MECH 4250: Operational Readiness Review
Composite Fiber Damage Analysis Device

Corp 15 – Highland Industries

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Summer Semester – July 24, 2015

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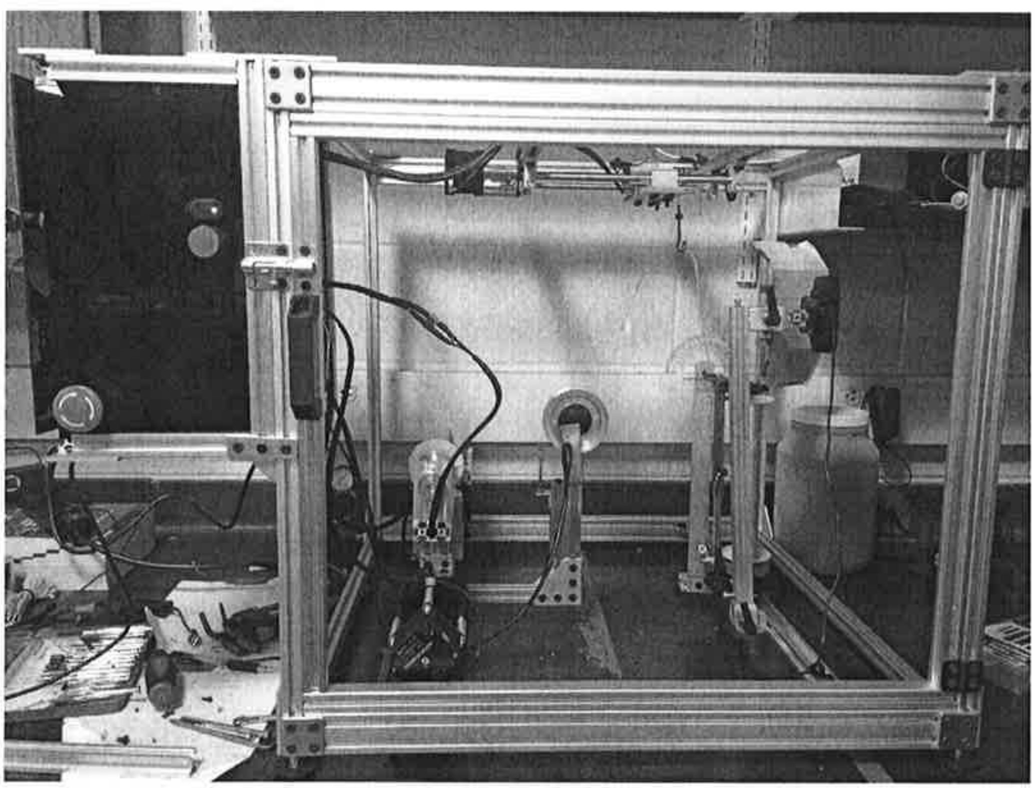


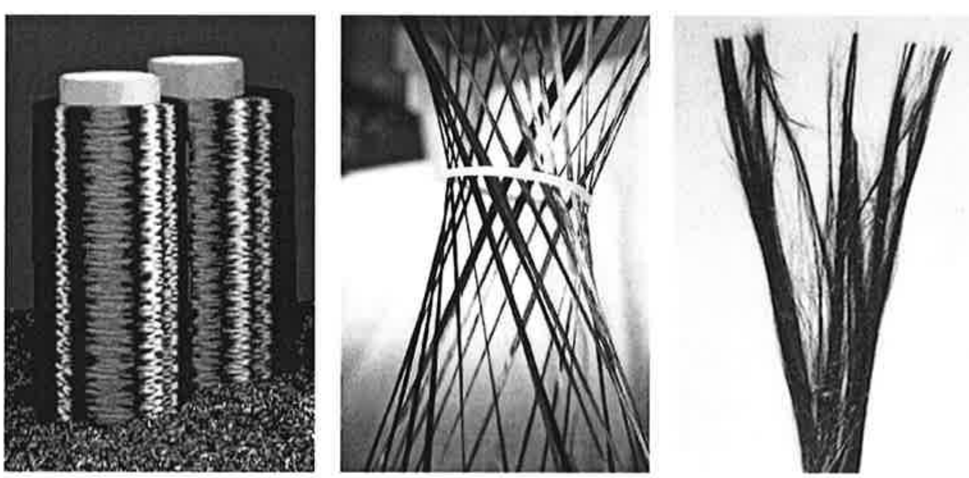
Abstract

High strength fibers are currently being utilized by many industries to develop strong, yet lightweight products that are built to last. Some fibers, such as those made from carbon, have had issues with breakages during the unspooling and weaving processes. These breakages weaken the fiber bundles, subsequently resulting in less dependable final products. The main purpose of this project was to develop a device that has the ability to pull a carbon fiber tow off of a carrier, measure and quantify the occurring damage of the carbon fiber tow, and then wind the tow on to a take-up bobbin. The device is n

By the end of the design process, a critical design had been developed and rendered using solid modeling techniques. Traditional systems and design engineering techniques were utilized to narrow down potential design concepts and to design a device that best accomplished the desired requirements and functionality of the device. In order to track the damage of the tow, it was determined that image capturing was the best option when compared to laser micrometers, photoelectric sensors, and other techniques. In order to allow for appropriate flexibility when testing the damage of the tow, several degrees of freedom were established when mounting the take-up bobbin, the camera, and the angle at which the tow can be pulled off of the carrier. The entire device was designed to be relatively compact and easy to use.

The device was designed to track and control several parameters of the tow in addition to fiber damage. The pull speed of the tow was made variable, as was the bobbin winding pitch speed. The pull speed was designed to be monitored by a Hall Effect sensor attached to a pulley and controlled by a motor mounted beneath the take-up bobbin. The tension in the tow was designed to be monitored by a load cell connected to a hanging pulley in which the tow would passes over. All of these monitoring systems combined to form a thorough inspection of the material which were intended to be used to make beneficial changes to fiber handling in the manufacturing environment.

Manufacturing of the device is nearly complete. Some changes were made to the critical design during the construction of both the physical parts and the code that controls the functionality of the device. The device is developed enough to pull tow from one bobbin to another while capturing images, measuring tension and speed of the tow, and providing the user with a damage report. Extensive testing and experimentation still needs to be done on the device in most areas. Particular areas include image analysis, tension patterns, and damage mitigation.



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Introduction

Highland Industries uses composite fiber to develop an array of strong, flexible products in various forms. One of the composite fibers commonly used is made from carbon, but other materials are also utilized. A single tow of carbon fiber is made up of thousands of individual, continuous carbon fibers. These carbon fibers are bundled together to create a high strength-to-volume product, which is a very attractive property in many industries. When the carbon fiber tow is handled in various ways, breakages occur along the tow, therefore weakening the end product. Breakages can occur due to a variety of issues including tension, spooling and unspooling techniques, friction, bending fatigue, contact with sharp edges, weaving patterns, and so on.

Therefore, the company was looking for a way to monitor the effects of these issues through the use of a simple, yet versatile, device. This report is going to identify the mission statement, the established requirements, the design developed for accommodating the stated requirements, the current status of the constructed device, and an assessment of how well the device functions, and improvements that can be added to the device . Other topics that will be covered include a bill of materials, risks involved with operation, and the mission environment.

A presentation of the Critical Design was given at the end of the first semester of the project. The information presented then is still contained within this report, along with additions and omissions from the Critical Design. Many aspects of the Critical Design were discussed following the presentation, however there were no clear objections or immediately requested additions to the design. Most comments and questions were about details with the coding, calibration, and future additions to the project. The main conclusion that was taken away from these discussions was that this device will need adjusting, mostly in regards to the data handling and coding, following completion of the device construction. The most important goals for the design construction were:

- Basic motion control of the motors and steppers
- Transfer of tow from the carrier to the take up bobbin
- Quality image capture
- Damage analysis

All other desired aspects of the device were secondary to these main goals, causing some aspects to be left for future development.

Systems Engineering

Mission Objective

The mission objective of this project is to develop a device that has the ability to pull a carbon fiber tow off of a bobbin, measure and quantify the occurring damage of the carbon fiber tow, display the results of the findings, and then wind the tow on to separate bobbin. The device needs to be versatile enough to allow for experimentation and determination of the effects of various tow-handling properties such as tension, tow speed, and tow routing.

The Manager's Project Contract of Deliverables further explaining the mission objectives for the construction phase of the project can be found in the Appendix of this report.

Requirements

The requirements of the device were broken down into system and subsystem categories. The device was trisected into the systems of structure, data acquisition and handling, and tow management. These requirements, as well as the systems and subsystems, were developed over the course of several interactions between the project team and the company sponsor. These requirements reflect the current understanding of the mission objective as they pertain to the most recent breakdown of system functions.

- System: Structure
    - Make the structure compact enough to transport easily
  - Subsystem: Cage
    - Support all mountings and the enclosure
  - Subsystem: Mountings
    - Allow components to be attached to the cage
  - Subsystem: Enclosure
    - Contain all enclosed objects
    - Adhere to NEMA 12
- System: Data Acquisition and Handling
  - Subsystem: Damage Detection
    - Detect damaged fibers
    - Overlook undamaged fibers
  - Subsystem: Quantification of Damage
    - Count number of damaged fibers
    - Quantify damage of the tow as a whole
  - Subsystem: Output
    - Run calculations on the number and quality of damaged fibers
    - Output the results
    - Allows output of data for addition analysis
- System: Tow Management
    - Unspool the fiber from the feed spool
    - Spool the fiber on the take-up spool
  - Subsystem: Tow Routing
    - Move the tow from the feed spool to the take-up spool
    - Do not cause any additional damage to the fibers
  - Subsystem: Tension
    - Measure the tension
  - Subsystem: Feed Speed
    - Measure the Feed Speed
    - Control the Feed Speed
  - Subsystem: Pitch Speed
    - Measure the pitch speed
    - Control the pitch speed

Architectural Design Development

Early Design Concepts

The very early stages of architectural development began with attempting to grasp and address the main requirements, objectives, constraints, and overall functionality of the device. The early stages of the conceptual design building process focused mainly on the issues of keeping tension in the tow and tow routing. Another topic of conversation included the type of sensor to be used to detect damage, but this topic was not reflected in the rough sketches of the early design stage.

Early concept studies established a set of desired qualities. An on-campus hairiness tester manufactured by Zweigle was studied to gain an understanding of available products. This device was not designed to test carbon fiber tows, or other composite fibers for that matter. Once tested with a bobbin of carbon fiber, a better understanding of desired qualities was established due to the relative failure of the machine when attempting to handle carbon fiber. Desired qualities included:

- Minimal contact points between the tow and the device
- Eliminate choke points and sharp edges
- Detecting damage early on in the tow-routing process
- Removing broken and floating filaments from the testing area

The relative successes of the hairiness tester also brought about certain desired qualities, including:

- Ease of operation
- Intuitive graphical interface
- Speed control
- Accurate instrumentation and analysis techniques
- Reliability

Developed Designs

Continued discussions and brainstorming led to a second round of designs, which contained several revisions due to updated requirements. Revisions included spooling the pulled tow back onto a bobbin, as well as pulling the fiber off of a carrier instead of just a bobbin. Several common ideas were shared among the group, including:

- Using the take-up bobbin and an axially attached motor to pull the tow through the system
- Keeping the sensor stationary relative to the tow
- Guiding the tow through the sensor

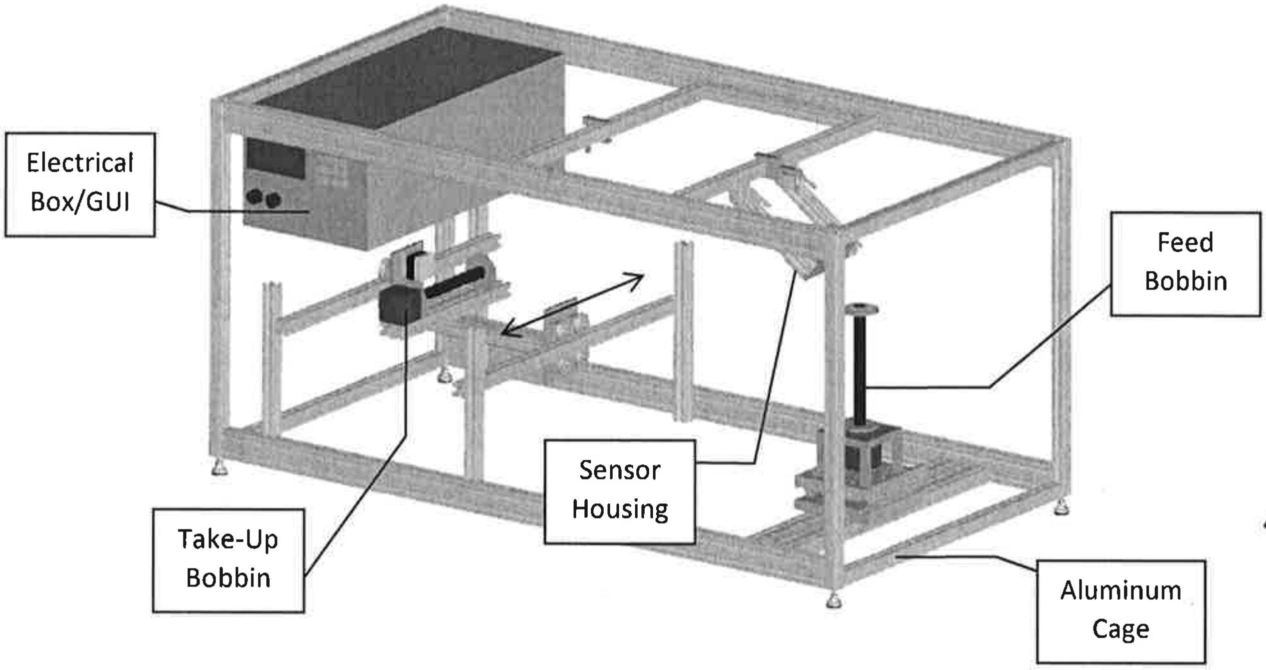


Figure 1: Early conceptual design

Preliminary Design

The preliminary design was a combination of ideas developed through the first two rounds of conceptual designs. This stage of design was where most decisions were made about device components and processes based on research and testing. Figure 1 shows the rendering of the conceptual design. The rough nature of the conceptual design left many areas of the design to be researched and specified. The main areas left to decide upon on were the damage sensor and tensioning device. Below is a quick summary of the sensor options that were researched and compared.

Sensor Options:

- Photoelectric Sensor
    - VSM Series Micro Sensors
        - $148.00
        - Made by Banner Engineering
    - 4-5 mm barrel housing
    - Response time of 2.5 milliseconds
    - Repeatability of 1 millisecond
    - Counts fibers along passing tow
    - Data acquisition complicated
- Laser measurement sensor
    - L-Gage LE550 Laser Gauging Sensor
        - $545.00
        - Made by Banner Engineering
    - Can measure flatness or diameter
        - Able to detect excessive material on a surface
    - Accurate Laser (within .5% of full scale range)

Figure 2 - Photoelectric sensor

- Programmable
- LED display, data needs to be interpreted

- Machine Vision
    - High speed camera captures the tow as it passes
    - Analyze images to record data
    - Can be extremely accurate
    - Many programs online
        - NI Vision
        - Microscan
        - OpenMV Cam
- Laser Micrometers
    - Examples:
        - Metralight's RX03/RX07
        - Keyence's LS-9000 series
        - Laserlinc's TLAser 122 & 130
    - Out of budget expensive($1000-$10k)
    - High resolution
        - Up to .025 microns
    - Accurate at high speeds
    - Data easily accessed by computer usb
    - Comes with program for easy data acquisition

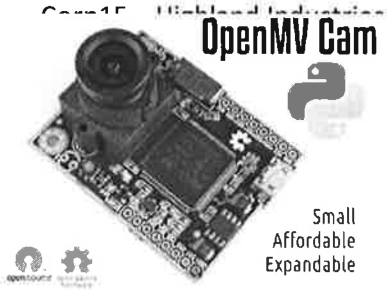


Figure 3 - MachineVision high speed camera

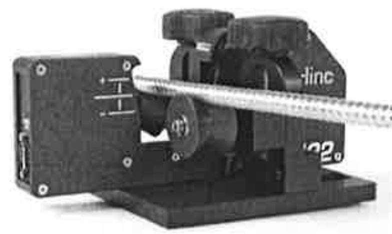


Figure 4 - Laserlinc's laser micrometer

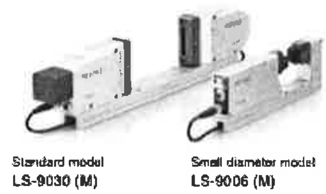


Figure 5 - Keyence laser micrometers

After much discussion within the group and with the industrial sponsor, it seemed that a laser measurement sensor was to be used for the design for measuring the damage of the tow. It was also established that, when using the device in the future, recording the various experiments with a camera would be valuable. In addition to the data being gathered from the laser measurement device, a video recording would provide secondary proof of damage as well as help the users to identify specifics about how damage was occurring.

The L-Gage LE550 Laser Gauging Sensor was chosen. Before implementation into the design, verification of the instrument needed to be established, meaning that the instrument needed to be proven to work and have the ability to detect loose strands on the tow. The sensor was tested at a nearby distribution center for the sensor company. Several passes of the tow were passed through the laser measuring device and results were not good. After consulting with the engineering staff at the center and from the results, it was determined that a laser measurement device was not a viable option given the project's established budget of $2,000.00. A high end sensor would be needed, which can cost close to $10,000.00. *Because of this verification step, it was determined that a new damage detection system was needed.*

The Camera Solution

The next best option was using a camera and image processing to detect damage. Early doubts about this option were obvious. Questions that needed to be answered were, but not limited to:

- Can a camera detect individual hairs?
- What kind of frame rate would be necessary?
- How would the images be analyzed?

Some of these questions would be answered over the course of the next few weeks through many hours of testing. A bobbin winder, which takes material off of a large spool and winds it neatly onto a smaller bobbin, was utilized. This device allowed testing to be done at different pull and pitch speeds, as well as different angles and tow routing scenarios. Many different cameras were tested including a GoPro Hero 3, a USB Microscope, a simple compact, and a high speed camera capable of recording at several thousand frames per second. The general set-up can be seen in Figures 6, 7, and 8. After rearranging the camera set up, changing the lighting, and replacing cameras, these results were found:

- Relatively basic cameras were capable of individual fiber detection
- Using a light source, it was found that filming the projection of the passing tow onto a backdrop magnified the image and reduced vibration at high speeds (which caused auto-focusing issues)
- Normal frame rates were capable of capturing the passing tow, eliminating the need for high speed cameras
- Pulling at low speeds did not produce vibration issues, removing the need for projection of the tow onto a backdrop.

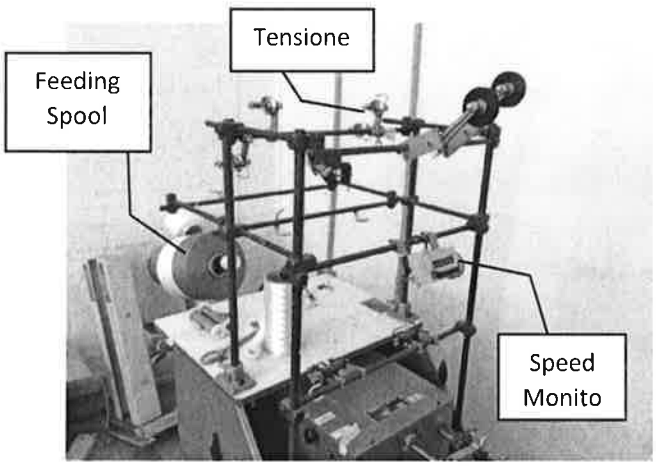


Figure 6: Bobbin winder feeding cage

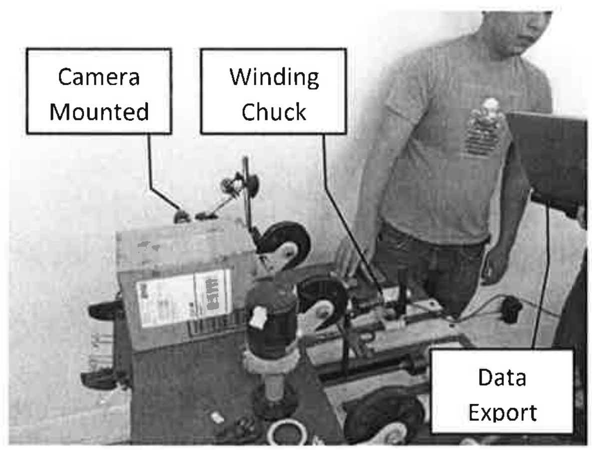


Figure 7: Bobbin winder with camera mounted

The camera selected for the device was the Logitech HD Pro Webcam C920. The specifications and description of this camera can be found in the Appendix.

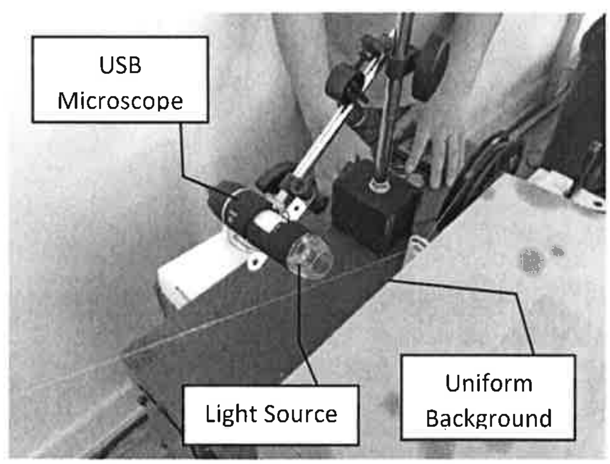


Figure 8: USB Microscope recording string

Tension Options:

Table 1 - Tension control pro/con matrix

Sensor	Advantage	Disadvantage
Load Cell	• Accurate (Error percentage ± 1%) • Output in unit of force • No moving parts • No electrical components • Fast Response • Single contact	• Calibration • Testing environment dependent • Mechanical/Electrical component (Strain gages)
Pressure Transducer (Three Wheel)	• Accurate (Error percentage ± 1%) • Uses Differential force to calculate output. • Fast Response • Not affected by testing environment	• Complex (Multiple parts) • Multiple contact Point • Uses a working fluid to measure pressure and then convert to a unit of force
Ultrasonic	• No Contact point • Diameter Compensation • Linear reading • Not dependent on material physical appearance.	• Requires a uniform flat surface • Area noise can affect readings • Sound waves could be absorbed by the material

The tensioning device that was chosen was the load cell due to its minimal contact points and ease of use. The load cell measures deflection by way of a voltage change. The cell outputs a voltage, which can then be converted to force through calibration, and then from force to tension in the tow.

Critical Design

The critical design was the final design developed before construction; it was the culmination of the design work done during the first semester of the project. These designs were the blueprints for what was to be built the following semester. Once construction began, the design began to change due to a variety of reasons (testing, ease of construction, available parts, etc). This critical design is simply what was intended to be built, not the final product.

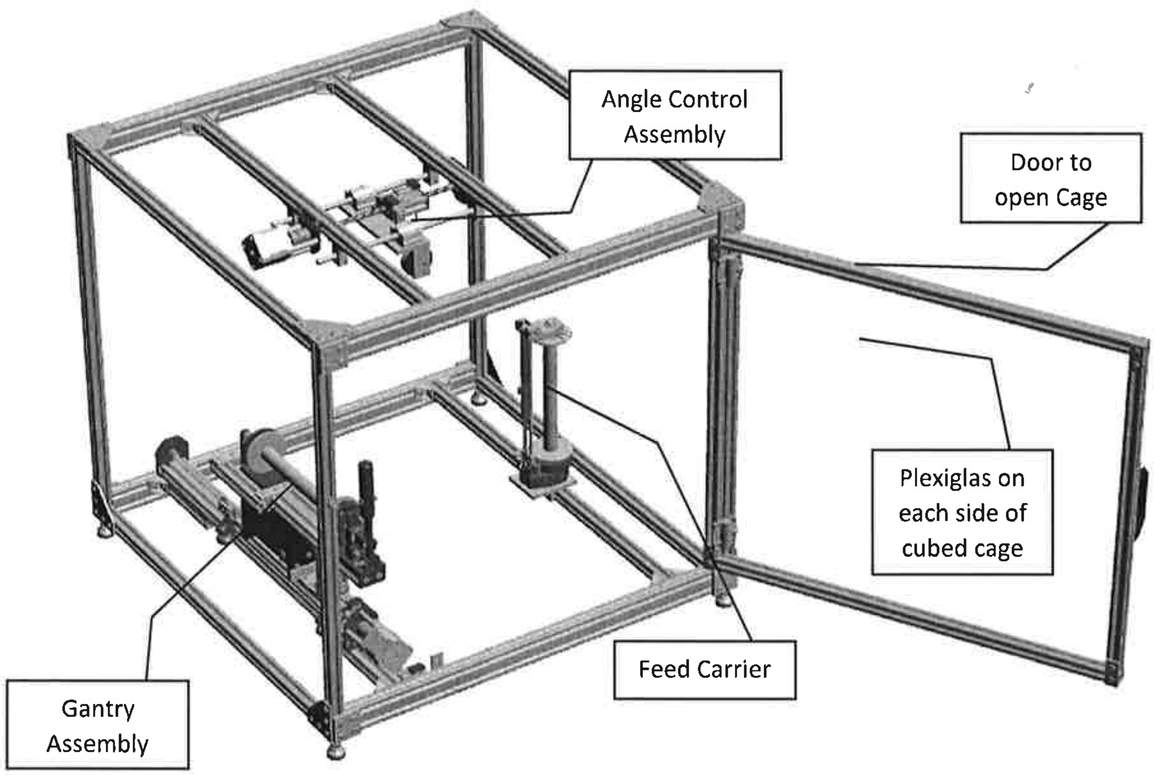


Figure 9: Skeleton model of final design

Main Assemblies

Gantry: The gantry in the final design controls the take-up bobbin's movement. A NEMA 23 stepper is located to the side of the take-up bobbin. This stepper allows for translational movement of the carrier, which is critical to the tow winding on to the bobbin at the correct speed and pitch angle. The gantry also houses the main motor for the device, which is located underneath the bobbin. This motor is connected to the take-up bobbin via a gear and belt assembly. The last crucial part in the gantry assembly is a stationary pulley. This pulley feeds the tow onto the bobbin as the bobbin is moving back and forth via the stepper.

Angle Control Assembly: The angle control assembly is mounted to the roof of the device. The assembly's main purpose is to control the angle with which the tow comes off of the carrier. As with the

Gantry, a NEMA 17 stepper controls the linear actuation of the assembly within the two support beams. This allows for fine-angle changes. The two support beams can also be moved translationally, allowing for larger angle movements in the same direction as the stepper. The assembly can also move in the perpendicular direction as well. This overall motion flexibility allows for greater manipulation of the tow routing in order to simulate manufacturing variations in carrier position. Hanging down from the assembly is a pulley. This pulley guides the tow off of the carrier. Supporting the pulley is the load cell which monitors the tow tension through calculation.

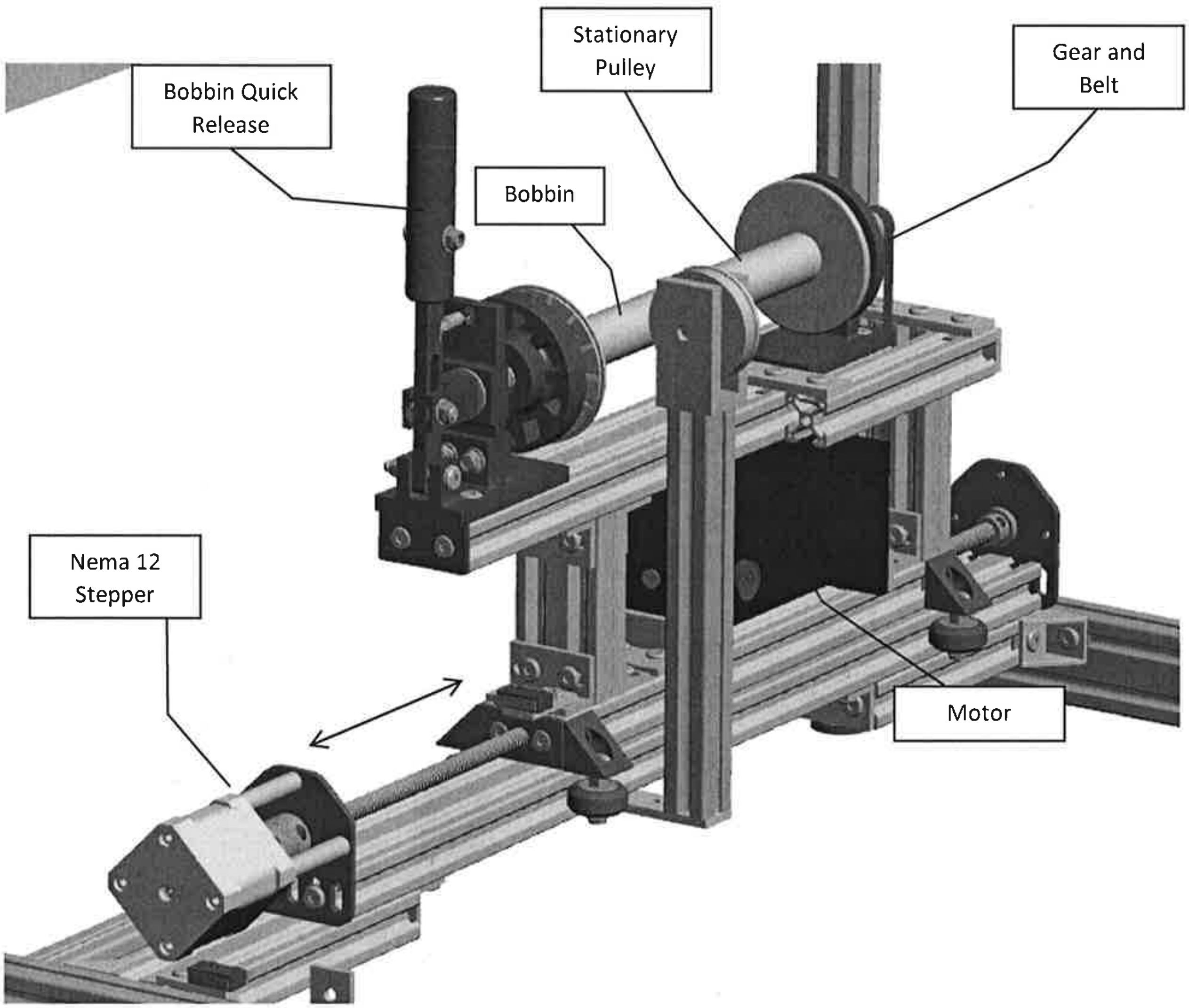


Figure 10: Gantry assembly with callouts

Electrical Box: The electrical box assembly is made up of an Arduino, and Beagle Bone Black, and a power supply. All data handling and power distribution will go through this box, including the graphical user interface control, motor and stepper control, and possibly image analysis. The electrical box is mounted outside of the main skeleton frame and Plexiglas in order to avoid floating fiber filaments that could damage or short the electrical components. On the front face of the electrical box is the graphical user interface (GUI). Main controls include:

- Start/Stop
- Pull speed input
- Pitch speed input
- Carrier pull angle
- Length of tow pulled

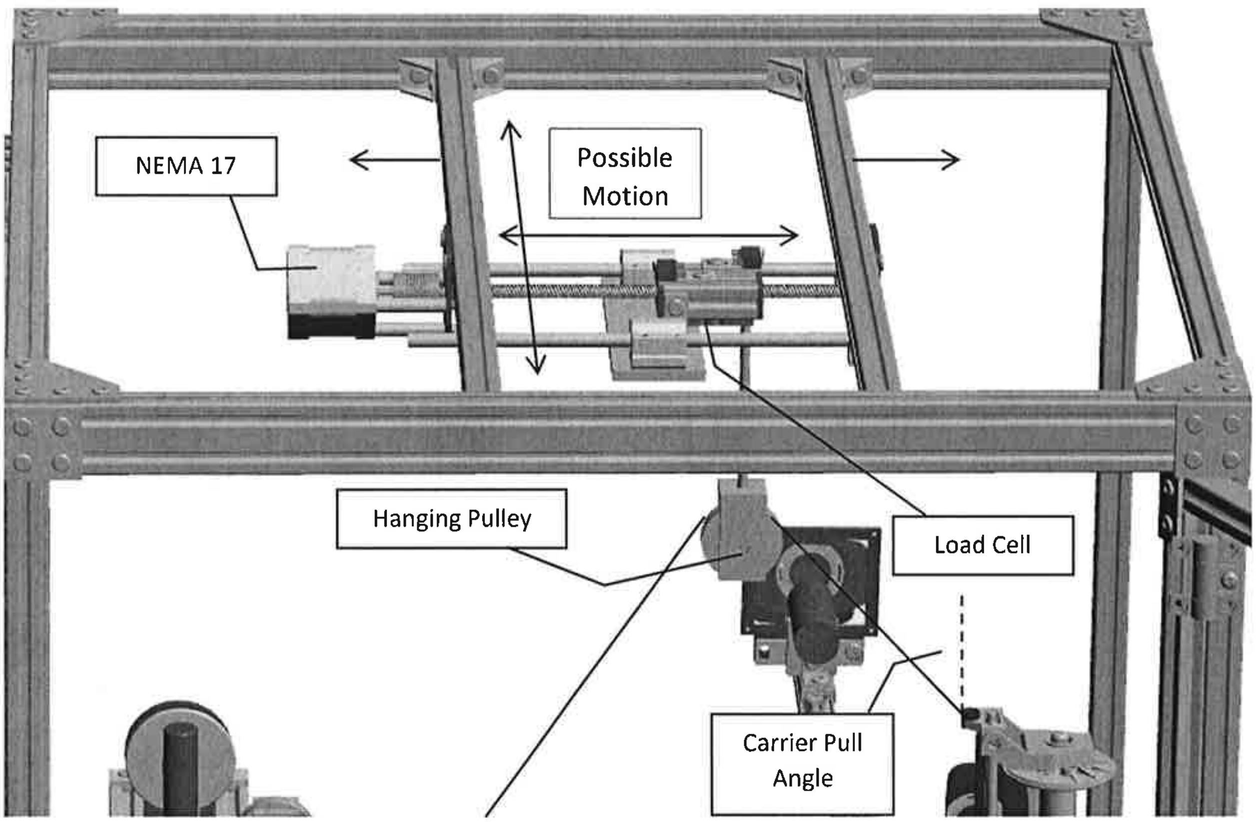


Figure 11: Angle control assembly

Vacuum System: The vacuum system will consist of a mounted compressed air adapter and filter attached to the frame near the electrical box as well as a series of hoses and vacuum cups running on the inside of the cage. The hoses and cups will be placed near the main contact points of the system (i.e. anywhere the tow touches a surface). These cups will collect loose, floating filaments and fiber balls that form from continued rubbing. These filaments will collect in the filter instead of settling at the bottom of the cage. In addition to the suction system, there will be a nozzle placed just after the carrier but before the angle control assembly. This nozzle will blow a soft stream of air at the tow to blow off any loose fibers or push the broken, but still connected hairs out away from the tow to help with detection by the camera and image processing.

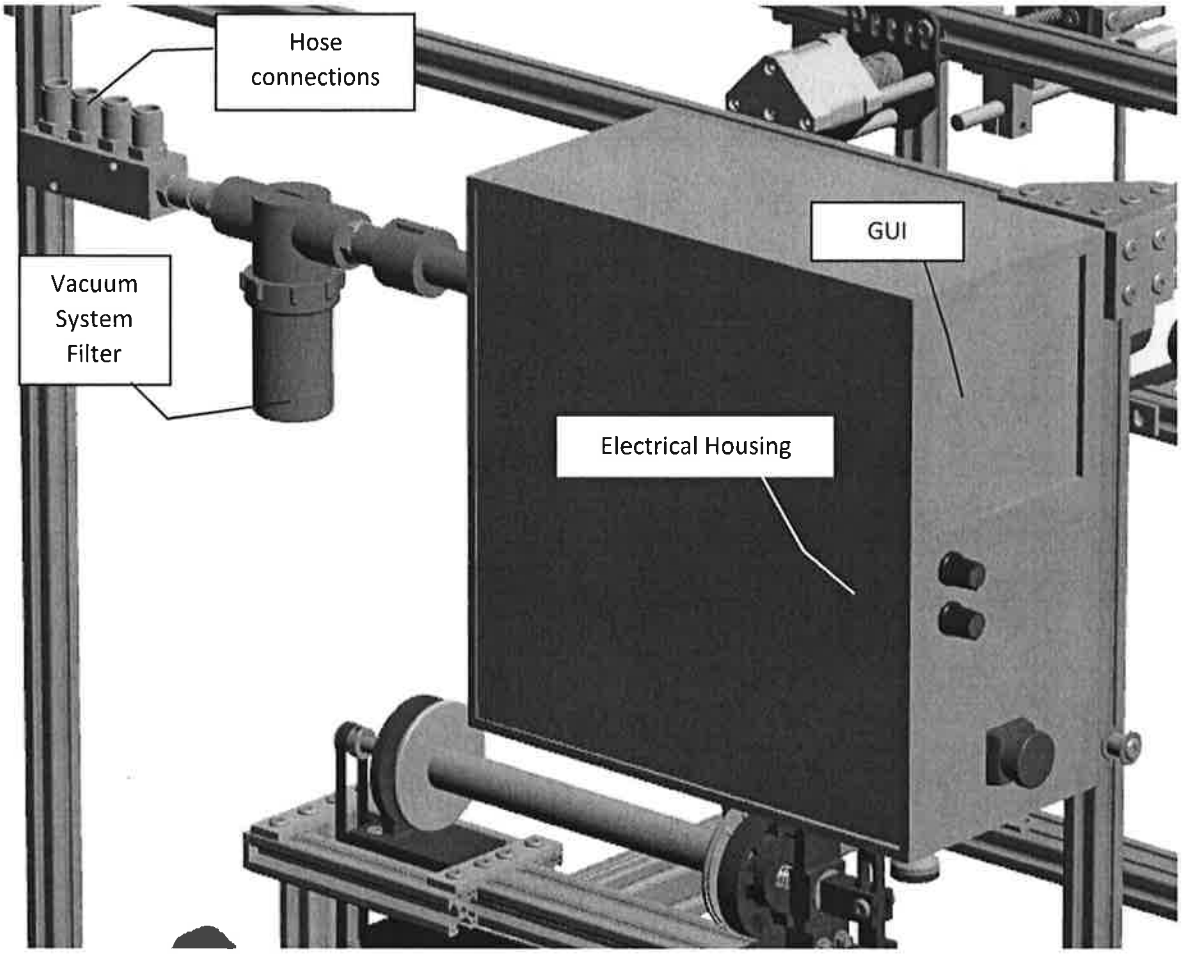


Figure 12: Electrical box and vacuum system

Sensors, Instrumentation, and Data Handling

Device	Location	Use
Camera 1	Above Feed Carrier	Captures tow damage
Camera 2	Adjacent to Feed Carrier	Captures routing within carrier, in hopes to relate tension and damage to carrier routing patterns
Hall Effect	Gantry (stationary pulley)	Monitors tow speed
Load Cell	Angle Control (pulley)	Measures tension in the tow
Switches	Gantry and Angle Control	Linear actuator limit indicators
Arduino	Electrical Box	User interface control
Beagle Bone Black	Electrical Box	Motor and transducer control, with possible image analysis processing

Construction

Several aspects of the Critical Design were either changed, removed, added, or incomplete during construction. The main differences between the construction and Critical Design renderings are as follows:

I. Vacuum System: removed
   - Low priority
   - No significant shedding of fiber to warrant implementation at this point
   - Recommended addition if shedding of fiber becomes an issue

II. Camera 2: removed
   - Was not essential to device functionality
   - Large amount of work to implement
   - Significant data handling
   - Significant resource requirements

III. Graphical User Interface: incomplete
   - Difficult integration
   - Possible to run device from computer currently
   - Highly recommended to add once main functionality of device is complete

IV. Bobbin Mounting and Release: changed
   - Easier to machine
   - Fewer pieces
   - Drawings located in Appendix
   - Figure 13

V. Hanging Pulley: changed
   - Changed to hanging eye-hook
   - More typical of manufacturing scenario
   - Requested by sponsor
   - Figure 14

VI. Bobbin Winding Eye-Hook: added
   - Guides tow onto take-up bobbin
   - Figure 13

VII. Image Backdrop: added
   - Provides scale for image analysis
   - Figure 14

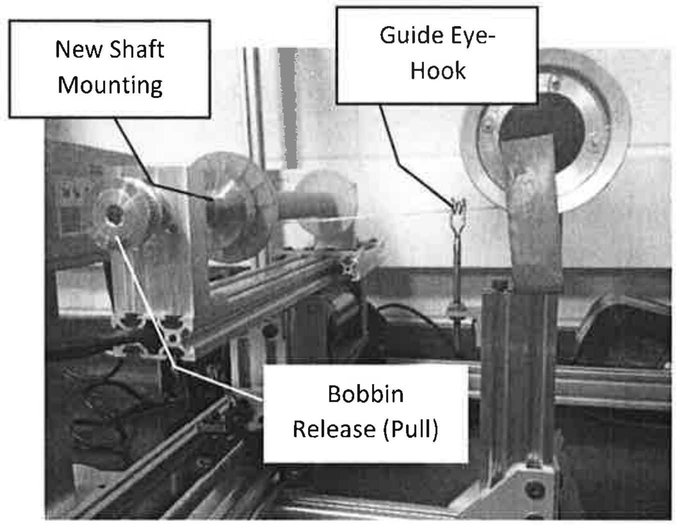


Figure 13: Take-Up Bobbin Mounting

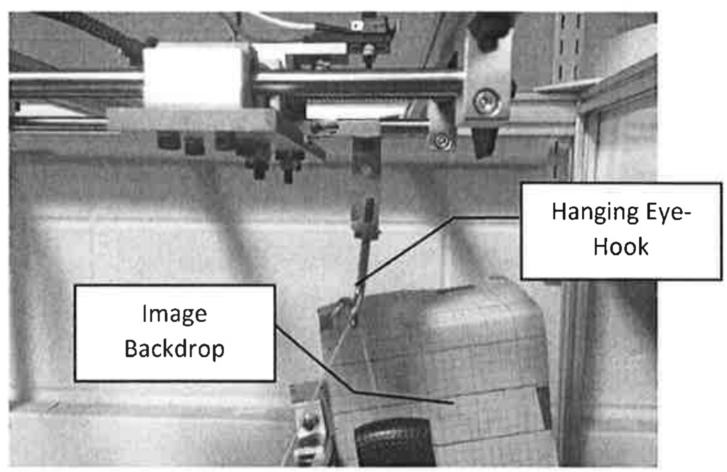


Figure 14: Load cell is now pulled by eye-hook instead of pulley

Bill of Materials and Budget Analysis

The complete parts list is still being developed, as is the total cost.

Concept of Operation

The concept of operation for the motion of the components and the tow from carrier to bobbin remains the same as it was for the Critical Design Review. Figure 15 illustrates the general path the tow would take during a trial of the device. Since the Critical Design Review, the nature in which the device starts and is controlled has become more detailed. It is not as simple entering a few pieces of information into a graphical user interface. It was intended for it to be this simple, but not enough progress has been made to install a user friendly interface capable of controlling the machine.

There are three main components that control the device in its current state – an Arduino Uno, a BeagleBone Black (BBB), and MATLAB programming. The Arduino is the board connected to the DC motor, the stepper motors, the load cell, and the Hall Effect Sensor. However, the BBB is the board that communicates to the Arduino to activate the components. The common relationship to describe this hardware situation would be to call the BBB the "master" and the Arduino the "slave."

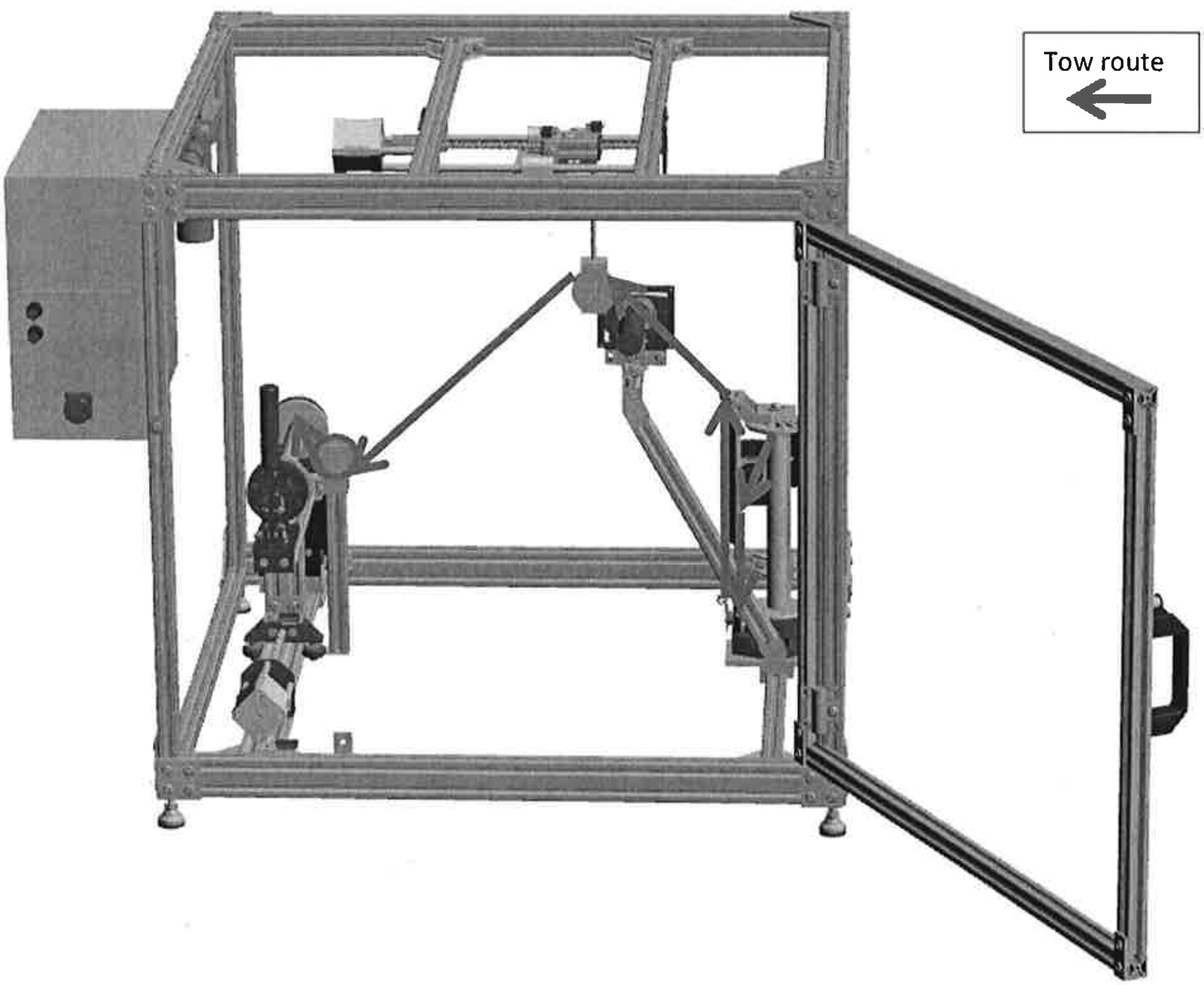


Figure 15: Full model of critical design with tow routing

Connecting to the BeagleBone Black for Image Analysis Control

Steps:

1. Plug in the BBB either by USB or a 5V power supply
2. Go to "My Computer" and select the drive with "BBB" and double click on the drive to open
3. Navigate to the drive labelled "BeagleBone Getting Started" and double click

Programming:

Two methods for coding:

4. Cloud9: This is a default program provided by BBB. You can access it by clicking on the drive labelled "BeagleBone Getting Started," navigating to and double clicking START (The label might be different if you have a different web browser as the default browser. **Note Internet explorer will not work**). Once the browser page opens, scroll down to step 3 and click on "Click here to launch:http://192.168.7.2". This is the default BBB web integrated development environment (IDE). Alternatively, you can connect your BBB to the internet via Wi-Fi or Ethernet and type in 192.168.7.2:3000 into your URL if your BBB IP address has not changed.
    a. To change the camera resolution, type:

    ```
    v4l2-ctl --set-fmt-video=width=xxxx,height=yyyy,pixelformat=1
    ```

    e.g. For 1920 x 1080:

    ```
    v4l2-ctl --set-fmt-video=width=1920,height=1080,pixelformat=1
    ```

    b. In the terminal window, type:

    ```
    cd boneCV/
    ```

    c. To compile code, type:

    ```
    gcc -02 –Wall 'pkg-config –cflags –libs libv412' grabber.c –o grabber
    ```

    d. Wait until the code compiles
    e. To execute code, type

    ```
    ./grabber -F -c 600
    ```

    -F forces format to be h.264, -c is how many frames captured. The default is 30 frames per second. To capture 20 seconds, type '-c 600' since 20 seconds for 30 frames per second is 600 frames.

5. SSH: Using a Secure Shell(SSH) program (OpenSSH, puTTY,ect..), find your BBB IP address and log in via the SSH program. Use to following information to log in.
   i. Login: root
   ii. Password: highland
   a. To change the resolution, type:

      v4l2-ctl --set-fmt-video=width=xxxx,height=yyyy,pixelformat=1

      e.g. For 1920 x 1080:

      v4l2-ctl --set-fmt-video=width=1920,height=1080,pixelformat=1

   b. In the terminal window, type:

      cd /var/lib/cloud9/boneCV/

   c. To compile code, type:

      gcc -02 –Wall 'pkg-config –cflags –libs libv412' grabber.c –o grabber

   d. Wait until the code compiles
   e. To execute code, type

      ./grabber -F -c 600

Arduino Control

- To change pull speed, change the 'float desired' variable in the code
- Units are in revolutions per minute
- It has to be in multiples of 5
- If you want to change the speed of the stepper, change the 'stepper.setmaxspeed' variable
- To adjust the angle, use the switch to change direction and use the button to pulse movement
- Eject the SD card to acquire tension readings.

Image Processing

All image processing is currently done in MATLAB. There are two versions of the image analysis code. The first is a manual version which can be used when the images in need of processing are already on the computer. The second version connects directly to the BBB to acquire the image files from the board's local storage. Once the folder containing the images is chosen, the user chooses an output folder to place the processed images in. The program then asks the user what type of files the images are, what to name the processed images, and what color the fiber in use is. Color is important as the material captured on the image needs to show up as black pixels to correctly calculate error. The images are processed by converting them to binary then using threshold and filter functions to reduce the noise in the images.

A base image is found by comparing the images and finding the one with the least amount of black pixels. This base image is then used to calculate an error percentage for the remaining images. The program also asks the user for minimum error percentage. Any image frame with error above the chosen minimum percent is considered damaged and is counted. Once the processing and calculations are done, the results are shown on the screen. The user is asked if they would like to export the data to an excel spreadsheet. Finally, the user is asked if they want to open the *measuretool* program. This program allows the user to measure the length and angle of the captured fibers and these measurements can also be saved. The *measuretool* program can be opened outside of the image analysis code if needed.

Validate and Verify

No tests were able to be run up to this point in time. Construction and development of the code, along with interfacing and troubleshooting, prevented the device from being completed early enough to run significant tests. Future testing should include, but not be limited to:

- Tension mapping (expecting a sinusoidal pattern as the fiber is pulled from different areas of the bobbin inside the carrier)
- Tension vs. damage
- Damage vs. change in the pull angle off of the carrier
- Damage analysis when compared to actual events taking place to ensure:
    - The image analysis is sufficiently picking up damaged spots
    - The image analysis is not being corrupted by a poor threshold
    - The damage scale is proportional to actual damage
- Performing enough test runs to handle potential issues with functionality

Once these tests are performed, it will be more clear whether the mission was successful or not and if the sponsor's requirements were met.

Interfaces

Many mechanical and electrical components were coupled together through interfaces for the designed machine. The first mechanical interface was all of the components being attached to the cage by use of fasteners and mounting devices. This interface allows the whole machine to be transported as a single piece. The tow routing subsystem is mechanically interfaced with the fibers through contact forces to route the fibers from the carrier to the take-up bobbin. Each motor was connected to an Arduino board. This Arduino board and all the sensors were electronically interfaced to the central processing unit. The motor will be electronically controlled by the information from the sensors via this electrical network. The electrical schematic can be seen in Figure 16. The bulk of the electrical components were housed in the electrical box mounted to main cage.

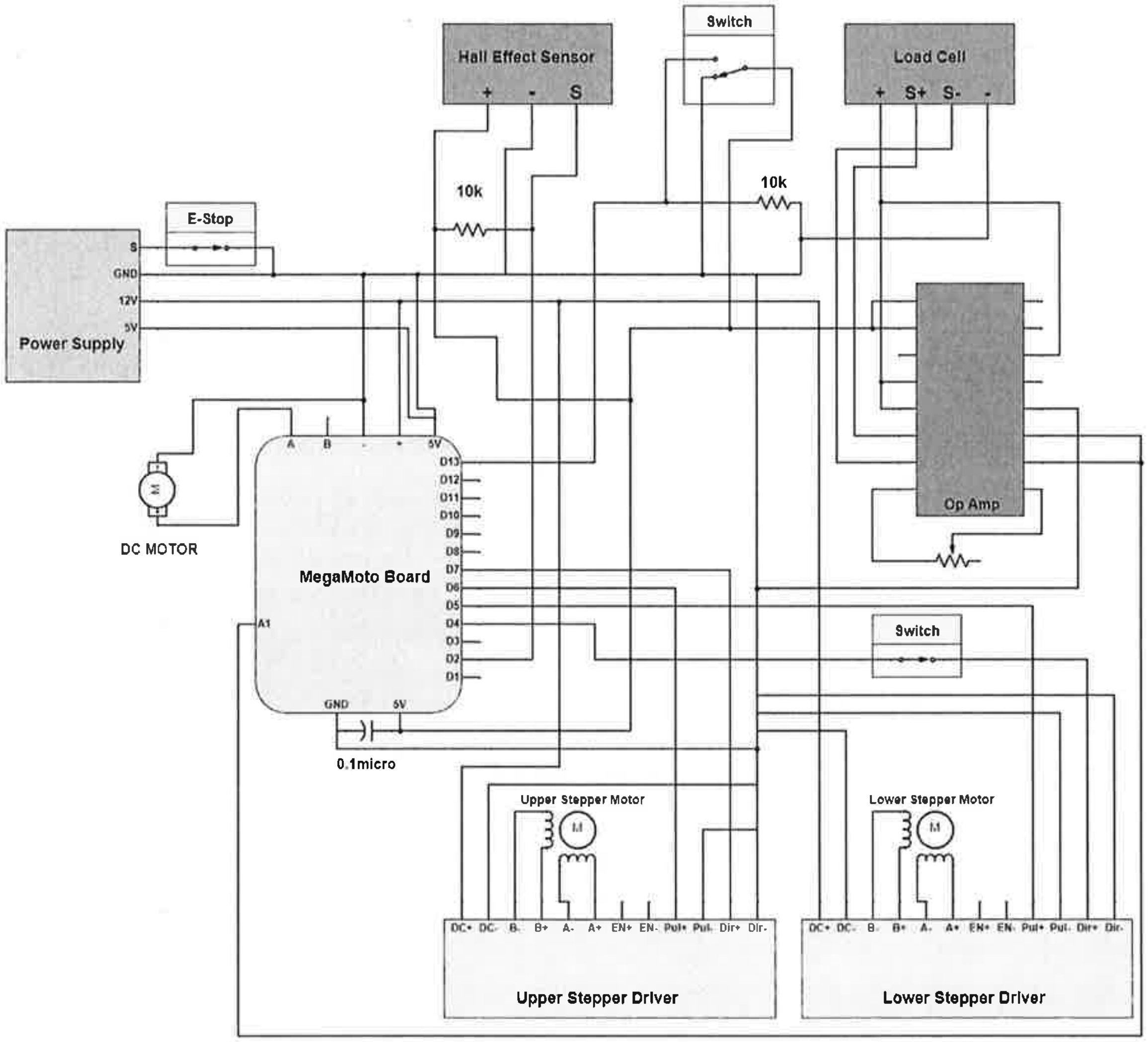


Figure 16: Electrical schematic

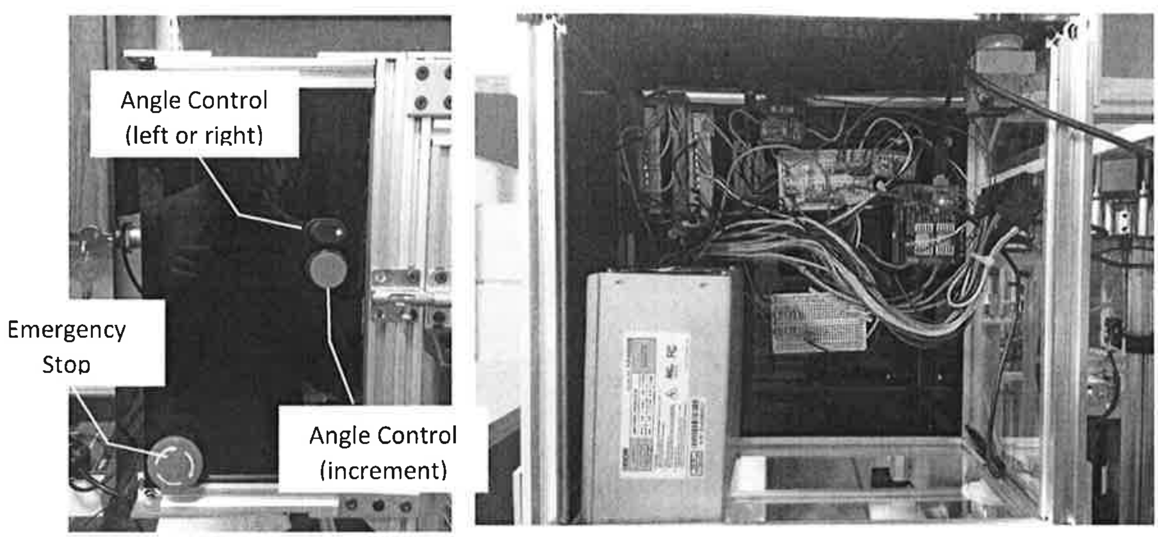


Figure 17: Control box inside and outside

Mission Environment

The environment is an indoor manufacturing plant. The work space will be air conditioned and isolated from extreme conditions. The design will be compact to allow for portability and to save space. Known disturbances would be from vibrations in our machine and surrounding machines, and also outside light interfering with the camera. To stop the vibrations, dampers can be used to stabilize the recording camera. Tinted fiberglass around the machine's skeleton can be used to block outside or excess light. One factor to be aware of is that the fibers from the material are conductive and can cause issues with nearby electronics. This can be solved by containing the main functions of the machine inside itself or a put a glass cover around the functions.

Technical Resource Budget

There were no real concerns when it came to technical resources being budgeted throughout the project. Weight and size were not issues; the device is adequately portable. A standard outlet is enough power to operate the device, and the power supply had no problem distributing enough power to each electrical component. The issue of memory storage was avoided by outsourcing the captured images to a host computer over Wi-Fi after each test run.

Risk Management

During operation, there is little to no risk to operator and/or onlookers. Risks that need to be monitored are mechanical and software failure. These failures are presented in the following table to show severity and possible solutions. All failures can be visually seen during operation and data collection.

Table 2: Risk assessment matrix

Risk Title	Risk Type	Severity	Occurrence	Effect	Solution
Camera Malfunction	Mechanical, Program	1	Low	Cannot acquire data	Repair or replace camera. Debug program
Motor Malfunction	Mechanical	1	Low	Operations cease	Repair or replace motor
Fiber build up	Environment	3	Medium	Damage to tow and routing	Use of a vacuum/air blower to remove loose fibers from tow
Loose fibers affect outside machinery	Environment, Mechanical, Safety	2	Medium	Possible machine failure	Contain design inside a see through cover. Use of a small vacuum or air blower
Loose fibers affect inside electronics	Environment, Mechanical	2	Medium	Machine and/or electronics failure	Contain electronics inside covers/boxes. Use of a small vacuum or air blower

Angle control locked up/stuck	Mechanical	4	Low	Unable to test fiber tow at different angles	Find cause and remove/fix. Worst case is to buy another part
Tow leaves spool/route during re-spooling	Mechanical, Environment	2	Low	Operations cease, Fibers build up inside machine	Stop operation and secure tow to bobbin before resuming

Configuration Management and Documentation

Documents and designs are saved on Dropbox for ease of use and availability for all group members and the company sponsor. A group email is also used, identified as corp15, to communicate between group mates, technical advisor, and company sponsor. A design notebook is also used to keep meeting notes and ideas as the design progresses.

Subsystems Design Engineering

As concept studies and development became more specific, developing subsystems required extended thought and research. First, it was important to find requirements for each subsystem because each subsystem could change the whole concept of the design. After development of the main concept, three systems were developed which were structure, data acquisition and handling, and tow management.

Starting with structure, it was important to design a device compact and light enough for portability. In order to attach components of the system easily, the structure system used a cage-type box design. Aluminum members were chosen for its rigid and lightweight properties. One of the requirements for the structure system is to meet NEMA 12 enclosure requirements because of the risks associated with floating carbon fiber filaments. This became less of an issue as the speed of pull decreased. Filaments were not being ripped off the tow and wafted into the air during slower pulling. It is still recommended to enclose the device, however, as even the smallest conductive filament can short a circuit.

For data acquisition and handling, damage detection, quantification of damage, and output subsystems were developed. In order to detect damaged fibers and overlook undamaged fibers, an image capture system was established and developed.

The tow management system managed the tow routing, tension, feed speed and pitch speed subsystems. The basic concept was to unwind the fiber from the feed bobbin and wind the fiber back on to the take-up bobbin. Designing the tow routing was a very delicate process because bad tow routing could have caused unnecessary damage to the fiber while feeding it through the various components. While feeding the fiber, tension can be measured to help determine its effect on fiber damage with the use of a micro load cell. A pitch speed control system needs to be developed due to its influence on other subsystems, including the feed speed and tension control subsystems.

Project Management

The group members were split and assigned different tasks to improve efficiency and to tackle multiple design problems. The tasks were closely related in the design so there was much communication between the members to insure the best integration of the different modules.

Table 3: Task distribution

Module	Task	Members
Component Development	Machining	BK
	Ordering	Tony
Image Processing	Image Analysis	Gabriel
	Image Capture	Gabriel/Tony
Motor Control	Interfacing	Tony/Luke
	Coding	Luke
Instrumentation	Implementation/Calibration	Luke/Tony
User Interface	Coding	Ryan
Device Communication	Wiring/Coding	Tony
Construction	Mounting	Tony/Luke/Ryan
	Electronics	Tony/Luke
Documentation	Design Notebook	Ryan
	DropBox	Tony
Report	Writing	Ryan/Gabriel

Conclusions

The project construction was accurately completed based up the Critical Design developed during the design phases. Minor changes and adjustments were made due to various justifications and complications. The device is very close to performing the base requirements with reasonable repeatability. Some work still needs to be done in order for this to be accomplished. Once these base requirements are met, extensive testing needs to be done in order to bring the device to a status of being useful to the sponsor and the industry. Recommended additions to the project include:

- Variable carrier design and movement to mimic manufacturing patterns
- Secondary camera analyzing the feed bobbin unwinding patterns
- More powerful local computing system
- Calibration of instrumentation
- Fine-tuning of motor control processes
- Improved speed control resolution
- Tension control

Appendix

Contents:

Manager's Project Contract of Deliverables

Date: 6/2/2015 Corp Number/Name: Corp 15/Highland Industries

Contract Title: Fiber Damage Detection Machine

Task: Our task is to create a machine that detects fiber damage locations on passing composite fiber tow and is able to analyze and display relevant data.

This machine will be able to pull the fiber at varying angles and take up speeds. The data is collected by two cameras, one recording the fiber before coming off the carrier and the other after coming off the carrier, and a load cell that measures tension. The load cell will be located on a pulley connected to the angle assembly and is between the feed carrier and take-up bobbin. The cameras will take images of the passing fiber; these images will then be run through a MATLAB program and be able to count and measure protruding fibers. The program will also display an error percentage of a fiber damage image versus a base undamaged fiber image. The fibers on the tow will be agitated by an air nozzle connected to a vacuum system. At multiple points during the tow's path, loose fibers will be vacuumed from the tow and be collected in a filter. This filter can then be weighed to find the mass lost from the damage along the fiber. The data from the cameras will be sent to a server or host computer for storage and further analysis through MATLAB. The data recorded, not including the MATLAB results, can be displayed on a GUI.

The GUI can also control the speed of the take up motor and the angle the tow is being pulled of the carrier. The GUI will be controlled by a BeagleBone Black board, which also controls the cameras. The BeagleBone Black will be running OpenCV to manage the image capture of the cameras. The capture speed of the cameras will increase when the speed of the motor increases. The BeagleBone Black will also communicate with an Arduino board to manage the speed of the motors. All the electronics will be contained in a power box located on the outside of the machine, with the GUI on the front of the box.

Measure of Performance (MOP): Success of this deliverable is whether the machine can be built and functions correctly by the chosen delivery date. The machine should be able to process the taken images and provide an error percentage, a damage count, and an average length of the fibers. These numbers can be related to a tension measurement and a mass loss measurement taken from loose fibers.

Interfacing Plan: This task will be divided between the group by assigning a member to each system of the machine:

Luke – Motor Control
Ryan – GUI
BK – Vacuum System
Gabe – Computer Vision/Image Analysis
Tony – Computer Vision/Image Capture

The electronics will be able to communicate between each other by Arduino boards for the motors and a BeagleBone Black board for the cameras. The GUI will be able to control motor speed and the position of the angle assembly.

My deliverable will be completed by: July 30th, 2015

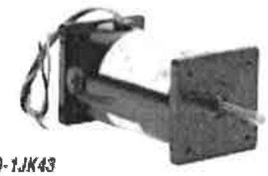
Student's Signature/Date (required)	Manager's Signature/Date (required)	Technical Advisor's Signature/Date (optional)

IronHorse DC Motor

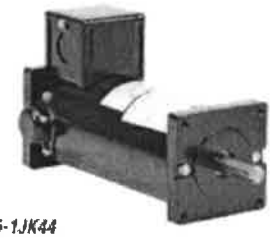
MTPM-P13-1JK42

IronHorse® DC Motors

MTPM Small-Frame Permanent Magnet DC Motors – 1/31 hp – 1/4 hp



MTPM-P10-1JK43 with flying leads



MTPM-P25-1JK44 with junction box

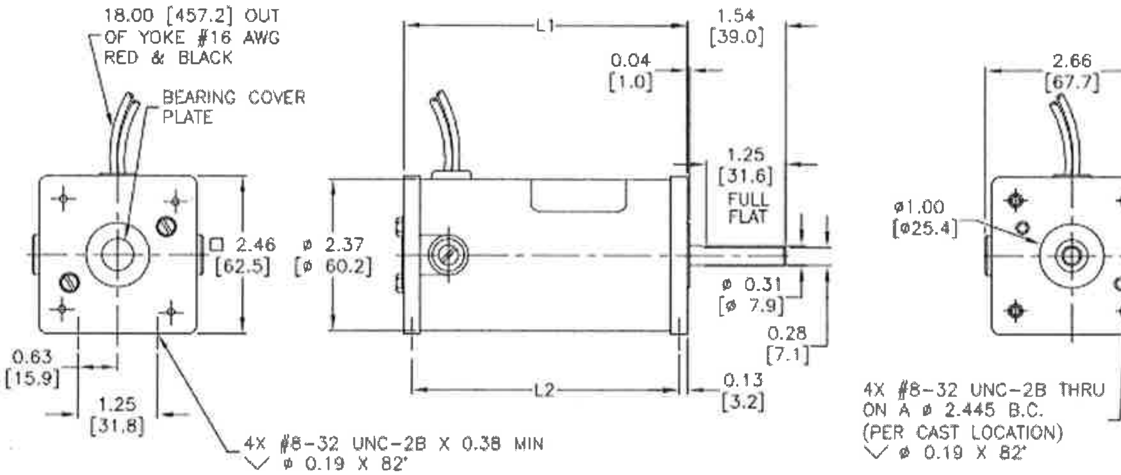
Selection and Specifications

Motor Specifications – MTPM Series Small-Frame Permanent Magnet DC Motors											
Part Number	Price	Voltage (VDC)	HP	Speed (rpm)	F/L Torque (oz-in)	F/L Current (A)	Shaft Dia (in)	Pilot Shaft (in)	Overhung Load (lb)	Wiring Type	Weight (lb)
MTPM-P10-1JK43	$71.00	12 24	1/20 1/10	1746 4252	28	4.83	0.3125	1.00	85	flying leads	2.75
MTPM-P13-1JK42	$77.00	12 24	1/17 1/8	1825 4224	32	5.39	0.3125				3.25
MTPM-P17-1JK43	$99.00	12 24	1/13 1/6	1841 4290	42	7.54	0.50	2.02	130	junction box	5.3
MTPM-P25-1JK40	$121.00	12 24	1/6 1/4	1732 3996	96 80	14.3 12.2	0.50				7.8
MTPM-P25-1JK44	$123.00	12 24	1/5 1/4	1854 4375	113 70	18.1 11.9	0.50				9
MTPM-P03-1L18	$70.00	90	1/31	1797	18	0.39	0.3125	1.00	85	flying leads	2.75
MTPM-P04-1L17	$77.00		1/26	1749	22	0.46	0.3125				3.25
MTPM-P05-1L19	$99.00		1/19	1917	28	0.68	0.50	2.02	130	junction box	5.3
MTPM-P13-1L19	$121.00		1/8	1917	73	1.4	0.50				7.8
MTPM-P14-1L19	$123.00		1/7	1740	86	1.61	0.50				9
MTPM-P07-1M24	$99.00	180	1/15	2440	28	0.42	0.50				5.3
MTPM-P13-1M19	$121.00		1/8	1855	73	0.73	0.50				7.8
MTPM-P14-1M18	$123.00		1/7	1828	84	0.83	0.50				9

Technical Information: http://www.automationdirect.com/static/specs/ironhorsepmdc.pdf

Dimensions (in [mm])

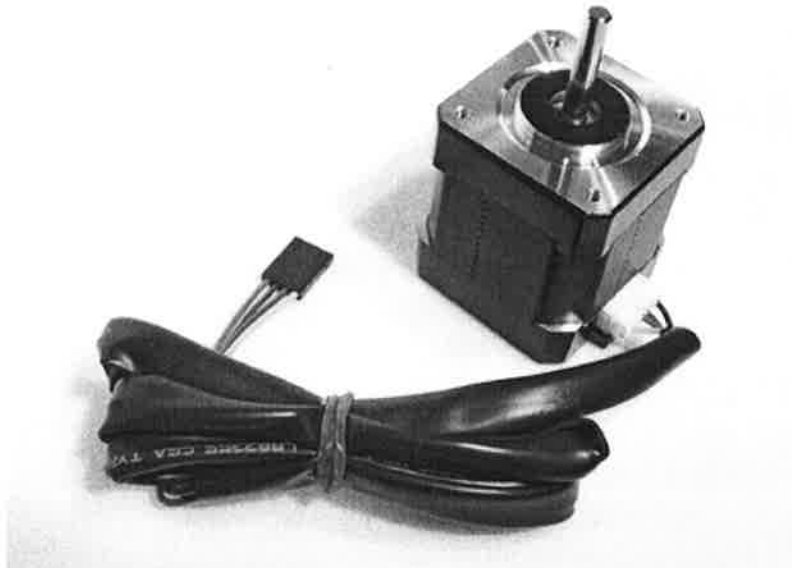
Model Numbers (MTPM-): P03-1L18, P04-1L17, P10-1JK43, P13-1JK42



MTPM-	L1	L2
P03-1L18, P10-1JK34	4.44 [112.8]	4.19 [106.4]
P04-1L17, P13-1JK42	4.94 [125.5]	4.69 [119.1]

NEMA 17 Stepper Motor

OpenBuilds



NEMA 17

Shaft Size: 5mm

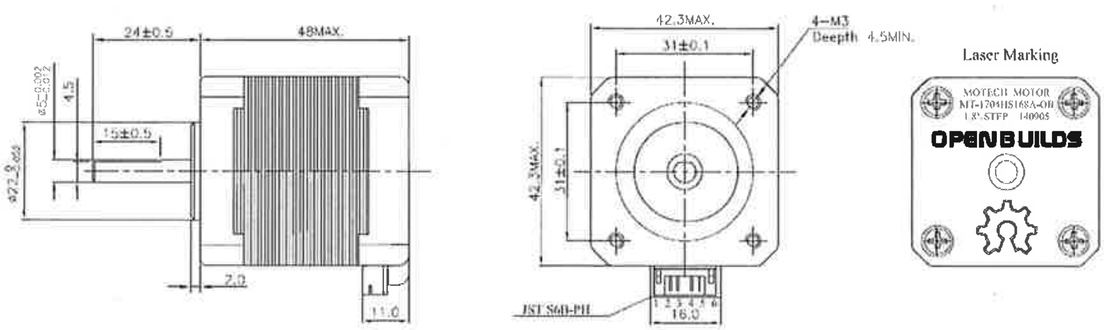
Torque: 76 oz-in - 5.47 kg-cm

Step Angle: 1.8

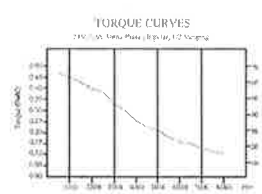
DC 1.68 A/Phase

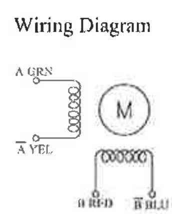
30" Covered Leads

4 Port Connector Standard



Items	Specs	Items	Specs
Phase Number	2 phases	Step Angle	1.8°±5%
Rated Voltage	2.8 VDC	Rated Current	DC 1.68 A / Phase
Resistance(20°C)	1.65±10% Ω / phase	Inductance	2.8±20% mH / Phase
Holding Torque	≥ 5.5 Kg-cm(77 Oz-in)	Detent Torque	0.2 Kg-cm REF.
Rotate Direction	ABCDA CW	MAX Starting PPS	2500 PPS
MAX slewing PPS	2500 PPS	Insulation Resistance	≥100 MΩ(DC 500V)
HI POT	AC600V/1mA/1S	Insulation Class	Class B
Rotor Inertia	68 g cm²	Weight	0.35 Kg REF.





Product URL: http://openbuildspartstore.com/nema-17-stepper-motor/

NEMA 23 Stepper Motor
OpenBuilds

This motor is sure to push your builds to the next level!

NEMA 23

Shaft Size: 1/4"

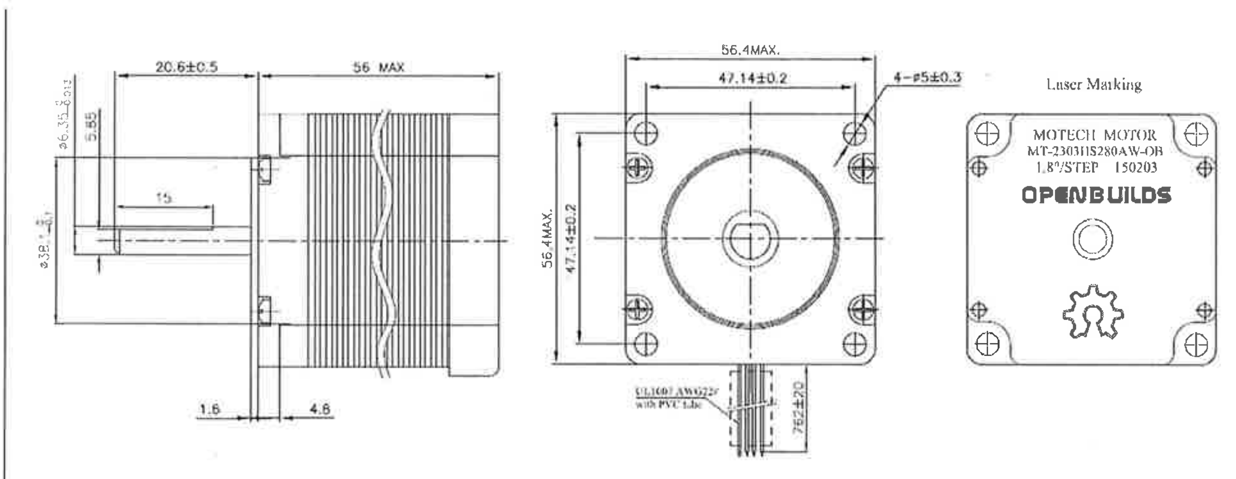
Torque: 175 oz-in

Step Angle: 1.8

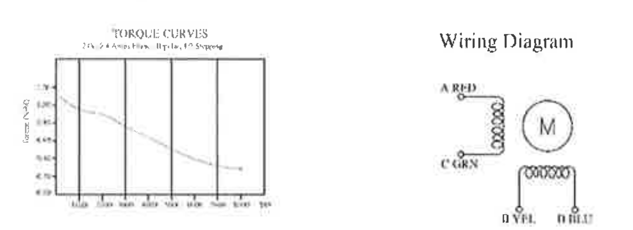
Peak current is 2.8A/phase

12" Leads (4 Wire Bi-polar)

Stepper diver input voltage 12/24V



Items	Specs	Items	Specs
Phase Number	2 phases	Step Angle	1.8°±5%
Rated Voltage	3.0 VDC	Rated Current	DC 2.8A / Phase
Resistance(20℃)	1.1±10% Ω / phase	Inductance	3.0±20% mH / Phase
Holding Torque	≥ 12.6 Kg-cm(175 Oz.in)	Detent Torque	400 g-cm REF.
Rotate Direction	ABCDA CW	MAX Starting PPS	2500 PPS
MAX slewing PPS	5000 PPS	Insulation Resistance	≥100 MΩ(DC 500V)
HI POT	AC600V/1mA/1S	Insulation Class	Class B
Rotor Inertia	300 g.cm²	Weight	0.72 Kg REF.



Product URL: http://openbuildspartstore.com/nema-23-stepper-motor/

Orion Power Supply (HP400DB)

Features

Compatible with Intel Pentium 4 and AMD
Dual 8cm fan for better heat dissipation
20+4 Main Power Connector Supports Latest "Desktop Motherboards"
3x Molex Connector
1x Floppy Drive Connector
3x SATA Connector
Single +12V rail provides plenty of power sources to support high end systems
Super Quiet Technology: Smart Fan Control Function Keeps Noise Level Under 22dBA
Excellent Protection Functions Provide Maximum Reliability: OVP (Over-Voltage Protection), UVP (Under-Voltage Protection), OPP (Over-Power Protection), SCP (Short-Circuit Protection)
Over and under voltage protection
High Efficiency (≤ 75%)
High Energy Power With Low Ripple Noise
100% Hi-Pot, Chroma & Burn-in Function Tested

Dimension : 150 (W) x 165 (L) x 86 (H)mm

Warranty: One Year

Specifications

Model Name	HP 400DB
Temperature Range	Operating 0°C~35°C, non-operating -40°C~70°C
Hold-up Time	16.6ms minimum at full load & normal input voltage
Humidity	5~95% RH
Power Good Signal	On delay 100ms to 500ms, Off delay 1ms
Overload Protection	100~150% load
Over Voltage Protection	+5V MAX 6.3V, +12V MAX 15.6V, +3.3V MAX 4.5V
In Rush Current	75A (PEAK) for 115Vac, 150A (PEAK) for 230Vac
Remote Sensing	+3.3V
Cooling Fans	Dual 8cm DC Fan

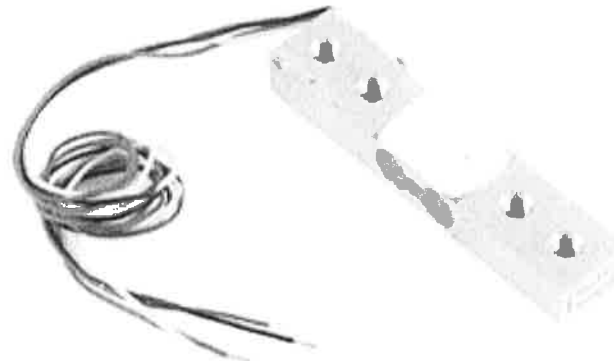
Input Characteristics		
Model	Voltage	Frequency
HP 400DB	115Vac / 230Vac	50 ~ 60 HZ

Output Characteristics								
Model \ Output	+3.3 V	+5 V	+12 V1	+12 V2	-5 V	-12 V	+5 VSB	Max Power
HP 400DB	16A	21A	15A	n/a	n/a	0.8A	2A	400W

Product URL: http://hecgroupusa.com/products/switching-power-supply/atx-12v/hp400db/

0.78 Kg Micro Load Cell
RobotShop

Details:



- Capacity: 780g
- Wheatstone bridge sensor
- Small size: 45mm x 9.3mm x 6mm
- Plugs into the Phidgets PhidgetBridge Wheatstone Bridge Sensor Interface
- Compensated temperature range: -10°C to +40°C
- Operating temperature range: -20°C to +55°C
- RoHS compliant

Wiring:
Red: 5V
Green: +
White: -
Black: GND

Sepcifications:

Precision0.05%F.S

Capacity780g

Non-Linearity0.05%F.S

Repeatability0.05%F.S

Creep0.1%F.S/30min.

Temp. effect on zero0.05%F.S/10°C

Temp. effect on span0.05%F.S/10°C

Zero Balance±1.5%F.S

Compensated Temp. Range-10°C~+40°C

Operating Temp. Range-20°C~+55°C

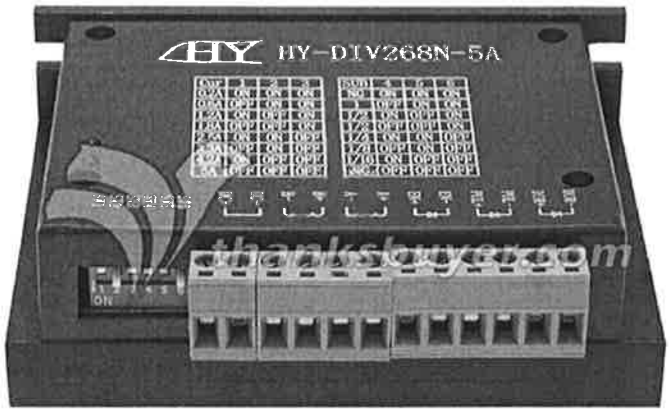
Safe Overload120%F.S

Maximum Overload150%F.S

Product URL: http://www.robotshop.com/en/micro-load-cell-0-78-kg.html#Specifications

Data Sheet URL: http://www.robotshop.com/media/files/pdf/datasheet-3132.pdf

Hybrid Stepper Motor Driver Controller



Features:
- High performance, cost-effective.
- Automatic idle-current reduction.
- Supply voltage up to 50V DC
- Output current up to 5.0A.
- Suitable for 2-phase and 4-phase motors.
- High speed optoelectronic isolation signal input.
- Single-chip PWM bipolar sinusoidal chopper ensures low vibration and high efficiency.
- 1, 2, 4 (New Mode), 8, 16 adjustable microstep control, motors run more precisely and smoothly.
- Equipped with the 3rd generation of breakout board, display panel and control pad to control the motor manually.
- Overload, overcurrent, overheat, overvoltage and undervoltage protection to avoid damaging your computer and devices.
- Cooling Aluminium Box Design for Cooling, and protect the driver board from being damaged by dirt, dust or other liquids.

Manual URL: https://www.rcscomponents.kiev.ua/datasheets/div268n-5a-datasheet.pdf

Logitech HD Pro Webcam C920

System Requirements

Windows Vista®, Windows® 7 (32-bit or 64-bit) or Windows® 8

For HD 1080p video recording:

- 2.4 GHz Intel® Core 2 Duo processor
- 2 GB RAM or more
- Hard drive space for recorded videos
- USB 2.0 port (USB 3.0 ready)

Recommended requirements for full HD 1080p and 720p video calling*:

- 1 Mbps upload/download for 720p
- 2 Mbps upload/download for 1080p
  (Requirements for H.264 and MJPEG formats vary)
- Visit your preferred video calling provider's website for exact information on system and performance requirements.

For Skype® in Full HD 1080p

Skype 5.8 for Windows*

Warranty Information

- 2-year limited hardware warranty

Package Contents

- Webcam with 6-foot cable
- User documentation

Part Number

PN 960-000764

Technical Specifications

- Full HD 1080p video calling (up to 1920 x 1080 pixels) with the latest version of Skype for Windows*
- 720p HD video calling (up to 1280 x 720 pixels) with supported clients
- Full HD video recording (up to 1920 x 1080 pixels) with a recommended system**

- Logitech Fluid Crystal™ Technology
- H.264 video compression*
- Carl Zeiss® lens with 20-step autofocus
- Built-in dual stereo mics with automatic noise reduction
- Automatic low-light correction
- Hi-Speed USB 2.0 certified (USB 3.0 ready)
- Tripod-ready universal clip fits laptops, LCD or CRT monitors

Logitech webcam software:***

Video recording: Up to Full HD 1080p video capture**

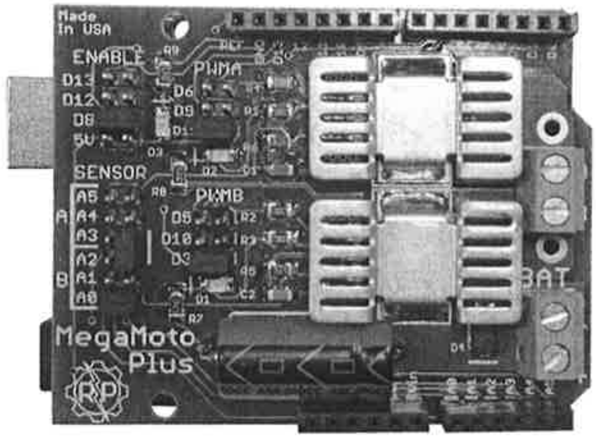
Photo capture: Up to 15 megapixels (software enhanced)

1-click Facebook®, Twitter™ and YouTube™ HD upload (registration required)

**Please download the latest version of Skype, Skype 5.7 Beta for Windows, which offers 1080p HD video calling.*
*** H.264 recording requires installation of QuickTime®.*
**** Requires installation of included software.*

Product URL: http://www.logitech.com/en-us/product/hd-pro-webcam-c920

MegaMoto *Plus* Motor Control Shield for Arduino



Supply voltage	5V to 28V (24V max battery rating)
Output Current (continuous)	20A (25A with fan)
Output Current (surge)	40A 5 seconds
Weight	1.3 Oz
Power chips	2 ea. BTN7960B
On Resistance	.016 ohm max at 25C
PWM Frequency	DC to 20kHz
Logic Interface	3V - 5V , minimum 1 pin required
Logic Inputs	Jumper select Enable and PWM source
Current Sense Outputs	0.0745V per Amp - 2.98V at 40A
Current Sense Pins	Jumper select the analog input connected
Current and Temp Limiting	Built in to power chips
Power Connectors	2 each screw terminals (14AWG wire) & solder pads for power wires
Enclosure	None

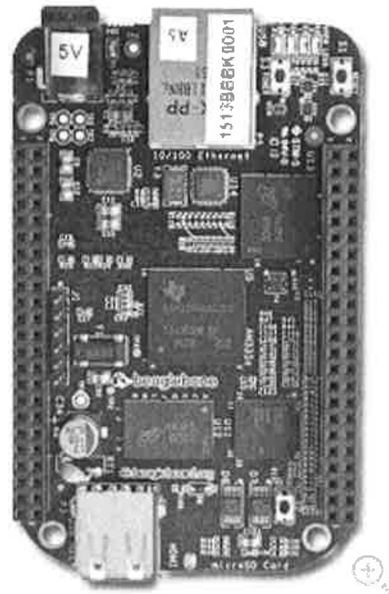
Product URL: http://www.robotpower.com/products/MegaMotoPlus_info.html

BeagleBone Black

What is BeagleBone Black?

BeagleBone Black is a low-cost, community-supported development platform for developers and hobbyists. Boot Linux in under 10 seconds and get started on development in less than 5 minutes with just a single USB cable.

Processor: AM335x 1GHz ARM® Cortex-A8



512MB DDR3 RAM

4GB 8-bit eMMC on-board flash storage

3D graphics accelerator

NEON floating-point accelerator

2x PRU 32-bit microcontrollers

Connectivity

USB client for power & communications

USB host

Ethernet

HDMI

2x 46 pin headers

Software Compatibility

Debian

Android

Ubuntu

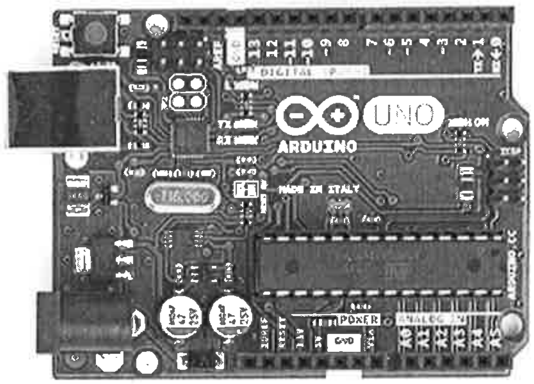
Cloud9 IDE on Node.js w/ BoneScript library

plus much more

Product Wiki: http://elinux.org/Beagleboard:BeagleBoneBlack

Product URL: http://beagleboard.org/BLACK

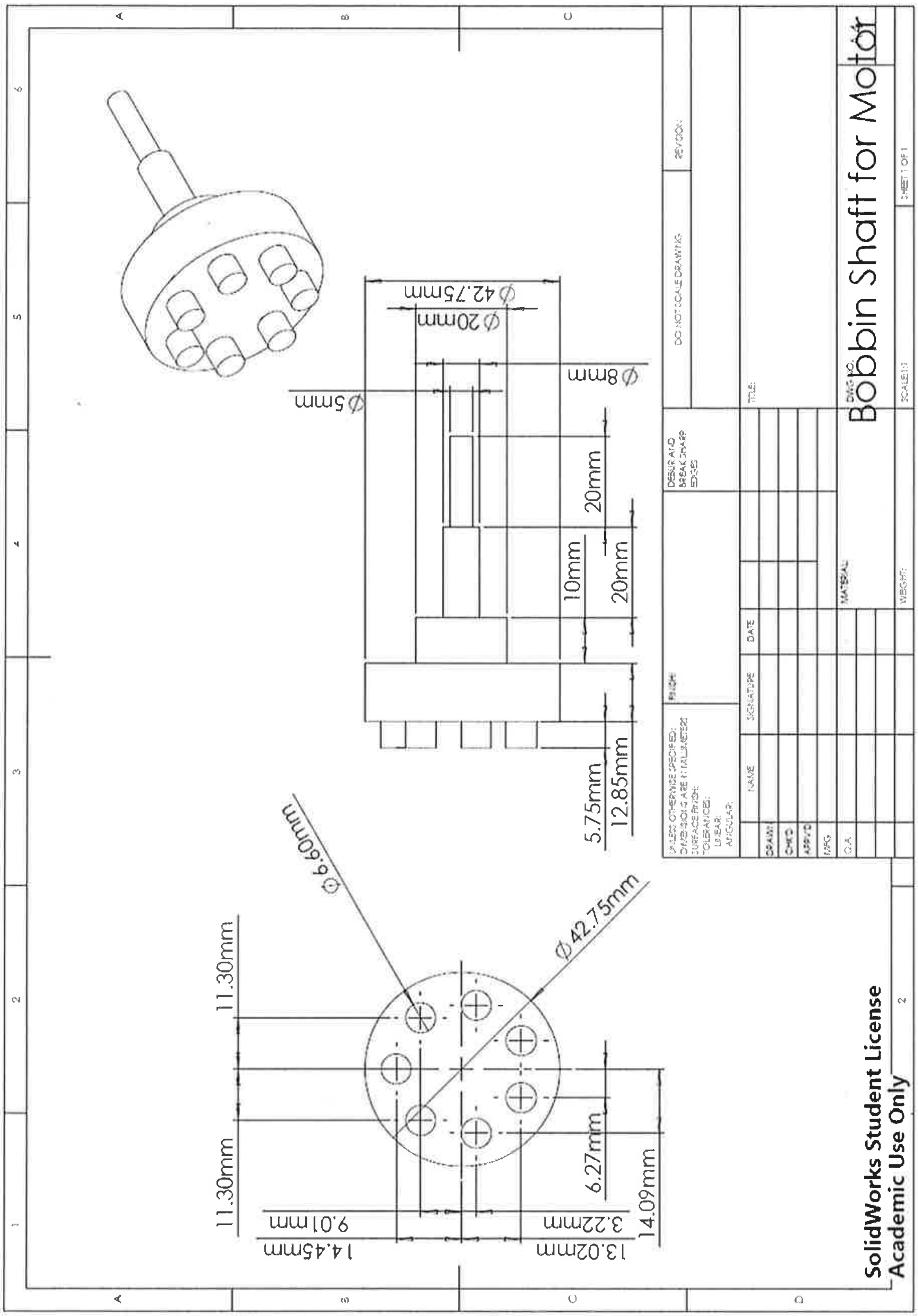
Arduino Uno R3

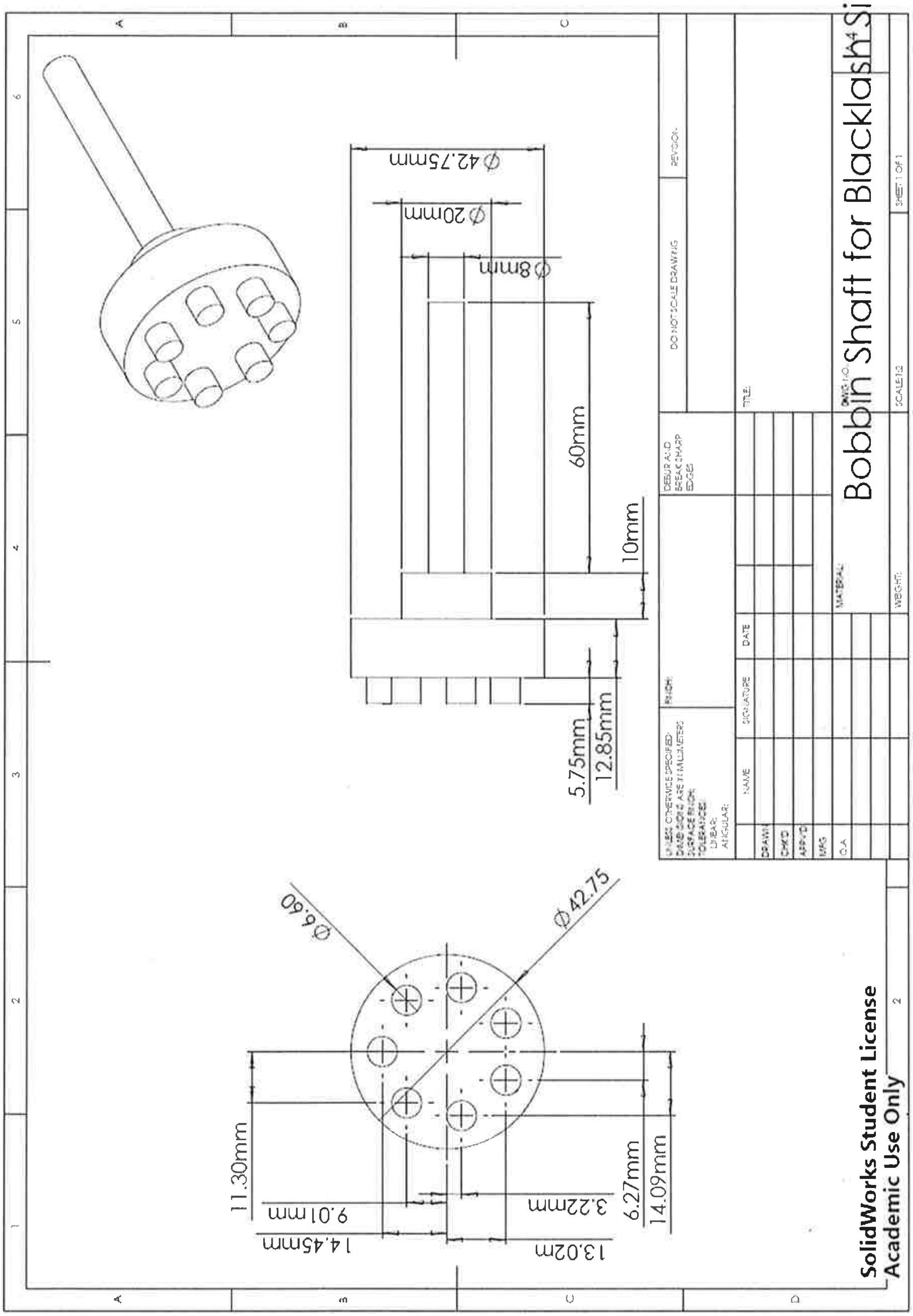


Summary

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz
Length	68.6 mm
Width	53.4 mm
Weight	25 g

Product Information URL: https://www.arduino.cc/en/Main/arduinoBoardUno


Bobbin Shaft for Motor
SolidWorks Student License
Academic Use Only
Ø42.75mm
Ø20mm
Ø8mm
Ø5mm
20mm
10mm
20mm
5.75mm
12.85mm
Ø6.60mm
Ø42.75mm
11.30mm
11.30mm
14.45mm
9.01mm
3.22mm
13.02mm
6.27mm
14.09mm



Bobbin Shaft for Blacklash Si
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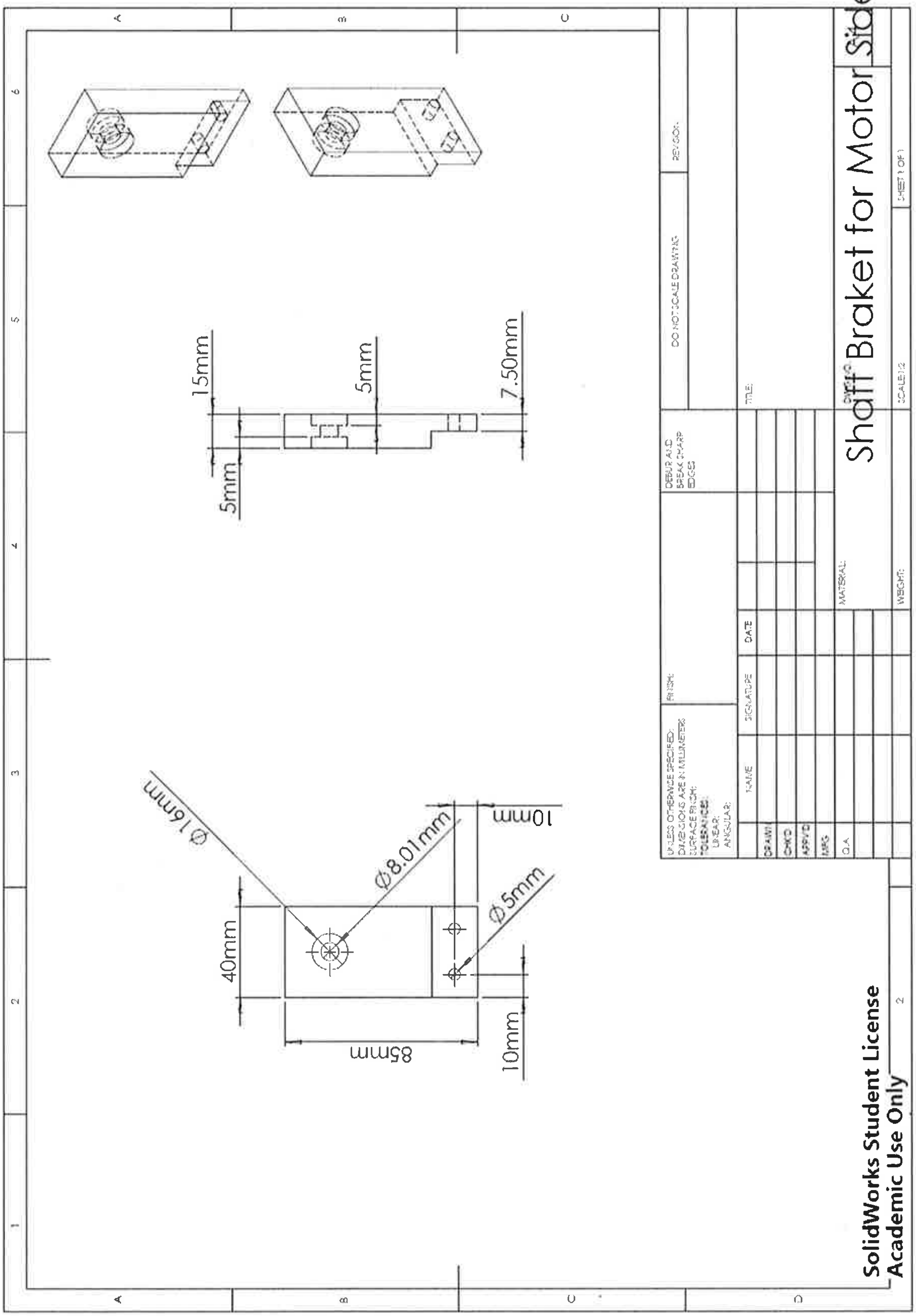
Ø42.75mm
Ø20mm
Ø8mm
60mm
10mm
5.75mm
12.85mm
Ø6.60
Ø42.75
11.30mm
9.01mm
14.45mm
3.22mm
13.02mm
6.27mm
14.09mm
DO NOT SCALE DRAWING
REVISION
TITLE:
DWG. NO.
SCALE:1:2
SHEET 1 OF 1
MATERIAL:
WEIGHT:


Shaft Braket for Motor Side
15mm
5mm
5mm
7.50mm
Ø16mm
Ø8.01mm
10mm
Ø5mm
40mm
85mm
10mm
DO NOT SCALE DRAWING
REVISION
DEBUR AND BREAK SHARP EDGES
TITLE:
MATERIAL:
WEIGHT:
SCALE:1:2
SHEET 1 OF 1
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