is likely to occur. Setup personnel must also make sure that the sensor cables (even the extensions) are tied down to prevent them from being pinched between the mold halves or inadvertently stretched by getting caught on something as the mold opens and closes.

CALIBRATING THE MOLD PRESSURE SENSOR

We have strived to make the calibration process as easy as possible. To meet that end, all of DME's sensors are "constant cal" which means the calibration of devices with the same catalog number are matched and allows the molder to swap devices without needing to recalibrate. Only the zero offset will require adjustment when changing a sensor. DME is extremely unique in this aspect. Most suppliers have a tolerance as much as +/-15%. DME's buttons, slides and hydraulic sensors are matched to within +/- 0.75% of full scales.

The DME-4000 process control system has the required calibration circuitry built in to properly calibrate sensors. It is possible that a calibration circuit may have to be added if the DME-4000 is not the intended controller. This methodology will be addressed in a future publication.

USING THE MOLD PRESSURE SENSOR

Over the last decade, molding machine manufacturers have almost all added pressure sensor inputs to their presses. It is unfortunate that many of them do not perform adequately, especially with small parts. For example, two American press manufacturers (as of my latest information) do not scan the cavity pressure signal fast enough to accurately trigger booster cutout. The typical scan speed is 100 Hz. This means 100 "snapshots" of the pressure signal are made per second. If cavity pressure reaches 10,000 PSI in one second, the best the controller will be able to control to is +/- 100 PSI (10,000 divided by 100). Internal studies have shown that a sampling speed of 4,000 Hz is preferred with a sample speed of 1,000 Hz being a bare minimum. This is a general statement that is meant to make sure that <u>all</u> applications can be accurately controlled. A very large slow filling part may run adequately at 100 Hz.

The DME-4000 does not experience the above mentioned scan rate problem because it is based on analog technology which "scans" continuously at an infinitely fast speed. DME cannot guarantee that the use of other control systems will result in the desired degree of control. Luckily enough, even some of the newest presses can be made to work with the DME-4000. This often requires that the machine manufacturer program in additional signal inputs and outputs in the press so that the DME-4000 can be interfaced to the machine logic.

The DME-4000 also adds the benefit of splitting the injection process into three distinct phases by adding a third stage hydraulic valve. Standard two stage presses often wind up walking a fine line between filling and packing in high volume and holding is low volume, and, filling in high volume and packing and holding in low volume. Molds that seem to bounce between short shots and flashes will benefit greatly from the addition of the third stage. Now the molder can fill the part to ~90-95% in high volume, switch to low volume to pack the part out to a consistent peak cavity pressure and then drop to the new third stage pressure which is set just high enough to keep plastic from discharging back out of the gate until the part is frozen.

Since peak cavity pressure is now attained in low volume, it is controlled more accurately. Attempting to reach peak cavity pressure in first stage is a problem because of "dynamic overshoot". Dynamic overshoot is the difference between the actual peak cavity pressure and the cutout setpoint. Because of momentum, the screw continues forward at high speed for a brief period after booster cutout. This causes a large overshoot in pressure beyond the desired setpoint. <u>When second stage (low volume) is used to achieve peak cavity pressure, this dynamic overshoot is greatly minimized,</u> thereby allowing a more gradual, controlled packout to peak pressure. The third stage pressure is a low volume, low pressure that is triggered by a second setpoint. It is this second setpoint that governs the control of peak pressure.

The last couple of paragraphs suggest that the user of a two stage control system may not be as successful at their task as they could be if they were using three stage control. For this reason, DME discontinued sale of its two stage controller ten years ago.

SUMMARY

DME highly recommends the use of the button sensor in lieu of slide sensors to reduce potential failures due to mishandling. All of DME's sensors are matched so that calibration is made as easy as possible. DME highly recommends against attempts to use hydraulic pressure as the means of triggering booster cutout. On very rare occasions it may actually work. These occasions are few and far between. While we sell hydraulic sensors, they are intended for process monitoring and should not be used for control purposes.

DME will assist the molder and mold builder and selecting the proper placement of a sensor, at least through an initial learning curve. Some tradeoffs may be made if an existing tool cannot be given an optimally placed pin.

DME highly recommends a three stage control system to break the process up into the logical fill, pack and hold functions. Existing two stage technology cannot do this correctly in many cases. Three stage control offers much more accurate control of peak cavity pressure and therefore final part weight and size. The DME-4000 is offered to meet this need.