Electromagnetic Recording and Playback Device

by

Dylan Chavez

Submitted to the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the degree of Bachelor of Science in Mechanical Engineering

June 2004

Signature of Author: ______________________________
Department of Mechanical Engineering
May 7, 2004

Certified by: ______________________________
Professor Steven B. Leeb
Associate Professor of Electrical Engineering and Computer Science
Thesis Supervisor

Accepted by: ______________________________
Professor Ernest G. Cravalho
Chairman of the Undergraduate Thesis Committee

Electromagnetic Recording and Playback Device

by

Dylan Chavez

Submitted to the Department of Mechanical Engineering
on May 7, 2004 in Partial Fulfillment of the Requirements for the
degree of Bachelor of Science in Mechanical Engineering

Abstract

The purpose of this thesis is the design and manufacture of an electromagnetic recording and playback device. The device was designed to record information onto a steel wire which can replay the signal. The device is of simple mechanical design, resilient to impacts, minor compression, and operator error. The design has a minimal number of parts and requires limited maintenance or replacement of parts. The device is comprised of three systems: a magnetic head, transport system, and a support structure. Each of these systems is described and mechanical drawings for all parts are included.

Thesis Supervisor: Steven B. Leeb

Title: Associate Professor of Electrical Engineering and Computer Science

Table of Contents

List of Figures

Introduction

This section will introduce the purpose of the design and the design's requirements, along with a brief history of magnetic recording.

Purpose

The purpose of this thesis is to design and manufacture a working conceptual model of a basic electromagnetic recording and playback device. The goal of the design and developed prototype is to serve as a model for a group of devices to be used in a 6.002 exercise. The device is to be of simple mechanical design, allowing the user to focus on the electronic control and manipulation without concern of mechanical limitations. The device should be resilient to a multitude of common incidents, such as impact, minor compression, and operator error. The design should have a minimal number of parts, which in the course of normal operation will require limited maintenance or replacement and in such an event will require limited mechanical skill and hardware.

History of Magnetic Recording

The concept of magnetic recording was developed in the nineteenth century and first documented by Oberlin Smith in 1878. Smith developed the concept, after examining the phonograph, with the intent of eliminating unwanted noise on recordings. During Smith's investigation of the idea he managed to create portions of a magnetic recording apparatus and conduct several trials. However, he was never able to create a system that could be used for recording acoustic sound. Smith published his work in 1888.

It was not until 1898 when Valdemar Poulsen patented and introduced a functional electromagnetic recording device that a working concept of magnetic recording was created. The device, called the telegraphone and shown in Figure 1, used a wire medium to record speech. Released as a device for dictation and telephone recording, the device was quickly imitated.

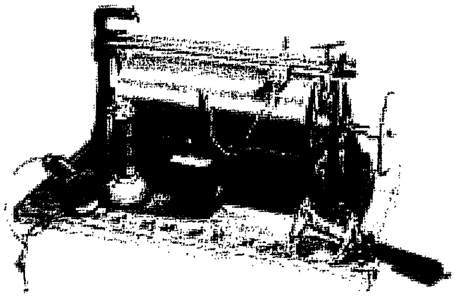


Figure 1: Poulsen's Telegraphone

Competition quickly led to improvements in the technology of magnetic recording. As the devices became more sophisticated, the recording medium changed from wire to other materials that were more flexible and contained more uniform magnetic properties. The added flexibility allowed for more information to be stored in smaller areas without damage. Eventually the same concepts Poulsen used to develop the telegraphone were used to develop the modern floppy computer disk, cassette tape and computer hard drive.

Design Criteria

This section will deal with the design criteria used to develop the concept of a magnetic recording device, and introduce possible designs for each component. The necessary parts for the construction of a magnetic recording device are relatively few in comparison to many other devices. A basic recording device must have the essential three components: a medium type, a head system, and a transport system. Each following section will discuss a portion of the apparatus and the factors affecting the design decisions.

Recording Medium

The purpose of the medium is to record changes in the magnetic field which is it is passed through. When determining what recording medium will be used, it is important to understand in what context the device will be used. This device will be used in a classroom environment and undergo high use and multiple operator errors; thus, aside from magnetic properties, it is important that the medium be durable.

Since the two major design criteria are that the medium be magnetic and durable the first decision to be made is the choice of material. Many materials contain magnetic properties but the two choices which were examined during the course of this work were metals and films.

Films such as cassette tape and videotape offer an inexpensive and abundant material which contains very uniform magnetic properties. These tapes are generally very thin, only 13.5 μm in thickness in audio cassettes, and comprised of plastic base, such as polyethlene terephthalate, with magnetic material impregnated onto it. The thickness and material allows for great flexibility and very limited shape memory giving the material the ability to be coiled and uncoiled with minimal effect to the material. However, these same material properties lead to very low strains necessary to permanently elongate or tear the material. Since the film is designed to live within a protective case, the strength under axial or shear loading is weak. Because of this, minor forces oftentimes can significantly deform the tape.

Metals, as opposed to plastic based tapes, offer a significantly larger strength and durability. The strength of metals makes them a better medium candidate for durability reasons, but metals often do not contain the magnetic uniformity found in tapes, nor are they as easily compacted for storage. The coiling of metal, strip or wire, is significantly more difficult due to its material properties, which require much thinner sections of material to make the material flexible enough to handle repeated coiling without plastic deformation of the material.

After exploring the possibility of materials for the medium, the next question becomes what type of surface or geometry the chosen material should take. Three possibilities were looked at in this case: wide thin medium, wires, and surfaces.

The concept of a wide thin medium, such as a tape or metal strips, offers several unique possibilities. First as it is thin and potentially very easy to coil, it allows for the possibility of reel-to-reel storage. Reel-to-reel is the storage method seen in audio cassette and VHS tapes, in which the medium is passed from one reel to the other over the magnetic head. Secondly wide thin mediums offer a very smooth surface for a head to travel over or to travel over the head; this would help to facilitate smooth constant motion. A smooth surface would also serve to minimize errors during playback or recording, which may present themselves due to thickness variations over the length of the strip. Despite the benefits of a wide thin medium there are negatives to the concept. The use of a tape requires that the tape be constrained in some manner so that the entire tape crosses the head, or that the control of the head can travel across the head at an exact rate, reliably in both directions, and without moving off a given path. It also requires that there be close proximity or contact with the head which is a source of friction over the entire head surface, and will potentially require larger torques to power the device.

Another option that could solve many of the problems presented with tapes or metal strips is an entire surface of medium material. This option limits the transport medium from reel-to-reel and would create the need for a head which could move along the medium, but would eliminate the problem of coming off of it. If the entire surface the head traveled over were a recordable medium, it would be possible to replay the recorded signal by simply retracing the head's path. This does not solve the issue of contact on medium surface, but would create a uniform surface for the head to slide over and lower the possibility of tearing or causing injury to the medium by sliding off and on.

The final option explored is the use of a wire as the recording medium. The wire offers several benefits; due to its geometry the wire offers an increase in durability under bending and axial loading to the material, and can be used in several ways to pass though the magnetic head, and theoretically offers the same number of storage methods as tapes or metal strips.

Magnetic Head

The purpose of the head is to record information onto the medium of choice by altering the magnetic polarity in sections of the medium, read the changes in polarity when the medium passes back across the head, and erase the polarity changes of the medium. The head system has to perform all three functions in order to be considered a viable recording system.

In order to accomplish the change of the medium's polarity, the head must subject the medium to changes in magnetic fields. One method used to achieve this is the use of an electromagnet. By utilizing the ability to change the field of an electromagnet based on what electrical current is placed through the coil, the polarity and strength of the magnetic field can be adjusted. By adjusting the magnetic field of the head, the medium is subjected to various magnetic fields as it passes the head.

The ability to read the medium can be accomplished through induction. Induction is the generation of an electric signal that is produced by the variation of magnetic flux through the circuit. By detecting the changes in magnetic properties on the medium, it is possible to retrieve the pattern from the recording medium.

Erasure is caused by the magnetizing of the recording medium in one polarity and for the entirety of the desired erasure area. To do this, a permanent magnet can be passed over the recording medium or a strong AC field can be applied through the coil of the head, simulating a permanent magnet.

Peak performance would occur if a separate head was specifically designed to handle each of the tasks. This increases the number of parts needed for a recording device and would make a mechanical change necessary each time the device is used in a specific manner. One of the goals of the concept is that it requires as little maintenance as possible and a change-over at each function switch in the recording/playback/erasing cycle would violate this design criteria. The use of a single head for the all three functions is desired. With a single head, trade-offs occurs between the various functions the head must accomplish.

The magnetic flux density the medium experiences is dependent on the core area, magnetic flux density of core, and the gap area across which the medium passes.

$$B_{gap} = B_{core} \frac{A_{core}}{A_{gap}} \quad (1)$$

The reason for the increase in the magnetic flux across the gap is to help create increase the magnetic field strength. Magnetic field strength is defined by

$$H = \frac{B}{\mu}, (2)$$

where μ refers to the magnetic permeability of air. Since μ is a constant, if B is increased a stronger magnetic field will be present. In order to maximize the flux that the medium is subjected to, a core with a large flux density, a large cross-sectional area and small gap cross-sectional area gap are desired for excellent recording. To further increase the flux density, the cross-sectional area of the gap should be decreased as much as possible. Increasing the magnetic flux in the gap can also be accomplished by increasing the magnetic flux of the core. The magnetic flux of the core (B_{core}) is determined by size and geometry of the core, the magnetic permeability of the material, the number of turns of the coil and the current passed through the coil. By increasing any of these factors the magnetic flux in the gap can be increased. In an effort to maximize the magnetic flux in the core, a material with high magnetic permeability and a large cross-sectional area is desirable. The core's area is limited by the design of the transport mechanism and space considerations with relation to the entire apparatus.

Transport System

The purpose of the transport system is to facilitate the movement of the medium past the magnetic head smoothly and efficiently enough to read, record, and to erase the magnetic sections of the recording medium. In addition, the system must account for the space to store the medium and a mechanism to move the medium and/or the head.

The amount of medium which is capable of being stored within the device is directly related to the amount of recording time of which the apparatus will be capable. In order to attempt to store as much medium as possible, several options were considered. Each of these options greatly affects the medium selection and needed motion, all of which are discussed with each medium storage method below.

The first medium storage method discussed is known as reel-to-reel and is commonly seen in cassette tapes. Reel-to-reel offers several benefits as a medium storage method: it allows for a fixed position magnetic head, can store long lengths of medium, and is possible to power with a single power source. Figure 2 shows a typical reel-to-reel system.

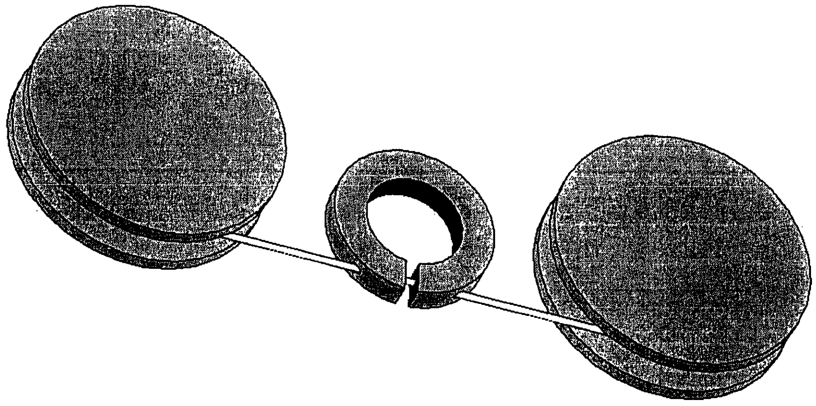


Figure 2: Reel-to-Reel System

The downside of reel-to-reel is that it requires a magnetic medium that is flexible enough to be coiled multiple times at a variety of diameters. This presents a limitation as many metals respond poorly to this type of strain. A reel-to-reel system also limits the thickness of a medium, or in the case of a wire, its diameter. This is due to the tendency of materials, especially metals, to return to their original shape. The amount of plastic deformation of a material is due to the material properties such as stiffness, the thickness of the material, and the radius at which the material is bent.

Unlike a reel-to-reel system a drum system fixes the medium's position to a moving object. The benefit of this design is that it insures the medium is not constantly undergoing changes in its curvature. An example of a drum system can be seen in figure 3. The negative aspect of this design is that the fixed medium limits the amount of medium that can be stored. Drum storage of the medium also causes the need for the magnetic head to travel along with the medium it is attached to. Powering this system requires either the use of two motors, which each independently move the drum and the magnetic head, or a single motor which is linked to both systems. In the case of the drum system the motion of each system requires velocity relationship to facilitate the motion of the medium past the head. Because of this dual motion, the placement of the medium or slack of the medium becomes a factor in the performance of the device.

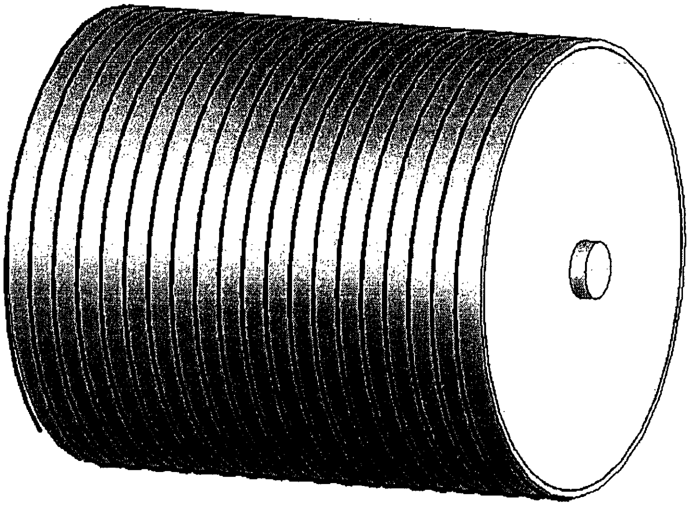


Figure 3: Drum System

In addition to the fixation of a medium to a drum, the drum system allows for the possibility of the drum surface being made entirely of magnetic medium, so that any portion of the drum may be recorded on. In this case the playback would require the exact trace of the path in which the signal was recorded. This would require excellent motor control and clean motion, but would eliminate possible off track running.

Design of Prototype

Steel wire was selected as the recording medium for the designed prototype. Steel wire is inexpensive, highly durable, has good magnetic properties and is readily available. These properties matched the established design criteria.

In the case of the prototype design because the steel wire was selected, for the design to work the wire must pass through the core gap reliably. There were two methods discussed to accomplish this. One method was to have the wire pass through an open groove in the center of the core at the surface, and the other was to have a enclosed groove, or hole, through which the medium passed. In the interested of the limiting operator error and maintenance it was determined that the wire should travel though an enclosed groove. Shown in figure 4 is the magnetic core with the enclosed groove design.

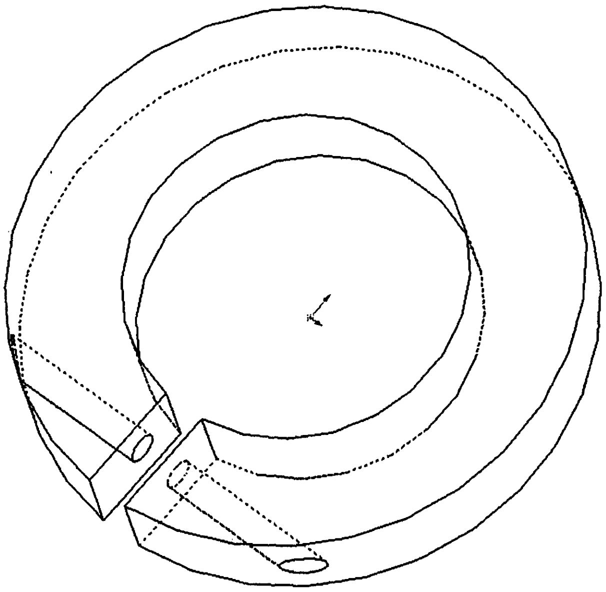


Figure 4: Iron Core of Magnetic Head

Iron was chosen as the core material because of its high magnetic permeability and ease to machine. The technical drawing and dimensions for the magnetic head are located in Appendix A.

In order to store the medium, the concept of the drum was implemented. This design choice was made in part due to the medium selection; due to the material properties of steel it does not perform well in situations where its curvature changes. This made the choice of a reel-to-reel medium transport less desirable. The option that presented the best attributes, considering the medium, was determined to be a large diameter drum which the medium was coiled around. The prototype assembly of the drum is shown in Figure 5.

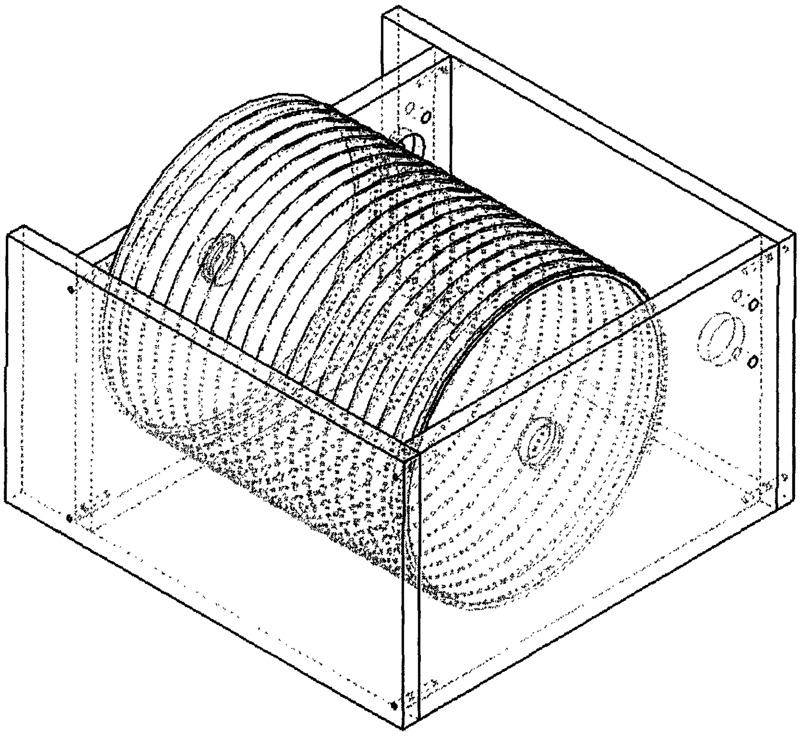


Figure 5: Prototype Drum Assembly

By using a large diameter drum that the medium was attached to the spring-back, straining and uncoiling of the wire were limited. The drawing and dimensions for this drum system can be found in Appendix B.

The decision to use a drum design for the medium storage greatly affected the design of the holding mechanism of the head. Since the drum storage method was implemented to facilitate the medium passing through the magnetic core, the head would be required to move along the medium. The design requires the head to travel linearly as the drum rotates in order for the magnetic core to pass a new section of wire. To accomplish this goal the lead screw design, shown in figure 6, was developed which would move the case for the magnetic head linearly across the drum at a rate, which could be determined.

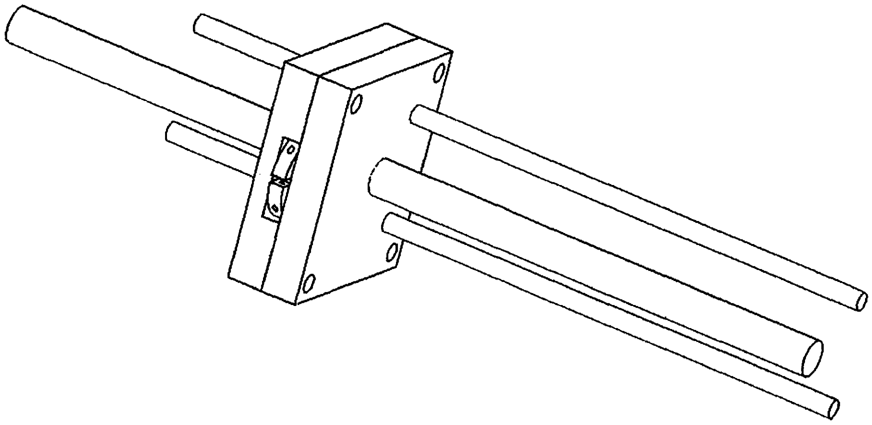


Figure 6: Prototype Lead Screw Assembly

The case in which the magnetic head is stored consists of a two-part box with a cavity in which the head rests. Part drawings and dimensions for the lead screw and magnetic case can be found in Appendix C.

In order to combine the storage and the magnetic head, a support structure was designed which positioned the magnetic head perpendicular to the axis of rotation of the drum. It also positioned the farthest section of the magnetic head case combination at a specific distance from the drum surface. This assembly is shown in Figure 7.

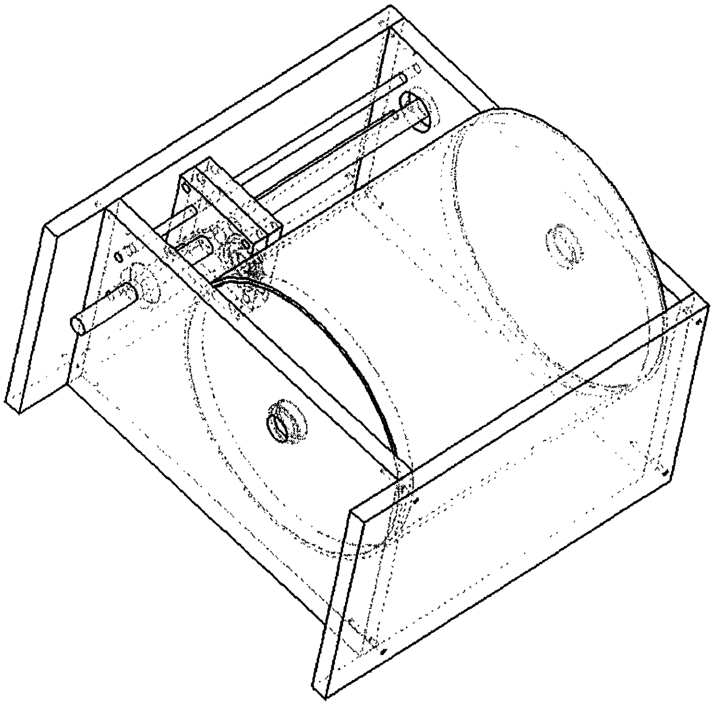


Figure 7: Prototype Drum and Lead Screw Assemblies with Support Structure

To limit friction, the lead screw and drum axes rested in bearings, which help facilitate a smooth rotation. The support structure was designed to encase all moving parts and increase the durability of the apparatus. Technical drawings for the support structure can be found in Appendix D.

Because the drum system and the magnetic head case function independently, it was decided that rather than couple their movement by linking the two systems, each system would have a separate power source. To accomplish this, separate DC electric motors, independently powered the rotation and the lead screw. Each motor was connected to its rotation device using a delrin coupler. The motors were mounted to the outside of the support structure through mounting plates attached to the motor. Drawings for this mounting system can be found in Appendix E

The material selection used to construct the designed apparatus was made based on cost, machinability, and magnetic or nonmagnetic properties. The support structure and the majority of the device was constructed using polypropylene, a non-magnetic material. The drum was made from polycarbonate and, with the exception of the bearings, all other parts were manufactured from aluminum. A materials list can be found in Appendix F.

Discussion of Prototype Design

This section will address the application of the prototype design and discuss its accomplishments as well as its limitations. After the assembly of the prototype device, the following observations were made about the performance of the systems both independently and as a collective apparatus.

Lead Screw

The lead screw linear transport mechanism performed as expected, delivering one inch of linear motion per thirteen revolutions of the DC motor to which the lead screw is attached. The friction between the threaded polypropylene hole and the aluminum lead screw proved to be significantly larger than expected. This is believed to be due to the malleability of the polypropylene, which resulted in poor threading and disconfiguration of the threads during operation. As a result a large torque was required to rotate the lead screw to deliver the desired linear motion at an acceptable speed. By boring out the threaded hole to a larger diameter it was possible to pressure fit a threaded nylon insert in place of the threads. See Figure 8.

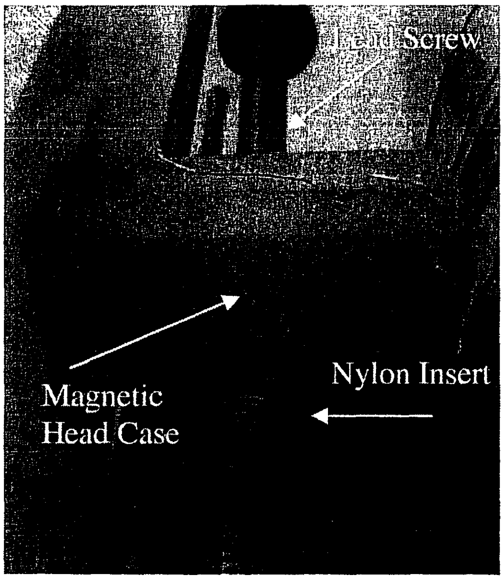


Figure 8: Magnetic Head Case with Nylon Insert

The nylon insert offered a stronger material which was able to interface with the aluminum lead screw without deformation. This resulted in significantly less friction and allowed for the increase of the operation speed and decrease of the required torque.

While it proved unnecessary for the required performance of the prototype, future improvements to the speed of linear travel and lowering of motor torque could potentially come from the addition of nylon bushings between the sliding rods and the magnetic head case.

Medium Storage

The performance of the drum was determined to be satisfactory. Despite initial concerns about potential non-uniformity of the drum's diameter, the amount of error proved to be minimal. The DC motor powering the drum's rotation was adequate and the attachment of the wire to the drum proved acceptable.

Coupling

The independent systems (medium storage and linear motion) operated satisfactorily independently; however, when coupled together via the medium and magnetic head unexpected problems developed.

It was discovered that friction occurring between the wire traveling through the head affected the performance of the system only after the wire around the drum was tightened, which was done to limit entanglements and ensure accurate placement of the wire. The problem stems from the placement of the hole in the magnetic core, which was forced to be straight for 0.7 inches as it traveled in the enclosed gap, as shown in Figure 9.

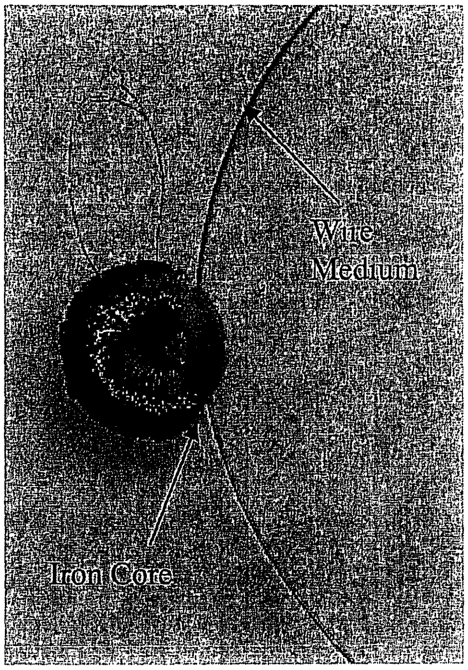


Figure 9: Original Iron Core

The linear section which the wire was required to travel though presented a problem: as the wire entered the head, it did so with a radius of four inches requiring the wire to be forced to have no curvature. The combined effect of friction between the wire and the iron core as the wire was fed into the hole, out of the hole, and the wire being straightened, proved to be large enough to overpower the system. This friction was further impacted by kinks and other discontinuities found in the wire.

This friction issue was overcome by redesigning the head in order to limit the length of the section of travel that required the wire be straight, as shown in Figure 10. The drawing and dimensions of the changes to the head are located in Appendix G.

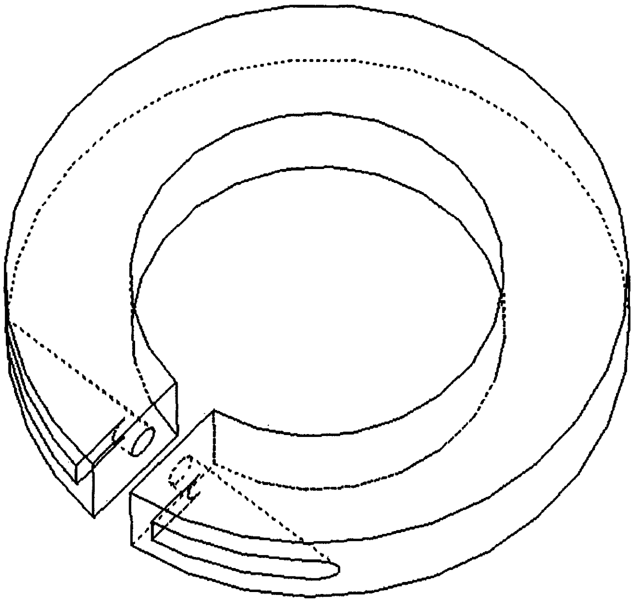


Figure 10: New Iron Core

Another problem observed during the operation of the systems was the behavior of the motors driving the two systems. Due to the larger, more outwardly placed mass of the drum, the ramp-up time to reach the expected speed turned out to be longer than the start-up speed of the linear motion of the magnetic head case. This led to the wire being pulled horizontally from its original location, causing the entire device to lock. If the operator slowed the motion of the magnetic head case during the initial ramp-up of the drum speed it was possible to avoid this problem. This, however, is not an ideal solution as it creates a period of time in which the wire is passing through the magnetic head at a varying rate before reaching operation speed, in addition to creating unnecessary difficulty for the operator. Fine adjustment of the motors in order to facilitate the needed ratios proved to be more difficult than expected.

A possible solution to these problems could be the coupling the two systems. The two systems could be linked via a timing belt system or gear system which would allow for the number of motors to be reduced to one, and ensure that the rotational motion and linear motion were in the necessary ratios without the need for minor adjustments.

Manufacture

Although possible to build with, and despite the advertised machinability and quality of polypropylene, which was chosen as the major material for manufacture of the prototype, the material proved to be poor. Polypropylene was difficult to machine, as it tended to warm up during milling processes, causing chips to clump and the material to expand and contract. The change in volume of the material proved difficult to deal with in cases where a high degree of precision was needed. Along with the threading issue previously discussed, these problems made polypropylene a poor material for the design.

To eliminate this problem in future manufacturing events it is advised to use polycarbonate. Despite its slightly higher cost, polycarbonate would prove to be a much more effective material to work with.

Bibliography

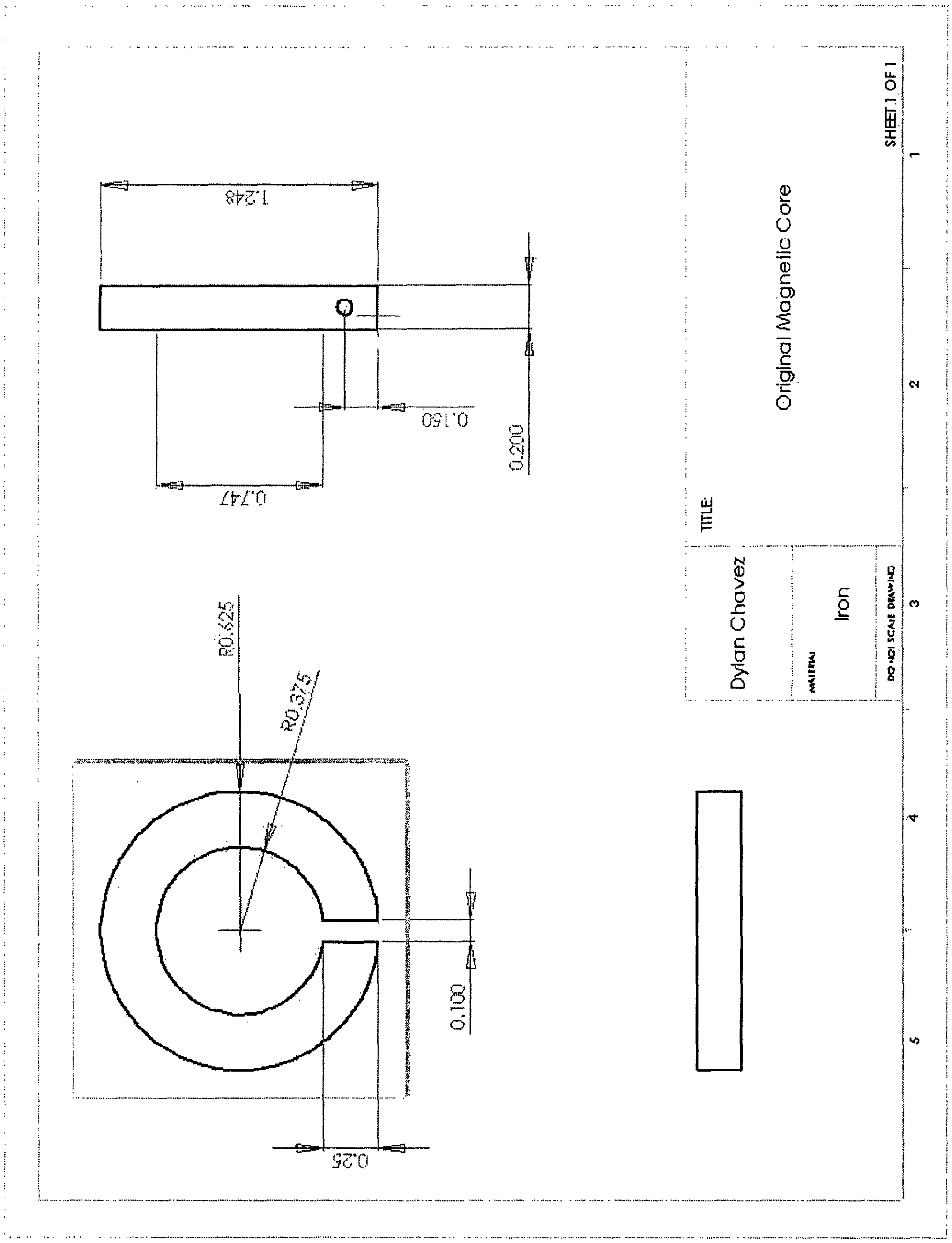
Marvin Camras, *Magnetic Recording Handbook*, Van Reinhold Company Inc., 1988

John C. Mallinson, *The Foundations of magnetic Recording* Academic Press, Inc, 1993.

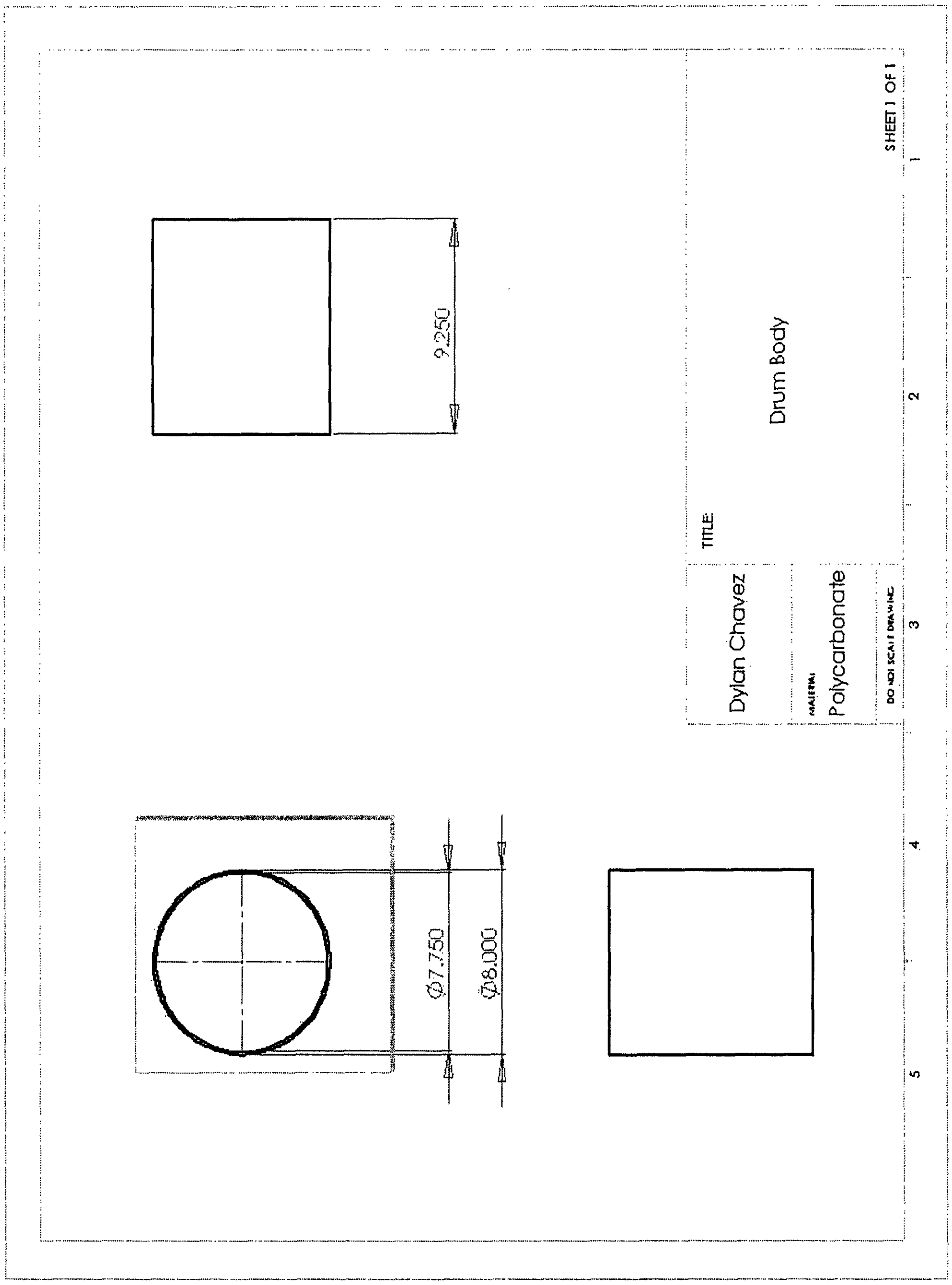
Eric D. Daniel, C. Denis Mee, Mark H, Clark, *Magnetic Recording: The First 100 Years*
Institute of Electrical and Electronics Engineers, Inc., 1999

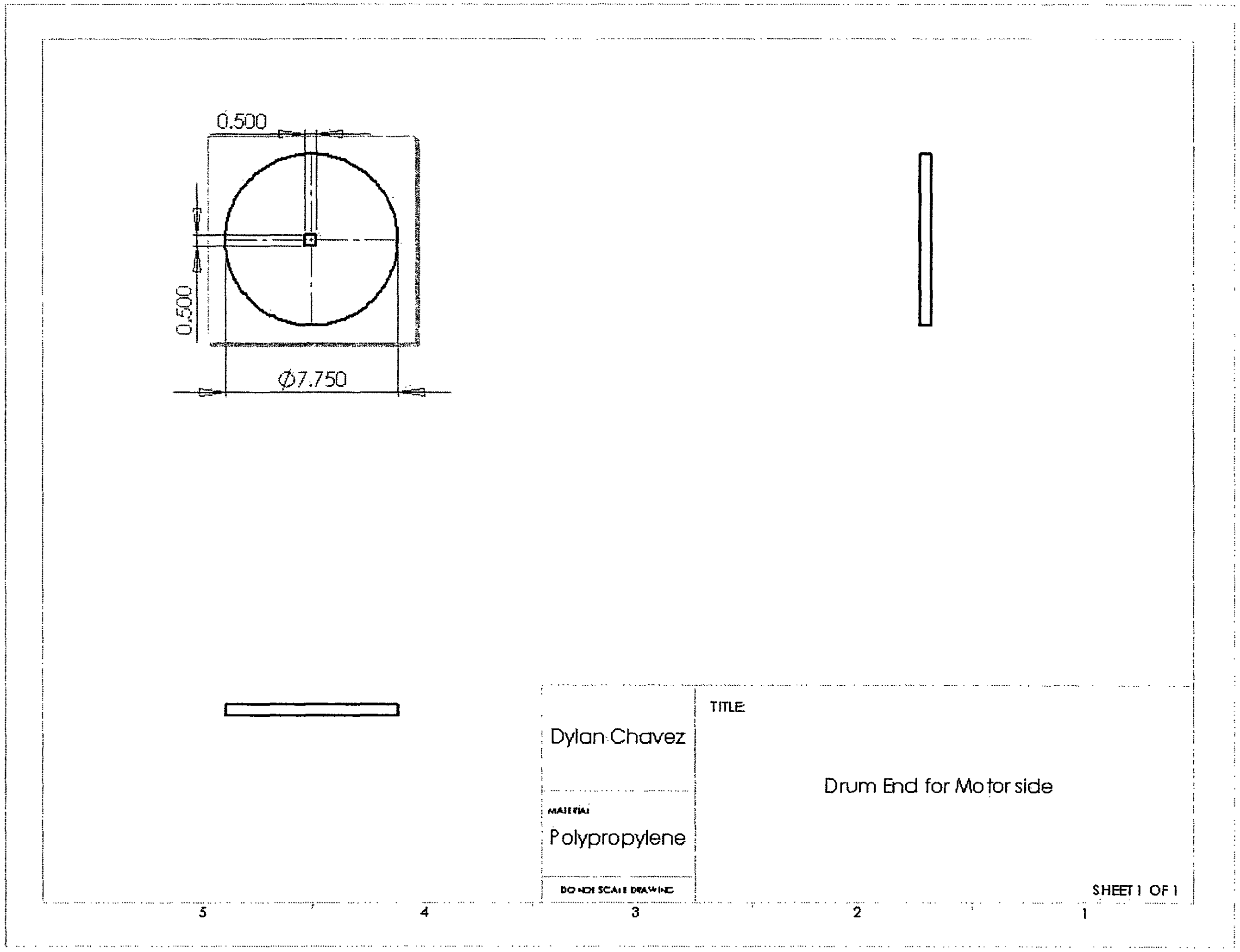
Warren Chow, *Electromagnetic Recoding on a Wire Medium,* MIT, 2003

Appendix A


1.248
0.150
0.200
0.747
R0.625
R0.375
0.100
0.25
TITLE
Original Magnetic Core
Dylan Chavez
MATERIAL
Iron
DO NOT SCALE DRAWING
SHEET 1 OF 1
1
2
3
4
5

Appendix B


9.250
Ø7.750
Ø8.000
TITLE
Drum Body
Dylan Chavez
MATERIAL
Polycarbonate
DO NOT SCALE DRAWING
SHEET 1 OF 1
1
2
3
4
5



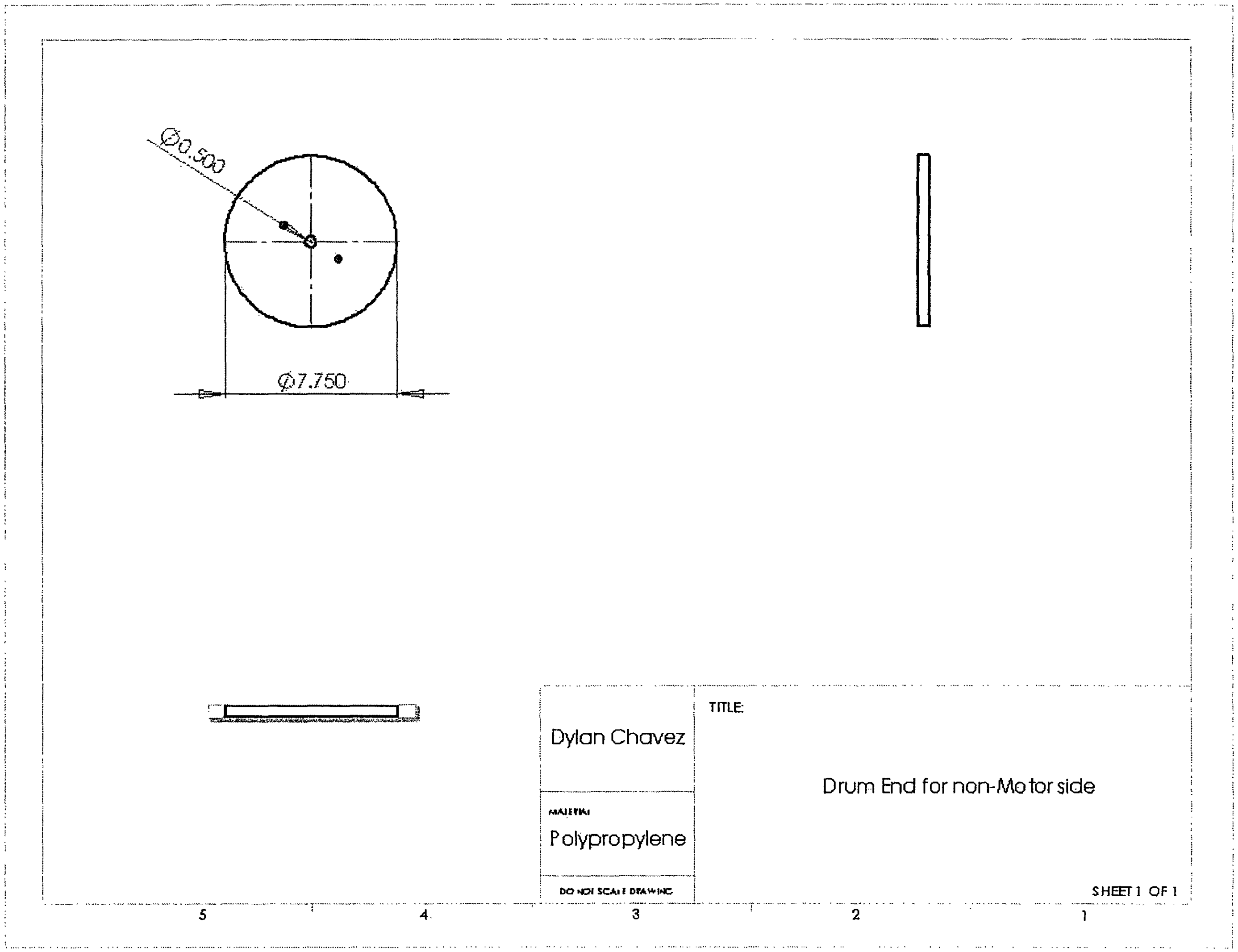
Dylan Chavez

MATERIAL
Polypropylene

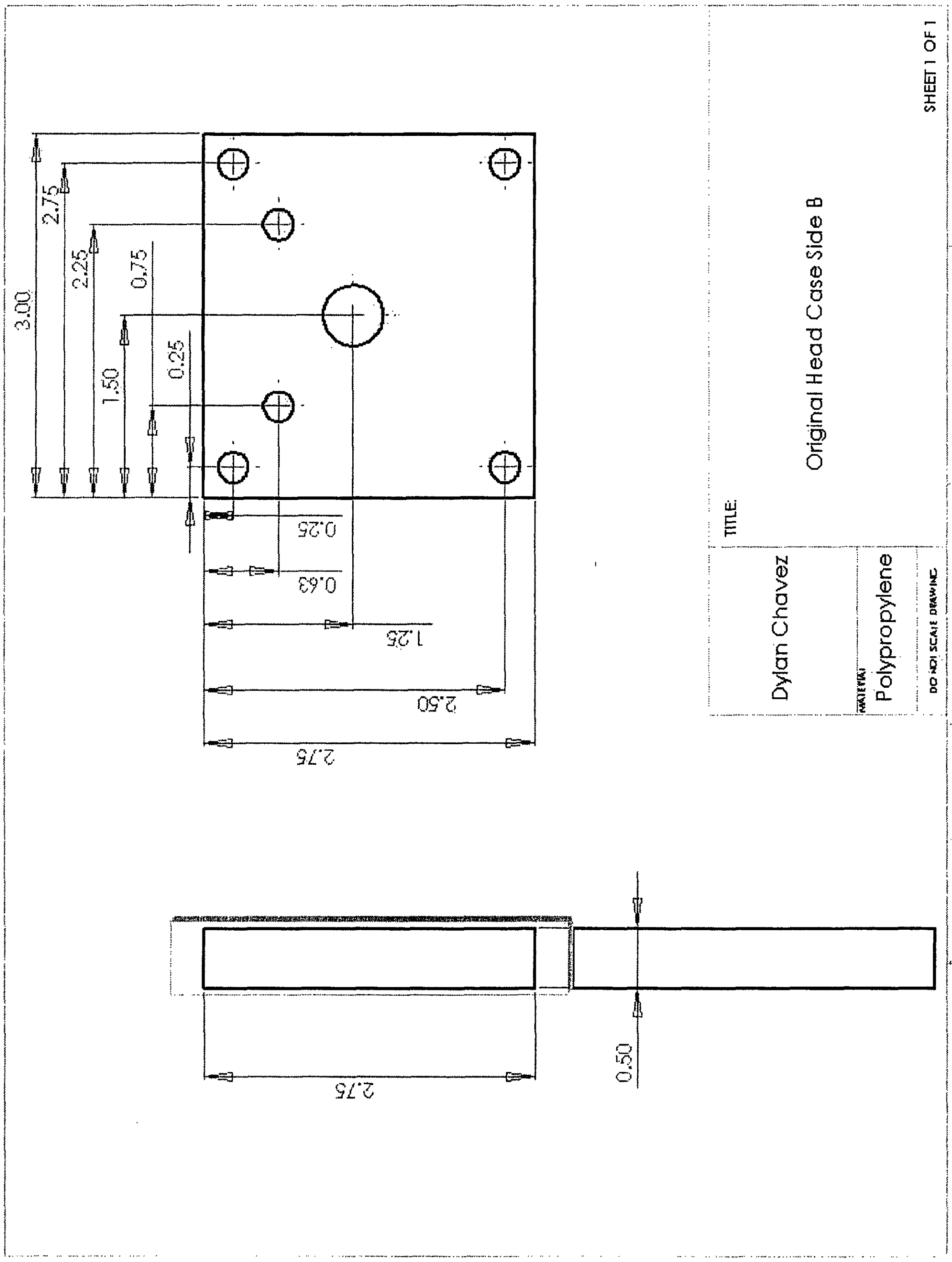
DO NOT SCALE DRAWING

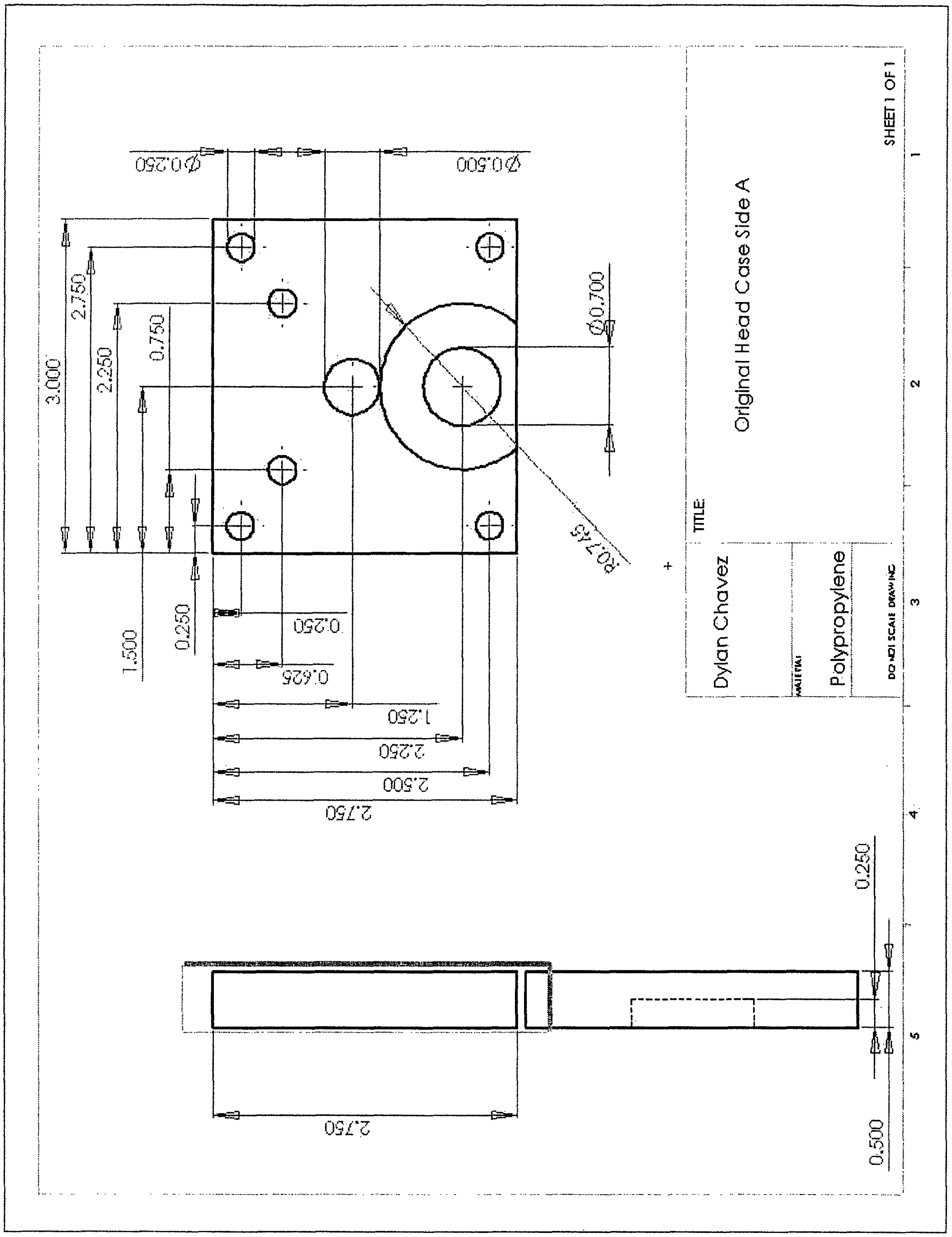
TITLE:
Drum End for Motor side

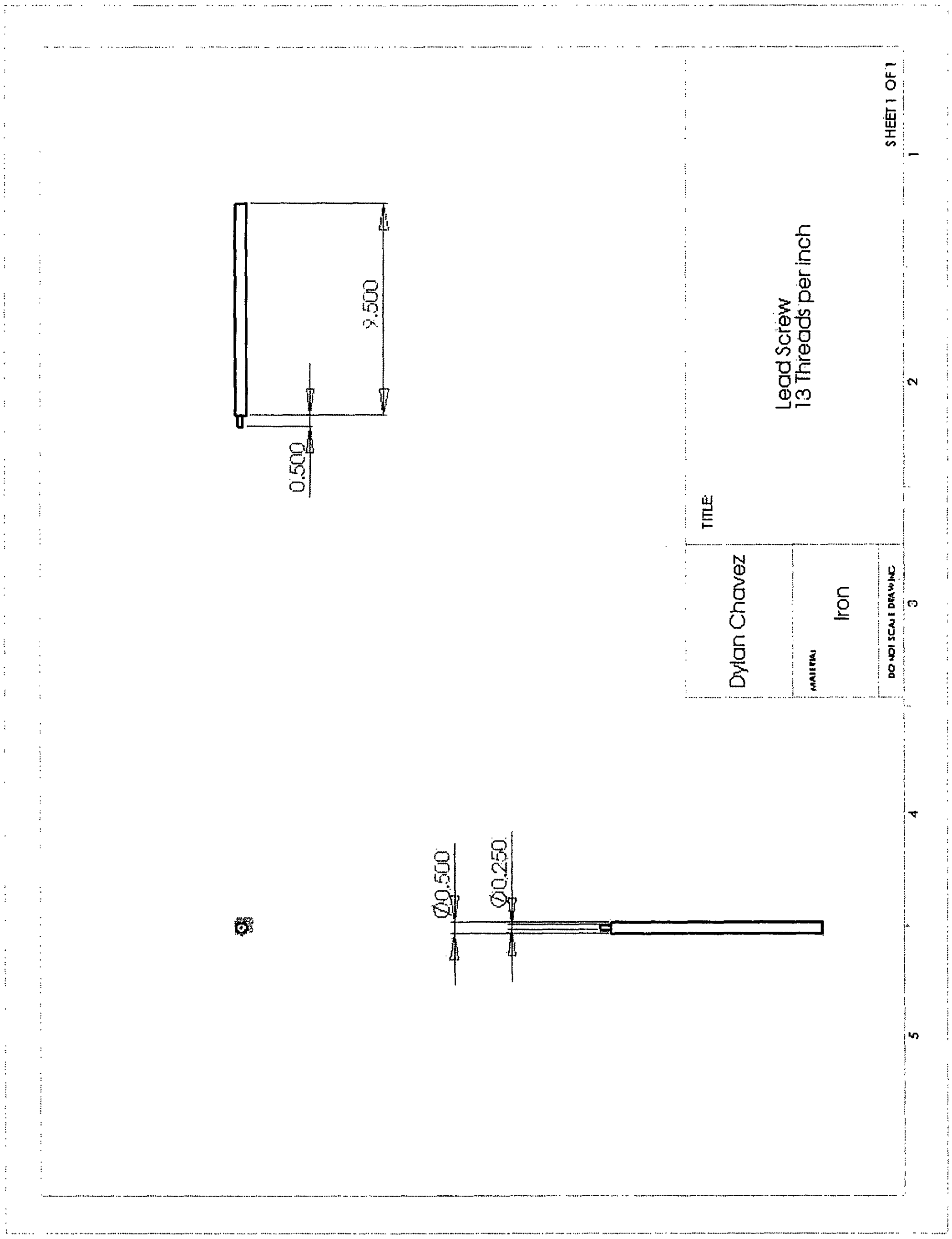
SHEET 1 OF 1


Ø0.500
Ø7.750
Dylan Chavez
MATERIAL
Polypropylene
DO NOT SCALE DRAWING
TITLE:
Drum End for non-Motor side
SHEET 1 OF 1
5
4
3
2
1

Appendix C


3.00
2.75
2.25
0.75
1.50
0.25
0.25
0.63
1.25
2.50
2.75
2.75
0.50
TITLE:
Original Head Case Side B
Dylan Chavez
MATERIAL
Polypropylene
DO NOT SCALE DRAWING
SHEET 1 OF 1
1
2
3
4
5


Original Head Case Side A
TITLE:
Dylan Chavez
MATERIAL
Polypropylene
DO NOT SCALE DRAWING
SHEET 1 OF 1
1
2
3
4
5
Ø0.250
Ø0.500
Ø0.700
R0.745
3.000
2.750
2.250
0.750
1.500
0.250
0.250
0.625
1.250
2.250
2.500
2.750
2.750
0.250
0.500



Dylan Chavez

MATERIAL

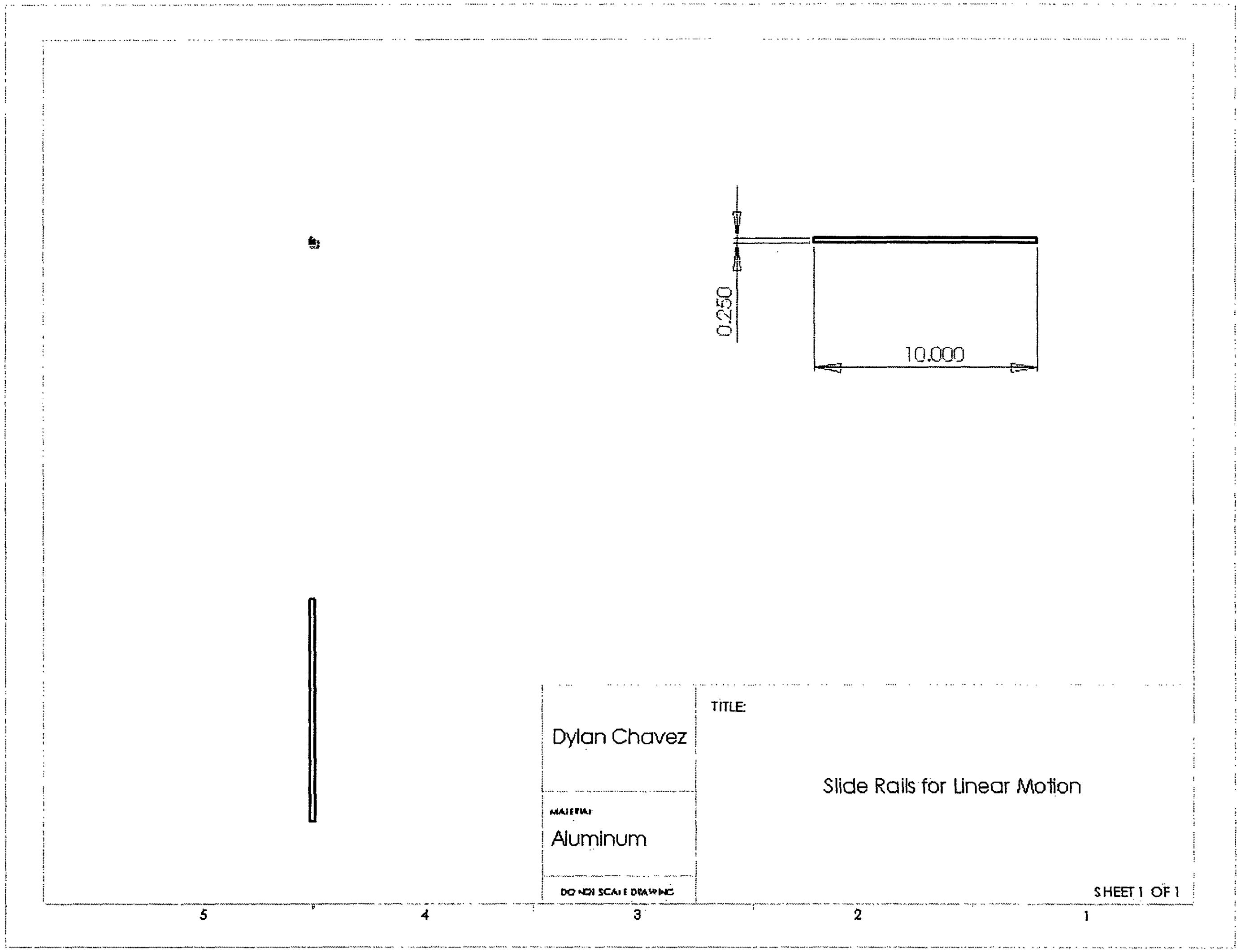
Iron

DO NOT SCALE DRAWING

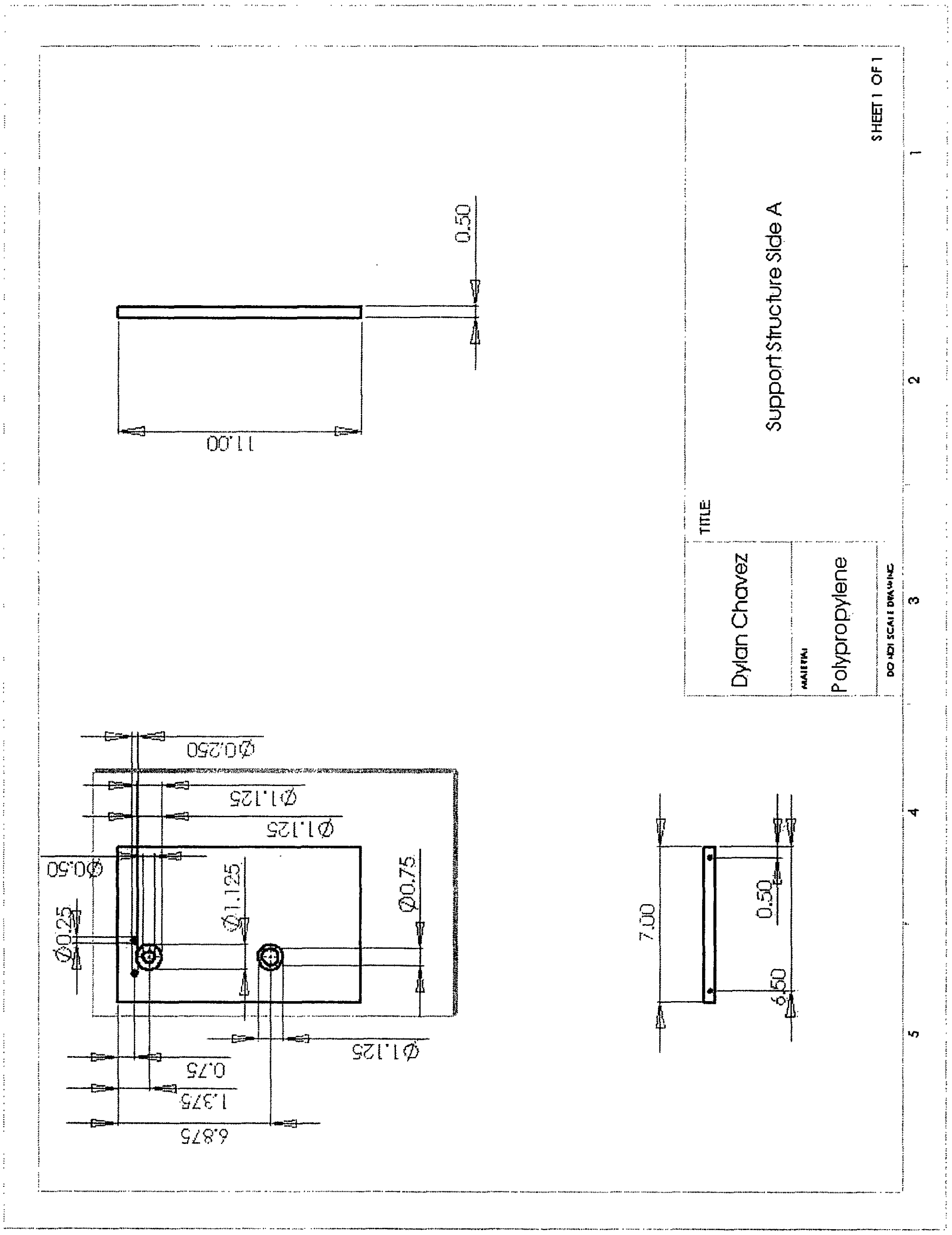
TITLE:

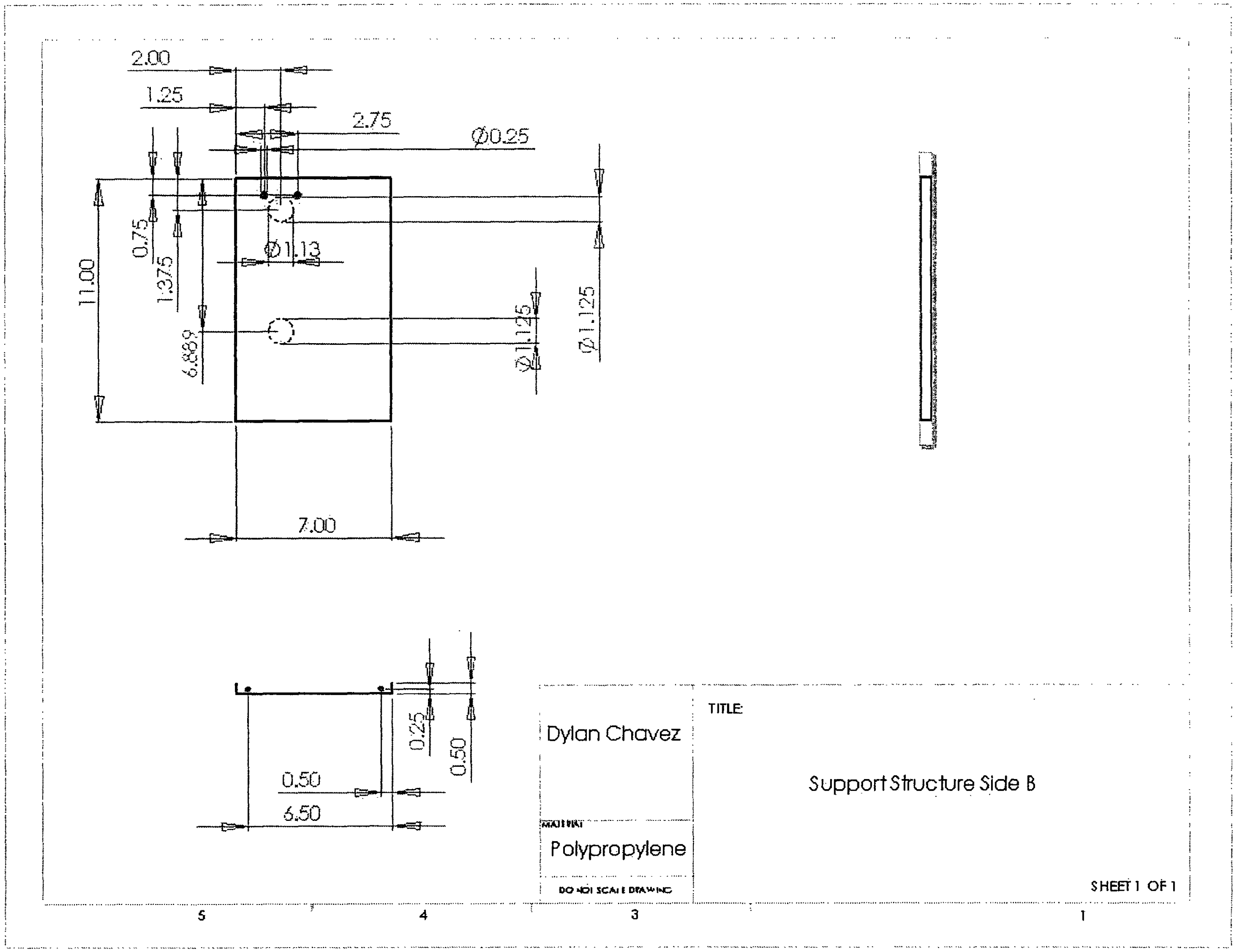
Lead Screw
13 Threads per inch

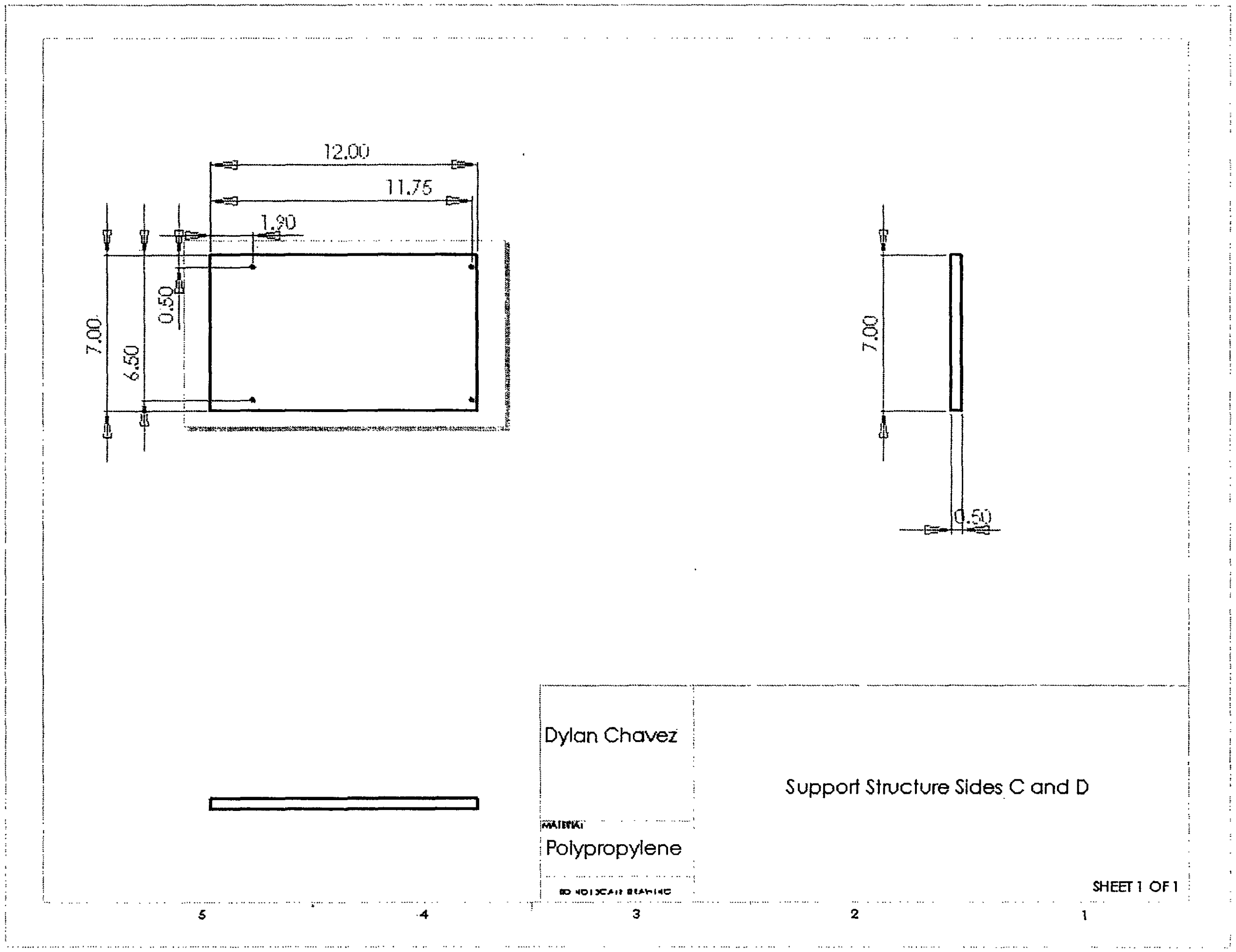
SHEET 1 OF 1


0.250
10.000
Dylan Chavez
TITLE:
Slide Rails for Linear Motion
MATERIAL
Aluminum
DO NOT SCALE DRAWING
SHEET 1 OF 1
5
4
3
2
1

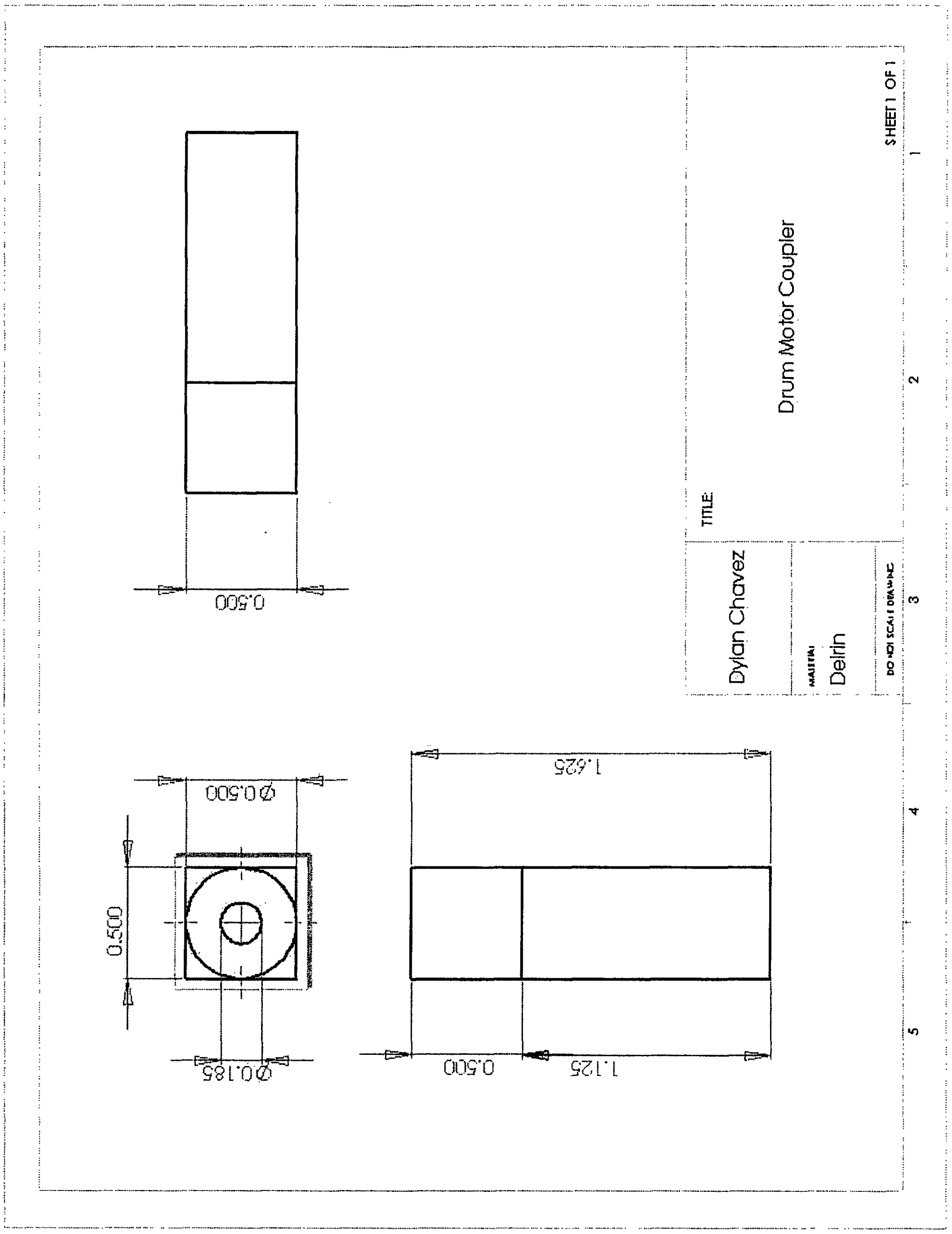
Appendix D

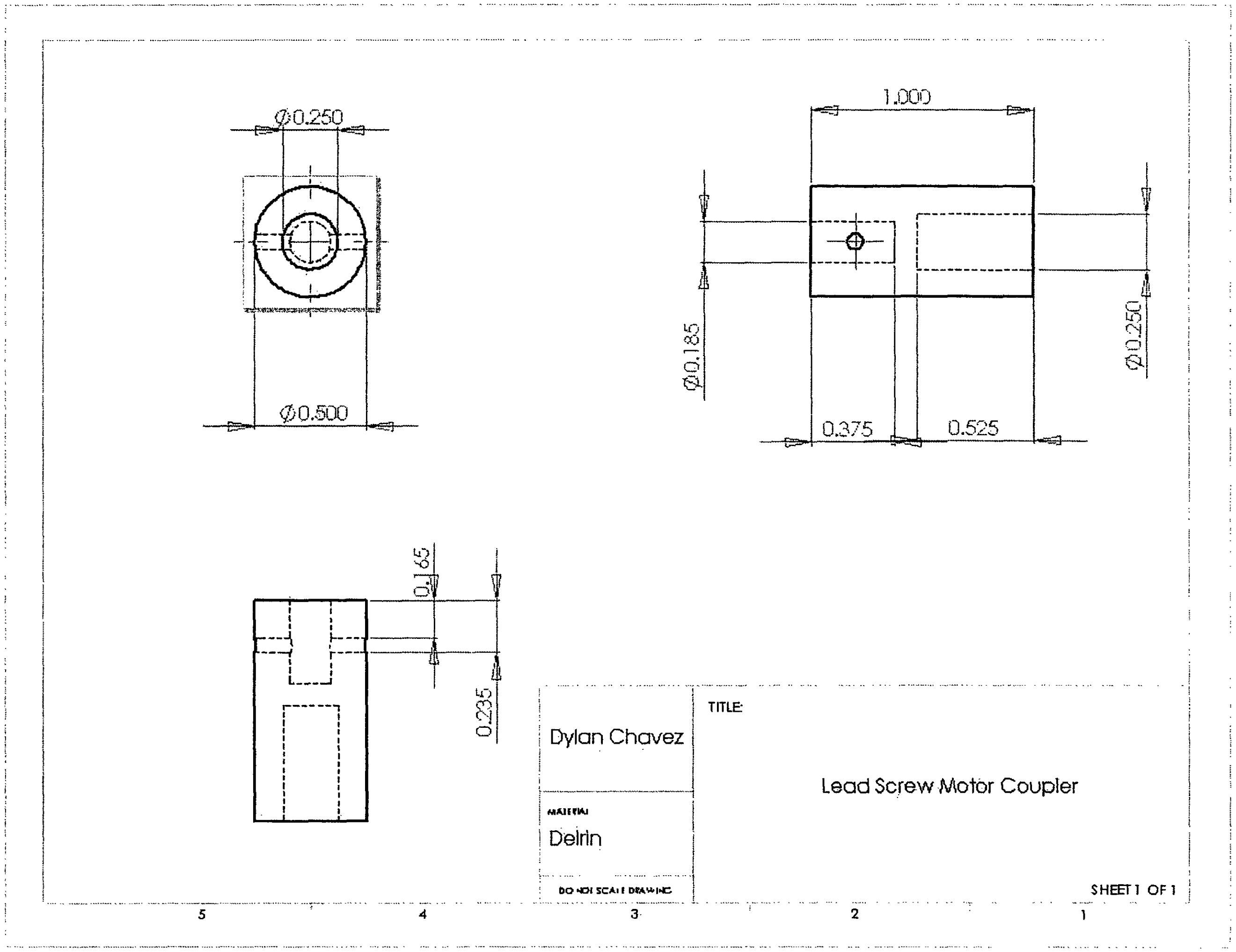

SHEET 1 OF 1
TITLE
Support Structure Side A
Dylan Chavez
MATERIAL
Polypropylene
DO NOT SCALE DRAWING
0.50
11.00
Ø0.250
Ø1.125
Ø1.125
Ø0.50
Ø0.25
Ø1.125
Ø0.75
Ø1.125
0.75
1.375
6.875
7.00
0.50
0.50
1
2
3
4
5

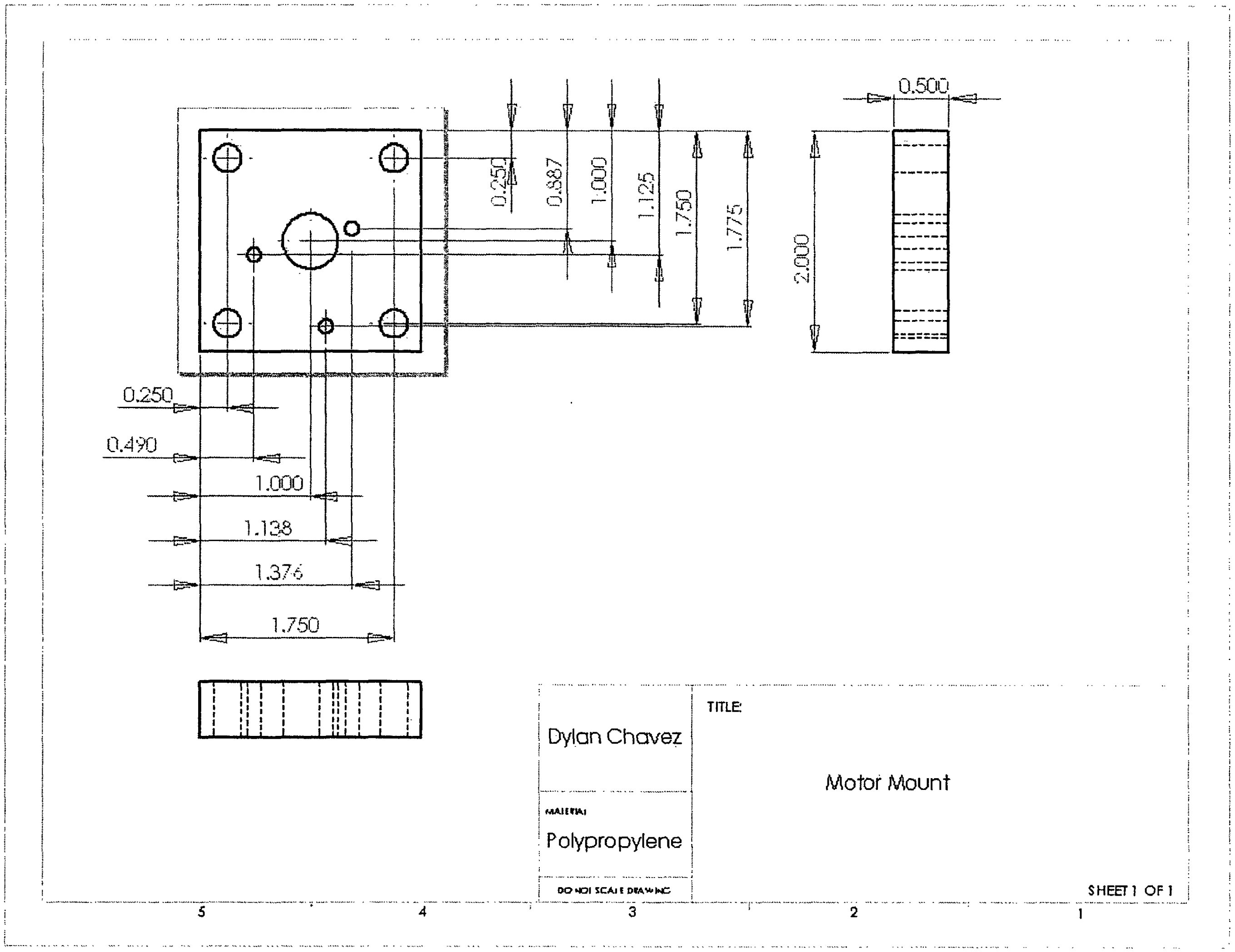

2.00
1.25
2.75
Ø0.25
0.75
1.375
6.889
11.00
Ø1.13
Ø1.125
Ø1.125
7.00
0.25
0.50
0.50
6.50
Dylan Chavez
MATERIAL
Polypropylene
DO NOT SCALE DRAWING
TITLE:
Support Structure Side B
SHEET 1 OF 1
5
4
3
1


12.00
11.75
1.90
0.50
7.00
6.50
7.00
0.50
Dylan Chavez
Support Structure Sides C and D
MATERIAL
Polypropylene
DO NOT SCALE DRAWING
SHEET 1 OF 1
5
4
3
2
1

Appendix E


SHEET 1 OF 1
TITLE:
Drum Motor Coupler
Dylan Chavez
MATERIAL
Delrin
DO NOT SCALE DRAWING
0.500
Ø0.500
0.500
Ø0.185
1.625
0.500
1.125
1
2
3
4
5


∅0.250
∅0.500
1.000
∅0.185
∅0.250
0.375
0.525
0.165
0.235
Dylan Chavez
TITLE:
Lead Screw Motor Coupler
MATERIAL
Delrin
DO NOT SCALE DRAWING
SHEET 1 OF 1
5
4
3
2
1

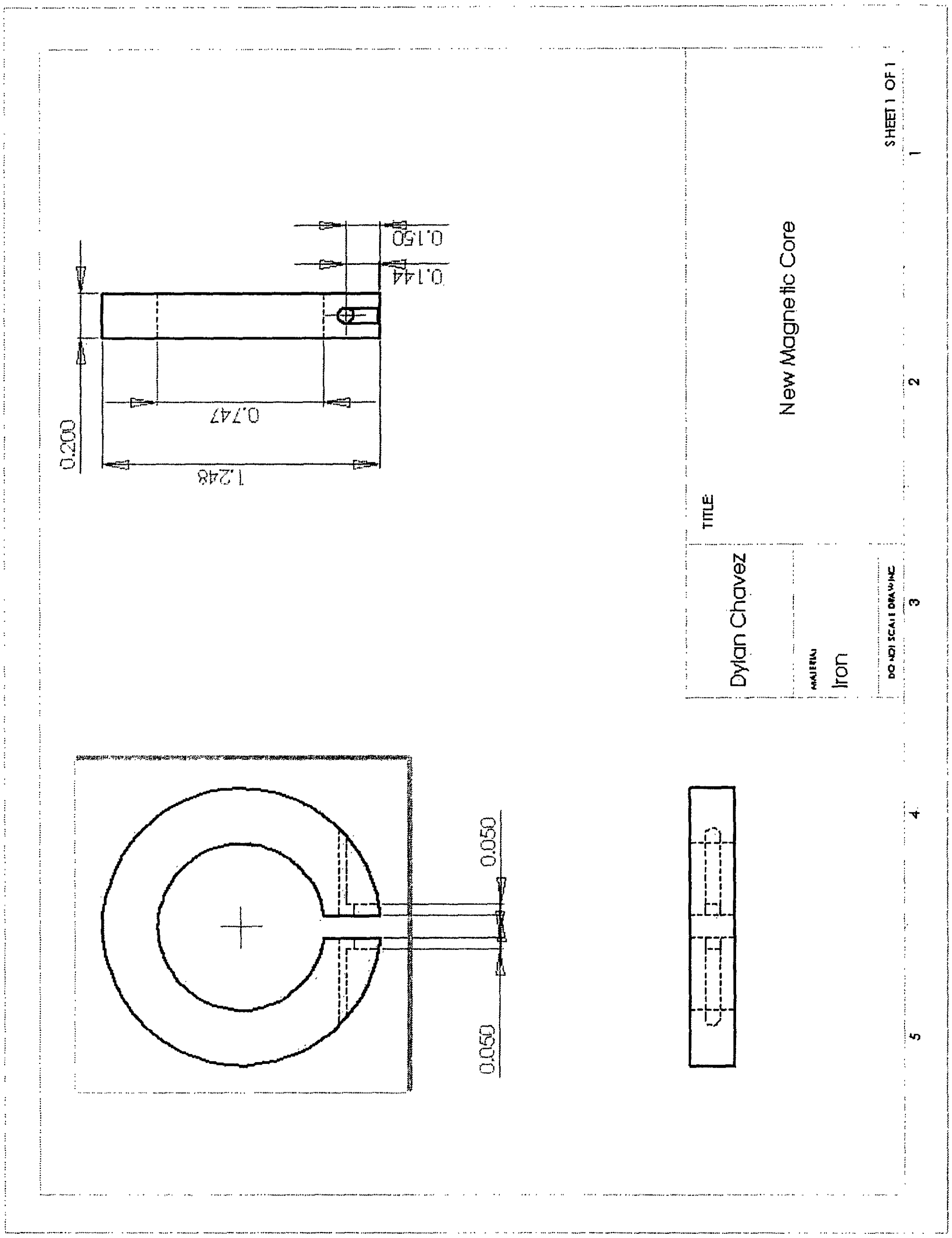

0.250
0.887
1.000
1.125
1.750
1.775
0.500
2.000
0.250
0.490
1.000
1.138
1.376
1.750
Dylan Chavez
MATERIAL
Polypropylene
DO NOT SCALE DRAWING
TITLE:
Motor Mount
SHEET 1 OF 1
5
4
3
2
1

Appendix F

List of Materials

Material	Quantity
Steel Ball Bearings Open Bearing No. R8 for ½" Shaft Diameter, 1-1/8" OD	4
6061 Aluminum Rod 1/4" Diameter 6' length	1
6061 T6 Aluminum threaded Rod 1/2" - 13 Thread, 3' length	1
Cast Gray Iron Solid Rod 1-1/4" OD, 1' length	1
Black Nylon 6/6 Hex Nut 1/2" 13 screw size, Packs of 50	1
Polycarbonate Hollow Rod 8" OD 7-3/4" ID	1
Polypropylene Sheet 1/2" Thick, 12x12"	6
Pittman Electric Motor 24 VDC	2

Appendix G


0.150
0.144
0.200
0.747
1.248
0.050
0.050
TITLE:
New Magnetic Core
Dylan Chavez
MATERIAL
Iron
DO NOT SCALE DRAWING
SHEET 1 OF 1
1
2
3
4
5