Bale Weight Measurement System

AGCO-Hesston Corporation

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EXECUTIVE SUMMARY

The purpose of this project is to determine the overall weight of any feedstock coming into a Hesston 5556-A baler. The preferred option by AGCO-Hesston was to determine the weight measurement of various types of grass as they enter the baler, but at a minimum determine the final weight of a completed bale. Eventually, AGCO-Hesston would like to sell the design as a factory option on their existing balers.

AGCO-Hesston implemented only a few constraints on the project. The various grass types were limited to straw, sorghum, switch grass, and alfalfa. The design team was asked to keep their research/working budget under $3000, and the total manufacturing cost for the finished design under $1,000. The design team was also asked to make the final design adaptable to the various types of grass mentioned above, and determine the weight of the grass within an accuracy of ±10%. Finally, the design should be customized for the 5556-A baler, but it should be able be implemented on the other various models offered by Hesston.

The design team was able to break the concepts down into two different aspects. The first part of the concept involves the weight on the hitch, while the second involves measuring the weight on each axle. For the hitch, a ring load cell will be placed between the top of the baler hitch and the tractor's drawbar. For the axle, a Digi-Star axle will replace the current spindles to determine the deflection, based on the size of the bale. This particular design will allow for the weight measurement as a function of distance and time, not just as a final weight of the finished product. The concept will also involve placing an inclinometer on the baler to determine the angle of the entire baler. From the position of the baler, we can calculate any x-direction forces that can be encountered.

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INTRODUCTION

COMPANY BACKGROUND

AGCO is a world renowned leader in the agricultural industry, serving as the country's second largest producer of agricultural equipment. In 1991, AGCO acquired the Hesston Corporation to fully develop the most dynamic team in baler performance. Since the acquisition of Hesston, AGCO has become a worldwide farm machinery company through market growth, strategic acquisitions and advanced agricultural solutions.

MISSION OBJECTIVE

The objective of this project is to determine the final weight of a bale of feedstock in a Hesston baler, but the actual desired concept would be able to determine the weight of the bale on a continuous basis.

REQUIREMENTS

The project aims to develop a sensor system capable of measuring the mass of a round bale. The two variations of this project involve continuous and single measurements. The single analysis will only take the weight of a finished bale. This form of measurement is the main objective for the project. The continuous measurement, on the other hand, reads the incoming mass flow as opposed to only the final mass. It is a better measurement in that we know the actual mass at any time and field location, and do not assume it to be the average of the final weight. This results in a higher resolution yield map with more detailed data of the field production. Although the final measurement approach would provide useful information to the farmer, it would not allow him to evaluate the productivity of his land. However, for research or scientific purposes, it may be desirable to have more accurate data. The project attempts to develop a continuous sensing model as well as looking at discrete sensing as an opportunity to develop a lower cost product.

The project adheres to some constraints which could pose possible limitations to the design. A budget of $3000 is allowed for research and development. The final product should have a manufactured cost less than $1000. Also, the design should seek to minimize the number and cost of alterations of baler components. This means installation should require little disassembly to get to the location where a sensor is to be installed. The design could modify existing parts with sensing apparatus so that no new parts need to be attached. For simplicity, the installation should be kept to minimum level of technical information, instrumentation, and\or tooling. The idea is to market this product as a kit which a person of no technical background could install by following simple instructions. The accuracy of the measurements should be ±5%. Concept design testing may show that this accuracy is difficult to achieve, in which case a ±10% accuracy may be sufficient. It may be decided that accuracy should be increased; giving rise to an increased cost of the product, but that decision is reserved for later. In any case, the accuracy of the sensor will be stated in the final design spec sheet.

CONCEPT PRESENTATION

BALING PROCESS

To understand the concepts that will later be explained, one must first understand the baling process. In most parts of the country, harvesting hay includes the use of a mower, rake, and baler. A healthy standing crop of hay will have a water content of 80 to 90 percent. First, the mower or mower-conditioner cuts the standing crop and lays it in a windrow to allow the hay to dry in the field until it reaches safe storage water content levels. Next, a rake and/or related equipment moves the windrow to aid the drying process, creates a narrower windrow and/or brings two or more windrows together for a more efficient baling operation. After the raked hay has dried to the proper water content, the baler gathers hay from the windrow and compresses the hay into a denser package (bale) for ease of handling, storing, and feeding.

For our particular concepts, we must concentrate exclusively on the hay baler itself. The most frequently used type of baler is a round baler. It produces cylindrically shaped "round" or "rolled" bales. The hay is simply rolled up inside the baler using rubberized belts, chains, fixed rollers, or a combination of rollers and belts. When the bale reaches a pre-determined size, the twine or mesh wrap that binds the bale is wrapped around the outside of the bale and tied. The back of the baler is opened up and the bale is discharged. Straw or fully-dried hay bales are complete at this stage, but if the bale is to be used as silage, it will also be wrapped in airtight plastic sheeting by another similar machine. Variable-chamber balers typically produce bales from 48 to 72 inches in diameter and up to 60 inches in width. The completed bales weigh from 800 lb to 2200 lb, depending upon size, material and dampness.

HITCH AND AXLE FORCE ANALYSIS

After studying and researching many options, our recommended design consists of a ring load cell, two Digi-Star load cell axles, an inclinometer, and possible a GPS receiver. In order to accurately get the weight of the bale inside of the baler, we must be able to accurately get the weight of the entire baler. We chose to place three sensors that measure weight at strategic locations around the baler. These locations are at the hitch and on each axle. Because the environment in which the baler works is not flat, we need to know the baler's weight in both the x- and y-directions if our coordinate system is fixed to the baler. This is where the inclinometer comes into play. It will give us the angle at which the magnitude of the baler's weight is directed. Our three weight sensors, explained in Figure 1, are all measuring the y-component of the weight at each point. The angle given by the inclinometer will also allow us to calculate the x-component and magnitude of the weight at each of the three points. Adding the magnitudes of weight measured at each location will yield the magnitude of the weight of the entire baler. Subtracting the weight of an empty baler from the entire weight will yield the weight of the bale.

Taking several samples of data from each sensor will allow us the plot the weight per time. With this, we would be able to display the final bale weight as well as the weight of the bale at any given time.

Using the GPS receiver to receive baler speed and path traveled information; we would be able to generate a 2-D yield map.

We chose this particular concept based on many different factors. Using the inclinometer, allows us to eliminate x-axis sensors for the hitch and the axles which kept the cost down. It also eliminated the need to design and manufacture a coupler which would have been necessary for the x-axis sensor on the hitch. Using just the ring sensor on the hitch also allows for an easy installation. The inclinometer can be installed almost anywhere on the baler, so a specific location will be determined after field testing has been conducted. We also chose to go with the Digi-Star load cell axles because there are no associated manufacturing or machining costs, and it is also an easy installation. These axles have also already been but though rigorous testing by Digi-Star and have also been used previously by AGCO. All sensors will be environmentally sealed so they will have longer lives. The GPS receiver will be placed on top of the bale in order to get more accurate information. A specific ring load cell and GPS receiver have yet to be chosen and are currently being investigated and evaluated. The output from all of our sensors will need to be condition, i.e. amplified and filtered, to increase our accuracy.

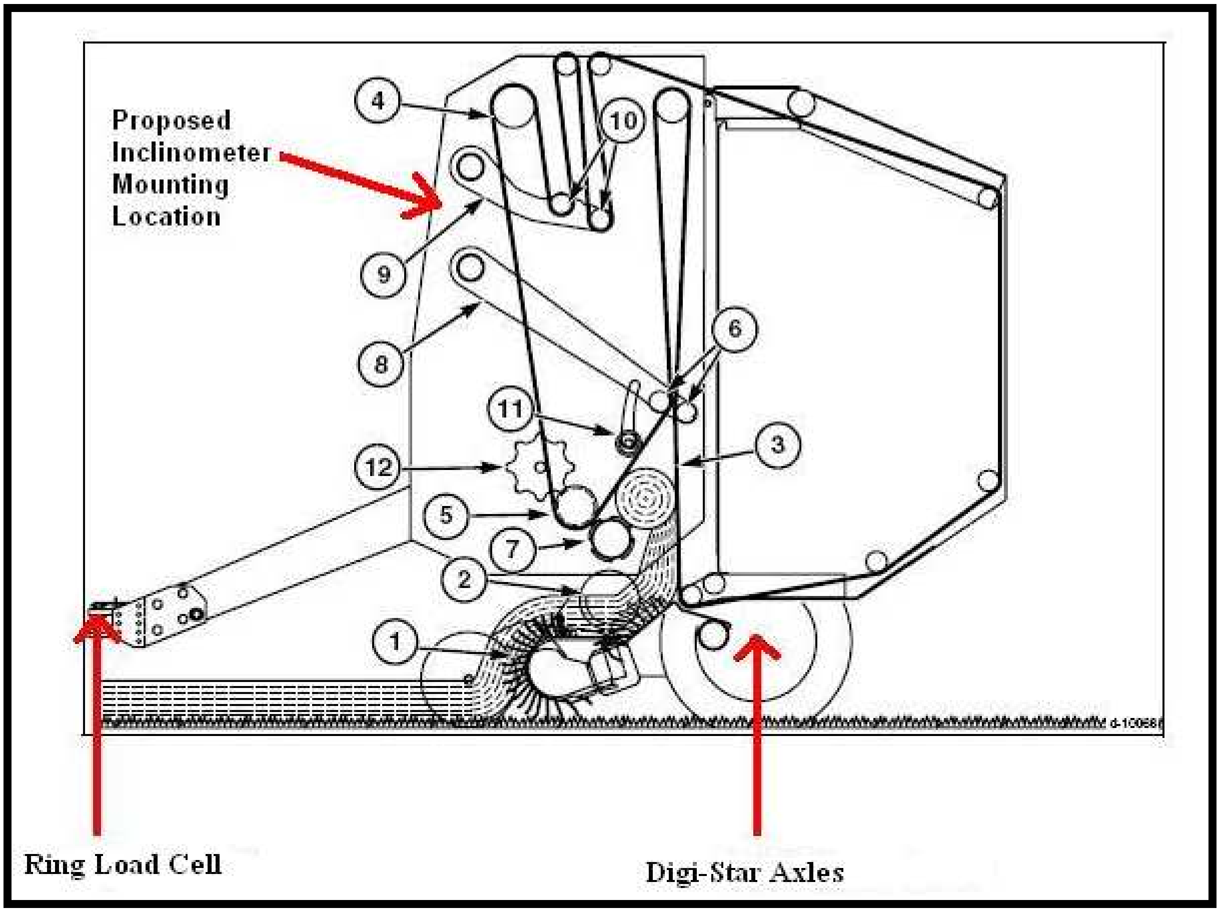


Figure 1

I. HITCH - RING LOAD CELL

A. FUNDAMENTALS AND THEORY

A ring load cell is classified as a force transducer that converts force or weight into an electrical signal. Most load cells consist of strain gages that are considered its “heart.” A strain gage is a device that changes resistance when it is stressed. The gages are developed from an ultra-thin heat-treated metallic foil and are chemically bonded to a thin dielectric layer. "Gage patches" are then mounted to the strain element with specially formulated adhesives. The precise positioning of the gage, the mounting procedure, and the materials used all have a measurable effect on overall performance of the load cell. Each gage patch consists of one or more fine wires cemented to the surface of a ring load cell. As the surface to which the gage is attached becomes strained, the wires stretch or compress changing their resistance proportional to the applied load. One or more strain gages are used in the making of a ring load cell. Multiple strain gages are connected to create the four legs of a Wheatstone-bridge configuration. When an input voltage is applied to the bridge, the output becomes a voltage proportional to the force on the cell. This output can be amplified and processed by conventional electrical instrumentation.

B. APPLICATION

For the project application, the proposed design uses a ring load cell to measure the hitch forces in the y-direction. Figure 2 is a representative model of the Omega LC 8300 that will be used in the final design.

Figure 2

C. INSTALLATION

*Note: Be careful not to crush or severe wires!

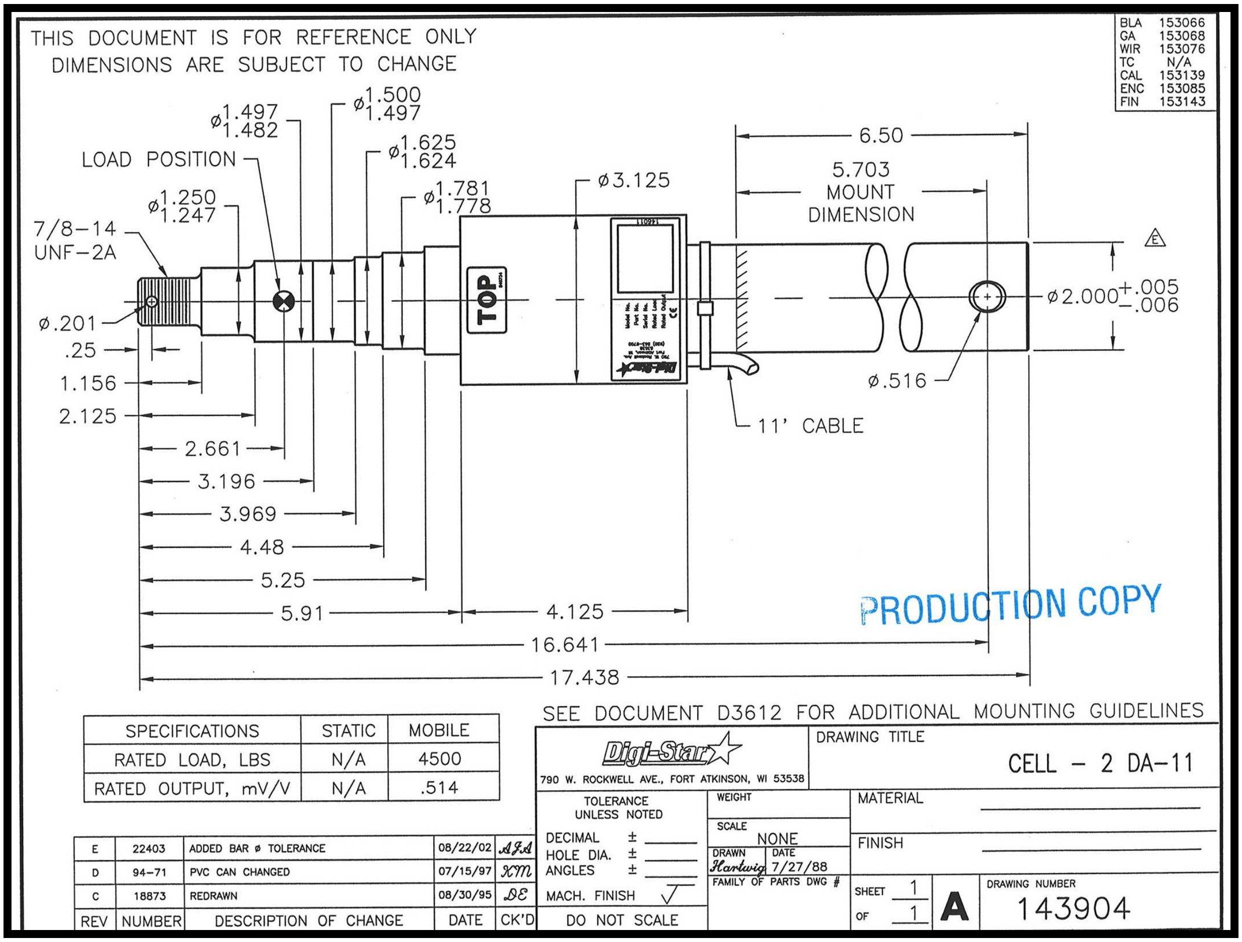
1. Slightly raise and support hitch of baler
2. Remove locking pin and raise hitch pin cover
3. Remove hitch pin
4. Place load cell between baler hitch and the top of the tractor drawbar
5. Place spherical washers on the top side of the load cell
6. If there is not enough clearance, raise baler hitch until there is enough
7. Reinstall hitch pin
8. Lower baler hitch slowly
9. Replace hitch pin cover and locking pin

II. AXLE - DIGI-STAR AXLE

A. FUNDAMETALS AND THEORY

Digi-Star Inc., a well known sensor manufacturer, currently makes a pre-manufactured spindle that houses load cells and strain gages. These models can include shear and differential axles. Both spindle types come with calibrated load cells, durable coatings, polyurethane-jacketed cables, double sealed electronic strain gage, and an impact-resistant enclosure. The greatest advantage of this spindle is that it will allow Hesston to cut out all manufacturing cost for the added sensors. Also, because the sensor is so easily mounted, it would add minimal time to implement on each baler. For illustration purposes, Figure 3 is a model of the actual Digi-Star axle to be used on the baler and Figure 4 portrays all of its modified dimensions.

Figure 3



SPECIFICATIONS	STATIC	MOBILE
RATED LOAD, LBS	N/A	4500
RATED OUTPUT, mV/V	N/A	.514

REV	NUMBER	DESCRIPTION OF CHANGE	DATE	CK'D
E	22403	ADDED BAR ø TOLERANCE	08/22/02	AJA
D	94-71	PVC CAN CHANGED	07/15/97	KM
C	18873	REDRAWN	08/30/95	DE

Figure 4

B. APPLICATION

The Digi-Star load cell axles will serve as the weight measurement system for the axles. They were slightly fabricated to fit the current baler design. The original Digi-Star axle is designed with a vertical bolt hole, but the current spindle on the baler has a horizontal bolt hole. Therefore, the axle was modified to fit the baler's axle's receiving tube. On the other hand, if this design were to be put into production, Digi-Star would possibly mount strain gages differently to fit our application. Another issue with installation is that the Digi-Star axle used has a slightly smaller diameter than the current baler axle. The difference in the two diameters is 0.063 inches which results in some unwanted slack. Further testing will focus on this difference to determine if this will cause any issues with the baler.

These axles are wired in a 350-Ω Wheatstone bridge configuration (each leg being a 350-Ω strain gauge) with anywhere from 0 to 50 Ω of span calibration resistance in series with the excitation. This bridge is housed under a small section of PVC pipe and then sealed with polyurethane.

Valid Specifications
Type = 2" Diameter Differential Axle
Sensor = Strain Gauge w/ 350 Ω Full Wheatstone Bridge
Capacity = 4500 lbs max
Input = 8 Vdc
Output = 0.514 mV/V @ 4500 lbs
Price = $276.30 each

The wiring color code is as follows...
Red = Excitation (+)
Black = Excitation (-)
White = Signal (+)
Green = Signal (-)

The six possible lead combinations have the following typical resistance values...

Red to Black: 375 Ω
Red to White: 262.5 Ω
Red to Green: 262.5 Ω
Black to White: 287.5 Ω
Black to Green: 287.5 Ω
White to Green: 351 Ω

Figure 5 - Top view and cross section view of Axle sensor

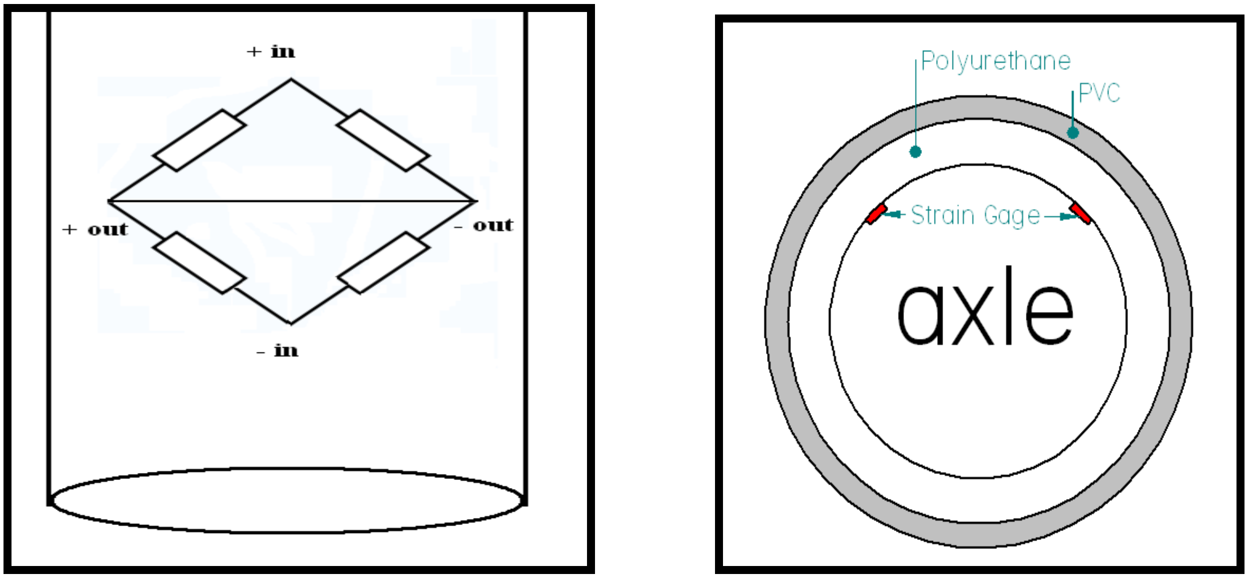


Figure 5

C. INSTALLATION

*Note: Be careful not to crush or severe wires!

1. Make sure baler is empty
2. Jack the baler from an appropriate location on the side to be worked on
3. Loosen and remove wheel lug nuts
4. Remove protective hub cap

5. Remove cotter pin
6. Loosen and remove hub nut
7. Remove washer
8. Remove outer cone bearing
9. Remove hub
10. Remove the inner cone bearing and seal if they are left behind
11. Loosen and remove spindle locking bolt nut and remove locking bolt
12. Remove spindle from receiving tube.
13. Installation is reverse of previous steps

III. INCLINOMETER

A. FUNDAMENTALS AND THEORY

An inclinometer operates using a capacitive sensor. Using extremely sensitive and low friction materials, gravitational forces move a sensing element across the plates seen in Figure 6. The capacitance changes in proportion to the amount of the plate that the signal must be transmitted through, which is turned into a time signal based on that capacitance. This time signal varies proportionally to the degree the inclinometer is positioned at. This is the signal that the DAQ will receive for further use.

Figure 6

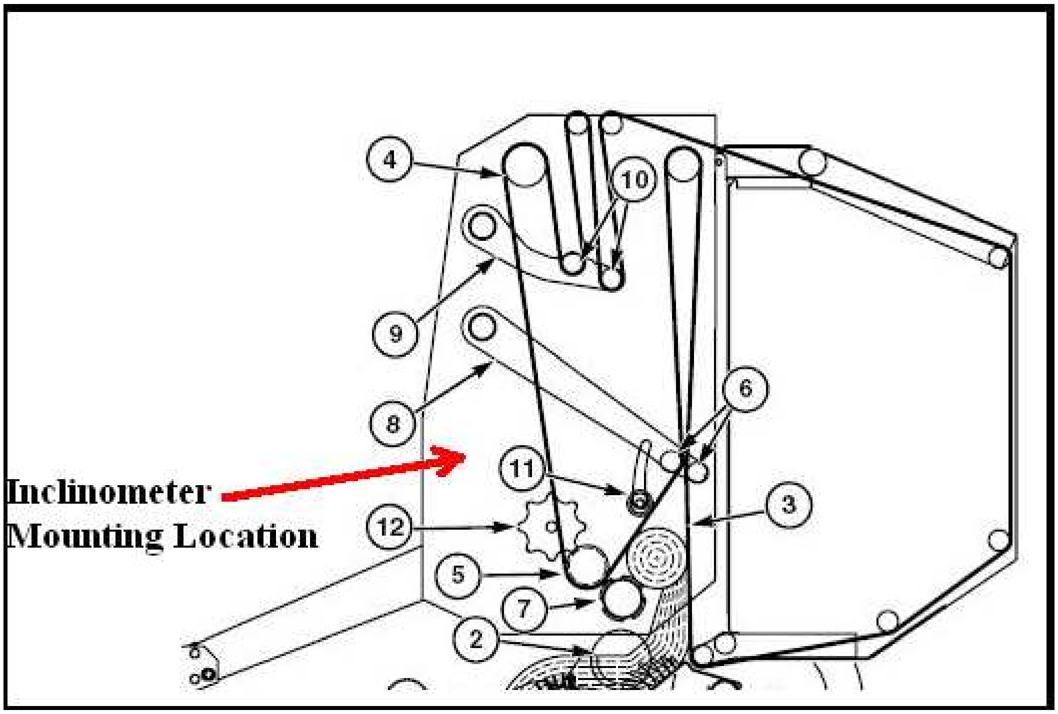
B. APPLICATION

The inclinometer we are using is a Rieker N3 series model as seen in Figure 7. We wanted an inclinometer that would be rugged enough to withstand the harsh conditions that agricultural equipment is often subjected to, so we chose a model that was made of die cast zinc that was hermetically sealed so that it would be unaffected by humidity changes in the environment. This Rieker model can handle harsh vibration and other environmental hazards, and contains all the necessary signal conditioning.

Figure 7

Inclinometer Installation:

The inclinometer was mounted on the baler inside of a component panel meant for other electronics. This housing will protect the inclinometer from moisture, rain, and debris. A sketch of the mounting location is included below:



This mounting location is inside an enclosed cabinet on the side of the tractor. This cabinet will protect the sensor from climate, dust, and object hazards.

C. INSTALLATION

1. Attach a laser level to interior side of the cabinet
2. Level the laser, and place inclinometer against the line produced by the laser
3. Drill hole through baler sheet metal with 3/32 drill bit
4. Tap both holes with 4-40 tap
5. Hold inclinometer in place and screw in both screws tightly

After this installation has been accomplished, sensor wires can be attached through the cabinet side holes. This installation process will be covered in electrical installation instructions in a separate document. The inclinometer's mounting location is out of the way of the other sensors as well, and its placement should not interfere with other parts on the baler.

D. PCB Power Supply

To create a more robust and professional system that is mass producible and tolerant of the harsh farm environment, a permanently mounted sensor circuit is necessary. A quality permanent sensor circuit consists of a printed circuit board with soldered components, an enclosure, and appropriate mounting techniques. A printed circuit board was designed by the team to accommodate the power requirements of the various sensors. The inclinometer requires 5 volts, the axle sensors require 8 volts, and the hitch load cell requires 10 volts.

The primary power supply for these sensors is the tractor battery, which has a voltage that can be in a fluctuating range centered at 12 volts. This fluctuating voltage was smoothed and controlled for the appropriate sensors via a voltage regulation circuit designed by Hesston's electrical engineers. The schematic for this circuit is shown below in Fig. 8.

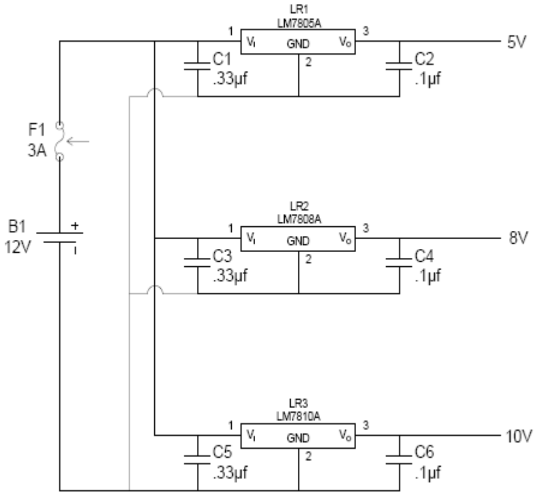


Fig.8

The components used to replicate the schematic were as follows:

Component	Mouser Part #	Specifications
Fuse>	576-0224003.HXP	250V 3A
C2,C4,C6 >	647-UKW1H0R1MDD	0.1uF 50V
C1,C3,C5>	647-UKW1HR33MDD	0.33uF 50V
5V Regulator>	512-LM7805ACT	3A 2% OUTPUT TOL
8V Regulator>	512-LM7808ACT	REGULATOR
10V Regulator>	512-LM7810ACT	REGULATOR

The circuit shunts the 12 volt fluctuating input into three distinct voltages. The voltage for the sensors is held constant by the voltage regulator semiconductor. A digital oscilloscope was used to measure the output of the voltage regulator to confirm that it was not fluctuating to an undesirable degree. The data from the oscilloscope recordings is displayed in the three figures below.

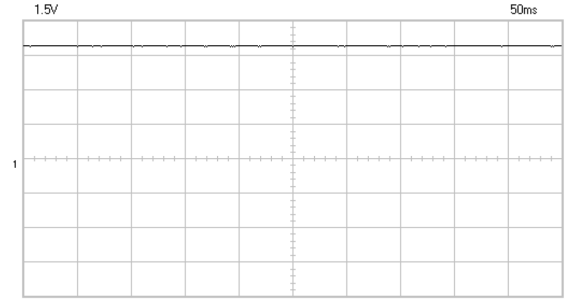


Fig 9.

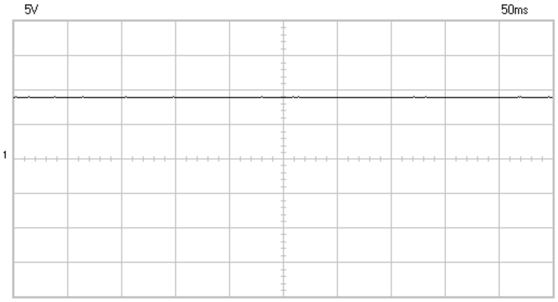


Fig. 10

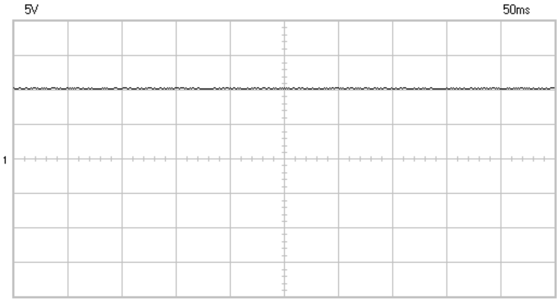


Fig. 11

Each figure displays a constant voltage readout from the regulated circuit. While the nominal input voltage is 12 volts, the power source used to supply the 12 volts was purposely varied to replicate the unsteady nature of the tractor power supply. The figures display the robust nature of the regulation circuit – the output is constant despite a varying input. The only time at which the output voltage will be affected by the input voltage is the point at which the input voltage drops below the desired output voltage. This will not be an issue on the tractor, as the tractor's alternator will not permit the supply voltage to drop this low.

The components were attached to the PCB using rosin core solder at a standard soldering station. Each component was tested to confirm a secure fit inside the PCB. A terminal block at the end of the PCB allows for the easy installation of sensor power wires. The board can be seen in Fig. 12 below.

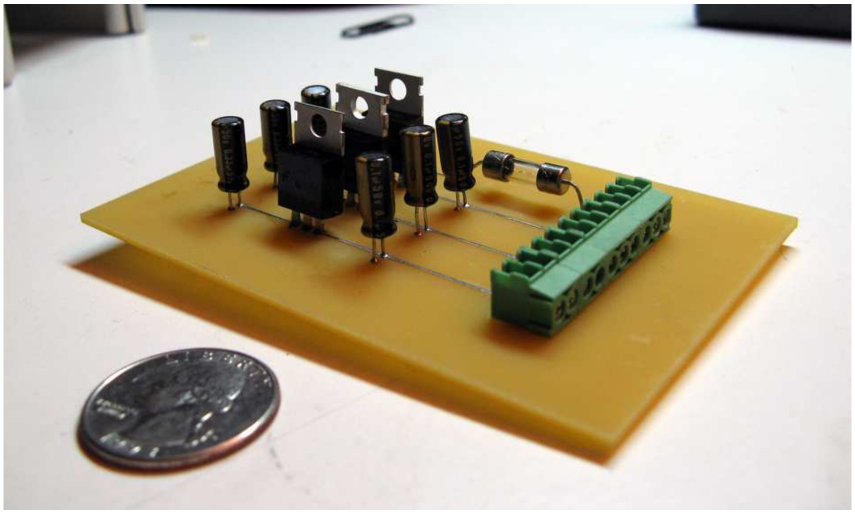


Fig. 12

The board was mounted securely using screws to the enclosure and tractor steel. The enclosure is a tiny housing that was readily available to the group. It can be seen in Fig. 13 below.

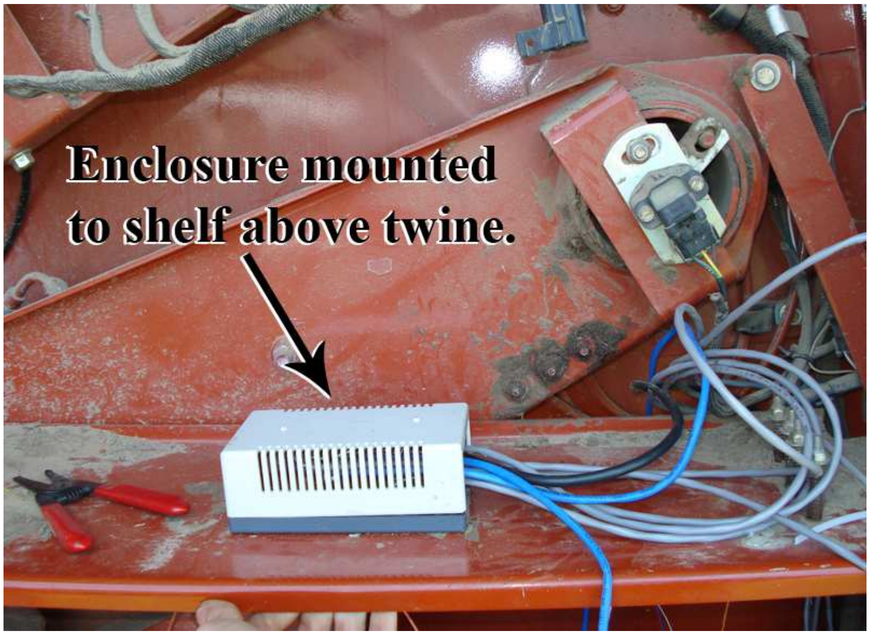
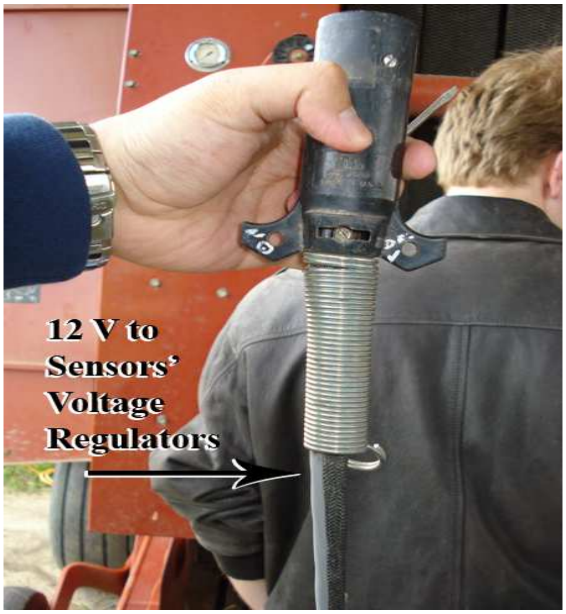


Fig.13

E. WIRING

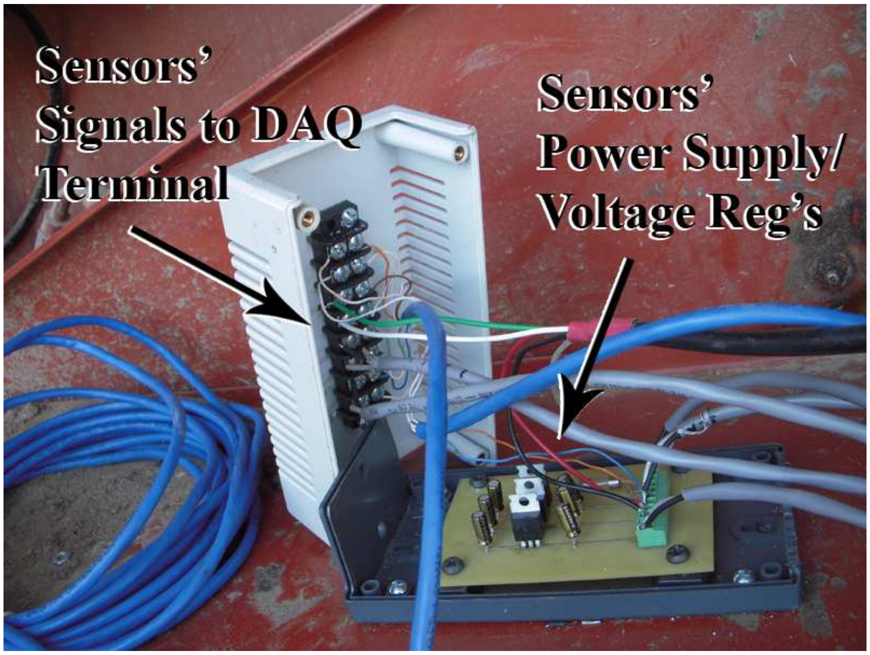
A main portion of our system setup was to connect all of the sensor's inputs to a power source, and to connect their outputs to the DAQ. We chose to use 2 conductor wires to send power from the tractor to the power supply, from the power supply to the sensors, and to receive signals from the sensors to the DAQ terminal block.

We unscrewed the pigtail's 12V output on baler's connector and installed wires to provide power to the PCB power supply.



An incoming (power + and -) and outgoing (signal + and -) wire was run for each of the four sensors. For each sensor, a 2 conductor wire connects its input to the power supply's terminal block. Also, a 2 conductor wire connects their output to the DAQ terminal. The wires were soldered with rosin core solder to make a strong physical connection with the wires that directly come off of the various sensors. The soldered connections were protected using electrical tape. Strain relief has been factored into the installation of the wires, and no wire should be experiencing unnecessary strain due to cable ties that have been placed strategically along the length of the wire. We ran wires through the cylindrical tube in the baler to connect to the left side axle sensor. The sensor wires were run parallel to existing hydraulic lines to prevent mechanical interference.

A terminal block was used to cleanly make the connection between the sensor signal wires and the DAQ. The primary signal wire is an 8 conductor Ethernet cable that. This is connected to the terminal block in the housing and routed to the DAQ. The DAQ will be connected via a USB connection to a laptop running our LabView program during baler operation.


Sensors' Signals to DAQ Terminal
Sensors' Power Supply/ Voltage Reg's


To DAQ/ Computer
GND AI0 AI4 GND AI1 AI5 GND AI2 AI6 GND AI3 AI7 GND AO0 AO1 GND

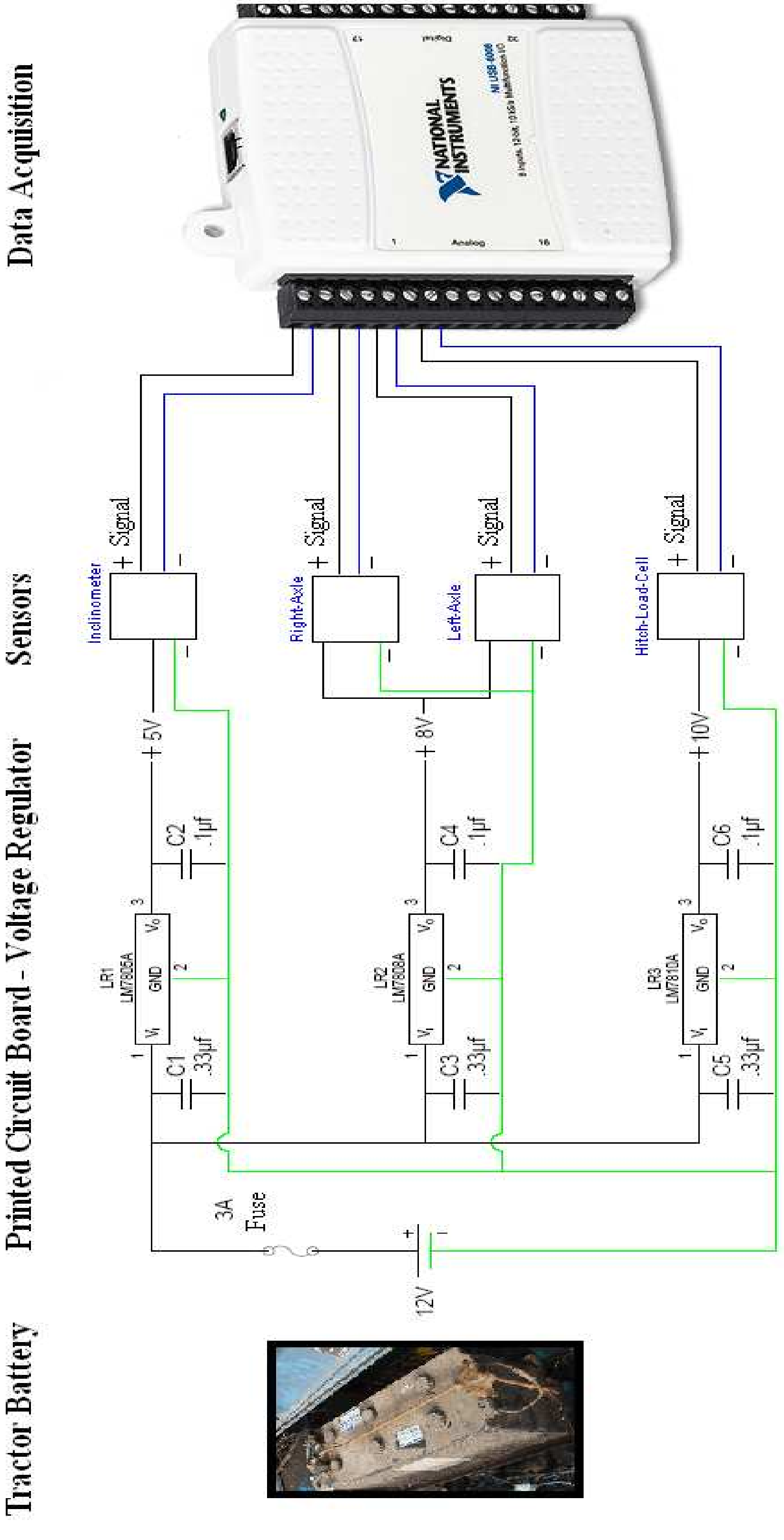


Figure 14 – Wiring Diagram

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ENGINEERING ANALYSIS

SOLID EDGE DRAWINGS

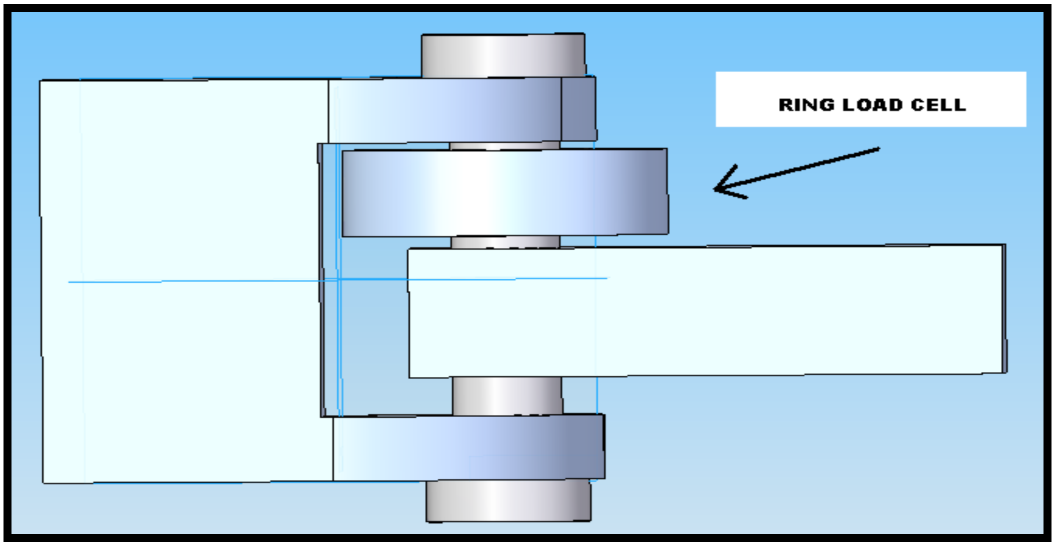


Figure 15– Omega Ring Load Cell placed between the baler hitch and tractor drawbar

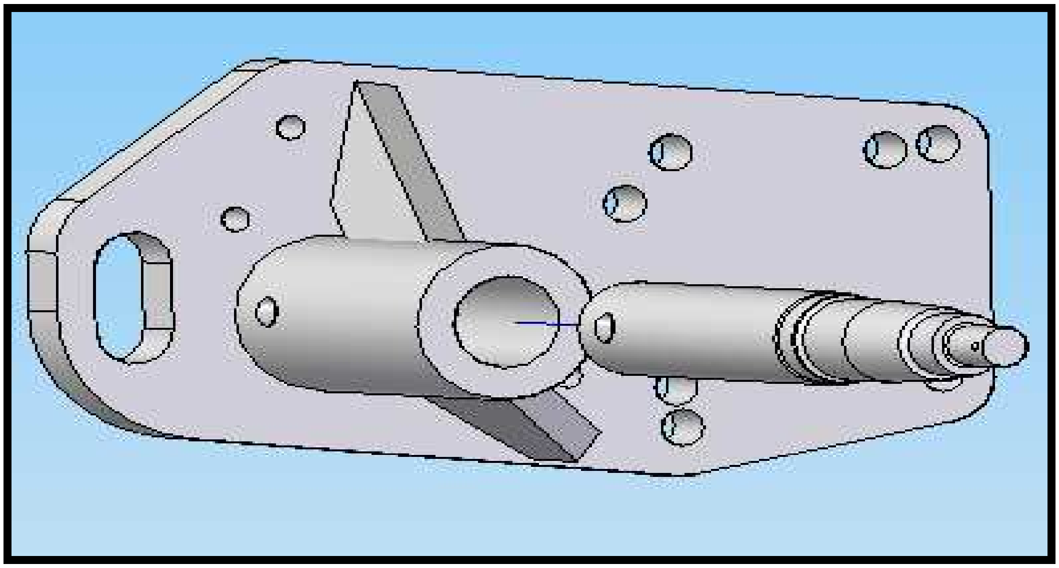


Figure 16 – Digi-Star Axle placed in the spindle of the baler

FREE BODY DIAGRAMS

I. FREE BODY DIAGRAM ON THE BALER

Figure 17 shows all forces and moments acting on the moving baler

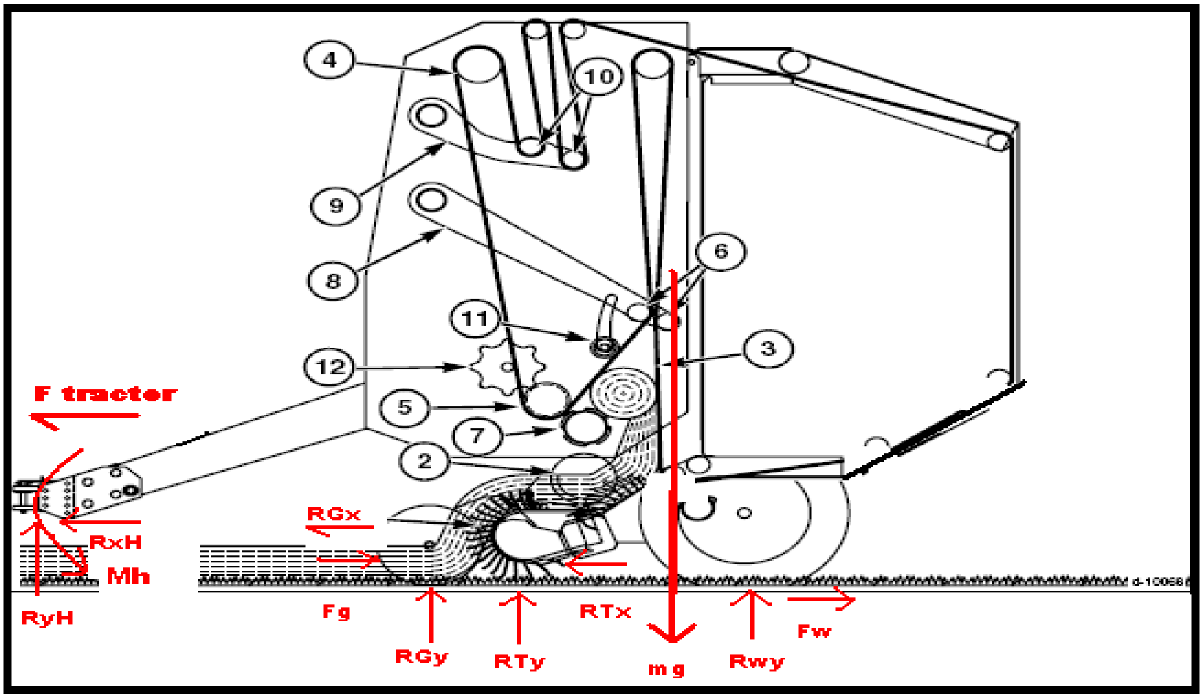


Figure 17

Initial Free Body Diagram

Through the use of our initial FBD of the tractor, we were able to narrow down the significant forces on the baler to only a few. Detailed below are the forces we neglected, and justifications for each.

- The baler is only connected to the tractor through the pin on the hitch, so all horizontal force is transmitted through this pin. The horizontal force on the wheels is negligible because the wheels are connected via bearing, leaving little frictional resistance. The horizontal force on the tines can also be neglected because these tines will only be in contact with the hay, which should exert little if any resistance to motion. This leaves only RxH, the force transmitted through the pin into the hitch of the tractor.
- The tractor's entire weight is transmitted to the ground through the two main wheels and the tongue connection to the tractor. The smaller wheels in the front of the hay tines are not load bearing wheels, and therefore can be neglected. The force on the hay tines is also negligible, because these tines will rarely, if ever, make direct contact with the ground. Therefore we can neglect the forces RGy and RTy, leaving only RyH and Rwy– the hitch reaction force and the force on the two rear wheels.
- There should be little moment force on the hitch of the tractor; this would only occur over bumps or other impact forces. These should have very little effect on the overall force transmitted through the hitch, so we have neglected the hitch moment Mh.

III. FREE BODY DIAGRAM ON THE SPINDLE

Figure 18 represents the forces applied to the spindle on the baler.

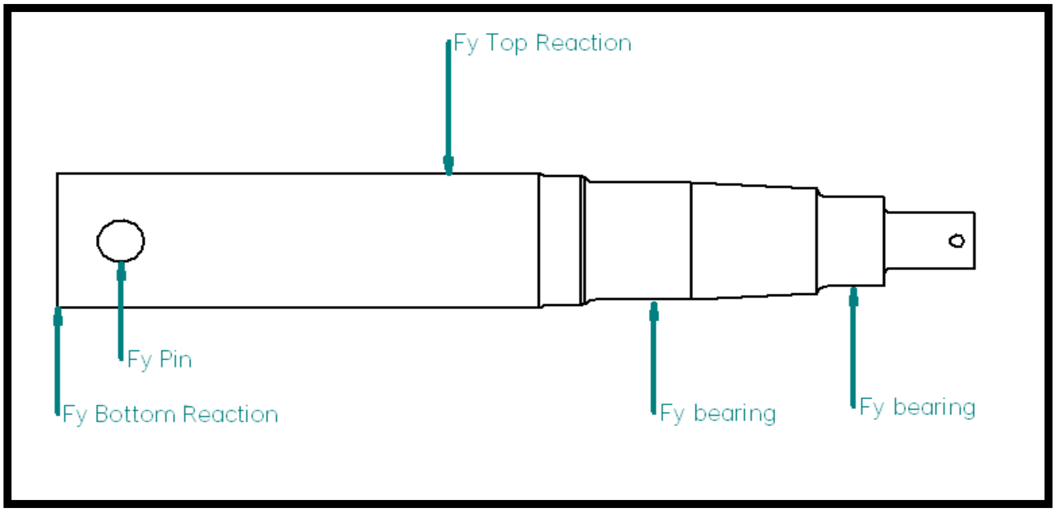


Figure 18

Hitch Connection

The hitch connection with the tractor is simplified below. The ring load cell surrounding the pin should be manufactured to have a tight gap with the pin connector so that there is no slop between them. To prevent high impact loads on the load cell and reduce this slop further, a bushing may be installed as part of the kit. This bushing will dampen all impacts the load cell might see, protecting it for prolonged usage.

IV. FREE BODY DIAGRAM ON THE HITCH

Figure 19 illustrates the forces acting on the ring load cell.

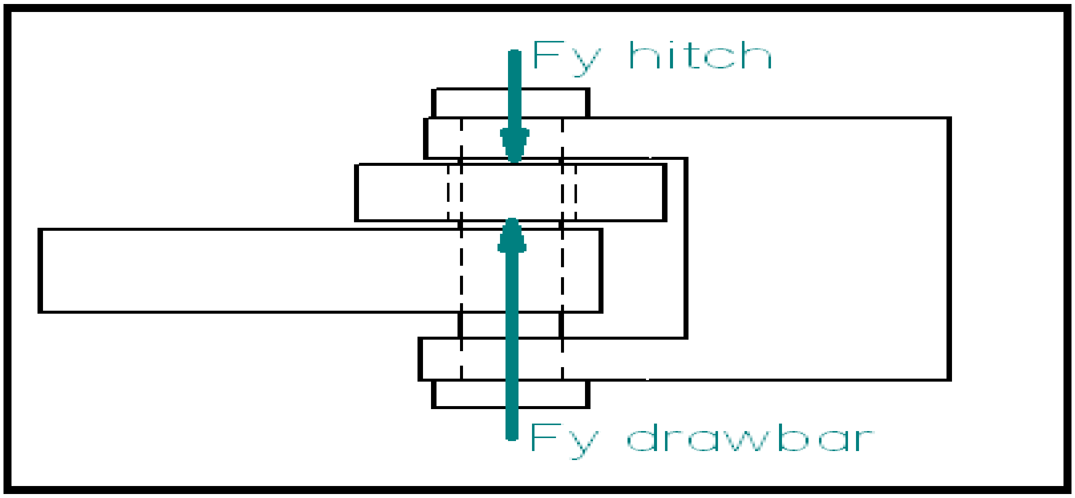


Figure 19

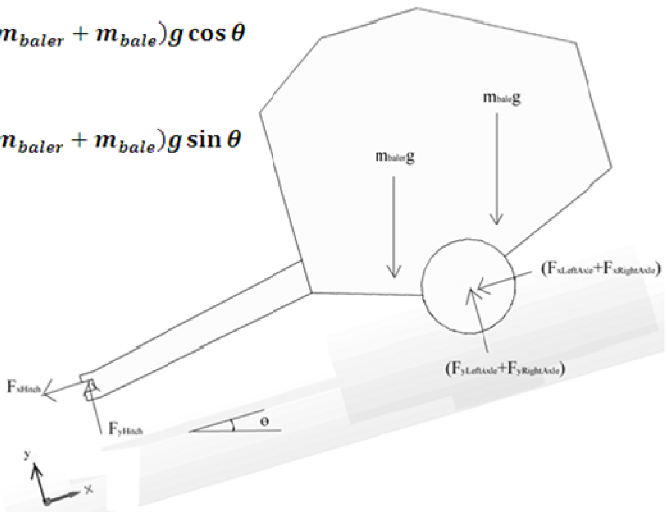
REACTION FORCE SIMULATION

A simulation of a typical baler run was used to calculate reaction forces at the hitch and axle. A total bale weight of 2200 lbs was used and reactions were calculated for the entire range of bale weights (0-2200 lb). The equations used in this simulation come from the free body diagram of figure 17. The forces at the roller, tines, and tractor are minimal and neglected on the FBD. Only the y-direction forces need to be calculated because by knowing the y-component of the bale weight and the angle of incline (theta), via a tilt sensor, the total bale weight follows. The axle reaction force shown is for one axle, assuming both axles equally support the load (no incline in the width direction of the baler).

As the bale increases in size, its center of mass shifts toward the rear of the baler, loading the axles further. The simulation accounts for this by assuming a linear path from the initial center of mass to the final position. This loading effect causes a non-linear response in the reaction forces. Another area of investigation was the effect of uphill and downhill inclines (-15 ° to 15 °), which shows how that the hitch supports a higher portion of the load for downhill inclines.

$$\sum F_y = 0 = F_{yHitch} + F_{yLeftAxle} + F_{yRightAxle} - (m_{baler} + m_{bale})g\cos\theta$$

$$\sum F_x = 0 = F_{xHitch} + F_{xLeftAxle} + F_{xRightAxle} - (m_{baler} + m_{bale})g\sin\theta$$



$$\begin{aligned}\sum M_{Hitch} = 0 = &(F_{yLeftAxle} + F_{yRightAxle})x_{Axle} \\ &- (F_{xLeftAxle} + F_{xRightAxle})y_{Axle} \\ &+ m_{baler}g(y_{CofGofbaler}\sin\theta - x_{CofGofbaler}\cos\theta) \\ &+ m_{bale}g(y_{CofGofbale}\sin\theta - x_{CofGofbale}\cos\theta)\end{aligned}$$

Figure 20

The results show the range of loads which will be measured by the hitch and axle sensors, non-linear curves due to a shifting bale, and incline effects. The load range at the hitch is about 250-1600 lb and the load range at the axle is about 3000-4200 lb. As seen in the graph, if the baler is tilted downhill, the hitch carries more load, and if tilted uphill, the axle carries more load. Inclines are shown to have a significant influence on the reaction forces. Also, the center of mass of the bale is moving as the bale increases in size. This bale shifting is the cause of nonlinearity in the reaction forces. The axles bear more load as the bale becomes centered above it, increasing the slope, while the hitch bears less of the weight, decreasing the slope. The curvature and magnitude of these reaction forces give an expectation of what should be seen when analyzing data from actual field tests with the real sensors.

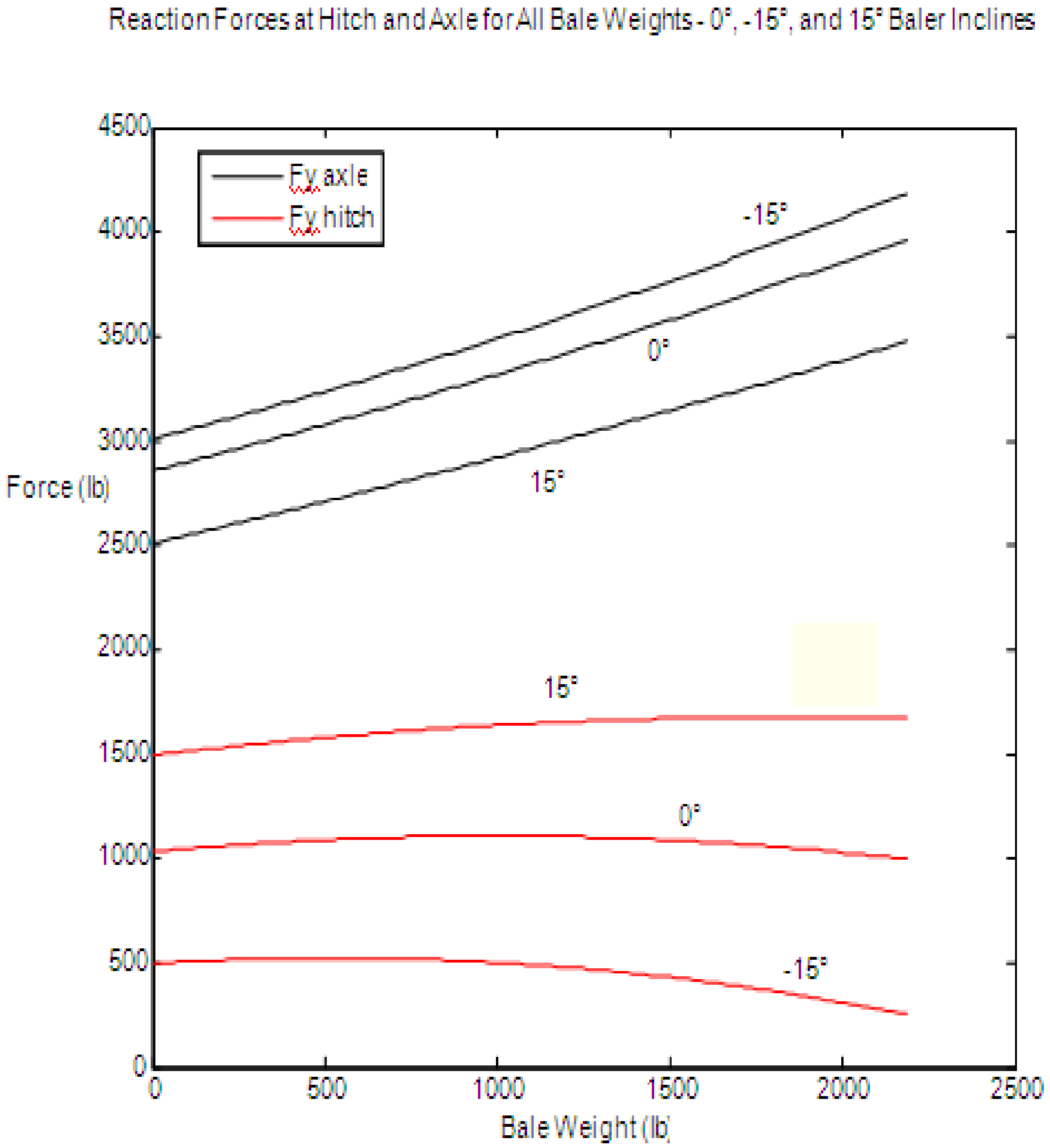


Figure 21

Figure 22 is the simulated graphs that would be recorded for the baling process.

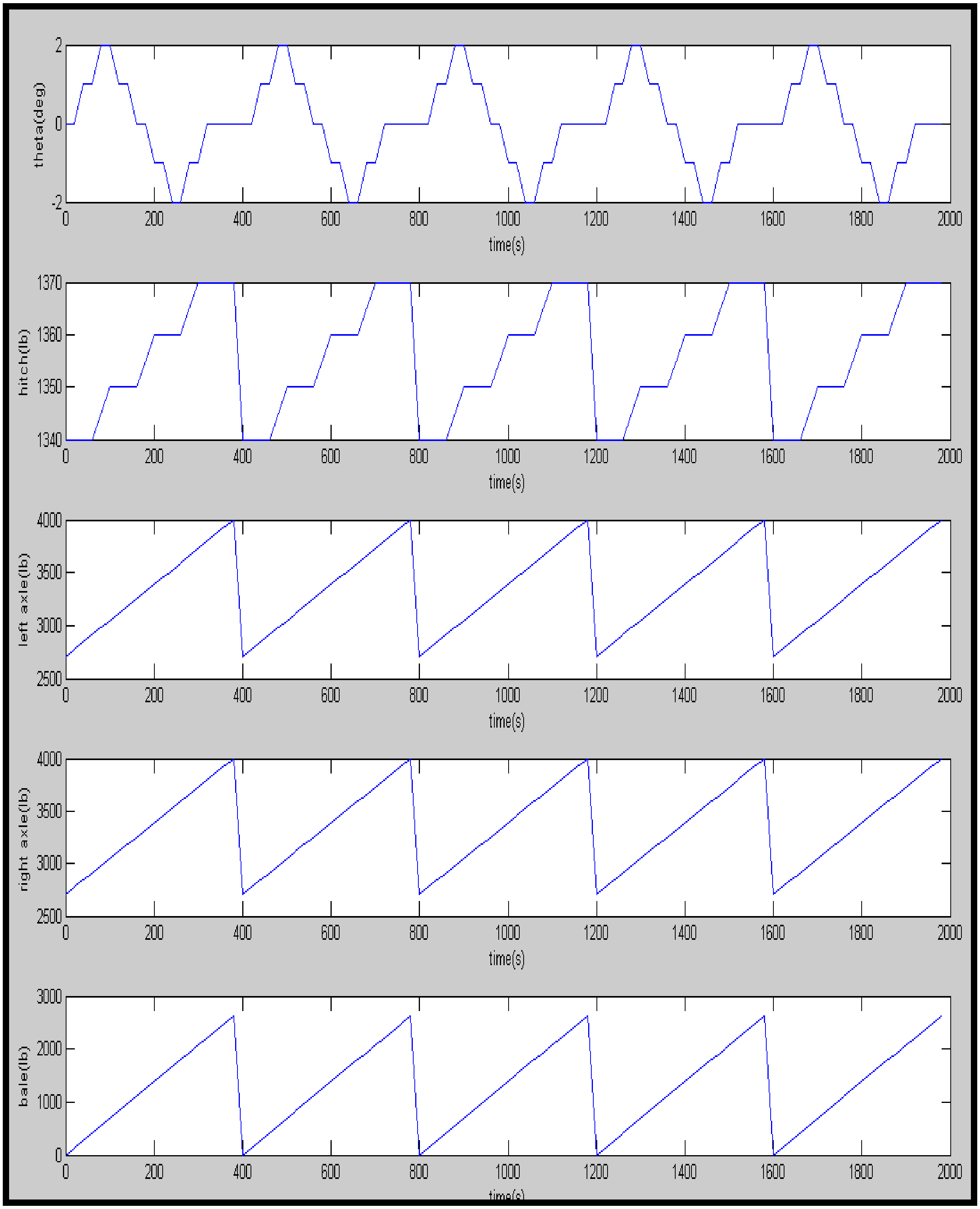


Figure 22

LABVIEW

For our testing purposes, we used LabVIEW. LabVIEW is a widely used visual programming language and environment. We will be using it for data acquisition and processing. During field testing, it will provide us real-time information about our sensors and ultimately the bale weight after the code is completed. Our LabVIEW program receives data collected by the National Instruments NI USB-6008 DAQ. The USB-6008 is the interface between LabVIEW and our sensors. It features up to 8 inputs, 12 bit resolution, and a max sample rate of 10 kHz. We will only be using the analog side of the device, although digital I/O is also possible. The input should be ≤ ±10 V and a maximum current of 50 mA. After it receives the sensors signals, it scales and converts it. Next, the signals are passed though a low-pass Butterworth filter. Lastly, all of the processed data for each sensor is written to an Excel file. Figure 18 is the LabVIEW program schematic that operates the entire system. This spreadsheet can then be called upon and read by Matlab, which uses this info to calculate bale weight. For production purposes, our LabVIEW will do these calculations and will include a functional user interface, or GUI.

The functions of the program are to record data, filter the signals, display real time data, and calculate bale weight. Following the block diagram (Fig. 1) the raw data of each sensor signal is initially recorded. Next each signal goes to a 4th order butterworth filter, 0.175 Hz cutoff frequency. The filtered signals are then displayed on the front panel for viewing in real time. The filtered signals are also recorded. Now that the data is filtered, the program calculates the bale weight (shown in orange wiring). Finally, the program displays the bale weight on the front panel and records this in a text file. A detailed description of the calculation is provided below.

The DAQ Assistant VI (virtual instrument) is where we set the data acquisition parameters which are sample rate, expected voltage range, and scale factors. The sample rate is set to 1 kHz which is also applied to all inputs on the board. It is important to set the expected voltage range as narrow as possible. This will allow the 12 bit DAQ to operate at its best resolution. Scale factors convert the signal, from volts to pounds, for example. The scale factors are those from the calibration data sheet sent to us by the manufacturers. It is necessary to correct these factors according to the power input, which is not exactly 8V, for the hitch, but 7.9V, for example. The corrected factors are listed below.

DAQ Parameters	Scale factor	Resolution	Sample Rate
Hitch	203000 (lbs/V)	0.5 lbs	1kS/s
Left Axle	1109615.2 (lbs/V)	2.71 lbs	1kS/s
Right Axle	1109615.2 (lbs/V)	2.71 lbs	1kS/s
Inclinometer	6.462 (deg/V)		1kS/s

So the minimum increment of the digital signal for the hitch load cell will be 0.5 lbs. An example calculation will explain this:

$\left(\frac{0.1mV}{2^{12}}\right) * 203\,\frac{lbs}{mV} = 0.5\,lbs$ where,

full scale output = 0.1mV

scale factor = 203 (lb/mV)

ADC resolution = 2^12

Bale Weight Calculation

The bale weight calculation is done by wiring the signals in LabVIEW with the appropriate operators. The wiring directly follows from the bale weight equation, which is derived from the free body diagram. The orange wires show how the calculation is constructed.

$$W_{bale} = \frac{(F_H + F_{LA} + F_{RA})}{\cos(\theta * \frac{180}{\pi})} - W_{baler}$$

System Accuracy

The accuracy of the system is largely determined by the use of signal conditioners and the quality of the DAQ board. The present system is cost effective as it uses a low cost DAQ device and no signal conditioners. Accuracy can be improved, at low cost, by amplifying the signals before they are sent to the DAQ. This can be done with a simple op-amp circuit. However a separate regulated voltage is needed to power the op-amps. Though the use of op-amps will introduce a small error into the signal, the error at the DAQ will be greatly reduced, improving system accuracy. Other options include NI’s C series DAQ boards which have built in signal conditioning and are more expensive. One such board which National Instruments specifically recommended for this application is the NI 9211 (see attached document). The 9211 performs better because it is designed for low sample rate applications (15 S/s), which is exactly what the bale weight sensor is.

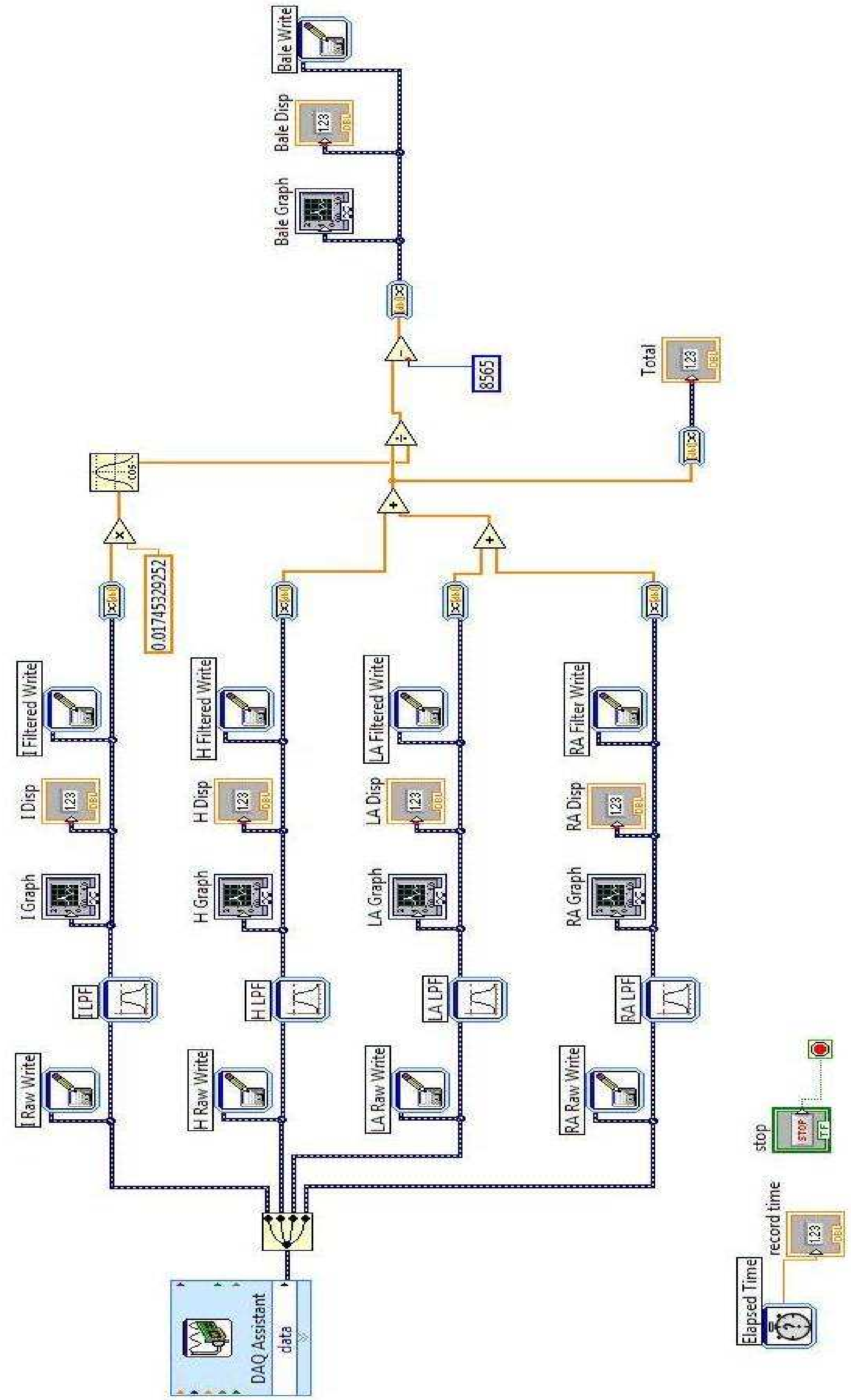
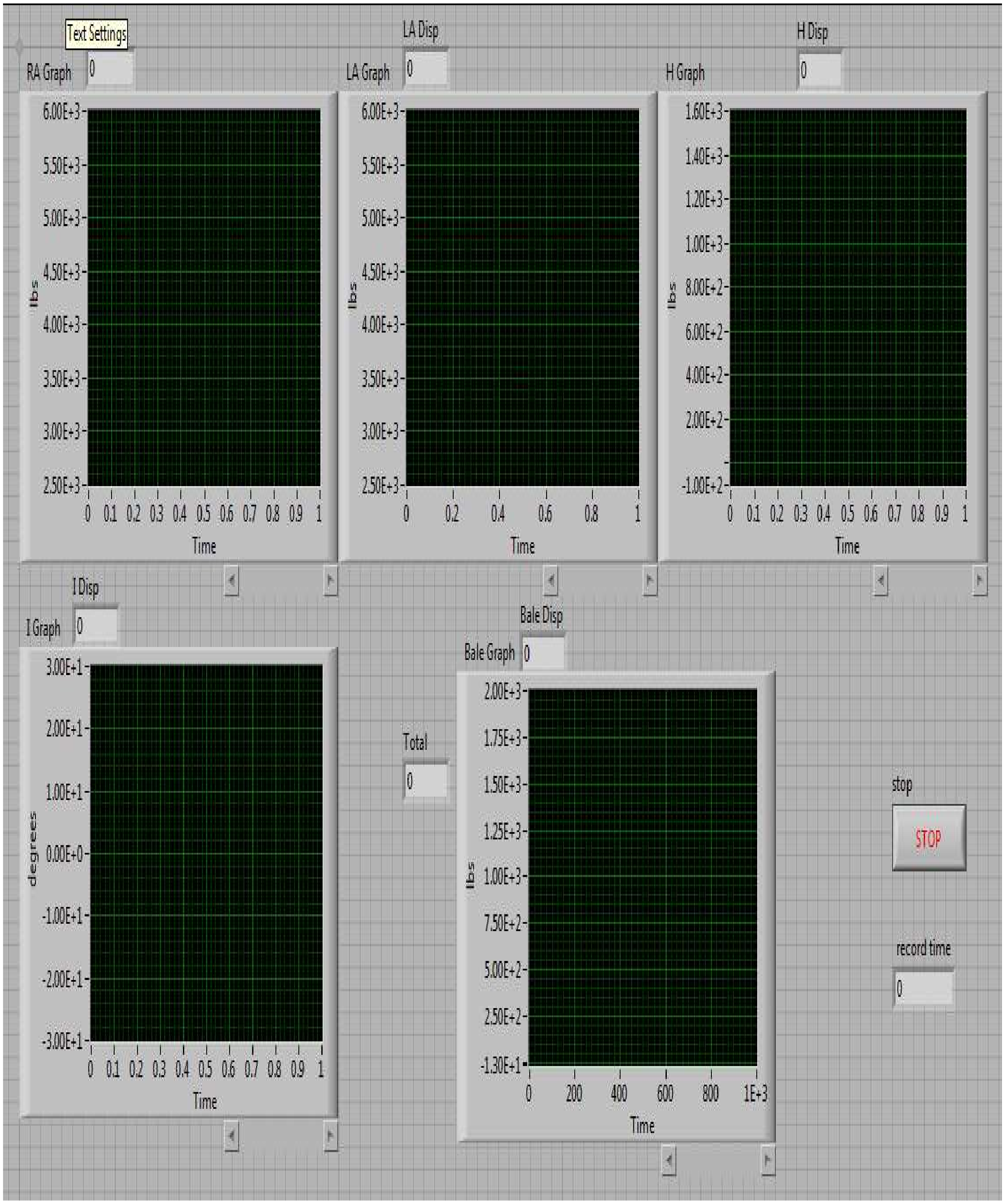

DAQ Assistant
data
I Raw Write
I LPF
I Graph
I Disp
I Filtered Write
H Raw Write
H LPF
H Graph
H Disp
H Filtered Write
LA Raw Write
LA LPF
LA Graph
LA Disp
LA Filtered Write
RA Raw Write
RA LPF
RA Graph
RA Disp
RA Filter Write
0.01745329252
8565
Total
Bale Graph
Bale Disp
Bale Write
Elapsed Time
record time
stop

Figure 23



LabView Front Panel GUI

SYSTEM TESTING

A. Individual Load Cell Testing

Tests were performed on each sensor after being installed on the baler to ensure that each one was still working properly on an individual basis. The sensors were tested individually by using a person of known weight as the applied load. He stood directly on top of the sensor so all of the weight would flow through the appropriate sensor. The data was collected and filtered. All of the sensors measured the weight within 10% accuracy. A summary of the data is shown in the table below.

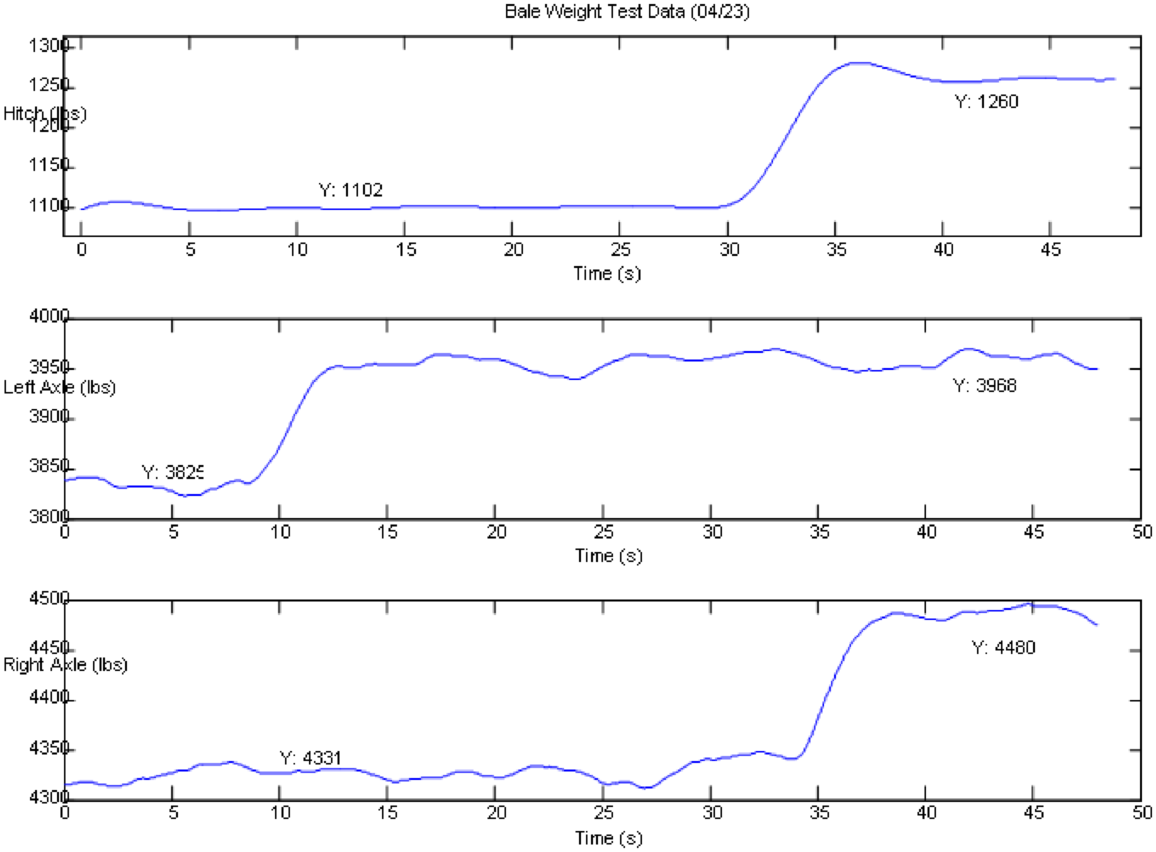


Table 1: Individual Sensor Data

Sensor	Measured Load	Percent error (154lbs applied)
Hitch	158	2.6%
Left axle	143	7.1%
Right axle	149	3.4%

B. Inclinometer Testing

The inclinometer has been attached to the appropriate voltage supply of 5 volts using a regulated power supply. The inclinometer was held in the center of a protractor and swiveled to two different test positions on the protractor; these were 15 and 30 degrees. The inclinometer outputs a voltage based upon its position with respect to the vertical. Using the scaling factor 6.462 mV / degree as established in the manufacturer's calibration sheet, the voltage readout of the inclinometer was translated into a degree measurement. This calibration was accomplished through a linear scale in LabView. The data for each position is shown below:

Holding at:		
30 Degrees	15 Degrees	0 Degrees
29.481024	13.7106	-0.482782
31.058067	13.7106	-0.482782
31.058067	13.7106	-0.482782
31.058067	13.7106	-0.482782
29.481024	13.7106	-0.482782
29.481024	13.7106	-0.482782
29.481024	13.7106	-0.482782
29.481024	13.7106	-0.482782
31.058067	13.7106	-0.482782
29.481024	13.7106	-0.482782
29.481024	13.7106	-0.482782
31.058067	15.287643	-0.482782
29.481024	13.7106	-0.482782
29.481024	13.7106	-0.482782
29.481024	13.7106	-0.482782
31.058067	15.287643	-0.482782
29.481024	15.287643	-0.482782
29.481024	13.7106	-0.482782
29.481024	15.287643	-0.482782
29.481024	15.287643	1.094261
29.481024	15.287643	-0.482782
29.481024	13.7106	-0.482782
29.481024	15.287643	-0.482782
31.058067	15.287643	1.094261
31.058067	15.287643	1.094261
31.058067	15.287643	1.094261
29.481024	15.287643	1.094261
29.481024	15.287643	1.094261
31.058067	15.287643	1.094261
31.058067	15.287643	1.094261

C. Entire System Testing

All necessary sensors have now been installed on the baler. The hitch load cell and two axle load cells are powered and their associated sensor wires have been attached to a data acquisition system. This data acquisition system was connected to a laptop with the complete LabView program running. The LabView program recorded over 170,000 data points for the complete test. These points have been condensed into 18 points in Fig. 24 below for easy viewing:

Time (s)	Hitch (lb)	Bale weight (lb)	Left Axle (lb)	Right Axle (lb)	Filtered Hitch (lb)	Filtered Left Axle (lb)	Filtered Right Axle (lb)
0	646.107496	-8564.998917	3191.146878	3832.615273	1.53E-11	0.000492	0.000591
10	749.359315	-2.292258	2626.868517	4398.429402	680.940493	3149.273848	4732.4934
20	542.855677	-7.335975	3191.146878	4964.24353	688.312146	3142.814747	4726.537132
30	439.603859	52.035138	3755.42524	3832.615273	686.897352	3163.095312	4767.042474
40	542.855677	182.718587	3191.146878	4964.24353	818.866786	3181.437876	4747.413924
50	852.611134	166.513314	3755.42524	4398.429402	814.71436	3170.558028	4746.240926
60	749.359315	371.779908	3755.42524	5530.057659	873.153513	3129.836234	4933.79016
70	749.359315	359.913857	4319.703602	5530.057659	913.271891	3100.793446	4910.84852
80	646.107496	434.880292	3191.146878	5530.057659	919.743027	3125.346452	4954.790813
90	749.359315	529.258688	3191.146878	5530.057659	892.397132	3258.706229	4943.155327
100	955.862953	574.513095	3191.146878	5530.057659	908.614688	3274.433063	4956.465344
110	852.611134	540.250685	3755.42524	4398.429402	884.814573	3288.385306	4932.050805
120	1059.114771	421.854572	3191.146878	4964.24353	933.869652	3119.273157	4933.711763
130	1059.114771	449.52216	3755.42524	4964.24353	932.542346	3132.387651	4949.592163
140	749.359315	157.129738	3191.146878	3832.615273	797.930862	3163.089779	4761.109097
150	749.359315	49.063214	3191.146878	4964.24353	692.628354	3153.531082	4767.903779
160	233.100221	25.170318	4319.703602	4964.24353	675.957147	3160.831758	4753.381413
170	542.855677	36.316498	3755.42524	4964.24353	678.040835	3150.030609	4773.245054

Fig. 24

The total bale weight is calculated by subtracting the steady state weight value of the baler from the total weight measured by the three sensors. The steady state baler weight offset used for testing was 8565 lb. This value can be seen as -8565 at time 0 as the system is first being powered up. The first weight spike is also a consequence of the sensor startup. After ten seconds the weight measurement has reached a steady state value centered around 0 lbs. This is the point at which load began to be applied. Three group members mounted the baler at a staggered pace. The first input was 155 lbs, the second input was 210 lbs, and the third input was 160 lbs. Each weight was held for a few seconds, and then removed in reverse order. This weight increase and subsequent decrease is evidenced in Fig. 25 below:

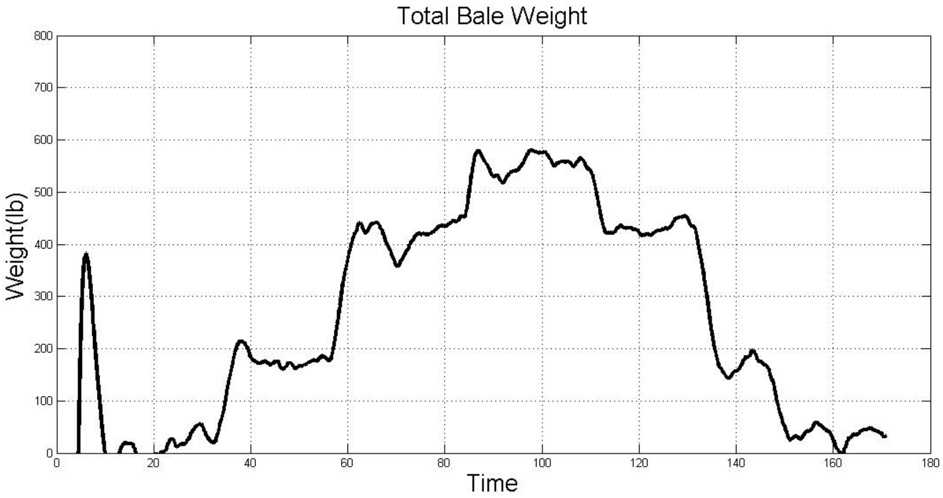


Fig 25.

The load can be seen to reach a steady value of about 170 after the initial weight application of 155 lbs. This computes to an accuracy of 91%, which is within the acceptable +/- 10% range. At this point, 210 lbs is added in addition to the previous load; the sensors indicate a steady state value of about 405 lbs after this. The accuracy of the system is 90% at this point, which again is acceptable. Lastly, 160 more lbs are applied, and the sensor output indicates a total weight application of about 550 lbs. The accuracy of the system at this point is 95%. The descending values and accuracies are roughly equivalent to the ascending values as seen in Fig. 25. The accuracy of the descending values never drops below 90%, which indicates that hysteresis is not a significant source of error in the system. Fig. 26 demonstrates this below:

Recorded Load	Actual Load	Accuracy
0	0	Varies
170	155	91.17647
405	365	90.12346
550	525	95.45455
405	365	90.12346
165	155	93.93939
0	0	Varies

Fig. 26

In conclusion, the sensor array works as intended albeit with some inaccuracy that falls within an acceptable range. The accuracy of the system can be improved somewhat by creating a better starting offset voltage. In this particular scenario the offset weight should probably be increased considering that all data inaccuracy is in the -10% range rather than the +10% range. More precise scaling factors and filtering programs would be another means to improve the accuracy of the data.

D. Field Testing

For testing purposes of the baler weight measurement system, the design team will work with the employees of EV Smith Research Center and members of the USDA team. We believe that the best way to determine if the system is working properly and accurately is through a series of test. These trials will be conducted throughout various stages of the project and will involve several different setups to ensure the accuracy of each measurement.

First, we will test the baler using by simply testing its weight in a static position. We will attach the baler to the tractor and connect all of the weight sensing devices. The measurement should be the direct weight of the baler as if it were empty. Next, the design team will place weights inside of the baler to serve as a static loaded measurement. This measurement will simulate a loaded baler in a stopped position. This aspect of testing will also help to determine the accuracy and precision of the system. These two phases of testing are scheduled to be completed by March 13, 2009.

To begin the dynamic test, we have elected to simply pull the empty baler and introduce noise into the system. This particular phase will let us know the effects of vibration on the system. For a weighted test, we can simply add the weights back to the baler and take dynamic measurements. These two tests should reveal all of the information that we need to ensure that our system is working properly. The dynamic load tests are scheduled to be completed and analyzed by March 27, 2009. After correcting any programming or testing errors, we can move on to the final testing stage, bailing stock.

We will begin by unrolling a role of hay and basically re-bailing it. If we simply unroll the bale and try to re-bale it in the formation that it’s in, we will not create a very realistic testing scenario. If they hay is simply unrolled from a bale, it will be in a row that is too thick to bale at normal speed. This reduction in speed will probably reduce the vibration, thus the system would not be tested in a realistic manner. The thickness of the windrows would also create a clogging problem for the tractor operator. To make the test as realistic as possible, we must go through the entire process of re-bailing the unrolled bale. The design team will unroll a bale, spread it out with a tedder, rake it, and re-bale it. The final testing stage is scheduled to be completed by April 17, 2009. The report/presentation is scheduled to be completed, if everything goes as planned, will be given April 27, 2009.

ECONOMIC ANALYSIS

TOTAL COST ANALYSIS FOR FINAL DESIGN

Table 2 represents the total cost associated with the proposed design. All manufactured and shipping costs are included.

CORP 5 COST ANALYSIS				
COMPANY	**INSTRUMENT**	**COST - EACH**	**QUANTITY**	**COST - TOTAL**
Rieker	inclinometer	$100.00	1	$100.00
Omega	load cell	$480.00	1	$480.00
Digi-Star	axles	$276.30	2	$552.60
National Instrument	Data Acqu Sys	$184.33	1	$184.33
Express PCB	PCB Board	$20.00	3	$60.85
Mouser	wire	$65.34	1	$65.34
Mouser	3A fuse	$0.53	1	$0.53
Mouser	.1 uf capacitor	$0.08	3	$0.24
Mouser	.33 uf capacitor	$0.08	3	$0.24
Mouser	5V regulator	$0.26	1	$0.26
Mouser	8V regulator	$0.26	1	$0.26
Mouser	10V regulator	$0.26	1	$0.26
Mouser	Terminal blocks	$1.91	1	$1.91
Mcmaster	spherical washer	$18.92	1	$18.92
`			**TOTAL COST**	**$1,465.74**

Table 2

FINAL DESIGN CONCEPT

After studying and researching many options, our recommended design consists of a ring load cell, two Digi-Star load cell axles, and an inclinometer. In order to accurately get the weight of the bale inside of the baler, we must be able to accurately get the weight of the entire baler. We chose to place three sensors that measure weight at strategic locations around the baler. These locations are at the hitch and on each axle. The environment in which the baler works is not flat. This leads to the conclusion that there will be forces from the baler's weight in both the x- and y-directions if our coordinate system is fixed to the baler. This is where the inclinometer comes into play. It will give us the angle at which the magnitude of the baler's weight is directed. Our three weight sensors are all measuring the y-component of the weight at each point. The angle given by the inclinometer allows us to calculate the x-component and magnitude of the weight at each of the three points. Adding the magnitudes of weight measured at each location yields the magnitude of the weight of the entire baler. Subtracting the weight of an empty baler from the entire weight yields the weight of the bale.

Taking several samples of data from each sensor allowed us the plot the weight per time. With this, we were able to display the final bale weight as well as the weight of the bale at any given time. If we using the GPS receiver to receive baler speed and path traveled information; we would be able to generate a 2-D yield map.

We chose this particular concept based on many different factors. Using the inclinometer, allows us to eliminate x-axis sensors for the hitch and the axles which kept the cost down. It also eliminated the need to design and manufacture a coupler which would have been necessary for the x-axis sensor on the hitch. Using just the ring sensor on the hitch also allows for an easy installation. The inclinometer can be installed almost anywhere on the baler. We also chose to go with the Digi-Star load cell axles because there are no associated manufacturing or machining costs, and it is also an easy installation. These axles have also already been but though rigorous testing by Digi-Star and have also been used previously by AGCO. All sensors will be environmentally sealed so they will have longer lives. The output from all of our sensors will need to be condition, i.e. amplified and filtered, to increase our accuracy.

RECOMMENDATIONS FOR IMPROVEMENT

- Hitch

  A specific height of tractor drawbar can be specified for each model baler. This will reduce the kinking seen at the connection between the tractor drawbar and baler hitch to create a more level contact angle between the two.

- Axles

  The Digi-Star axles used with our system have a diameter of 2” exactly. The balers’ receiving tube has a diameter of 2.063”. This gives us a difference of 0.063” which allows the axles to be mounted easily but results in some excessive slack in between the two which could create some unwanted noise in the sensors’ signals. The easiest and most cost effective solution to this would be to design and produce a sleeve out of sheet metal that would take up some of the slack. Also, the Dig-Star axle had to be modified in order to interface properly. We had to mill 0.62” off the end of the axle and relocate the bolt hole. For large scale production, Digi-Star would manufacture axles for this system that would not need to be modified.

- Wiring

  All of our sensors’ wires were soldered to the longer wires. We recommend the use of plug connectors instead of being soldered. This would allow for easy replacement of the sensors.

- PCB and Housing

  For our prototype system, the printed circuit board used for our sensors’ power supply was mounted in a casing that we happened to already have. This saved us from having to purchase one, but it is not one that we would recommend for the system if it were to go into production. It has vents on the top and side which would expose the circuitry to the environment. The top half of the casing is also not able to fasten to the bottom half. The bottom half is mounted to the baler. We recommend the use of housing in which the two halves are hinged in order to allow easy access. It should also be hermetically sealed to protect the circuitry. Currently our PCB and sensors’ signals terminal block make use of screw terminals. In order to keep the housing hermetically sealed, we recommend the use of plug-style connectors to interface between the outside and the inside of the housing. For instance, the wire with 12V input for the PCB would have a male connector on the end of it and the housing would have the female connecter mounted and sealed on the side of it which would then be wired to the PCB. These style connectors would be used for all wires being input and output of the housing which also includes power being sent to the sensors, signals received from the sensors, and signals output to the DAQ.

- Data Acquisition

  Data acquisition is a very important part of our system. It needs to be very precise in order to guarantee reliable data from the sensors. The present system is cost effective as it uses the low cost NI-DAQ 6008 device and no signal conditioners. Accuracy can be improved, at low cost, by amplifying the signals before they are sent to the DAQ. This can be done with a simple op-amp circuit. However,a separate regulated voltage is needed to power the op-amps. Though the use of op-amps will introduce a small error into the signal, the error at the DAQ will be greatly reduced, improving system accuracy. Another option is to use National Instrument's C series DAQ devices instead of the DAQ 6008 use which have built in signal conditioning and are more expensive. One such device, which National Instruments specifically recommended for this application, is the NI 9211 (see attached document). The 9211 performs better because it is designed to read in the mV range, which is the range of our sensors output, with greater accuracy.

- LabView

  The input voltage to each sensor will vary slightly from run to run. This means the scale factor will be slightly off each time. To correct for this, a voltage feedback control which auto-adjusts the scale factors, can be incorporated into the program.

- Entire System and Integration

  Additional software could be developed and included to the existing tractor's onboard computer instead of using LabView. The sensors signal wires would be routed back to the tractor instead of being sent to a DAQ/Laptop.

CONCLUSION

The purpose of this report is to explain the basic concepts and prototype that will allow AGCO-Hesston to accurately measure the weight of a completed bale and of incoming feedstock. Using the prototype will allow for an accurate weight measurement, as well as provide a base for future developments in crop yield mapping. The benefits of being able to incorporate this particular design should give AGCO-Hesston the leading edge in this particular aspect of the industry. The design is somewhat simple, yet it still accomplishes all objectives and allows for a low cost addition to the existing line of balers. With the implementation of this design, the operators and sponsors will now have greater access to information about their fields for more efficient farming.

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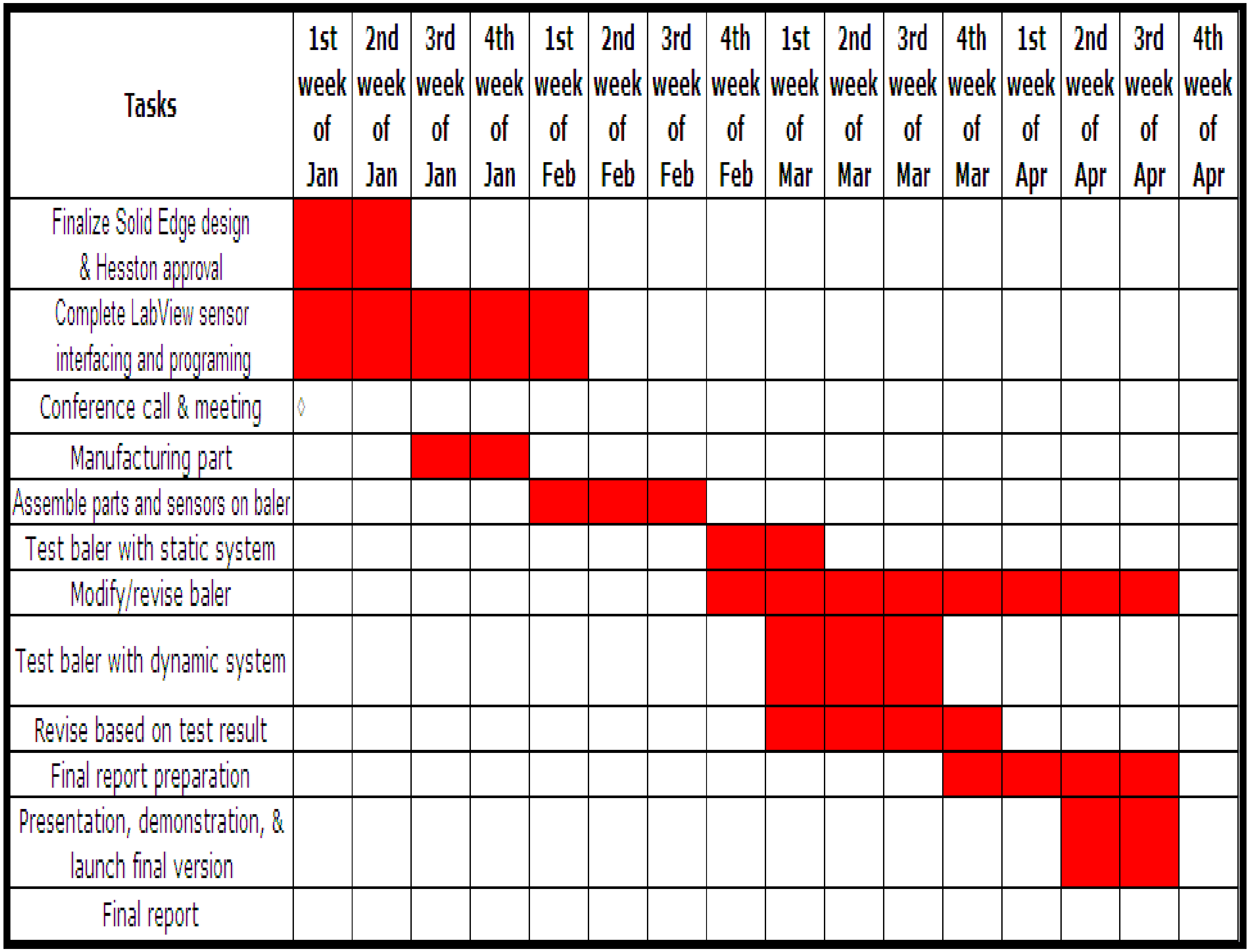
APPENDIX

GANTT CHART



Tasks	1st week of Jan	2nd week of Jan	3rd week of Jan	4th week of Jan	1st week of Feb	2nd week of Feb	3rd week of Feb	4th week of Feb	1st week of Mar	2nd week of Mar	3rd week of Mar	4th week of Mar	1st week of Apr	2nd week of Apr	3rd week of Apr	4th week of Apr
Finalize Solid Edge design & Hesston approval	🟥	🟥														
Complete LabView sensor interfacing and programing	🟥	🟥	🟥	🟥	🟥											
Conference call & meeting	◊															
Manufacturing part			🟥	🟥												
Assemble parts and sensors on baler					🟥	🟥	🟥									
Test baler with static system								🟥	🟥							
Modify/revise baler								🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
Test baler with dynamic system									🟥	🟥	🟥					
Revise based on test result									🟥	🟥	🟥	🟥				
Final report preparation												🟥	🟥	🟥	🟥	
Presentation, demonstration, & launch final version														🟥	🟥	
Final report																