SURGE SUPPRESSION— A NEW MEANS TO LIMIT SURGING

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Abstract

A surge suppressor, somewhat similar to a dynamic seal, is shown to affect surging. Theory and experimental data are presented showing reduction in very short term surging— specifically screw beat.

Theory and experimental data are then presented showing the combined effect of surge suppression and automatic screw speed control on very large surges.

Theory for a novel surge suppressor with self renewing (non-stagnant) character is presented. Experimental data is presented showing the combined effect of this surge suppressor with automatic screw speed control on typical surges.

Introduction

Surging, the change in output of an extruder, is a common problem in extrusion. Surging changes the dimensions of the extrudate and limits extrudate tolerances in production. It is well known that surging is reflected in pressure measurement in the extruder.

Most commonly, pressure is measured in the extruder barrel so that the magnitude of the pressure and the stability of the pressure are known. Pressures are also measured in transfer pipes and in die lands. Pressure measurement is also common on the suction and discharge side of metering pumps. Pressure variation reduces due to frictional resistance as pressure measurements are taken downstream from the screw.[a]

There are two traditional methods of limiting surges.

Metering pumps (gear pumps) have a nearly fixed displacement with rpm. A metering pump placed between the extruder and the die can, therefore, isolate the extruder surges from the die. Suction pressure at the metering pump is controlled by sensing the pressure and then varying the screw speed slightly to change the output. Pressure variation at the output of the pump will typically be small and sometimes as low as plus or minus 0.00145 (10 PSI) at about 0.36 PA (2,500 PSI) or about 0.4%. This is about the limit of the transducer's ability to sense pressure[b].

Improved screw designs are also known to reduce surging. One study suggests using a trial and error approach where, "The knowledge for making an optimized screw must exist from previous success with the material in question at the conditions required on a given extruder sizing (sic) or must be achieved through some trials on a production sized extruder."[c]

Dynamic Seals

Dynamic seals (sometimes called 'viscous seals') are used in different types of polymer processing equipment such as discharge driven extruders, some gear pumps, mixers, and drum extruders. Essentially, a shallow depth, helical, narrow width channel rotates in the opposite direction of the processing tool. Polymer in the processing tool is pumped into both the die and the dynamic seal. The pressure in the seal was thought to reach a simple dynamic equilibrium with the processing tool.

Designers have traditionally minimized the volume of material in the seal and the axial length of the seal. This allowed them to minimize the space required for the seal through the use of shallow channel depths and narrow helix angles. For an isothermal Newtonian fluid, the maximum melt pressure generation (in the metering section of a screw or a dynamic seal) at no discharge condition (Q=0) is a given[d] by:

$$\Delta P_{max} = \frac{6\pi \cos \theta_b N D_b \mu l}{\sin \theta H^2} \quad (1)$$

Where ΔP= pressure drop, dyne/cm.^{2}, H = channel depth in cm., θ = average helix angle in radians, θ_b= helix angle at barrel surface in radians, N = frequency of screw rotation in revolutions per sec., D_b = inside barrel diameter in cm, μ = viscosity in dyne-sec/cm^2, and l = axial distance, cm.

A known problem of dynamic seals is that the polymer in the seal is stagnant and can therefore degrade with time and contaminate the processed material.

Theory To Suppress Short Term Surging

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[a] Stewart, E. L., Barrier Screw Considerations for Cast and Extrusion Coatings, Antec '95, p.30.
[b] Dynisco bulletin 100/85, p. 6 (Repeatability for 10,000 psi transducer).
[c] Stewart, E.L, Barrier Screw Considerations for Cast Film and Extrusion Coating, Antec '95, p. 26.
[d] Tadmor & Klein, Engineering Principles of Plasticating Extrusion,1978, p. 221.

Apparently, because 'sealing' was the design objective, there was little reason to consider the effect of maximizing the displacement of the dynamic seal for other purposes. This is the fundamental distinction between a dynamic seal and a surge suppressor.

Referring to Figure 1, the general layout of a surge suppressing device is shown. The layout is shown for a typical horizontal extruder though, in practice, the surge suppressor has only been used on vertical discharge driven screws.

In operation, we thought that polymer should be pumped from the metering section of the screw and into both the surge suppressor and the extrusion die. The fill length of the surge suppressor would automatically increase or decrease with surges from the metering section of the plasticating extruder. Thus, material removed from the surge would be 'stored' during the high pressure part of a surge. If so, then this part of the surge would not exit the die and would not make the extrudate larger. The extrudate would become more uniform.

During the trough of a surge, the 'stored' material would be returned to the flow stream and pumped out the die. Therefore, material would be added to the die output and the extrudate during a period when the extrudate would otherwise have become smaller. The extrudate would become more uniform.

First Apparatus And Results

Because it is well known that pressure variations in the extruder reflect the physical surges from an extruder, we assumed that if we measured pressure variation we would have an accurate measurement of surging. A 25 mm (1 inch) diameter off line surge suppressor was built and connected to a transfer pipe (Fig. 2) to a 12 mm (1/2 inch) extruder. The transfer pipe and off line surge suppressor were turned off and LDPE was processed through the 12 mm (1/2 inch) plasticating extruder at 20 rpm. Pressure was measured and recorded on a strip chart at the end of the metering section of the plasticating extruder (Fig. 3).

The transfer pipe and surge suppressor were heated to operational temperatures while the plasticating extruder continued to rotate at 20 rpm. The surge suppressor speed was also rotated at 20 rpm. Pressure in the plasticating extruder was again recorded (Fig. 3).

The figures show that short term pressure variation, thought to be caused by the screw flight[e] passing the pressure sensor, was reduced from about 0.003 PA (23 PSI) to 0.00174 PA (12 PSI). The results showed substantial dampening of short term surging.

Theory To Suppress Long Term Surging

It is commonly known in the industry, although the author could not find printed confirmation of this, that pressure controllers (such as are used to control screw speed on the suction side of gear pumps) have been tried on extruders without gear pumps. On several occasions the author tried to remove long term surging using conventional pressure controllers. Locations in both the transfer pipe between the die and extruder and in the extruder barrel itself were tried. The results were consistently discouraging.

Whenever the automatic screw speed control was engaged, reasonably stable pressures were made much worse. Private conversations with a manufacturer of pressure transducers confirmed that this was a common experience. Consequently, the manufacturer does not recommend that their controller be used except on the suction side of a gear pump. Similar conversations with processors, consultants, and extrusion machine builders confirmed that failure to control pressure by means of altering screw speed (without a gear pump) was common.

Because we knew that pressure controllers worked to correct long term surging on the suction side of metering pumps, we thought that perhaps short term surging somehow interfered with the operation of conventional pressure controllers. We thought that if this were true and if the surge suppressor dampened short term surging effectively, perhaps standard pressure controllers could be used in conjunction with surge suppressors to reduce variations in output.

We decided that the way to test this idea was to intentionally create a significant pressure variation in an extruder where a surge suppressor was present. Our previous experience had taught us that stable pressures were worsened by standard pressure controllers without metering pumps. So, if the standard pressure controller could significantly reduce a large pressure variation, then we might have grounds to proceed further.

Second Apparatus And Results

A 16 mm (5/8 inch) extruder was equipped with an integral surge suppressor and a general purpose 3:1 apparent compression ratio, 24:1 extruder where the screw was equally divided between metering, compression, and feed zones. We processed dried nylon-6 pellets in this screw knowing that a higher compression screw (4:1 to 4.5:1) is recommended.

Figure 4 shows that with the pressure controller turned off, a pressure variation of 0.21 PA (1,450 PSI) was recorded in the extruder barrel. Figure 4 also shows that when the automatic screw speed controller was activated, pressure variation was reduced to a total variation of 0.058 PA (400 PSI).

Theory To Eliminate Suppressor Stagnation

[e] Ibid., Pages 412-413.

Referring to figure 5, it was thought that if a surge suppressor were created with two side by side channels, one deep and one small, that polymer would flow into both channels. The fill length of the deep channel would be longer than the shallow channel. So, the polymer in the deep channel would be, in part, next to an empty shallow channel. However leakage flow over the intervening flight between the channels, should cause material to move from the deep channel into the shallow channel. Because the shallow channel is a more efficient pump than the deep channel (as shown in Equation 1), the polymer should then move out the shallow channel and into the process stream. Thus, the surge suppressor would not have stagnant material within it.

Third Apparatus and Results

A 12 mm (1/2 inch) extruder was tested with a dual channel surge suppressor similar to Figure 4 with channel depths of 0.4 mm (0.015 inch) and 0.6 (0.025 inch). A clean screw processed LDPE with yellow pigment through a 2 mm (0.078 inch) rod die. Presumably, the yellow pigment filled both surge suppression channels. After 30 minutes, unpigmented LDPE replaced the pigmented material. After 3 hours, the screw was removed. No pigment was seen in the surge suppressor.

Theory To Improve Pressure Stability

It had been demonstrated that unstable pressures could be improved when a surge suppressor was combined with a standard pressure controller (in the nylon experiment above). It had been demonstrated that the dual channel surge suppressor could avoid stagnation. We thought that perhaps we could reduce a conventional surge rather than the extremely large surge in the nylon experiment. Further, that we could process a somewhat thermally sensitive material in the dual channel suppressor.

Fourth Apparatus and Results

The extruder described in the third apparatus had an additional pressure sensor added in the transfer pipe region so that pressure could be measured and controlled from either the extruder barrel or the transfer pipe. We processed PVDF, a somewhat thermally sensitive material though a small die at about 7 rpm.

Figure 6 shows the chart recording of pressure with and without automatic screw speed control in the transfer pipe.

Note that this would be the typical position where pressure would be measured at the output of a metering pump. With automatic screw speed control, the pressure variation in the transfer tube was about plus or minus 0.00145 PA (10 PSI) pounds at various control pressure settings between 0.5536 PA (3,680 PSI) (about 0.3%) and 0.4176 (2,880 PSI) (about 0.4%). Barrel pressures were recorded at the same time and were about plus or minus 0.0116 PA (80 PSI).

Figure 7 shows the barrel and transfer pipe pressure traces at 0.5336 (3,680 PSI) pressure control setting in the transfer tube.

Pressure control was then switched to the barrel. At pressure control settings between 0.2494 PA (1,720 PSI) and 0.3074 PA (2,120 PSI), pressures were held at about plus or minus 0.00145 (10 PSI) (about 0.5%). At a pressure setting of 0.319 PA (2,220 PSI), pressure variation increased to about plus or minus 0.002175 (15 PSI) (about 0.7%). The pressure control was turned off and the barrel pressure was then recorded at about 5 rpm to be about 0.348 PA (2,400 PSI) plus or minus 0.029 PA (200 PSI) (about 8.5%).

Conclusion

A theory was presented for a surge suppressor that did not have stagnant areas. Obvious degradation, that might have been seen as discoloration or carbonized material, did not evidence itself in the extrudate. This is encouraging given a somewhat thermally sensitive material processed at very slow screw speeds.

A theory was presented that may lead to a simple method of controlling extruder pressures by linking surge suppressors and a pressure control of screw speed.

Pressures less than 1% were held in the transfer pipe. It is usually assumed that such pressure stability can only be achieved through the use of metering pumps.

It is particularly interesting that barrel pressures were controlled within 0.00145 PA (10 PSI). Consider that when the pressure control was located in the transfer pipe, the upstream pressure in the barrel showed 8 times greater pressure variation than the downstream pressure!

Unfortunately, we are unable to measure less than 0.00145 PA (10 PSI) in these pressure ranges. So, we cannot say what the downstream pressure was. But, the implication is that the pressure variation ought to be much less. If this work can be expanded, it would be both a useful and cost effective solution to many surging problems.

Further experimental and theoretical work is in progress.

Keywords: Surging, Suppression, Pressure Variation

Figure 1

Surge Suppressor Operation

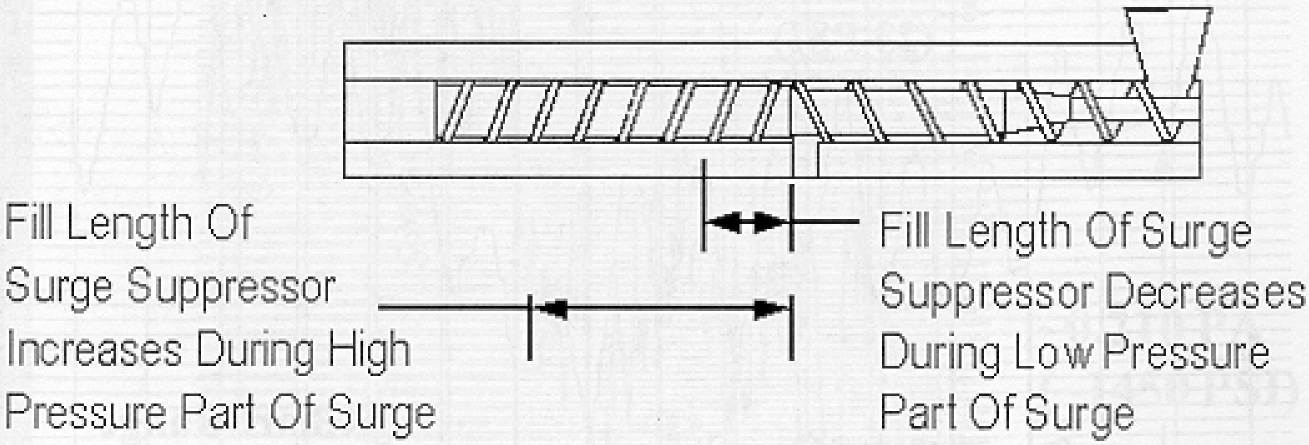


Figure 2: **Off Line Surge Suppressor**

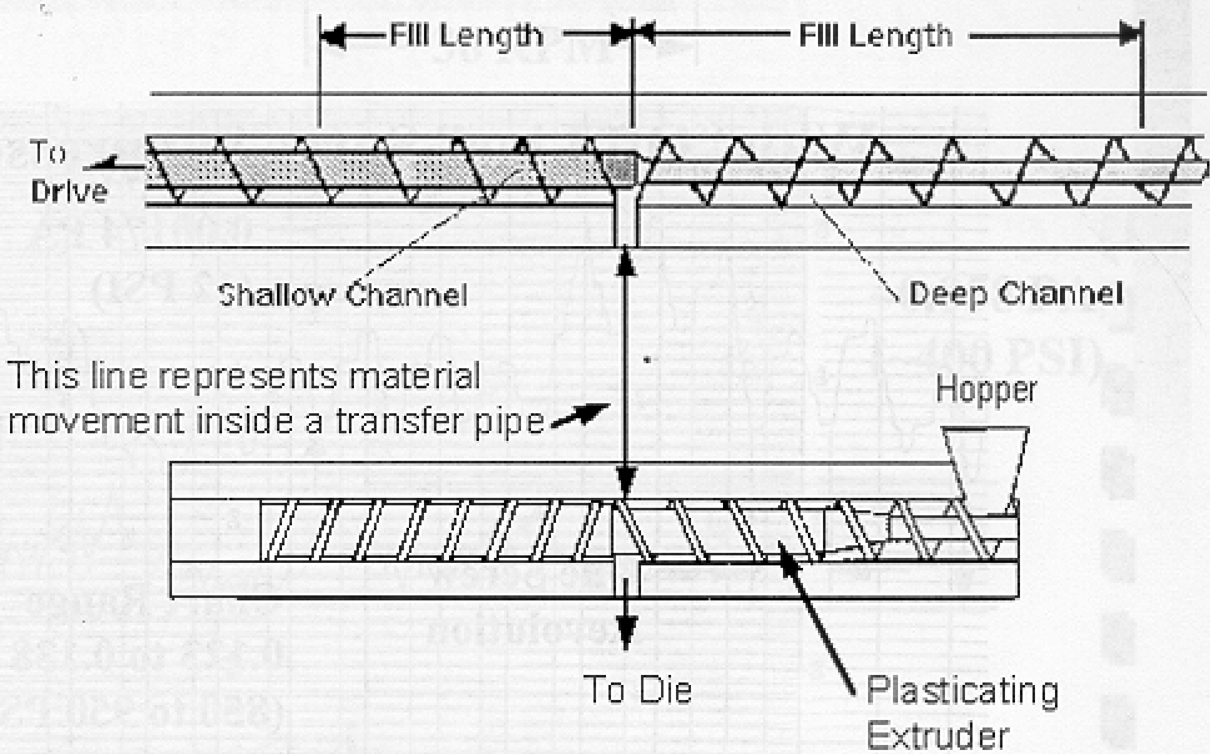
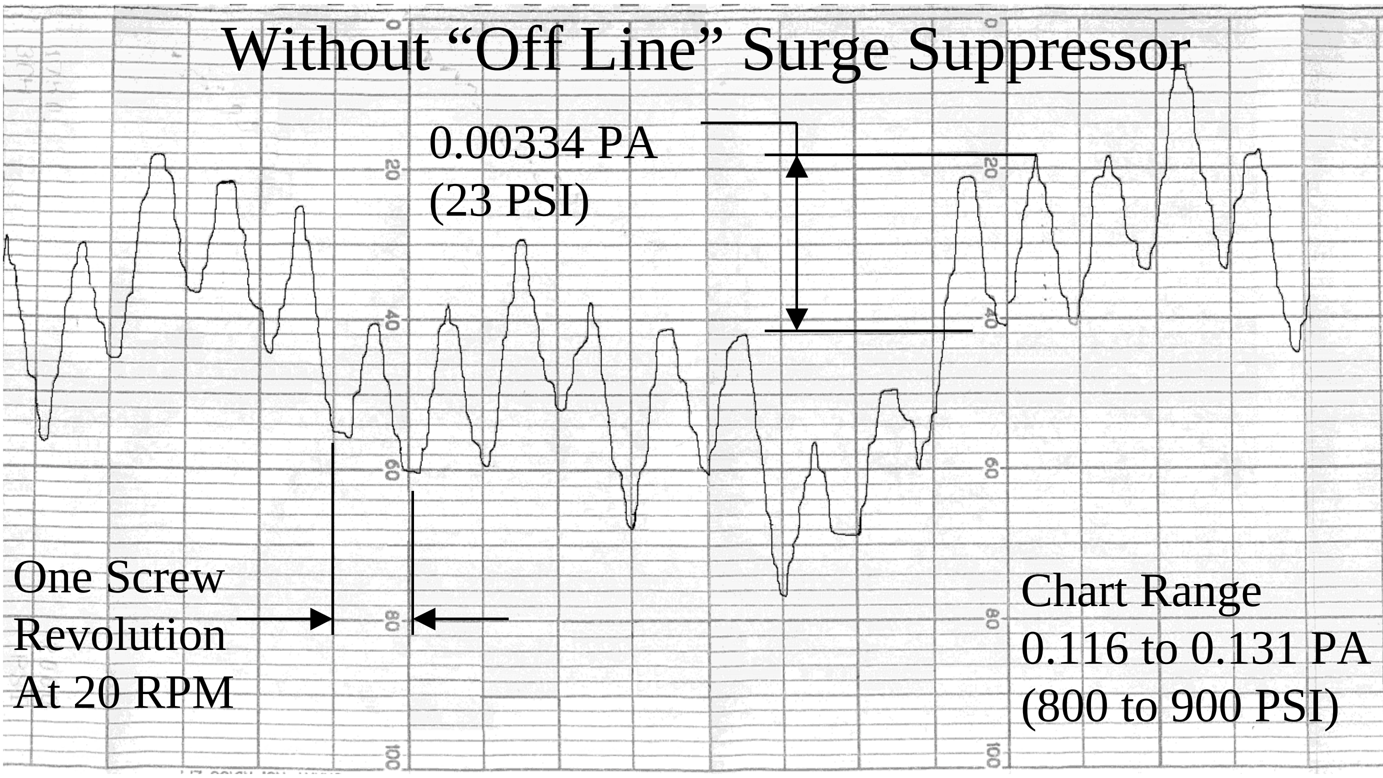


Figure 3


Without “Off Line” Surge Suppressor
0.00334 PA
(23 PSI)
One Screw
Revolution
At 20 RPM
Chart Range
0.116 to 0.131 PA
(800 to 900 PSI)

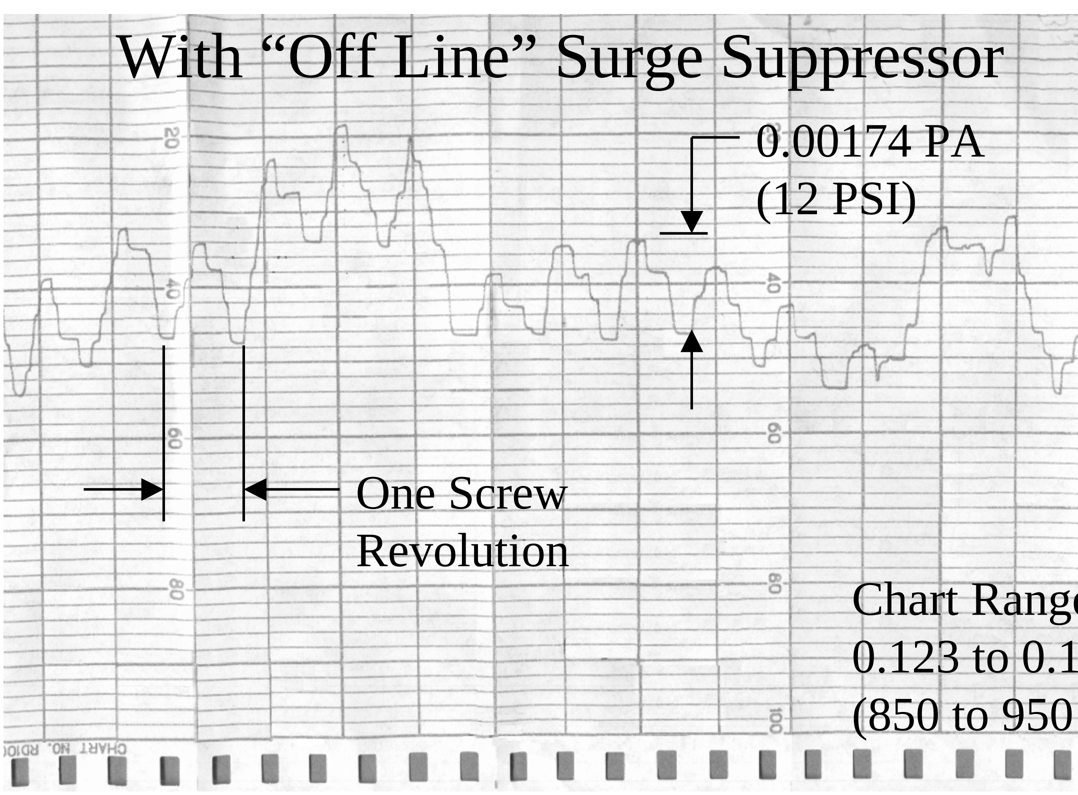
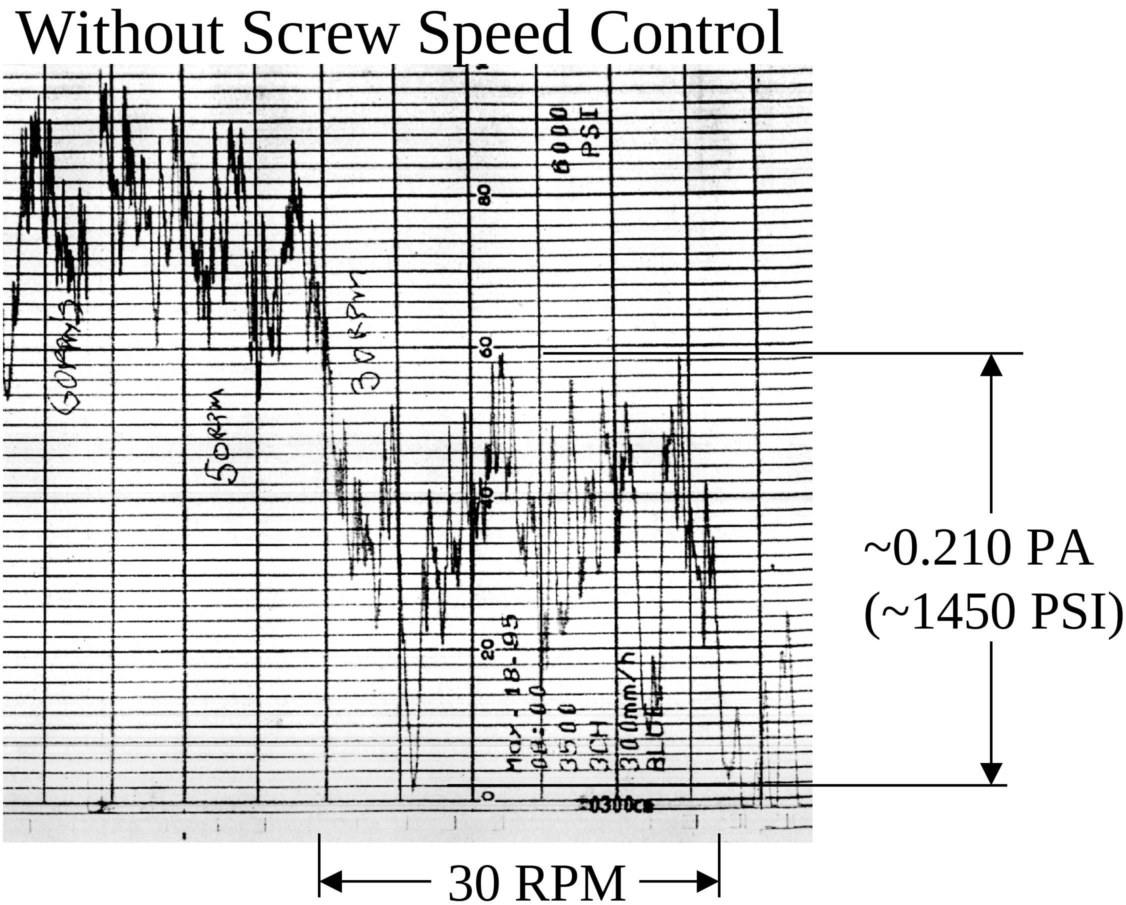
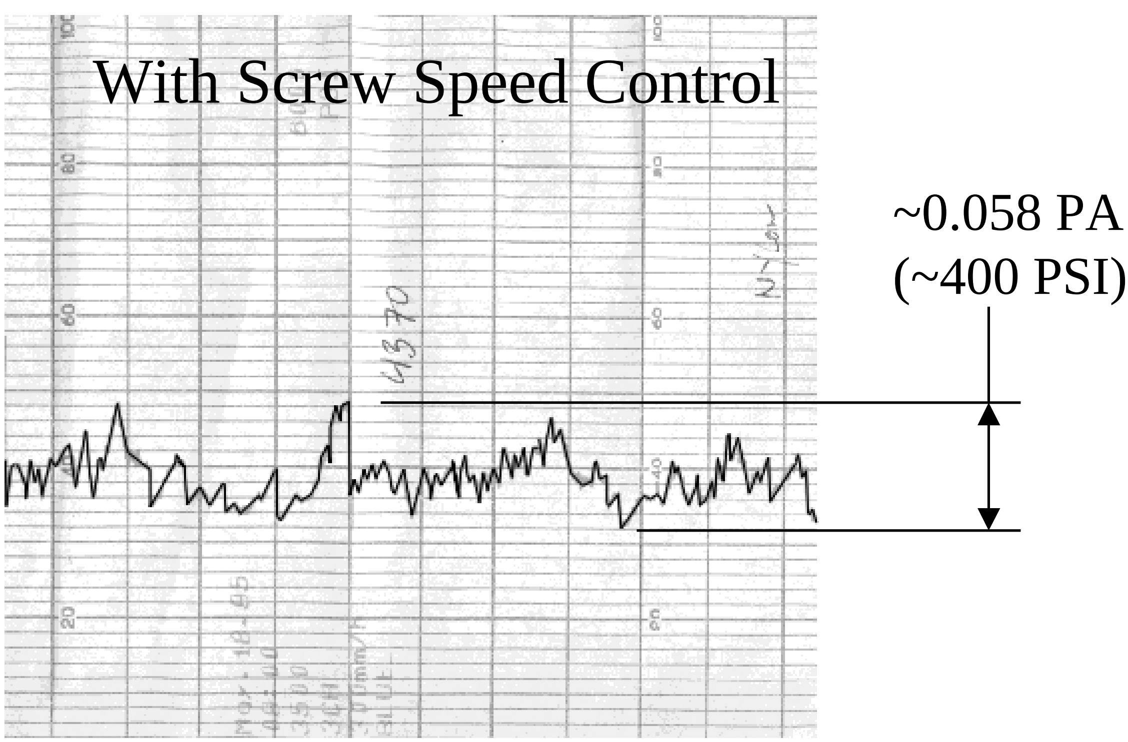

With “Off Line” Surge Suppressor
0.00174 PA
(12 PSI)
One Screw
Revolution
Chart Range
0.123 to 0.138 PA
(850 to 950 PSI)

Figure 4



Without Screw Speed Control
6000
PSI
~0.210 PA
(~1450 PSI)
30 RPM



With Screw Speed Control
~0.058 PA
(~400 PSI)

Figure 5

SURGE SUPPRESSOR WITHOUT STAGNANT ZONES

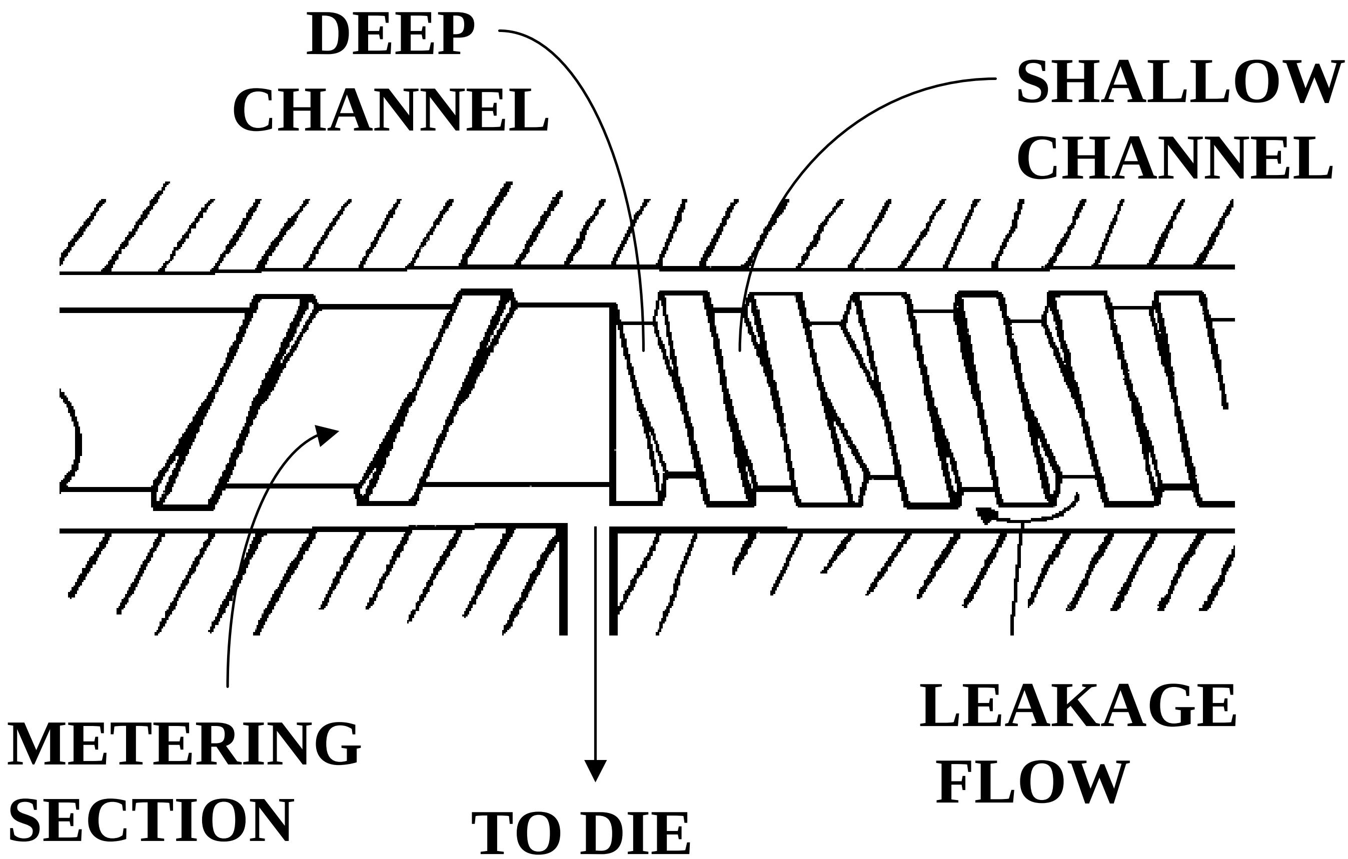


Figure 6

Pressure In Transfer Pipe With Surge Suppression and Auto-Screw Speed Control

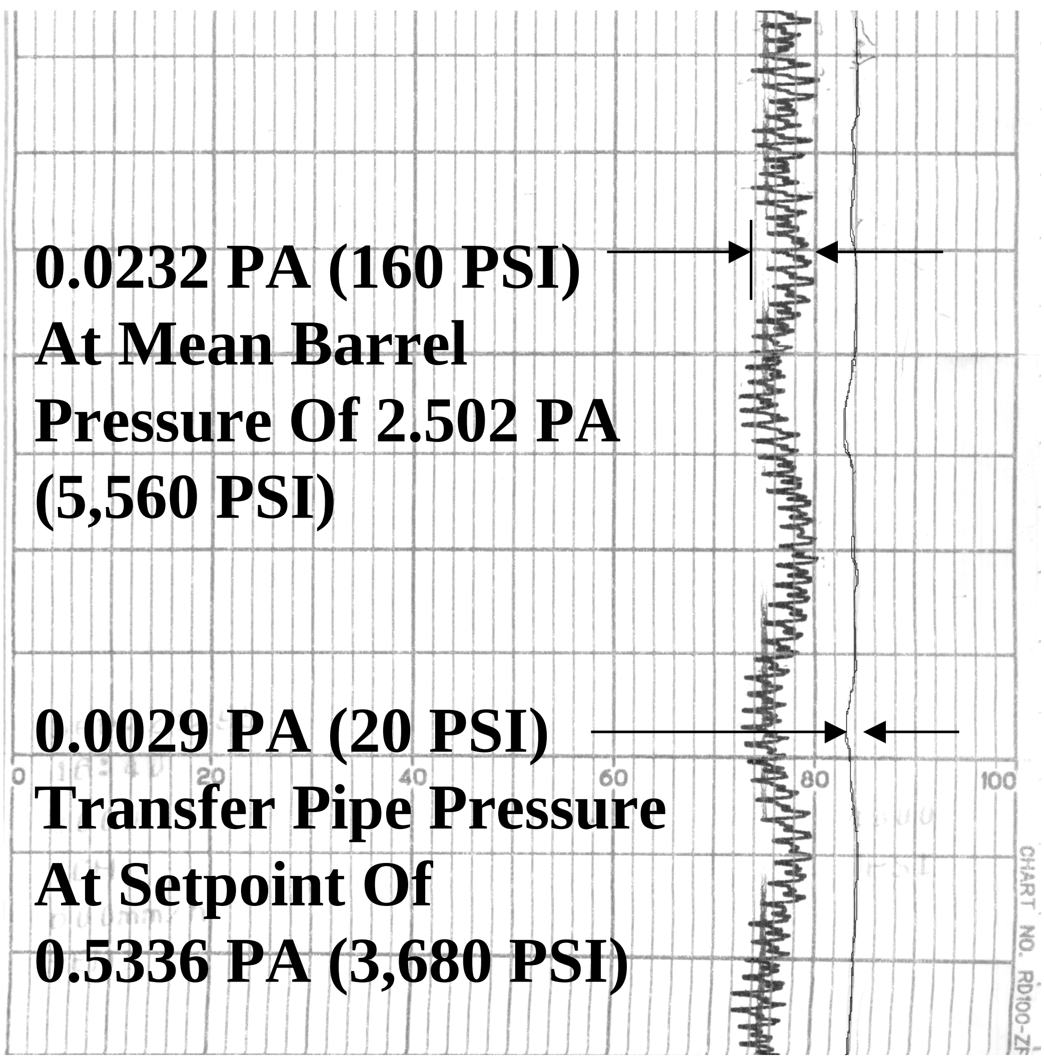


Figure 7

Surge Suppression & Automatic Screw Speed Control With Control Point In Barrel

At Setpoints