MECH 4240 Preliminary Design Review
Composite Fiber Damage Analysis Device

Corp 15 – Highland Industries

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Abstract

Composite 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 composite fiber bundles, subsequently resulting in less dependable final products. The purpose 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, and then wind the tow on to another bobbin. Once this device has been developed, the device would be used to quantify the damage done when isolating various damage-causing issues. This testing will allow for the mitigation of tow damage, therefore allowing for the development of a stronger, more reliable carbon fiber product in the long run. At this point in time, a preliminary design has been developed and rendered using solid modeling techniques. Traditional systems and design engineering techniques have been utilized to narrow down potential design concepts and to design a device that best accomplishes the desired requirements and functionality of the device.

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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 is looking for a way to monitor the effects of these issues through the use of a simple, yet versatile, device. This report is mainly going to identify the mission statement, the established requirements, the preliminary design developed for accommodating the stated requirements, and how the device is imagined to function. Other topics that will be covered in some detail include an early estimate of the materials needed along with their costs, risks involved with operation, and the mission environment.

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.

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
        - Control 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 these discussions were not reflected in the rough sketches of the early design stage.

Early concept studies established a set of desired qualities that the device was wished to possess. 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
- Minimal friction

The following set of pictures illustrates some early concepts.

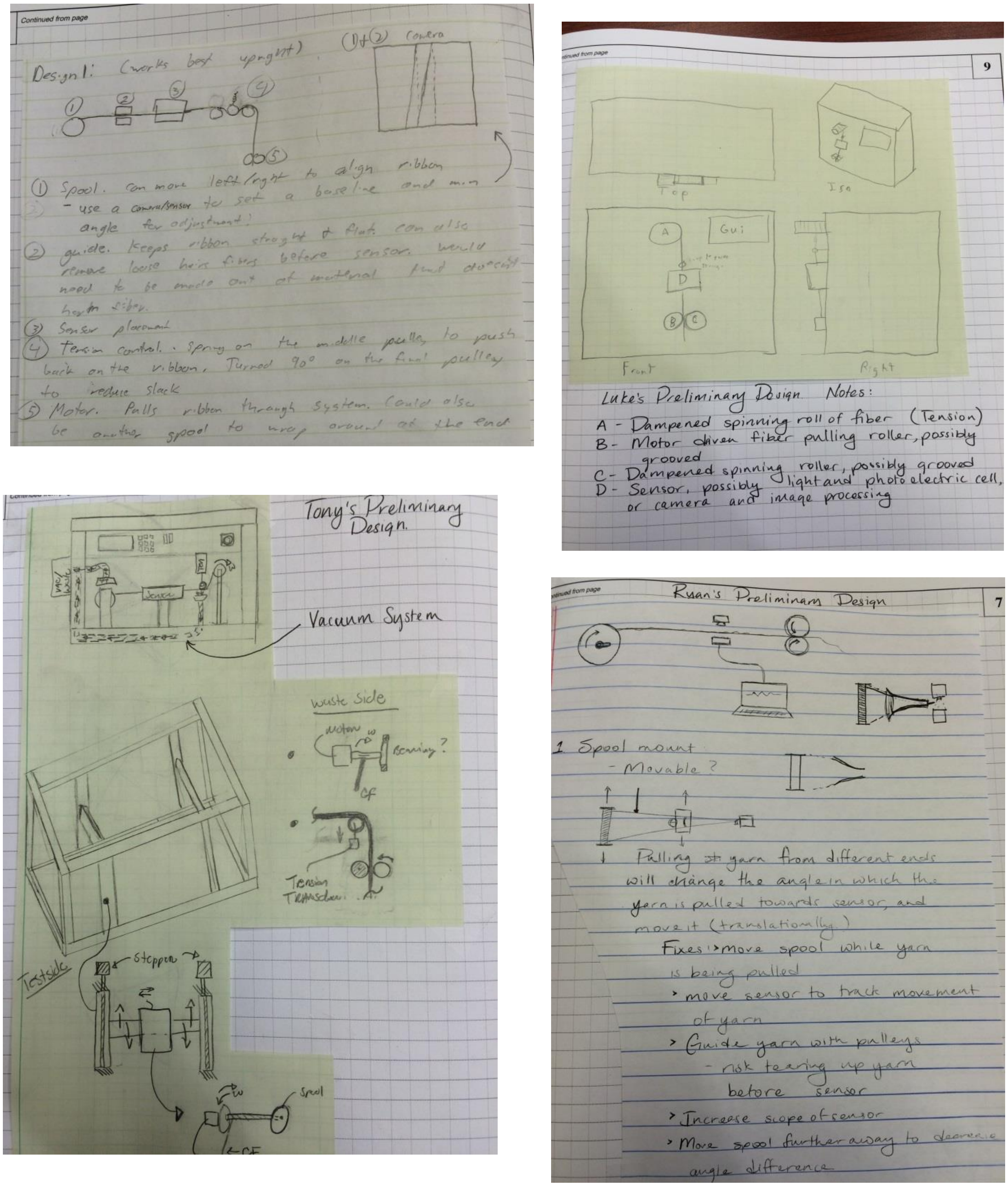

Figure 1 - Early concept sketches

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 tested tow back onto a bobbin, as well as pulling the fibers 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
- A few of the developed designs rendered can be seen below.

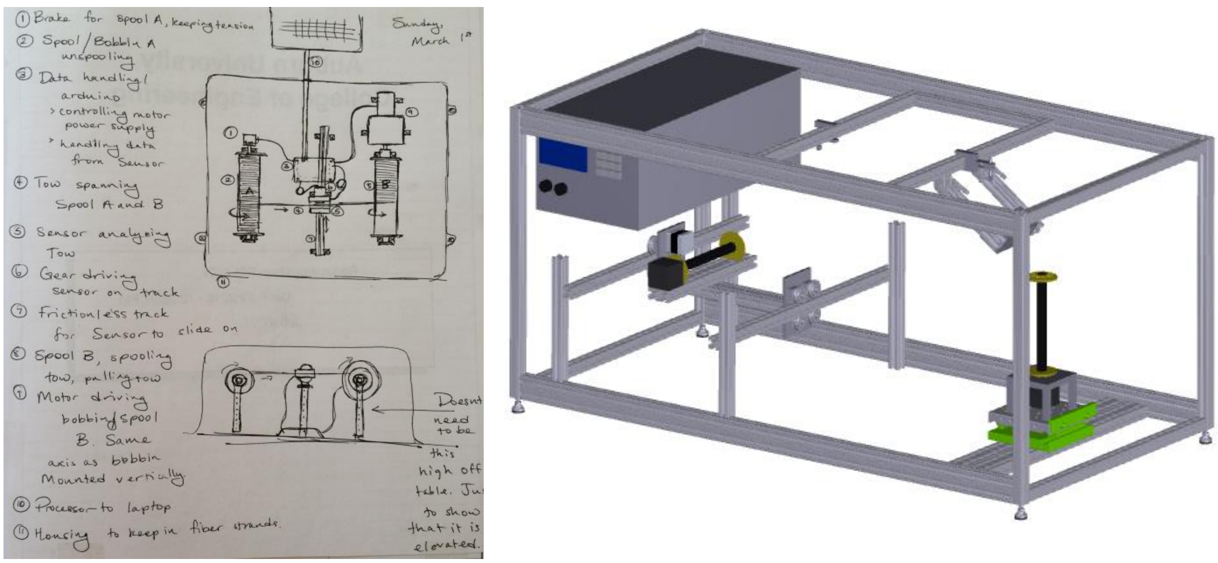

Figure 2 - Further developed conceptual desings

Preliminary Design

The preliminary design is a combination of ideas developed through the first two rounds of conceptual designs. Figure 7 shows the rendering of the preliminary design. The main areas left to decide upon on are the damage sensor and tensioning devices.

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)
  - 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 - Photoelectric sensor

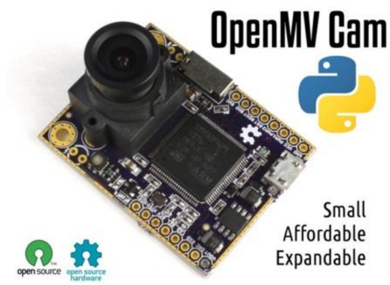

Figure 4 - MachineVision high speed camera

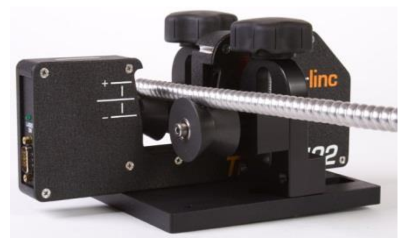

Figure 5 - Laserlinc's laser micrometer

Figure 6 - Keyence laser micrometers

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.	• Complex (Multiple parts) • Multiple contact Point • Uses a working fluid to

	• Fast Response • Not affected by testing environment	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

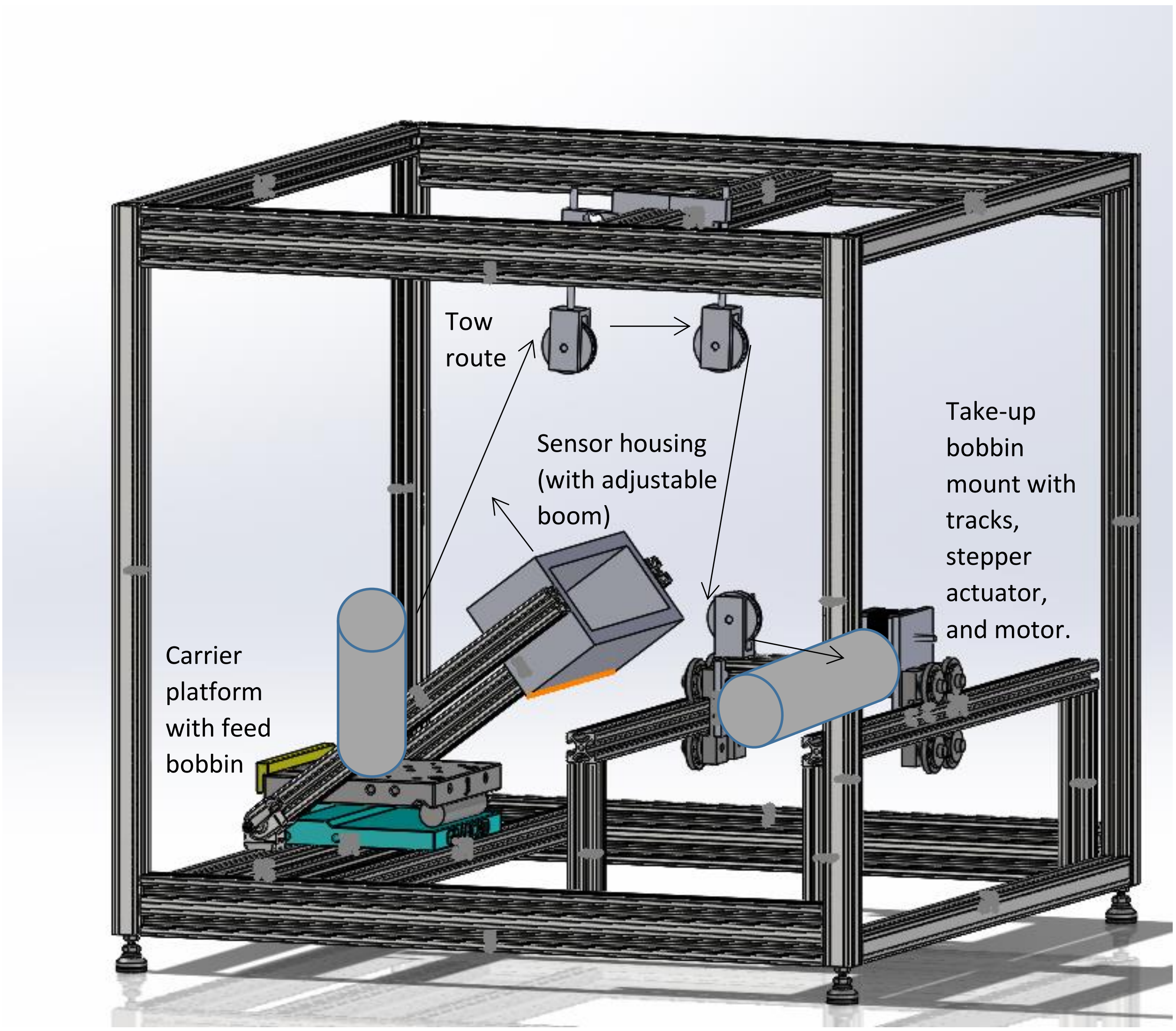

Figure 7 - Latest preliminary design rendering

Concept of Operation

The preliminary design show in Figure 7 would operate as follows:

1. The tow would be pulled through the entire system, from bobbin to bobbin, demonstrated by the series of arrows labeled “Tow route.”
2. Once attached, the motor that is aligned axially with the take-up motor would be activated, creating tension in the tow and pulling the tow through the system.
3. As the tow is being pulled, it would pass through the sensor housing and the sensor.
4. This sensor would identify breakages that are present on the tow, count the breakages, and quantify the data.
5. The data would be presented to the user.
6. As the devices runs, the take-up bobbin would move laterally back and forth to ensure that the bobbin is being spooled with the correct pitch. This lateral movement would be controlled by a stepper actuator.
7. The feed bobbin and carrier would be attached to a platform that possesses the ability to change the angle in which the tow leaves the carrier.
8. The sensor housing is attached to a boom, and the angle of that boom could be adjusted in accordance with the tow orientation.
9. Somewhere along the tow path a tension control device would be added to measure and adjust the tension if necessary.

Validate and Verify

Validation and verification will be postponed until a final design has been established. Developing a plan to validate and verify at this point in the preliminary design phase could be superfluous, as many aspects of the design could change before finalization occurs.

Interfaces

Many mechanical and electrical components will be coupled together through interfaces for the designed machine. The first mechanical interface is 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 will mechanically interface with the fibers through contact forces to route the fibers from the feed roll to the take-up roll. Each motor and sensor will be electronically interfaced to the electrical network be means of electrical wire. The motor will be electronically controlled by the information from the sensors via this electrical network.

Mission Environment

The environment is an indoor manufacturing plant. The work space will be air conditioned and isolated from extreme conditions. The only disturbance would be from the vibrations of other machines in use, which has a negligible effect on the design. The design will be compact to allow for portability and to save space. 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

Table 2 shows the estimated costs of two options, A and B. These two options differ only in the sensor that would be chosen for each device. Because an initial budget was established to be $1,000.00, research was done to find inexpensive, yet suitable sensors.

Table 2 - Estimated cost

Parts Name	Size	Part Number	Quantity	Price per Quantity	Total Option A	Total Option B
Two-Slot Single Corner	24 in	47065T113	8	$8.35	$66.80	$66.80
T-Slotted Frame Double 6-Slot	24 in	47065T107	5	$12.85	$64.25	$64.25
Swivel Leveling Mount	N/A	6111K82	4	$5.95	$23.80	$23.80
T-Slotted Frame 4 Solid	24 in	47065T101	3	$8.35	$25.05	$25.05
VSM Series Convergent	N/A	VSM4AN6CV20	1	$148	$148	
LE550 Laser Measurement Sensor	N/A	LE550I	1	$545		$545
Total*					$327.90	$724.90

*Total doesn't include stepper, take up motor, or tension system

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 management matrix

Risk Title	Risk Type	Severity	Occurrence	Effect	Solution
Sensor Malfunction	Mechanical, Program	1	Low	Cannot acquire data	Repair or replace sensor. 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 machinery	Environment, Mechanical, Safety	2	Medium	Possible machine failure	Contain fibers inside a see through cover. Use of a small vacuum or air blower
Feed angle 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 during respooling	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 become more specific, developing subsystems require lots of studies. First of all, it is important to find requirements for each subsystem because each subsystem can change the whole concept of a preliminary design. After develop concept, three systems are developed which are structure, data acquisition and handling, and tow management.

From the result of the concept development preliminary design lead subsystems development. Starting with structure, it is 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.

For data acquisition and handling, damage detection, quantification of damage, and output subsystems needs to be developed. In order to detect damaged fibers and overlook undamaged fibers, a sensor system has to be established. Photoelectric sensors, laser measurement sensors, high speed cameras and laser micrometers are all options that can be used for fiber detection subsystem. One of the sensors has to be chosen for easy, yet accurate counting of the number of damaged fibers. Depending on the sensor, output methods can be a number of different methods (e.g. image analysis, machine vision programming, etc). Sensors for this type of damage detection vary in cost significantly.

The tow management system manages the tow routing, tension, feed speed and pitch speed subsystems. The basic concept is to unwind the fiber from the feed spool and wind the fiber back on to the take-up spool. Designing the tow routing is a very delicate process because bad tow routing can cause unnecessary damage to the fiber while feeding it through the various components. While feeding the fiber, tension needs to be measured in order to control feed speed and to maintain a constant tension. Load cells, pressure transducers (three wheels), and ultrasonic sensors are all options for tension control. There are advantages and disadvantages for each method which were shown in Table 1. 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

Project management for the preliminary design review was divided among the design group as it consists of five people. A majority of the early objective understanding, research, and concept design was done as group. Constant communication with the company sponsor and technical advisor was needed to understand the mission objectives and further concept development.

As the design concepts became finalized, the focus of the group turned towards researching components, specifically the hairiness and tension sensors, and other building materials. The group split to work independently on acquiring pricing and part information and creating CAD models in SolidWorks.

Once the preliminary design review is over, the goal of the group is to finalize the chosen design and acquire parts and the correct sensors. Machine vision cameras will be looked into with greater detail. Then the group will focus on researching, collecting, and testing the data given by the sensors. Ideally, the entire design will be completed before the final review and construction can begin.

Conclusions

From the research conducted for the project, it was determined that a simple design of a cube roughly two feet on each side is ideal for transportation as well as functionality. The cage will need to be constructed of lightweight yet durable material so aluminum is planned to be used. Plexiglas will be used for the enclosure to adhere to NEMA 12 and allow the user could see inside during operations. The sensor chosen for use in the design was a photoelectric sensor due to price constraints, while still accommodating the need for the high resolution and accuracy. Tension will be measured through means of a load cell mounted to a pulley. A motor shall be used to spin the take-up spool to move the fibers from the feed bobbin to the take-up bobbin, while a stepper evenly distributes the fibers across the take-up spool. Overall the design completes all required functions and is contained within the budget. The next steps are to finalize and dimension the design, order the parts, and begin building the machine.