Redesign of a Single Screw Extruder

Project Number: SYS 0088

A Major Qualifying Project Report

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

In Mechanical Engineering

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Date: April 25, 2012

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1. extruder redesign
2. plastic
3. single screw

ABSTRACT

This project involved the redesign of a two decade old single screw plastic extruder. Diagnostics and troubleshooting revealed a malfunction in the motor controller resulting in motor failure. The specifications for a new motor controller were developed that can make the machine fully operational. Design and construction of a cooling system was also needed to maintain the structure of the extruded molten plastic as it exits the die.

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Introduction

The extrusion process began in the 1800s by means of preheating the metal and forcing it through a die via a hand driven plunger known as squirting. Extrusion is now possible for metals, polymers, ceramics and concrete. Plastic extrusion began in the 1930s and the continuous process has been applied to manufacturing at high volume. Plastics have been very popular in the modern world and learning about the process interested us from the start. Learning about how pellets can be heated and formed into the desired shape through a die is important for the process to be improved upon. Learning the process and troubleshooting using our skills of engineering to reverse engineer the extruder has been a true challenge. Upon the completion of this project future students who are interested in extruded plastics will be given the opportunity to test material properties and learn the ins and outs of how an extruder works.

Fixing this single screw extruder isn't our only task as we implemented design also. When given the extruder the motor wouldn't run and there wasn't a cooling system for the extruded product. Design of a water bath seemed to be the simplest and most effective way to cool the extruded plastic. When the material originally comes out hot and gravity pulls the material down which makes it stretch and lose its shape. With a roller system and water bath the material will strengthen and keep the desired shape. A place to store and organize the extruded material is also necessary since the extrusion process is continuous and lasts up to an hour, depending on the amount of material put into the hopper.

Another reason for this project is for future students to be able to run material properties testing on different resins and comparing the results. Fixing the extruder benefits others by giving them our troubleshooting process, videos of taking the extruder apart, CAD drawings and model, pamphlet of how extruders work and a water bath cooling system. Completion of this project will give us a great deal of knowledge of experience in the engineering field, knowledge of the extrusion process and troubleshooting skills for the future.

Background

History

To properly troubleshoot and repair an extruder we must first understand what a plastic extruder is. Plastic extrusion is used to create a multitude of different products ranging from garbage bags to plastic tubing. Extrusion has been around as early as the 1800s known at that time as squirting. Extrusion comes in three different forms; direct, indirect and hydrostatic which all have their pros and cons. The type of extrusion we are studying is direct extrusion, also known as forward extrusion, and is the most popular of the three forms of extrusion. It is the process of moving material through a die of the desired shape of the cross-section. An extruder works by melting down plastic pellets, called resin, that are then forced down a barrel by a screw where they continue to melt and are finally pushed out through a die that gives them their final shape. The extrusion process can be continuous, potentially producing any desired length of material, or semi continuous to produce many pieces of material. The process may be hot or cold.

Types of Extrusion

The other two types of extrusion mentioned earlier are indirect and hydrostatic. Indirect extrusion, also known as backward extrusion, keeps the die stationary while the billet, heated material which profiles are extruded, and the container move together. The length of the stem, place where the die is held, is the potential maximum length the extrusion can be. With indirect extrusion friction is much less which increases the speed of the process and ability to extrude more small and challenging profiles. Impurities or defects in surface of billet will affect the extrusion therefore billets are very important and need to be taken care of. The last type of extrusion is hydrostatic extrusion which utilizes pressurized liquid around the billet and can be done as hot, warm or cold. Process must be concealed to contain the hydrostatic medium. The two ways to pressurize the fluid are constant-rate and constant-pressure. Constant-rate extrusion uses a ram or plunger to pressurize the fluid in the container while constant-pressure uses a pump to pressurize the fluid and then pump it into the container.

Types of Extruders

There are many types of plastics extruders of all different sizes and with all different purposes. They can be grouped into two basic types; single screw and twin screw. We are, obviously, using single screw extruders which are useful machines when production of a pure polymer is necessary. Single screw machines do not require pre pelletizing as twin screw machines do and are also equipped with many accessories that might not be found on twin screws such as heat/pressure controllers, wider range of screw geometries and automatic feeders for continuous production. Twin screw extruders are machines used for compound production when two or more resigns are required to be mixed and extruded. The two screws are placed on top of one another for the material to mix fully so the compound can be extruded uniformly.

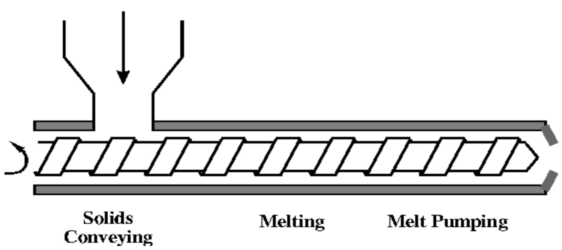

Figure 1 Single Screw

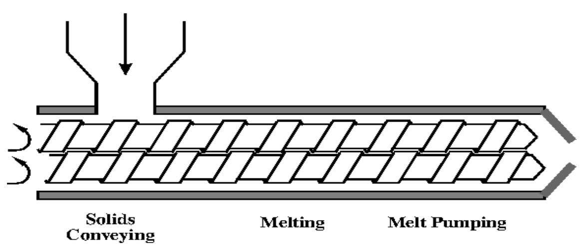

Figure 2 Twin Screw

Types of screws

Basic screw design:

The screw is usually contained inside a tight fitting barrel on the extruder. It is normally driven by a variable speed motor and is a decidedly efficient device capable of processing several tons of plastic per hour. The screw is divided into three zones: the feed zone, the compression zone, and the metering zone.

The feed zone delivers plastic resin pellets from a gravity fed hopper into the barrel to begin the longitudinal movement of the plastic. Using axial rotation the screw threads move the plastic down the barrel. Within the barrel, heaters help the plastic develop a tack to increase its friction against the barrel wall. Without this friction the plastic could not be conveyed forward and would merely rotate inside the screw.

In the compression zone, also known as the transition or melt stage, the root diameter of the screw increases while the height of the flight decreases. The resin is melted here because of compression, shearing and heating produced in the barrel. Next the melted plastic moves through the metering zone. In this zone the screw diameter remains constant and the melted plastic which is under high pressure is pumped into the extruder die.

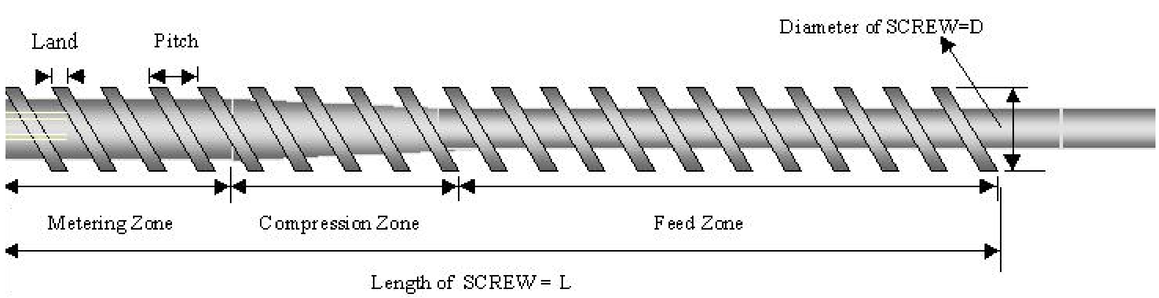

Figure 3 Typical Screw

Barrier Screws:

Sometimes the basic extrusion screw does not completely melt the resin. In this case another type of extrusion screw may be necessary for the desired melt. The barrier screw, which is designed to counter this problem, implements the use of addition flights attached to the transition zone so as to separate molten and solid plastic to different channels. As the solid pellet moves forward it melts due to shear against the wall and flows into the liquid channel. The liquid channel gradually grows wider as the solid channel narrows.

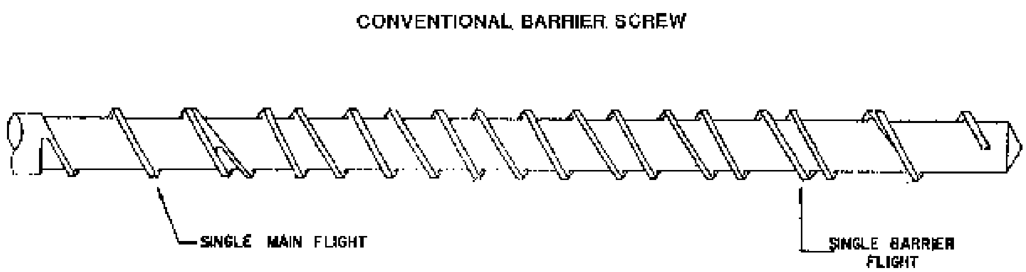

Figure 4 Conventional Barrier Screw

Mixing Screws:

When mixing two different additives, a more efficient way is to mix extrusion materials with twin screw extruder. Some single screw systems can, however, be used for mixing. Though general-purpose screws are available, different plastics require differently calibrated extrusion screws. The length-to-diameter ratio, pitch, length of each zone and helix angles of a screw must all be matched to the plastic type being used. The screw must also be designed to suit a specific type of die.

Objectives

- Understand the extrusion process works and gain knowledge about extruders
- Disassemble and clean the extruder parts and troubleshoot it to ensure its proper operation
- Design and construction of a cooling system as the plastic exits out of the die
- Try to extrude various commercial resins

Overall Methodology

The extruder required much work when it first came into our possession. With need for a power source great enough to handle the machine before proper diagnostics could begin, we removed the heating clamps and cleaned away any residue that had built up over the years of neglect. We then proceeded to open and check the gear system for any pitting or scarring that may have occurred. After the gears were deemed to be in working condition, they were re-oiled to ensure smooth movement. A trip was made to New England Plastics in Woburn, MA to see extruders in work and to learn the basics of the extrusion process from a commercial viewpoint.

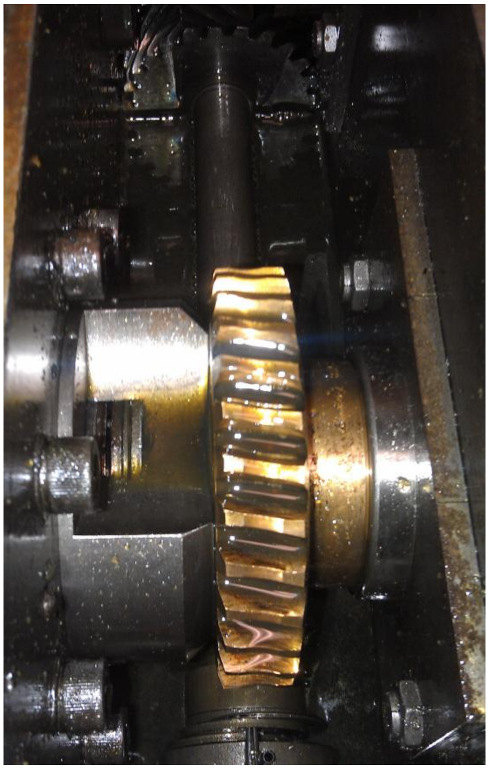

Figure 5 Gear Box

Once the new outlet was installed in Washburn 250, the extruder was successfully turned on. At this time the heating clamps were operational and capable of heating the barrel to appropriate temperatures.

Figure 6 New Outlet

The motor and screw however, still would not turn. A visit to the UMASS Lowell plastics department provided us with necessary information to get the screw turning. We implemented these techniques as described in later sections and were able to successfully turn the motor and drive the screw. (Link to YouTube video of extruder successfully running can be found in Appendix B)

The extruder was run multiple times and eventually the screw jammed up and causing the motor controller to fail resulting in the motor not turning once again. We attempted many different approaches to fix the controller, including ordering electrical components to replace the failed ones, to no avail. We also attempted to research replacement controllers, but without the name plates on the motor it was nearly impossible to determine a proper controller. Under the guidance of faculty members on campus, specifically Doug White of the Goddard shops, we were directed to Bigelow Electrical in Worcester, MA for assistance in developing a new motor controller. A new controller was designed by the people at Bigelow but the price of such a new system was staggeringly high and could not be implemented into the extruder.

While the extruder was operational and we were extruding polypropylene we noticed that the plastic could not support itself as it exited the die. Again from our trips to New England Plastics and

UMASS Lowell, we were exposed to the use of water cooling systems for the molten plastic immediately as they flow out of the die. We were able to design and build a much less sophisticated prototype water cooling system to prevent the plastic from collapsing under its own weight. This system unfortunately was not able to be tested due to the failure of the motor prior to its completion.

Methodology

Power

The power for this device required a special outlet to be installed in the Washburn 250 lab: 220 Volts 30 Amps. The single screw extruder is three phases and each phase draws 120 volts. The motor however, only draws two phases totaling 220 volts. The plug has four prongs and a lock feature on one of the prongs to ensure the plug has contant flow of power. This also protects the extruder from a sudden loss of power during a heating/extruding phase which could cause catastrophic damage.

Figure 7 220 Volt 30 Amp Power Plug

Motor Not Turning

When originally received, the extruder was in rough shape and the motor would not turn when the power was applied. This could have been the result of many different things. A visit was made to UMASS Lowell, one of the leading plastics/polymer departments in the Northeast, in order to gain insight on potential problems. There we were educated to potential causes of the motor not turning with the most likely cause due to a buildup of hardened plastic on the screw and in the barrel. The following steps were suggested to us to get the motor and screw turning: heating the extruder up to temp (approximately 150 degrees Fahrenheit or to the melting temperature of previous plastic used) and letting the barrel heat soak for 30-45 minutes, removing and cleaning the die once heated to unplug the outlet channel, removing the threaded end cap, and finally removing and cleaning the screw. Applying these steps and with the help of some WD-40 in stick points (not on the actual screw) we were able to successfully get the motor to turn and capable of turning the screw with enough force to extrude plastic.

Figure 8 Unattached Motor

Screw Removal

Screw removal is a vital step in the cleaning process of a plastic extruder. There are also a wide variety of screws available for different applications of the extruder that can be changed out accordingly. A YouTube video link can be found in Appendix B. The following steps need to be followed when removing the screw (more detailed guide can be found in Appendix A):

- Turn on the machine and let the barrel heat up for 30-45 minutes at a temperature of approximately 150 degrees Fahrenheit.
- Unfasten the bolts holding the die onto the screw and remove the die.
- Remove threaded end cap from the drive end of the screw.
- Feed a threaded rod into the opening created by removing the threaded end cap in the previous step.
- Tap the end of the rod with a hammer or mallet to free the screw key from the key way.
- The screw then can be slid out from the barrel by hand.

Figure 9 Screw Removed

Cleaning the Screw

To properly clean the screw once it has been removed, brass tools should be utilized. Brass tools are utilized because brass is a softer material and will not scratch or damage the screw. A good tip for cleaning the screw is to let the molten plastic harden a little bit so that it can be peeled off in chunks. If he plastic hardens too much, simply reinsert the screw into the barrel for a few minutes until the plastic softens once more and continue the cleaning. A proper cleaning should also involve cleaning the barrel. This is simply using some brass wool on a stick or rod to remove any plastic that may be stuck to the barrel wall.

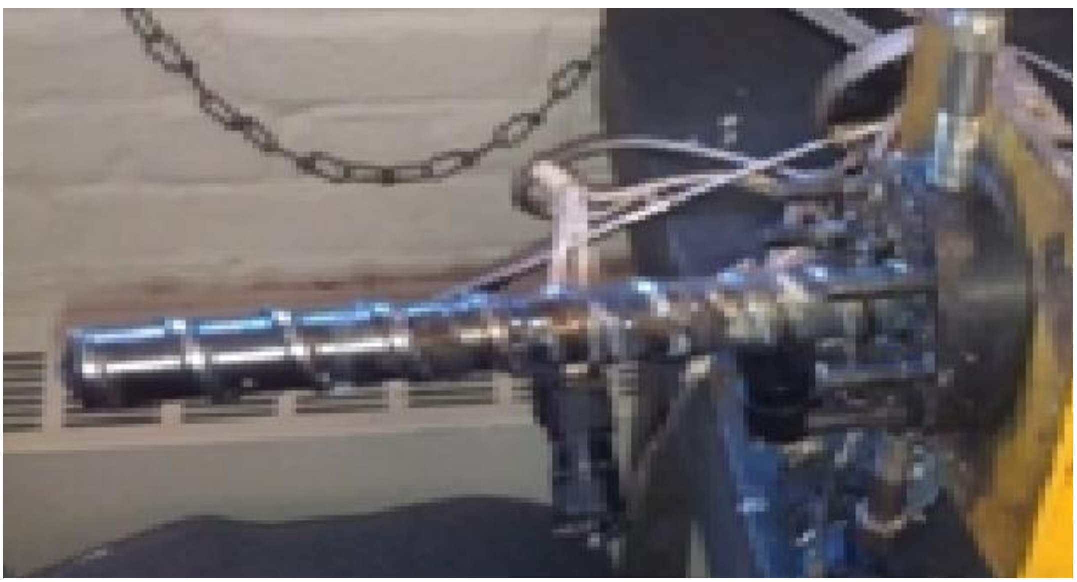

Figure 10 Dirty Screw

Figure 11 Clean Screw

High Torque Levels/Blown Fuse

Once we were able to get the motor and the screw to turn, we then had the capability to extrude plastic. Multiple successful runs of the extruder followed and we began to notice a different problem. The torque levels required from the motor to turn the screw had increased significantly from the point when we first ran the extruder. The high torque levels drew more power from motor with less screw turning. This problem can severely damage the gears and motor if unattended to. As a result, the motor failed and would not turn once again. In an attempt to remedy this issue, we checked the motor's brushes and their connections. We had to tighten the connections on all brushes which were loose and potentially the cause of energy and power loss. When this solution did not revive the motor, it was suggested to us by Doug White in the Goddard Hall shops that we replace multiple parts that made up the motor controller. After gathering the part numbers we proceeded to attempt to purchase these new parts to little success. Since this machine is over 20 years of age, many of the part numbers for the components we needed had changed or no longer existed. Contact with faculty in Atwater Kent provided us with some resources for the parts we believed would fix the problem we were currently facing. We used McMaster-Carr and Mouser companies to look for replacement parts but most of the parts were outdated or discontinued. We were able to match the part numbers for a few of the parts and have them ordered. When we attempted to have these parts installed however, we came to the stark realization that they were not compatible with the controller system in place. Again we sought the guidance of Doug White of the Goddard shops and he directed us to Bigelow Electrical in Worcester, MA for assistance in acquiring a new motor control. The motor was removed from the extruder and brought in to George Hilditch, the shop foreman at Bigelow, for evaluation. With no name plates on the motor to provide its specifications, we acquired the armature and field voltages that helped lead to discovering the revolutions per minute (3450), and the horsepower (5). The motor was tested and found to be in good working condition solidifying the theory that the motor controller was indeed the source of the problem. The workers at Bigelow were able to spec out the correct motor controller but for a price far beyond our budget.

Figure 12 Motor Controller

Missing Parts

A few minor parts were missing from the extruder upon arrival in our hands. A thermocouple bung, which holds attaches a thermocouple to the barrel, was one of these parts. Without this piece, the thermocouple sometimes few out of contact with the barrel and did not read a consistently accurate temperature. While the absence of this piece may seem like a minor issue that could be solved simply by placing the thermocouple back into the hole in the barrel, it can actually be quite damaging to the machine. When the barrel reaches approximately165 degrees Fahrenheit cooling fans kick on and blow air across the barrel to prevent overheating. If the thermocouple was not reading the correct temperature of the barrel because it had fallen out, the fans will not kick on to prevent the overheating. A new bung was purchased to remedy this problem.

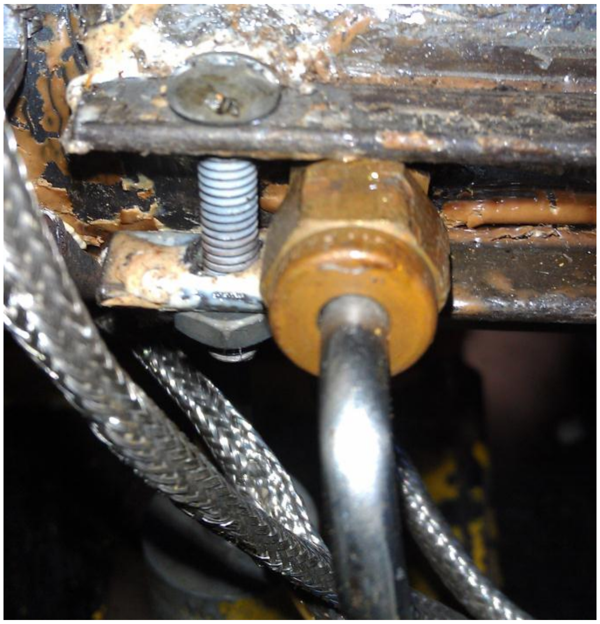

Figure 14 Bung Attached to Barrel

Figure 13 Thermocouple Bung

The extruder contains a gauge that shows the revolutions per minute at which the screw is turning. The source for this number is a disc that spins along with the threaded end cap and transmits the revolutions per minute to the gauge. The disc and the threaded end cap are usually joined together by a belt or gasket that allows the disc to move at the same rate as the spinning screw and threaded end cap. Without this part, it is very difficult to regulate the speed of the motor as the speed dial is not very practical.

Figure 15 Nonfunctional Speed Gage

Figure 16 Missing Gasket for Speed Gage

Problems with Screw Key

A key is used to connect a rotating machine element to a shaft or in our case the screw. The key allows for torque to be efficiently transmitted and prevents relative rotation between the two parts. In order for a key to be effective, a keyway or keyseat, a slot for the key to fit into, must be present on the rotating section. This whole joint is called a keyed joint and still allows relative axial movement between the parts. When the motor controller failed, the key on the screw also popped out of the keyway and actually detached from the screw itself. Luckily there was no damage to the screw itself and the key was magnetic and reattached easily without the need for any machining.

Figure 17 Screw Key

Necessity for Water Bath

When the extruder was still operational, the plastic that we extruded immediately fell limp as it left the die. Failure to support its own weight as it exits the die is due to the plastic still being mostly melted. One resolution to this problem is to lower the temperature at the die so that the plastic is not as hot when it exits. As an add on to that solution, lengthening the die would allow for the plastic to be in the cooler die section for longer where it can be supported by the die as it hardens. The drawback to this solution is that the plastic can harden too much and get stuck in the die. This would cause a build up in the barrel and not allow the screw to turn freely potentially damaging the motor. A remedy for cooling the plastic that we came up with was the design of a water bath system to cool the molten plastic directly as it is ejected from the die.

Figure 18 Sagging Molten Plastic From Die

Technical Appointments

New England Plastics

Our first extruding facility we paid a visit to was New England Plastics in Woburn, Massachusetts. After planning an appointment with Tony we decided to make a binder of pictures to present to each facility so whomever we spoke to could have a gist of what type of extruder we are working with. After putting the pictures we desired on a USB drive, Rita was generous and printed everything for us so that we could have a binder presentation of our project. When we arrived at New England Plastics on December 13th we were given a quick tour of their facility. We were curious to see an extruder in use, receive simple troubleshooting tips, check out different dies and possibly get an old one, see different screws and also possibly get an old one, and also see if they have any referrals to other places willing to help.

Figure 19 Close-up of Die

We were able to learn about the different parts of the extruder, see different dies and learn how the die created the profile of the final product. Tony allowed us to take videos of running extruders, although the extruders in their facility were all twin screws. This is where we able to see the extruder create a final product of the compound made of different resins. All of New England Plastics' extruders were mixing or compound extruders while our extruder is used for pure polymer extrusion. Tony was not able to help us too much on our extruder but helped us understand the process a little better and see it for ourselves. We saw different types of dies used in manufacturing and also different screws and how both of these parts play a big role in how the extruder functions and what the final product looks like. He recommended getting a pamphlet, or diagram, on single screw extruders to help us in the troubleshooting process.

The visit was short but the tour helped us understand the differences in extruders as well as see them in use. Tony gave us a contact that could help fix our extruder, Davis Standard, since he felt he couldn't help us further.

University of Massachusetts Lowell

Our reverse engineering research led us to discover possible troubleshooting techniques to solve our dilemma of the nonfunctional motor. Without being able to successfully remove the motor or screw our troubleshooting became limited so we contacted the Plastics Department of the University of Massachusetts Lowell for their guidance. Professor David Rondeau of Umass Lowell, our primary contact, advised us to try to remove the screw which could be removed by unlocking the key lock attached to the gear box. The screw could not be removed from the gear box so he invited us for a visit of their plastics department as we provided further information about our extruder and its problems. On December 16th, 2011 we made a trip up to their Plastics

Department to met Professor Rondeau, Charles Currie who was a technician for Umass Lowell, and Professor Orroth. The visit lasting several hours provided us with great details of exactly how an extruder functions, pictures and a video (link can be found in Appendix B), and also some materials to take back to WPI.

Professor Rondeau explained how extruders have a safety interlock and require a certain temperature that must remain on for a period of time before the extruder can function properly. Generally, an extruder needs a period of 45 minutes to warm up which allows the thermocouples to set up and read correct and steady temperatures. This time allows the barrel and screw to soak up in heat to melt plastic which could cause jamming or damaging results. Waiting another twenty to thirty minutes will guarantee all material in the barrel is liquid and the screw can safely be removed for cleaning. For the extruder machines in their department, the screw is removed by pushing the screw inward and turning the screw clockwise which frees the screw from the gear box. The screw can then be pushed out from the back as long as the die and die plate is removed first. Proper cleaning of the screw is done so by fully removing the screw and using brass tools, due to them being softer than steel, which will not scratch or damage the screw or barrel. After the screw and barrel are fully cleaned the screw is placed back into the barrel and ready for use. Professor Rondeau said this maintenance process must be preformed after every use of the extruder for optimal performance.

Our next contact was with Professor Orroth who had been with the Umass Plastics Department for many years. He used his wisdom and technical knowledge to explain how to remove necessary parts to be able to remove the screw and motor. After we explained our machine in some detail he recommended that it is necessary to take out all bolts and screws from the die, so the screw can be accessible. The die is attached by the die plate which is held by six bolts and screws all of which need to be removed.

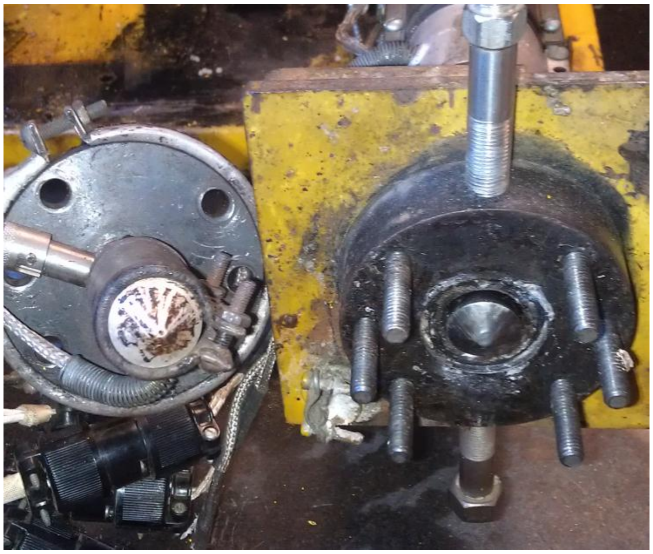

Figure 20 Removed Die from Die Plate

After the extruder is properly heated and ready then the screw can be fully removed. Professor Orroth mentioned to avoid tempering with the pressure transducer because their extruders use the readings of the pressure to detect any malfunctions and could automatically shut down the extruder, if necessary. Because our pressure transducer is not attached to a computer hook up this is not as important for our extruder since our table top extruder doesn't read the pressures.

Figure 21 Pressure Transducer

Lastly Professor Orroth recommended us to study the control panel of the extruder to get a better understanding of each components function and to talk with Charles Currie, who could be of help in the matter.

The last contact we had on our visit to Umass Lowell was with Charles Currie who was an Electrical technician. Charles explained most of the control panel and some of the electrical components in the extruder. The thermocouples of the extruders at their Plastics Department used similar thermocouples to the ones our extruder used which Charles said had to be J or K thermocouples. Each of these thermocouples had protective casings around the wires to ensure they did not get too hot or damaged. After we showed Charles our binder of pictures of our extruder he was concerned that we would struggle to control the temperature. He installed all of the digital temperature output readings on their extruding machines and told us controlling temperature by voltage directly instead of a digital control would be quite difficult.

Figure 22 Our Manual Adjustable Temperature

Figure 23 Umass Digital Adjustable Temperature

Charles mentioned that the pressure transducers also detect if pressure is building in the barrel and for newer machines is standard practice to use them.

At the end of our visit the three instructors met as a group with us to give a summary of our visit as well as let us take photos and videos of running extruders. Professor Orroth showed us their resin storage and gave us some Polypropylene resin take back to school and use.

Figure 24 Resin Close up

Figure 25 Bag of Polypropylene Received

Since Professor Rondeau recommended brass tools for cleaning and we did not have any brass in our MQP lab he gave us two pairs of brass tools to use to properly clean the screw and barrel.

Figure 26 Brass Tools Received from Umass

He also mentioned that copper gauze can be used to help clean the barrel if the tools he gave us couldn't fully remove the plastic. All three instructors gave us their contact information and Charles made sure that we would email him with updates on our extruder and that he would answer any questions that we had. On our way out of the building Professor Rondeau gave us two books on extruders and the troubleshooting process on extruding machines. This was our first reading material we received about single screw extruders and we knew it would come in handy later in our project. Overall the visit was a huge help to our success with the extruder and it was a great experience to see the University of Massachusetts Lowell's impressive Plastics Department.

Design of Cooling System

Background

Extruded plastic is still molten when it leaves the die after being extruded and can sag or lose its shape. Without proper cooling, die swell (figure below) can also occur leading to inconsistent dimensions of the extruded product and degraded material properties. Commercial extruding companies have sophisticated cooling methods which utilize the use of vacuums to help plastic from collapsing from its own weight while it is being cooled. While the water bath and roller system we designed is not as sophisticated as these machines that rapidly cool plastic for commercial use, it is crucial in the extrusion process for our applications.

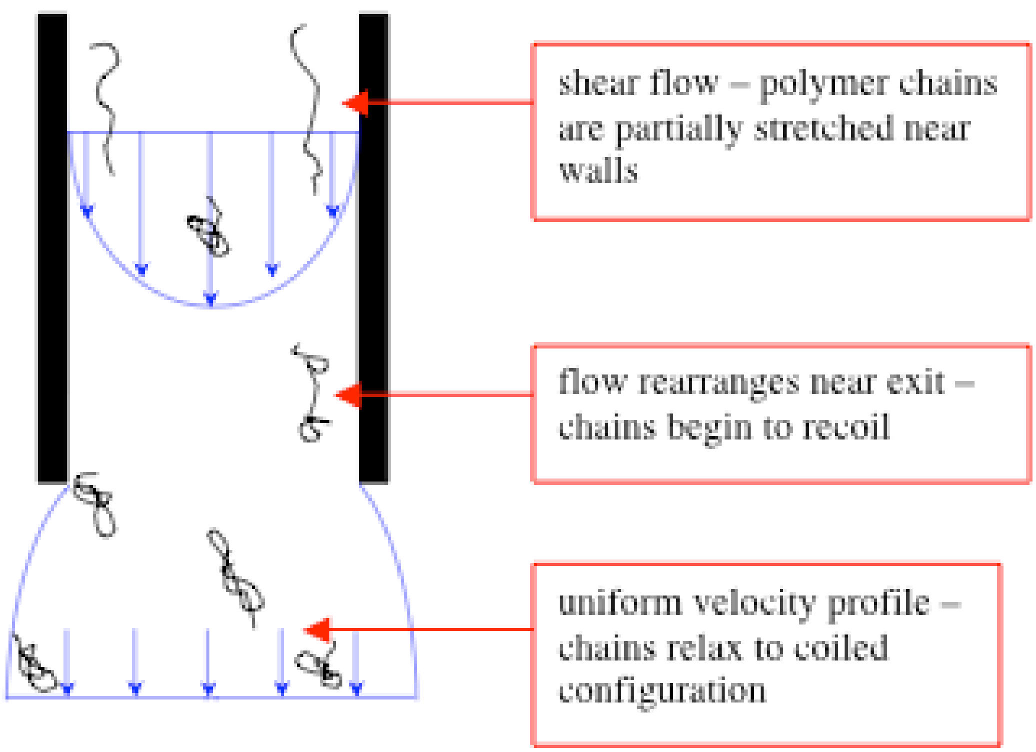

Figure 27 Schematic Outline of Polymer Dynamics in Die Swell

Initial Design

The initial design for a cooling system was to utilize a pumpless design that would not recycle the water used. This system would contain a shower head like structure hooked up to a water source by a hose. Once the water had showered over the molten plastic and collected in the basin, it would flow through a drain and out of the system. We originally hoped to buy a roller table and have the extruded plastic roll across it while being showered with water, but budget and size constraints did not allow for a store bought table. As a result a homemade roller table needed to be built.

Prototype

Two slabs of aluminum were pocketed in the machine shop and the aluminum rollers were cut down from round stock. The ends of the rollers had to be lathed down to the diameter roughly the size of purchased bearings. The bearings allow the aluminum rollers to freely rotate. This roller table sits on top of a basin that catches the water being showered over the plastic and is located directly as the plastic exits the die. In the bottom of the basin is a drain where the water is removed from the system.

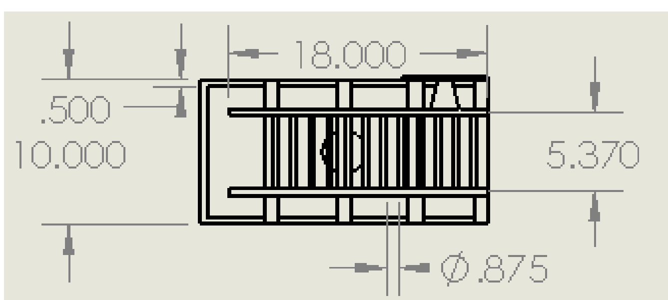

Figure 28 CAD Drawing Top View

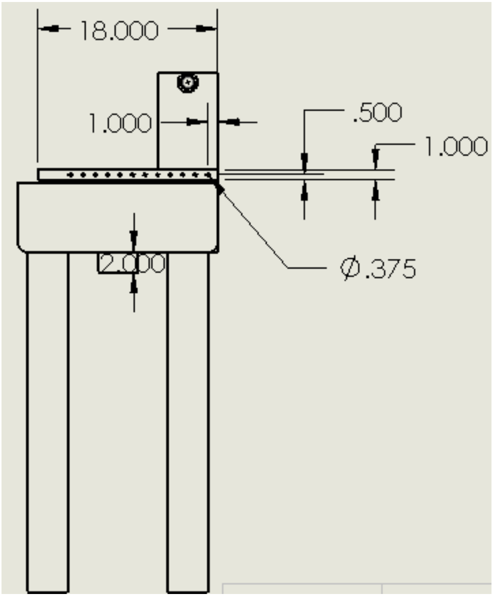

Figure 29 CAD Drawing Front View

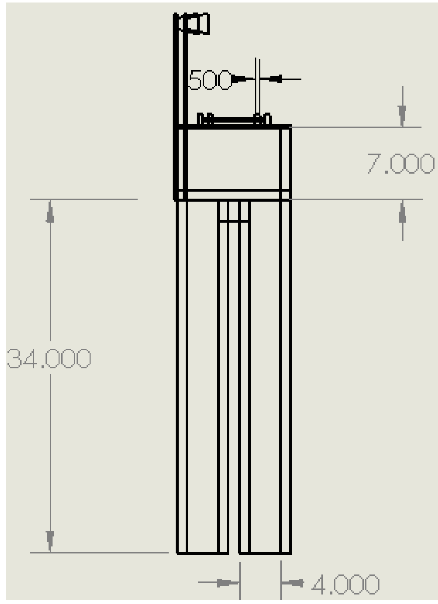

Figure 30 CAD Drawing Side View

A prototype was built to test the feasibility of the design. Unfortunately due the failing of the motor controller before the prototype was built, successful testing of the cooling system could not be implemented.

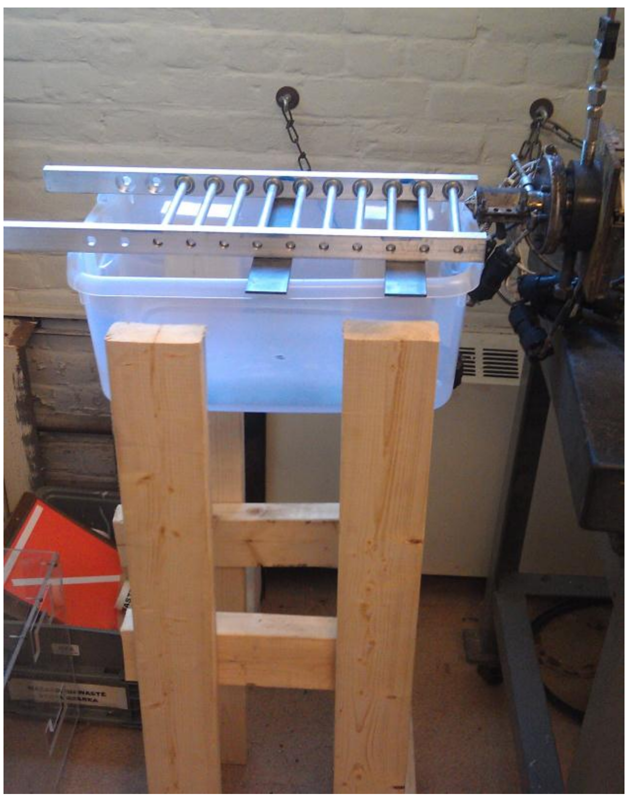

Figure 31 Cooling System Prototype

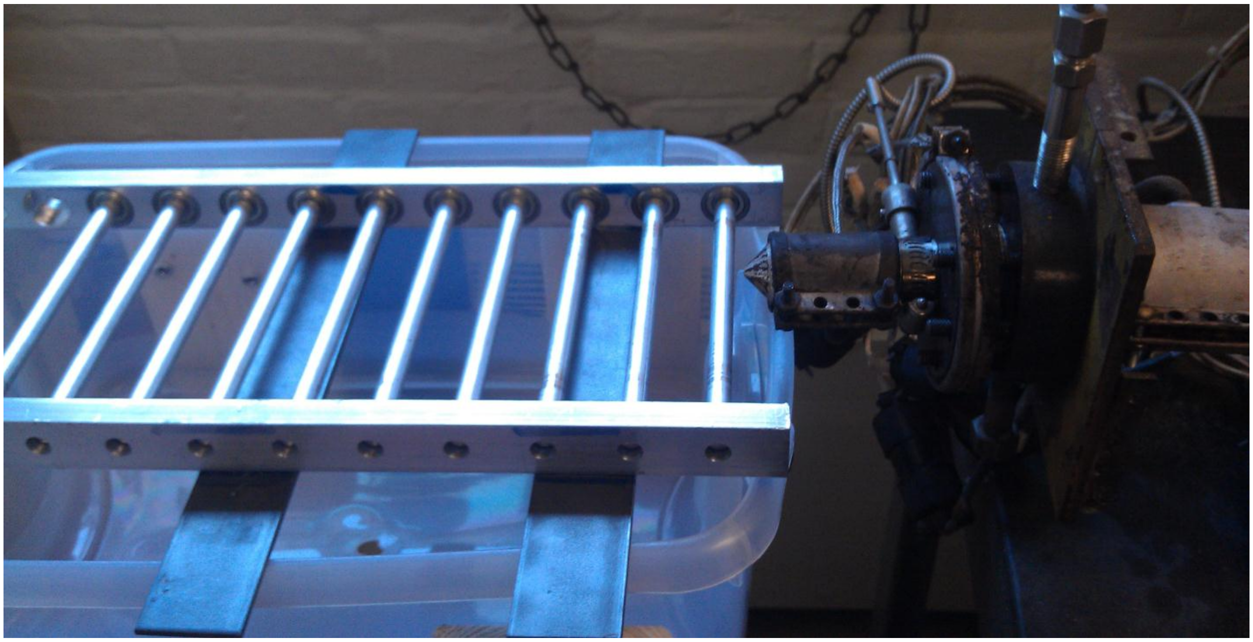

Figure 32 Close-up of Prototype

Future and Complete Design

If budget and resources were not an issue, a much more intricate design could have been set in place. First we had wanted to test the feasibility of our prototype to determine if move forward and improving the design was worthwhile. As stated earlier in the above sections, the motor controller failed before the prototype was built and tested. Under the assumption that the water would sufficiently cool the plastic as it rolled along the rollers to maintain its structure, we made some improvements to the prototype design.

The future design would feature a system that recycled the water in a cycle and would not require access to a sink or other water source. In order for the device to be an independent cycle, a water pump would need to be implemented to push the water back through the system and showered over the molten plastic again. An issue with recycling water that is used to cool hot plastic is that the water will begin to warm with every pass and not cool the plastic as efficiently.

To remedy this, a small refrigerant cycle would need to be built equipped with a heat exchanger, a compressor, a condenser and a pump or expansion valve.

Another improvement to the prototype design would be the implementation of proper materials. Ideally the roller table and basin would be made of stainless steel to decrease the chance of rust and also to improve the rigidity of the structure. Sturdy metallic legs would also be implemented to ensure stability.

Summary

The major accomplishments of this project include the retrieval of the proper specifications for a new motor controller, the design of a water cooling system, the replacement of missing parts, the creation of a detailed screw removal and cleaning guide complete with pictures of each step and a video of the process, and becoming educated with the extrusion process. With no information available for this machine, learning how to properly use and run the machine was a very tedious process.

As stated earlier, a cooling system is an integral part of the extrusion process. A prototype water cooled system was designed and developed for placement immediately after the die.

Also a very detailed screw removal and cleaning guide was also completed. This guide contains a step by procedure for this process equipped with pictures (Appendix A). A video of the process is also available through a YouTube link provided in Appendix B.

Finally a design of a new motor controller was also developed with the help of Bigelow Electric in Worcester, MA. The new controller contains a digital control opposed to the arbitrary knobs currently on the front of the extruder. Unfortunately, the high cost of the controller did not allow for us to implement it into our project. However, Bigelow has supplied us with the specifications for the new controller and a future project, most likely ECE, can use this knowledge to finish the resurrection of the machine.

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Appendices

Appendix A

Screw Removal and Cleaning Guide

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What you will need:

- Adjustable Wrench

- Brass tools

- Oven Glove

- Hammer/Mallet

- Threaded Rod

The following steps need to be followed when removing the screw:

- Turn on the machine and let the barrel heat up for 30-45 minutes at a temperature of approximately 150 degrees Fahrenheit.

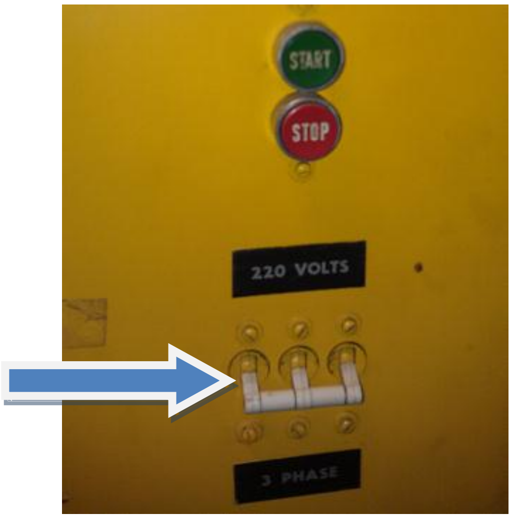

Figure 33 Power Switch

Figure 34 Digital Temperature Gage

- Unfasten the bolts holding the die onto the screw and remove the die (use an oven glove as the die is very hot).

Figure 35 Die Bolted on

- Remove threaded end cap from the drive end of the screw.

Figure 36 Threaded End Cap

Figure 37 Close Up of End Cap

- Feed a threaded rod into the opening created by removing the threaded end cap in the previous step.

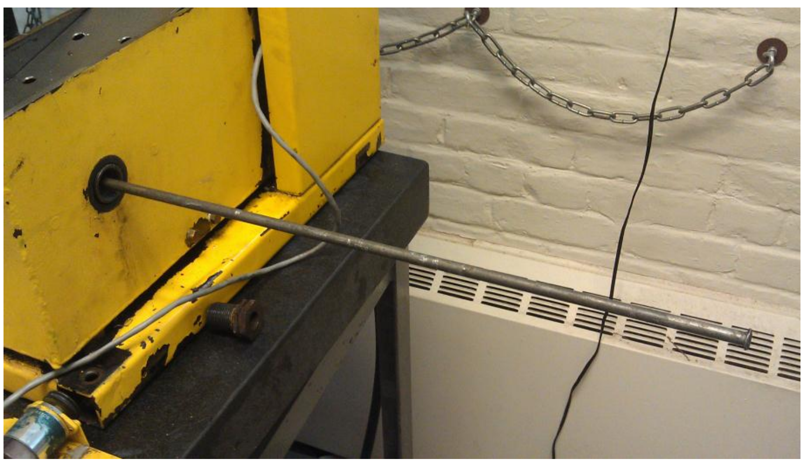

Figure 38 Threaded Rob in End Cap

Figure 39 End Cap Removed

- Tap the end of the rod with a hammer or mallet to free the screw key from the key way

Figure 40 Hammer Hitting Threaded Rod

- The screw then can be slid out from the barrel by hand. (Video available in Appendix B)

Figure 41 Screw Removed

- Use brass tools to scrape the built up molten plastic away (as plastic solidifies it becomes easier to peel away in chunks).

- If Plastic becomes too hard to remove, stick back into heated barrel until softened once more.
- Once thoroughly cleaned, reinsert screw into barrel being sure that the screw key aligns with the keyway of the drive.

Figure 42 Screw Key

Note: You may have to tap the end of the screw with a mallet to fully reinsert. Use a piece of brass in between the mallet and the screw so as not to damage the screw.

Figure 43 Brass Tool Against Screw

Appendix B

Screw Removal YouTube Video

http://youtu.be/mUrihcYJDz4

Extruder Running YouTube Video

http://youtu.be/U9myL3ZQ4q0

Umass Lowell Extruder Running YouTube Video

http://youtu.be/GngTdLrthu8