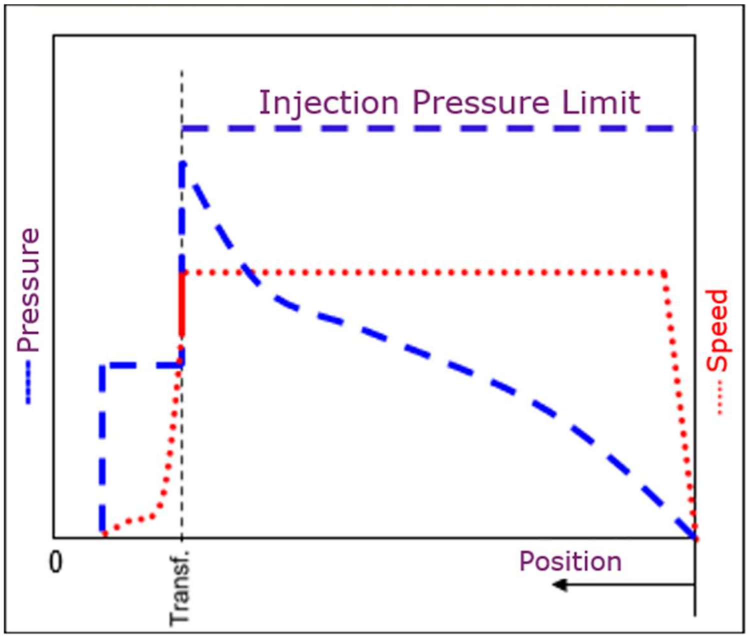
III. Process Graphs

- **Molding with Graphs**
- **PVT Diagrams**

Molding with Graphs

If your machine is equipped with injection graphs, you should learn how to use them. Even though the graphs will vary depending upon the equipment manufacturer, they should provide the same information.

Injection graphs describe the behavior of the melt during the time that the mold is filling.



III-1. Graph of ideal injection

The horizontal axis describes the displacement, or position, of the injection screw. The maximum position represents the recovery position plus decompression. The transfer position is the point at which injection ends, and hold begins. The minimum position "0" is the point at which the screw is in its most forward position, with zero cushion.

The right vertical axis represents the speed, or velocity, while the left vertical axis represents injection pressure.

Once injection starts, the screw accelerates from its maximum position until it reaches the adjusted injection velocity; it then maintains that velocity until the transfer position, which is the end of the injection stage.

After transfer, you will observe minimum velocity. Remember that, after the transfer position is reached, the remaining 5% of the mold will be filled and consequently, a minimum screw velocity will be observed.

Note that during the injection stage the pressure continually increases. During the fill, the melt seeks to attach to static surfaces, which could be the mold's walls or on top of plastic already attached to the mold's surface, and it will resist flowing. Since pressure is the result of this flow resistance, the pressure will increase as the amount of material in the mold increases.

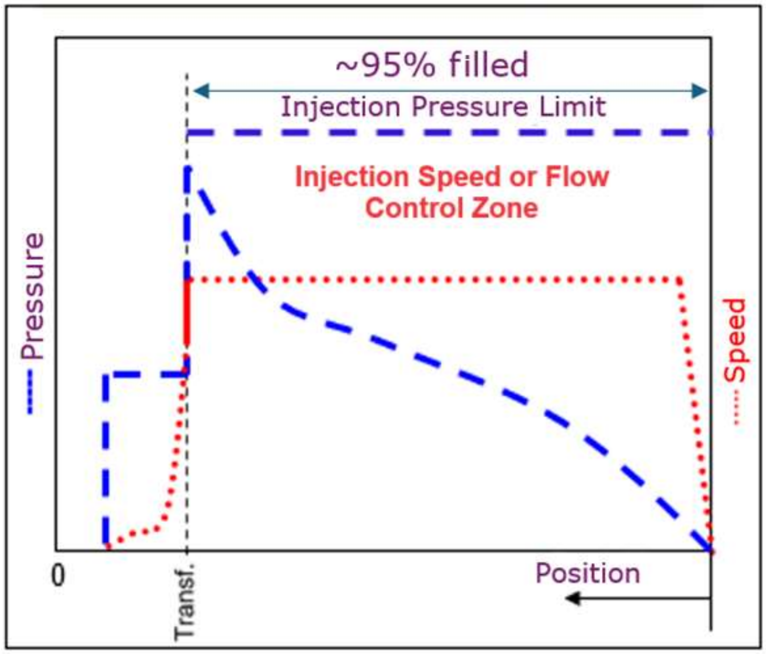
If the pressure decreases, it may be due a decrease in the injection speed (flow). Previously we established that ***Universal*** molders use one single velocity, with very few exceptions. Under normal conditions, pressure will always increase until reaching the transfer position, the position where the mold is filled close to 95%. Do not try to overfill the mold during the injection stage; a 95% fill is enough. Do not try to maximize this amount; there will be no real benefit.

Some molds exhibit extreme difficulty in filling: for example, nylon ties which are long and thin, or micro-molding applications with narrow and awkward spaces for filling. In such cases, a filling percentage greater than 95% may be required.

Also, remember that the injection pressure limit should always be greater than the injection pressure. Program the injection pressure limit to be 5% to 10% higher than the injection stage pressure.

It is important to know that some controllers are equipped with more than one injection pressure limit, one for each injection velocity. Remember that ***Universal*** molders try to mold with only one injection velocity. Now, if your controller requires more than one pressure limit, program them to be 5 to 10% above the maximum injection pressure.

For example, if the injection pressure reaches the injection pressure limit because the cavity gate is blocked with solidified material, the screw will still try to reach the transfer position. If the limit is not properly adjusted, the pressure will continue to increase and the excess melt, corresponding to the blocked cavity, could surpass the clamping force and cause the mold to open.



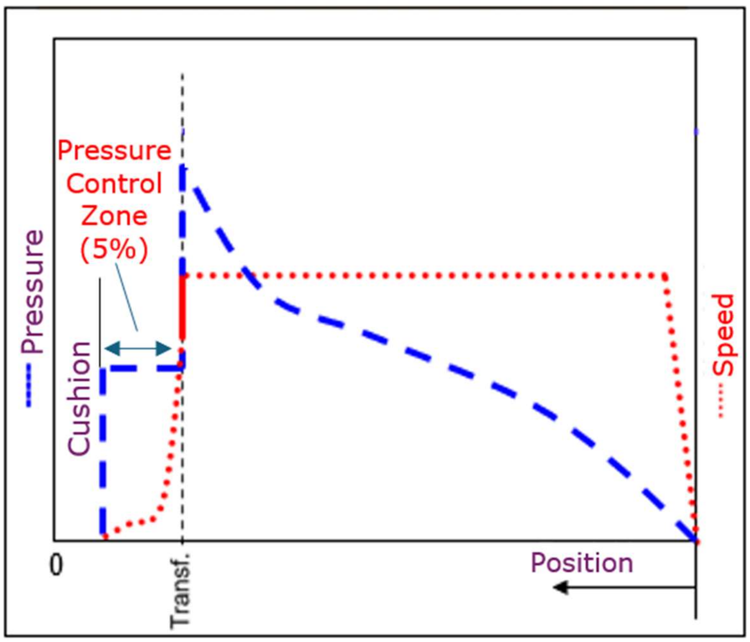
III-2. Control zone graph of injection speed or flow

In summary:

- During the injection stage, approximately 95% of the volume of the mold (cavities and runner) is filled.
- During the injection stage, the injection pressure limit is programmed, which should never be reached since its only purpose is to protect the machine and the mold.
- Pressure is the result of the opposition to flow; the more the melt enters the mold, the more the opposition increases. Assuming that there is only one injection speed, the pressure will increase until the reaching the transfer position.
- The injection pressure limit should be programmed to 5 to 10% more than the injection stage pressure.
- The cushion position should be less than the transfer position.

In some processes with the holding stage off (where the holding pressure is set to zero) or with a very low hold pressure (5% of the pressure at the time of transfer), it's possible that the cushion position might be greater than the transfer position. This phenomenon has been observed in servo-electric injection units, where the servo control tries to reduce the holding pressure (programmed to zero or very low) by retracting the screw. As a result, the cushion position could end up above the transfer position, even if the injection was adjusted to 95% of the total fill. Furthermore, this effect has also been observed in hydraulic injection units. In this case, the holding pressure is significantly lower than the pressure at the time of transfer, which pushes the screw to a position higher than the transfer position. This phenomenon is intensified in hydraulic units when attempting to fill beyond 95% of the fill.

After transfer, the hold stage/zone is started. In this stage, we control pressure, and velocity is a result. The cavities are packed and held until the gates solidify.



III-3. Graph of hold zone or pressure control

We can see that the pressure is being controlled and the velocity, although minimum, shows some movement.

It is not normal for the hold pressure to be greater than the pressure at transfer. We have found processes in which the hold pressure was greater and have discovered that they were filling much less than 95% of the melt required during the injection stage. Once the transfer and recovery positions were properly adjusted, the hold pressure was less than the transfer pressure. How much less should the hold pressure be than the transfer pressure? It will depend on the mass dimensions.

These graphs should be similar when the molds include hot runners. The difference between cold and hot runners is the objective of reducing material consumption since the hot runner never solidifies. The melted material in the hot runners will be part of the next cavity fill; even with hot runners you still must inject, pack and hold until the gates freeze.

There exist some molds with hot runners that include valves in each gate. When activated, these valves create the gate freeze effect. Their operation is simple, once the cavities are packed, the valves in each gate are activated, sealing them so no melt can pass. The signal that closes the valves originates from the signal that corresponds to the hold time. Once these gate valves have completed their function they open, permitting fill like any other gate.

The objective of these valves is one of providing an improved cosmetic finish of the molded part fill point and a reduction of the hold time since there is no need to wait for the gates to solidify.

In summary:

- During the hold stage, velocity is the result of pressure control, and its magnitude will be insignificant.
- During the hold stage the remaining cavity volume, which had not been filled during the injection stage, will be filled.
- The hold pressure is maintained until the gates solidify.
- In this stage we only consider filling the cavities; the effect that we are looking for is the mass dimensions of the parts in the cavities. Remember that we are molding parts and not runners.
- The farthest position, which should never be equal to zero, is called the cushion. If you reach the zero position, that could mean that the process is out of control. One reason could be a defective check ring,

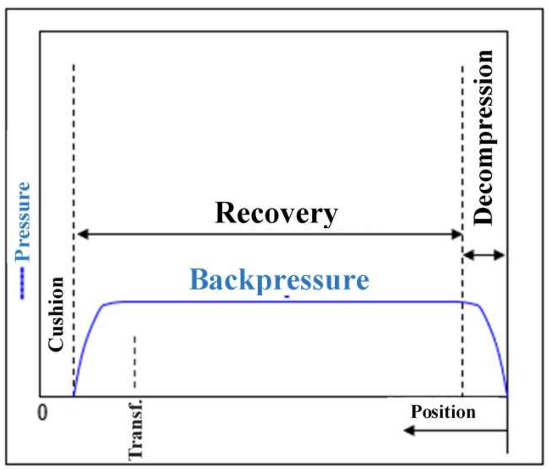
possibly scratched or worn, that is not properly sealing against the screw.

Identify each control zone:

- Injection: the zone that controls injection velocity (flow).
- Hold: the zone that controls hold pressure and time.
- Cooling: the zone that controls the temperature of the mold and cooling time.

Recovery and decompression occur during the cooling stage.

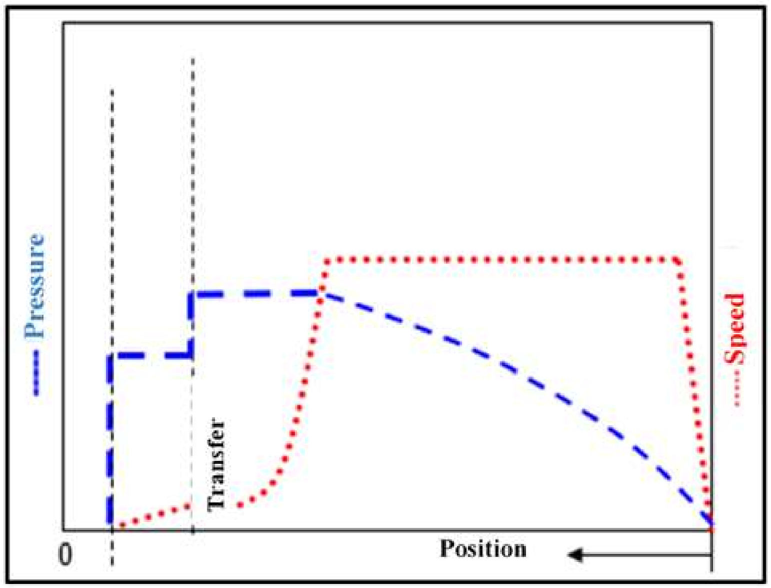
Recovery happens when the screw rotates and fills melt in the barrel for the next cycle. The graph below illustrates the pressure during recovery, which should be equal to the adjusted backpressure. Once the screw fills with the required volume, the plasticized material is decompressed in order to avoid drooling during demolding.



III-4. Graph of recovery zone

One of the advantages that we obtain from molding by graphs is that with a simple glance we can determine if the process is within or out of control, and even people that are not necessarily molders could interpret the process's behavior in each stage of the graph.

The following graph illustrates the results of an incorrectly programmed, limited injection pressure.

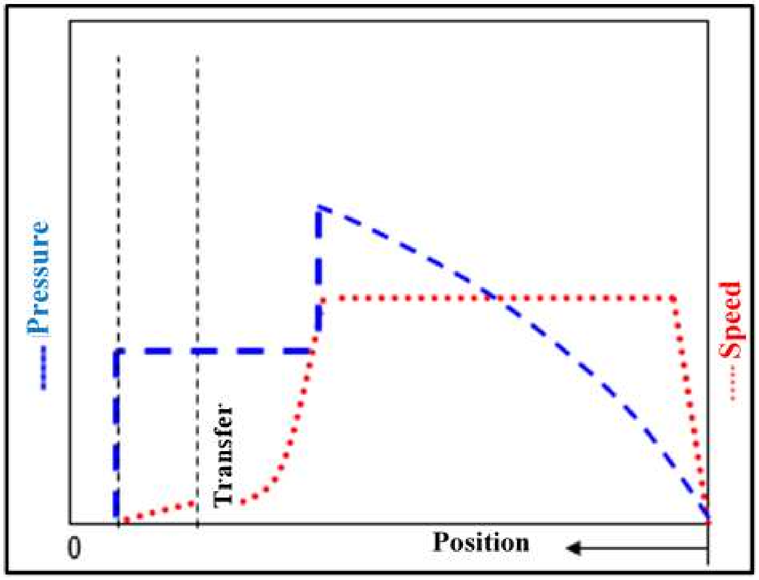


III-5. Graph with limited pressure

You can clearly observe that the injection speed is out of control due to the injection pressure limit being adjusted too low. The injection pressure limit should be adjusted to 5 to 10 % higher than the injection pressure required to fill the mold, in order to control the speed.

Limiting the injection pressure is a practice used for defective molds that create flash. If your industry allows you to operate molds under this situation, and you find yourself having to operate with this condition, consider reducing the injection speed. Although this is not the best scenario, you will be controlling the speed. Understand that the injection pressure is reduced when you reduce the injection speed.

The following graph illustrates the results of a premature transfer.

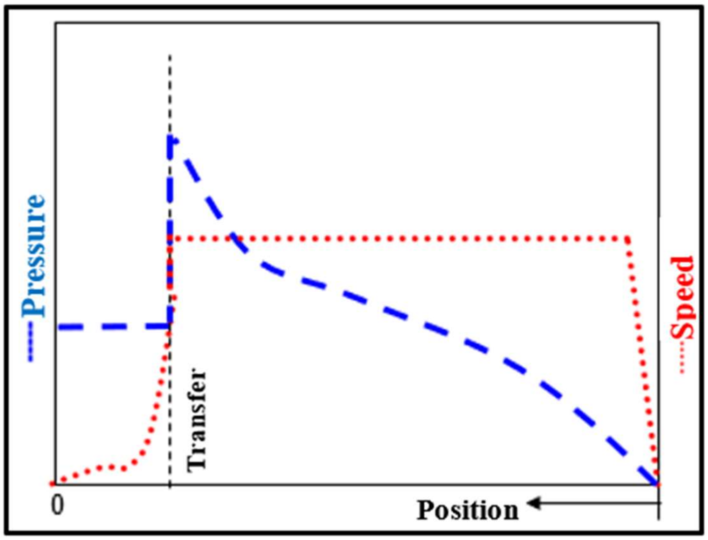


III-6. Graph illustrating premature transfer

For some reason, the transfer occurred prematurely; this could have been the result of a second transfer method that was programmed. For example, if transfer by position and transfer by pressure were programmed, the first of these conditions to be met would initiate the transfer. If this were the case, the transfer would occur based on pressure and not position.

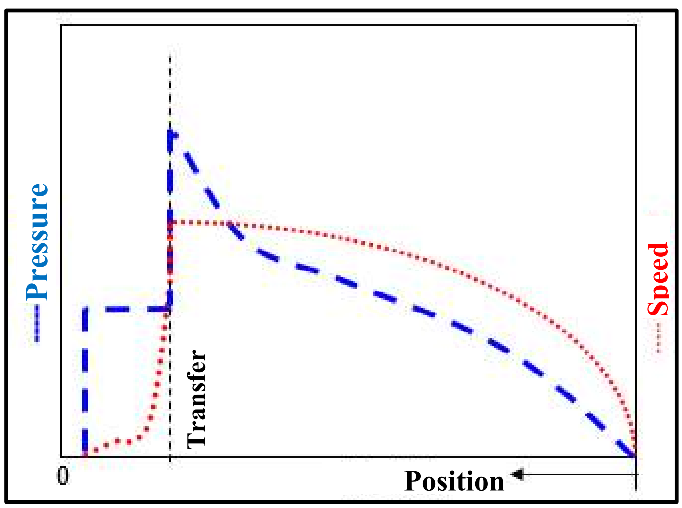
A graph showing a defective process due to zero cushion is illustrated in the following figure. It clearly shows that the screw moved completely forward, emptying the barrel entirely. No cushion exists, and there is no control of the mass dimensions. This could be caused by a worn check ring.

It is important to remember that the cushion position should always be less than the transfer position and should never be equal to zero.



III-7. Graph illustrating cushion equal to zero

The following graph illustrates a defective process due to a limited injection speed. Here the operator was not aware that the programmed injection speed was not being reached or did not verify the fill graphs. This process is clearly out of control and the injection time, a highly significant value, could fluctuate uncontrollably. As a general rule, you do not program process values that cannot be reached.

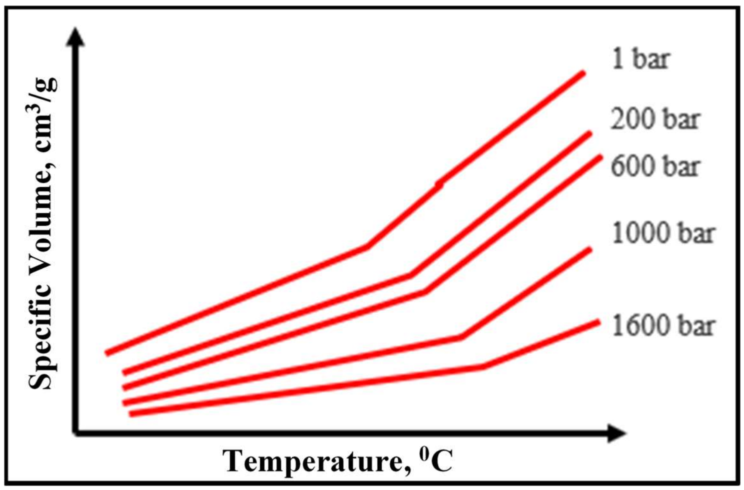


III-8. Graph illustrating unachieved programmed injection speed

Molding with graphs is a powerful tool. Understand your equipment and strive to maximize the utilization of the graphs. Copy and enlarge these graphs and post them throughout the molding room, and you will appreciate their benefits.

PVT Diagrams

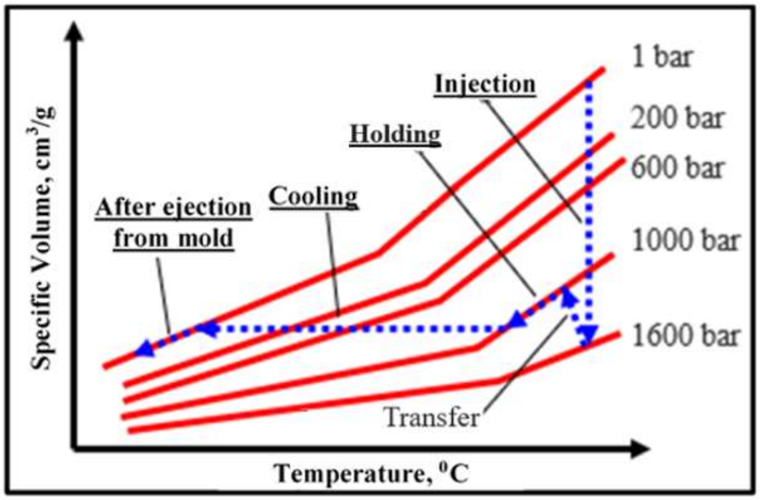
For the benefit of the molders that use pressure and temperature sensors in the cavities, we will take these concepts to a PVT (Pressure, Specific Volume and Temperature) diagram.



III-9. PVT (Pressure, Specific Volume and Temperature) diagram

The vertical axis represents the specific volume, the inverse of density: specific volume = volume/mass. The horizontal axis represents the melt temperature. The solid lines represent grafts of constant pressure, from 1 bar to 1600 bars. Note that the value of pressure increases as you go down to the next line. The movement within a graph line represents a specific volume at a unique melt temperature.

Note in the following PVT diagram the dashed lines representing the molding stages.



III-10. PVT diagram with molding stages

Before injection, the material decompresses. Once the injection stage begins, the pressure increases, compacting the material at a relatively constant temperature.

Once the transfer position is reached the pressure control zone begins, normally at a pressure lower than the transfer pressure.

The cavities are packed at a constant pressure; consequently there will be more material per unit of volume, causing a reduction in specific volume. During the holding stage the melt loses heat, and as is expected, the graph illustrates a reduction in temperature.

Once the gates have solidified, the holding stage ends, and the cooling stage begins. The parts remain pressurized and restricted inside the cavities while cooling. The heat is rapidly removed with a minimum reduction in specific volume. The compressed melt solidifies, and the pressure decreases.

Once the cooling time expires, the parts are ejected from the mold into the room's environment where they continue to cool and shrink at a constant pressure.

Once again, molding with graphs is a powerful tool; utilize it. It is a fast and effective method of verifying the processes even when you are not a molder.

Questions

1) During the injection stage we control injection pressure.
    a. True, we control pressure and temperature.
    b. False, we control injection velocity.

2) We can fill 100% of the cavities during the injection stage.
    a. True, 100% is completed in the transfer.
    b. False, 100% is completed during the holding stage.

3) The injection stage should end when
    a. the injection time expires.
    b. the pressure limit is reached.
    c. the transfer position is reached.

4) In the holding stage we achieve
    a. thermal dimensions.
    b. mass dimensions.
    c. constant speed.
    d. a homogeneous melt.

5) In the holding stage we control
    a. backpressure.
    b. fill velocity.
    c. hold pressure and hold time.

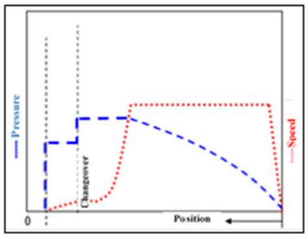
6) The holding stage should end
    a. when the gates solidify.
    b. by position.
    c. by pressure.

7) In the cooling stage we control
    a. fill time and the pressure limit.
    b. the flow of oil in the hydraulic cylinder.
    c. cooling time and the mold temperature.

8) In the cooling stage we want
    a. to eject parts with adequate mass dimensions.
    b. the external dimensions.
    c. to eject parts with adequate thermal dimensions.

9) The cushion can equal zero.
   a. True, that way we control mass dimensions.
   b. False, we cannot control mass dimensions.

10) Pair the graphs of out-of-control processes with their respective flaw description.



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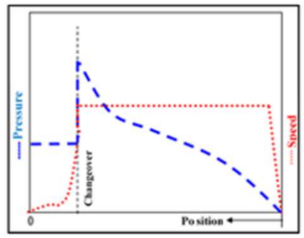

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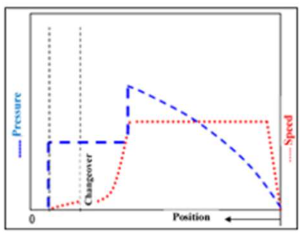

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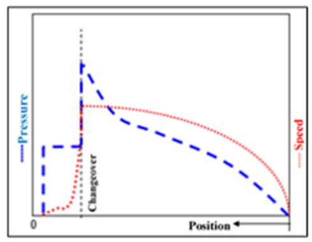

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a. Zero cushion

b. Programmed velocity was not reached

c. Premature transfer

d. Limited pressure