

TROUBLESHOOTING GEAR PUMP ASSISTED SINGLE-SCREW EXTRUSION PROCESSES

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Abstract

Gear pumps are often used in tandem with single-screw extruders to increase rate, decrease resin consumption, improve process stability, and decrease the extrudate temperature. When a process is unstable, it is often not obvious if the extruder is unstable and the gear pump is operating well, or the extruder is operating well and the gear pump operation is unstable. This paper will describe a few operations where gear pumps improved a process, how they can be used in unstable processes, and approaches to troubleshooting lines using gear pumps.

Introduction

Gear pumps are often positioned between smooth-bore single-screw extruders and dies, providing several processing advantages. These advantages include the mitigation of pressure surges and thus flow surges from the extruder, a decrease in the discharge temperature by generating part of the pressure required for the die by the pump instead of by the extruder, reducing resin consumption, and for rate increases [1,2]. For example, if the extruder is operating with a relatively small pressure oscillation with time (or pressure surge) to the inlet of a gear pump, the gear pump will provide a nearly constant outlet pressure and flow rate to the downstream equipment such as a die. Stable operations with a gear pump will allow plant personnel to operate at the lower specification limits for sheet or film and thus reduce the resin consumption per unit of product. If a gear pump is contributing to the generation of the discharge pressure for the downstream equipment, the metering section will operate with a higher specific rate as compared to a process without a pump. Extruders that operate at a higher specific rate will generally operate at a lower discharge temperature [3]. A gear pump used with a two-stage, vented screw can allow high operating rates at higher discharge pressures while not causing material to flow into the vent.

For gear pump assisted extrusion, the extruder control algorithms are set to maintain a constant pressure to the inlet side of the pump by the extruder. The pump is operated at a constant rotational speed and thus it delivers molten polymer at a very steady and controlled rate. A schematic of a gear pump assisted extrusion process is shown in Figure 1 for a single-stage extruder. If the pressure to the inlet of the pump is less than the set point value, then the control algorithm will increase the screw

speed of the extruder. Conversely, if the inlet pressure is too high the control system will decrease the screw speed. For properly designed systems, the screw speed will only have relatively small changes to compensate for slight changes in the pump inlet pressure. But for extrusion processes that are not operating properly and show severe flow surging, the screw speed will have large variations.

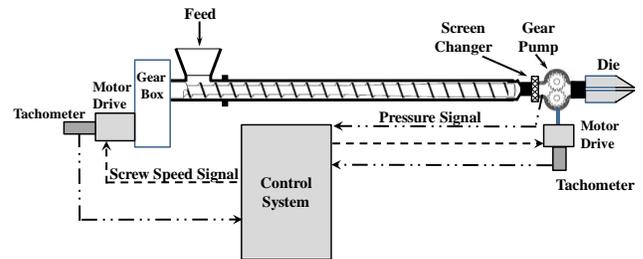


Figure 1. Diagram of a typical gear pump installation for a single-stage extruder and a screen filtering system. The control schematic for extruder screw speed is included.

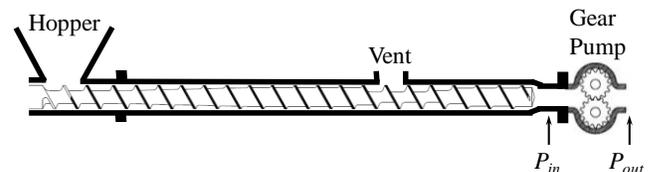


Figure 2. Schematic of a two-stage, vented extruder with a downstream gear pump.

Gear pumps allow higher rates and higher discharge pressures for two-stage, vented extruders. A schematic of this process is shown in Figure 2. Since the vent is at atmospheric pressure or under vacuum, all pressure required to operate the die for a system without a gear pump must be generated in the second-stage metering section of the screw. If the pressure required to operate the die is higher than what the second stage metering channel can develop, then molten resin will flow into the vent opening. A gear pump, however, can allow higher rates and higher discharge pressures while eliminating vent flow. For this case, the metering section only needs to generate enough pressure to operate safely the pump, a pressure typically about 2 to 8 MPa. This pressure level is high enough to keep the gear channels completely full of resin and maintain lubrication in the bearings. The pump will then increase the pressure to a higher level as required

by the downstream equipment. Moreover, if the gear pump is generating most of the pressure required for the downstream equipment, then the screw and extrusion process can be optimized to a lower discharge temperature [4].

The goal of this paper is to show the attributes of positioning a gear pump in tandem with a single-screw extruder, and provide troubleshooting methods for tandem operation.

Temperature Reduction

A gear pump is a common method to decrease the discharge pressure from the extruder, especially if the discharge pressure required by the die is relatively high. Decreasing the discharge pressure from the extruder will cause the specific rate to increase and the discharge temperature to decrease. A schematic for the axial pressure and temperature for a single-stage process is shown in Figure 3. Here the pump is generating the pressure rather than the metering section of the screw, allowing the discharge temperature to decrease. For example, a process and die required a pressure of 21 MPa for operation at a rate of 400 kg/h for a high density polyethylene (HDPE) resin with a melt index of 0.08 dg/min (190°C, 2.16 kg). If all of the pressure is provided by a single-stage 114.3 mm diameter extruder (screw design fixed), the discharge temperature will be about 242°C, as shown by the operating curve in Figure 4. Here the specific rate for operation is 4.7 kg/(h rpm). But if a gear pump is positioned between the extruder and the die such that a portion of the required pressure is generated by the pump, then the specific rate for the operation of the screw will increase (causing the screw speed to decrease at a fixed rate) and the discharge temperature will decrease. For example, if the inlet pressure to the gear pump (discharge pressure from the extruder) in this case was 8 MPa, the extruder would discharge at 231°C and operate at a specific rate of 6.3 kg/(h rpm). Thus, the discharge temperature could be decreased by 11°C and the specific rate increased by 1.6 kg/(h rpm), as shown in Figure 4.

Some temperature increase will occur as the resin passes through the gear pump. This temperature increase is small compared to the decrease in temperature due to using the pump to increase the line pressure. The actual extrudate temperature will depend on the design and operation of the screw, the shear viscosity of the resin, the pressure contribution from the pump, and the design of the pump.

Surge Suppression

Flow surging is defined as the oscillatory change in the rate of the extruder while maintaining constant set

point conditions. Flow surging can originate from many different sources including improper solids conveying, melting instabilities, flow restrictions, and improper control algorithms [3,4]. Gear pumps are very effective at mitigating pressure surges originating from the extruder, and thus they have the capability of minimizing the resin consumption in the final product for a process with a mild flow surge to maintaining a level of production for processes with severe flow surging.

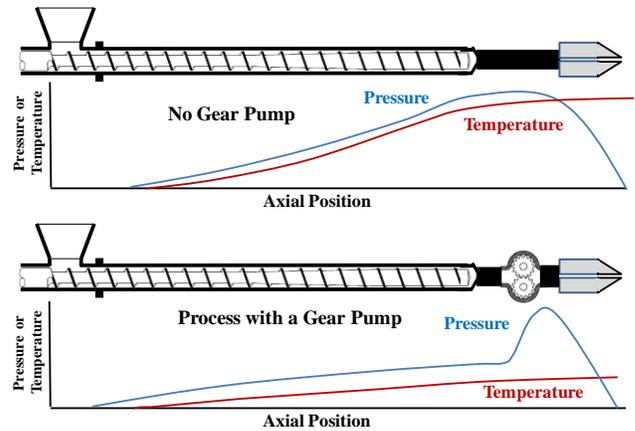


Figure 3. A schematic of the axial pressure and temperature for processes with and without a gear pump. The rates for both processes are the same, but the discharge temperature for the process with the gear pump is less than that for the standard process.

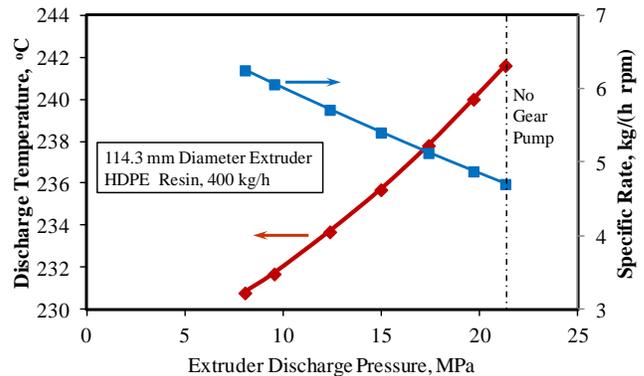


Figure 4. Operation of a 114.3 mm diameter extruder running a HDPE resin at 400 kg/h as a function of discharge pressure.

A severe and random flow surging problem limited the production rate for a large-diameter, two-stage, vented extruder [5]. If it were not for a gear pump positioned between the extruder and die, this extrusion line would not have been operable. The surging did, however, limit the output of the line to about 70% of its potential rate. The

maximum potential rate is the rate that the extruder can run at high screw speeds and with proper operation. The extruder was 203.2 mm in diameter and had a 40 length-to-diameter (L/D) barrel. A schematic for the extruder and gear pump arrangement are shown in Figure 2. The extrusion system was used to make a sheet product.

Steady-state operation of the extruder is shown by the first 400 minutes in Figures 5 and 6. The data for these figures were from the same production run. The extruder was running a high-impact polystyrene (HIPS) resin at 2250 kg/h and a screw speed of 99 rpm for a specific rate of 22.7 kg/(h rpm). This specific rate was about 14% higher than the specific rotational flow rate calculated for the first-stage metering section, indicating that a negative pressure profile exists in the section. The negative pressure gradient is expected for a first-stage metering section of a vented screw that is operating properly; i.e., the first-stage metering section was full of resin. To maintain the stability, the extruder screw speed was reduced such that extruder was operating at about 70% of its potential maximum rate. That is, at screw speeds higher than 99 rpm the extruder was more likely to transition from a stable to an unstable operation.

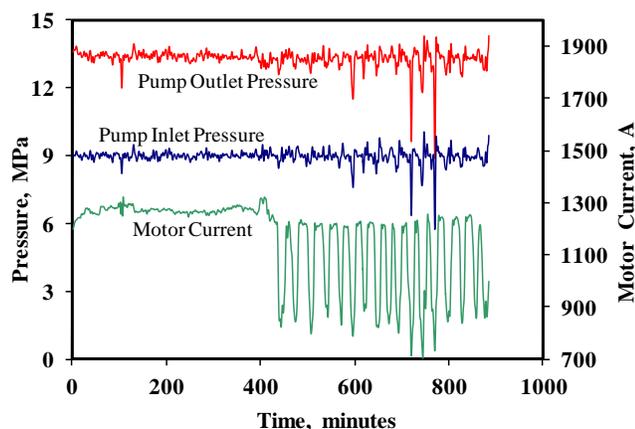


Figure 5. Pump inlet (extruder discharge) and outlet pressures and motor current for stable and unstable extrusion for a large-diameter extruder running HIPS resin.

During this first 400 minutes, the inlet pressure to the pump was relatively stable, and the discharge pressure to the die was also acceptable, producing prime product. At about 410 minutes into the run, the extruder started to operate unstably, as indicated in Figures 5 and 6. The processing change that caused the extruder to go from a stable operation to an unstable one was not known, but it could have been due to minor changes in the bulk density of the feedstock or cooling water fluctuations to the screw. The root cause for the event and technical solution were provided earlier [3,5] and they are beyond the scope of this

writing. As shown in Figure 6, the extruder screw speed was oscillating between 100 and 180 rpm during the period of the instability. During this unstable period, however, the gear pump control allowed the pump inlet pressure to oscillate at only a low level. The outlet pressure from the pump (pressure to the die) had a similar level of oscillation as in the inlet pressure, as shown in Figure 5. The oscillation in the outlet pressure, however, was acceptable for making prime product. Resin consumption was higher than normal during unsteady operation because the product was varying widely between the upper and lower control limits for sheet thickness rather than operating close to the lower control limit. If the pump would not have been on this line, prime product could not have been produced when the extruder was unstable. Although the pressure oscillation observed here was unacceptable, the pump was able to allow production during the time required to make the process modification to mitigate the surge.

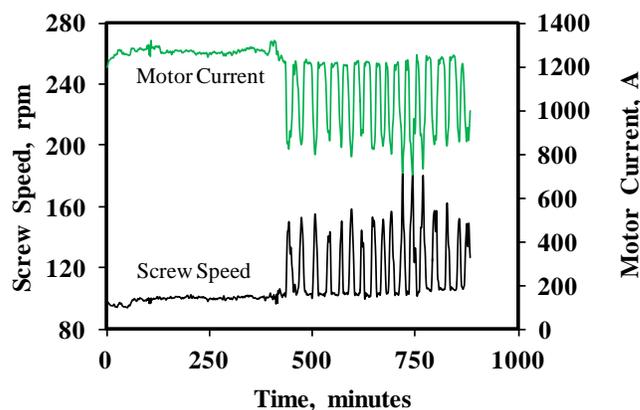


Figure 6. Screw speed and motor current for a large-diameter extruder running stable and unstable.

Gear Pump Pressure Control

A poor control algorithm for the pump can cause some variation in the extruder screw speed, causing large variations in the inlet pressure to the pump. This type of control-induced surging can occur even though the process as designed is inherently stable. To determine if the control algorithm is inducing the surging, the screw speed of the extruder should be operated in a manual mode and at a constant speed. If the controller is inducing the surging, placing the process in manual control mode will stabilize the process.

Transient process data were collected for an extruder with a downstream gear pump, as shown in Figure 1. For this case, the control algorithm was controlling the speed of the screw such that the inlet pressure to the pump was maintained at 8 MPa for a polycarbonate (PC) resin. Although the variation in screw speed was not excessive at

67±1.5 rpm, the variation in motor current seemed quite high at 540±90 A. At about 16 minutes into the run, the extruder was switched from automatic to manual screw control; i.e., the screw speed was held constant at 67 rpm. As shown by the data in Figure 7, the motor current variation was unchanged, indicating that the screw speed control algorithm was not inducing the variation in the motor current. During the period that the screw speed was held constant, the pressure to the inlet of the pump slowly increased, as shown in Figure 8. This pressure was increasing because the screw was operating at a speed that delivered a rate slightly higher than that needed by the pump. When the control was placed back into the automatic mode, the screw speed was decreased initially to compensate for the higher than desired pump inlet pressure.

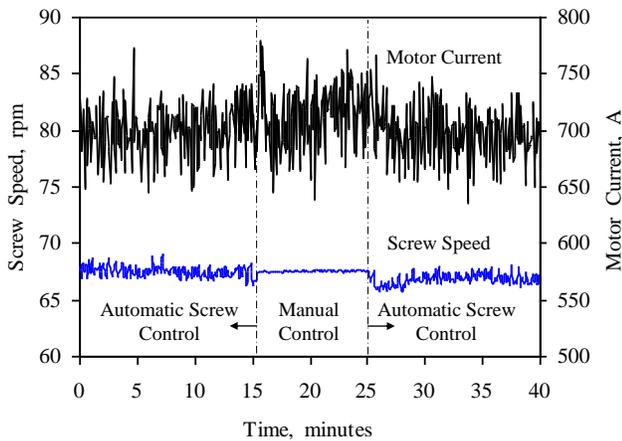


Figure 7. An extrusion process with a downstream gear pump with the screw operating in inlet pressure control and followed by the screw in manual operation (constant screw speed).

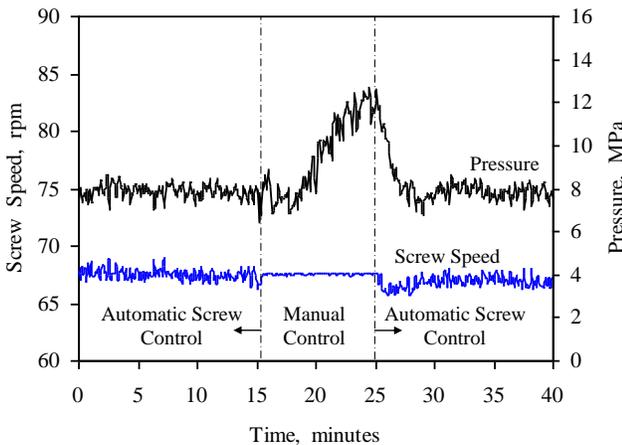


Figure 8. Pressure at the inlet to the gear pump for the data presented in Figure 7. The pressure increased during manual control because the flow rate of the extruder was slightly higher than the rate of the pump.

The large level of variation in the motor current during constant screw speed control suggests that the extrusion process was unstable, and the control algorithm was not the root cause for the variation in the motor current. The root cause and technical solution for mitigating the surge are provided elsewhere [3].

In another case, a single-stage extruder with a gear pump running a low density polyethylene (LDPE) resin was operating with a pressure oscillation at the discharge of the extruder. Like the previous case, it was not known if the extruder or the control algorithm for the gear pump was causing the instability. The pressure oscillation during the unstable period is shown in Figure 9 for the first 7 minutes of data collection. Like before, the gear pump controller was placed into manual mode such that the extruder screw speed was held constant. As shown in Figure 9, the pressure at the inlet to the gear pump was relatively stable when the screw speed was in manual control. When the control was turned back on, the pressure variations resumed. These data indicate that the control algorithm was causing the pressure surges to the inlet of the gear pump. In this case the proportional gain of the controller was set too high for the process. When the gain was reduced, the process became very stable with the pump in automatic control mode.

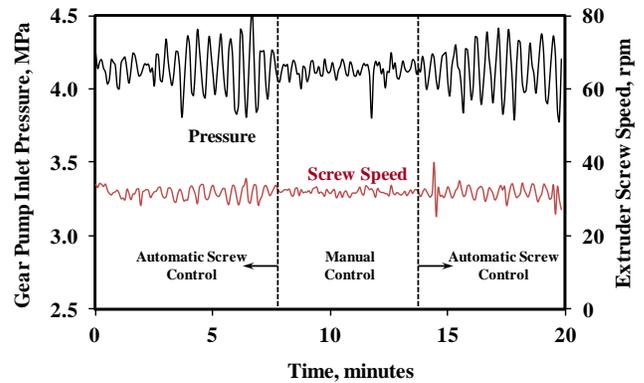


Figure 9. Process dynamics for a gear pump with a poorly designed control system.

Placing the screw speed controller in manual mode is recommended when minor levels of flow surging are observed with a process where the screw speed is controlled from the inlet pressure of a gear pump. This procedure will correctly guide the troubleshooting process to focus on the extruder or the gear pump.

Gear Pump Seizing

A polystyrene (PS) sheet line was constructed using a two-stage, vented extruder and a gear pump. On several

occasions the bearings on a gear pump would seize. In both cases, the gear pump was identified as the root cause of the failure, and claims were placed against the manufacturer. After the third pump seized, a full evaluation of the line was performed. The analysis indicated that the first-stage metering section of the extruder screw was not controlling the specific rate of the process as designed. Instead the specific rate was about 90% of the flow due just to rotation; i.e., historically known as the drag flow rate. Here the rate was controlled by a poorly designed solids conveying section. During typical operation, the extruder would operate with the first-stage metering channel at essentially zero pressure, and the second stage metering section would use only two diameters of filled length to supply an inlet pressure of 6 MPa to the pump. On very rare occasions, the solids conveying section would deliver a large amount of material such that first stage metering section was operating at 120% of the specific rotation rate. This event would completely fill the second-stage metering section such that a very high and nearly instantaneous discharge pressure would occur. This pressure was estimated at about 60 MPa. This high pressure coupled with a low pump discharge pressure of 15 MPa created enough differential force to deflect the rotors and overload the gear pump bearings, leading to the seizing of the pump.

For a normal control scheme, the controller for the screw speed would have decreased the screw speed to match the 6 MPa inlet pump pressure set point. But because the pressure surge happened extremely fast, the controller could not respond fast enough when the high pressure surge occurred, causing the catastrophic failure of the pump.

The solids conveying section of the screw was modified through screw design and process temperatures such that the first-stage metering channel was always operating full and under pressure at a specific rate of 110% of the calculated rate due just to screw rotation. The pump never seized again.

Improperly Designed Metering Section for a Two-Stage Screw

A gear pump system was added to an existing 114.3 mm diameter, two-stage, vented extruder on a PS sheet line as detailed in Figure 2. The extruder discharge pressure before the addition of the pump was about 20 MPa, and the process was fairly stable and operated well. The screw channels were previously optimized to a pre-specified rate and a discharge pressure of 20 MPa. After the addition of the pump, the extruder discharge pressure was reduced to about 10 MPa. The line could not be operated at more than 70% of the potential rate due to the excessive oscillation in the inlet pump pressure and consequently the fluctuation in

screw speed. The problem was analyzed and found that solids conveying in the first stage of the screw was performing as expected and that the flights were full and pressurized in the first stage of the screw. Since the discharge pressure of the second stage was decreased by half, the length in the second stage that was required to generate the discharge pressure was decreased significantly, moving the position downstream where the second-stage meter becomes first filled with resin. A schematic of the axial pressure profile with and without the pump is shown in Figure 10. For the line without the pump, a typical pressure surge will cause the fill position to start 1 diameter earlier and would cause the discharge pressure to increase to 22 MPa or 10% as indicated by the dotted blue line. When the line was configured with the gear pump, the same surge would increase the extruder discharge pressure to 12 MPa, or an increase of 20% as indicated by the dotted red line. The higher percentage of pressure increase caused the higher pressure oscillations at the inlet to the gear pump and caused the controller to oscillate the screw speed. When the pump was not installed, the pressure fluctuation was about 10%. Although this level of fluctuation is not acceptable, it did allow the line to produce acceptable sheet.

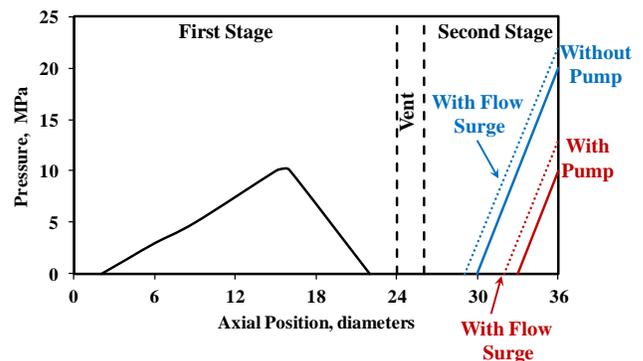


Figure 10. Axial pressure profile for the PS sheet line with and without a gear pump. The blue dotted line is the expected pressure profile for a high pressure surge without the pump, and the red dotted line is the same surge with the pump.

With the gear pump installed, additional screen packs were added to increase extruder discharge pressure to the original 20 MPa. With these conditions, the screw speed could be increased to full rate with the pressure relatively stable at the inlet to the pump. Long term solutions were found to be an adjustable melt restrictor valve installed directly after the extruder to induce resistance and cause a higher extruder discharge pressure, or the redesign of the second stage of the screw for the expectation of reduced extruder discharge pressure.

Although either solution will work, the preferable course of action is to redesign the second-stage metering section for the reduction in extruder discharge pressure, allowing the processor to take advantage of lower energy and discharge temperature afforded by the pump. For this case, the second-stage metering channel was too deep relative to the depth of the first-stage metering channel. As expected, a similar problem occurs when the second stage is not optimized with the first-stage metering section for processes without gear pumps [6].

Discussion

Using a gear pump to control rate and to generate a portion of the pressure required for the die is an excellent method to allow a process to operate near the lower control limit of the product thickness, reducing the consumption of resin per unit area for a sheet line. For new installations, the design of the extruder screw should be optimized for the inlet pressure required by the pump. For the addition of a gear pump to an existing extrusion line, the processor should consider the process changes that will occur when the discharge pressure from the extruder is reduced, especially for two-stage, vented machines.

Gear pump rotors are positioned using specially designed bearings. These bearings and rotor shafts are lubricated with molten resin from the extruder. That is, a very small portion of the resin flow from the high pressure outlet side of the pump is flowed into the bearing annulus and then into the low pressure inlet side of the pump. The design of the bearing depends on several factors including resin rheology, differential pressure, and rate. The differential pressure is defined as the outlet pressure minus the inlet pressure. If the differential pressure becomes too low, resin flow to the bearings will be reduced or interrupted, shortening the life of the bearings or causing the pump bearings to seize.

Summary

Gear pumps positioned between single-screw extruders and dies can provide advantages including reducing the discharge temperature, reducing instabilities from the extruder, and reducing the resin consumption to make the final product. Reductions in extruder discharge pressure can also extend the operation life of screws, barrels, and thrust bearings while reducing energy consumption. However, while applying this technology processors must be aware in the change in dynamics of the extrusion line for normal troubleshooting principles. Troubleshooting process problems associated with this type of process were presented.

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