Mobile soil bin development and testing

by

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Abstract

In 2050 the world's population is projected to be over 9 billion people, creating a need for more agriculture production than ever before. One way to increase production of crops is to get them planted in an optimum planting window. This allows the crops to take the most advantage of the longer days during the growing season thus increasing their yield.

The growing size of farms and reduced amount of farmers puts more pressure on each remaining farmer to mechanize more heavily, and to get more acres planted faster in order to get crops planted in time. Most areas have an optimal planting window of a few weeks. This drives a need for planters to get bigger so one man can plant more acres in a day. Besides getting bigger, planters are also getting able to accurately plant faster. Today many of the new planters are "high speed," meaning they are able to plant at speeds of 7 to 10 mph.

The typical research and discussions of high speed planters tend to focus on the speed effects on the seed placement, emergence, planting rates, active downforce systems, metering systems etc. There is little discussion on the effects these higher planting speeds have on the draft requirements of the row unit itself. There needs to be more knowledge about the relationship between soil and planting tools in order to optimize power and performance of the tools to minimize fuel consumption, labor, and soil compaction.

In order to test the draft forces of various tillage and planting tools in different field conditions there needs to be a machine that can repeatedly test multiple tools in multiple field conditions over a wide range of speeds. This paper is about the development of such a machine. The Cultivation Assessment Test Apparatus (CAT App.) is a device used to pull tillage and planting tools at a consistent depth at different speeds measuring the draft and downforce requirements during tests.

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Acknowledgements

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Dedication

To my wife Charlotte, who pursued a man working fulltime and working on his Master's Degree, and supported my educational pursuit during our time of courting, our engagement and the first year and a half of our marriage. Praise God, the little one will arrive after I graduate, I can't wait to hold you Tiny Thing!

Chapter 1 - Literature Review

In 2050 the world's population is projected to be over 9 billion people (United Nations, 2015), creating a need for more agricultural production than ever before. As there are no other continents to be discovered we have to use what we have for cropland more efficiently. Currently, 12% of the global land area is being used for agricultural crops, this is, land that supports crop production that isn't used for infrastructure, grasslands, forests, or barren (United Nations, 2011).

The growing size of farms and reduced amount of farmers puts more pressure on each remaining farmer to mechanize more heavily, and to get more acres planted faster in order to get crops planted in time. Most areas have an optimal planting window of a few weeks (University of Nebraska-Lincoln, 2016). This drives a need for planters to get bigger so one man can plant more acres in a day. Besides getting bigger, planters are also getting able to accurately plant faster. Today many of the new planters are "high speed," meaning they are able to plant at speeds of 7 to 10 mph (Anderson, 2016).

Today's bigger, heavier equipment is able to get more done in a day, but poses damaging effects to the soil by compaction because it requires bigger tractors with more horsepower. As quoted from an article from the AgWeb Farm Journal, "'Horsepower requirement is definitely a conversation that needs to occur when switching to a high-speed planter," says Jacob Swanson, John Deere product manager. "It simply takes more horsepower to go faster, and that's accentuated in rolling terrain or softer soils'" (Anderson, 2016). Compaction resulting from this heavier equipment reduces the air available to plant roots, reduces water infiltration rates, and limits root growth.

We need ways to minimize the weight of these machines to better utilize the soil's potential for crop growth. We can minimize the weight of agricultural vehicles by optimizing the tools that interact with soil to perform their designed function with the least amount of power required to do that function. If the same function can be performed by a lighter vehicle, compaction will be minimized and thus there will be more crop growth potential. Furthermore, a lighter vehicle will also increase fuel efficiency making our natural resources last longer, and increasing the producer's profit margin.

In the ASABE standard for Draft Relationships for Tillage and Seeding Equipment, planter draft is largely only effected by the rolling resistance of the transport wheels, gauge wheels, and press wheels (Harrigan, 1994). According to the standard, when calculating planter draft for planters the machine parameters effected by speed are both multiplied by zero, therefore suggesting that there is no effect of speed on planter draft requirements.

Nearly all modern planters use a double disc opener set-up to form a furrow for the seed. The double disc openers are essentially two coulters that are at a slight angle to each other to form a wedge that will cut through the soil and residue and move the dirt around the seed delivery mechanism. In the 1994 ASABE standard, coulters show a linear relationship with speed. In a study of rolling resistance of pneumatic agricultural implement tires, it was found that there is a relationship between rolling resistance and velocity that is impacted by soil compaction (Pierrot, 1968). In the automotive industry tire rolling resistance is being studied and refined to improve fuel economy due to the increase of rolling resistance with speed (Redrouthu, 2014). Though automobiles travel at considerably higher speeds then agricultural planters in the field, per row unit on a typical planter there are at minimum, two gauge wheels, and two closing wheels. On a 24 row planter, that’s 96 wheels engaging the soil. A small change in rolling resistance of these components will be multiplied by nearly 100.

The typical research and discussions of high speed planters tend to focus on the speed effects on the seed placement, emergence, planting rates, active downforce systems, metering systems etc. There is little discussion on the effects these higher planting speeds have on the draft requirements of the row unit itself. There needs to be more knowledge about the relationship between soil and planting tools in order to optimize power and performance of the tools to minimize fuel consumption, labor, and soil compaction. Studying the draft requirements of planters and becoming more knowledgeable about the relationships the row unit has with the soil can direct the exploration of new designs to require less downforce and less draft thus reducing the vehicle power and traction requirements, which in turn will reduce the vehicles impact on the soil by creating less compaction.

Current methods of studying draft requirements of tillage and planting implements and their tools are shown in Figure 1. Soil bins (Image of Soil Bin and Processor, 2018) and tractor and implement configurations (Research Tools, 2018). Soil bins are used to study the draft forces on isolated tools in a soil media that can be replicated for very precise and repeatable tests (Liu, 2002). Tractor and implement configurations vary from drawbar hitch dynamometers to instrumenting tools on the machine to measure their individual draft as part of the implement. This later method of testing tillage or planting draft helps give overall data for the entire tool, is mobile and allows real field conditions to be tested.

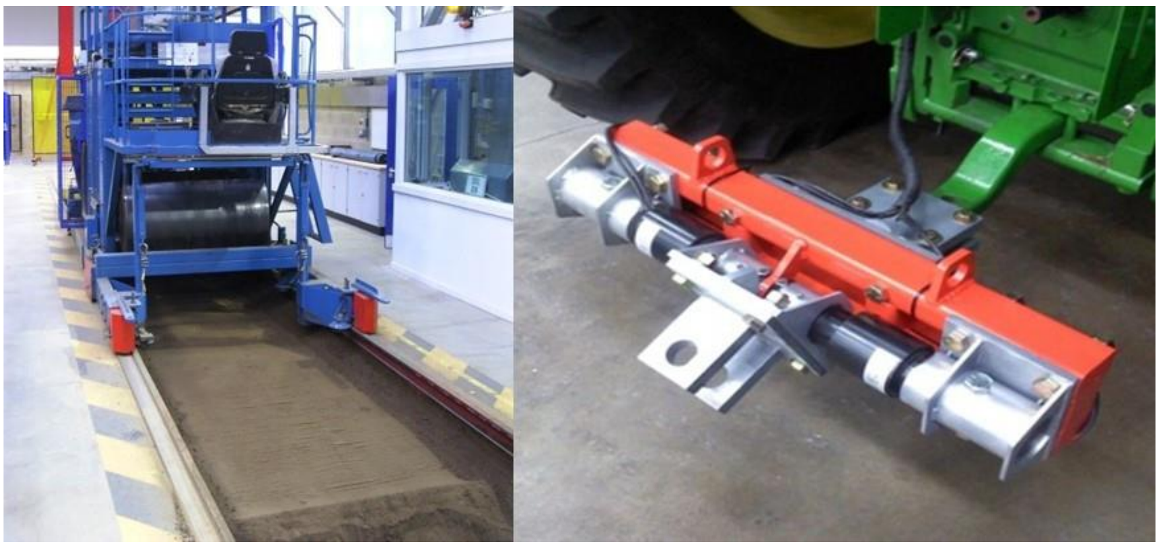

Figure 1: Current testing methods for measuring draft. Soil bin (left), Drawbar dynamometer (right).

To bridge the gap between these two methods of testing there needs to be a machine that can both be mobile--testing real field conditions, and be precise--isolating the tillage and planting tools from the rest of the implement. As seen in the diagram in Figure 2, the Cultivation Assessment Test Apparatus (CAT App.) fills the gap between the two existing methods.

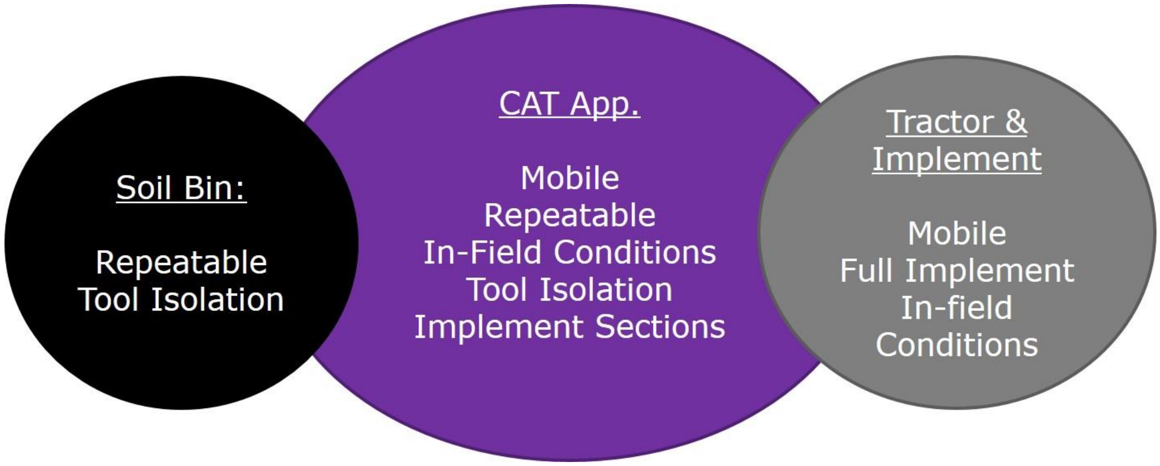

Figure 2: Gap in existing testing methods for tillage and planting tools

Chapter 2 - Design

During the development of the CAT App. the design process, depicted in Figure 3 (Research Guides, 2018), was used to come about to a final design that would be a good solution to meet the design criteria. To meet the project scope the CAT App. design has evolved from an original gantry and winch concept to a multi-use test bed with auxiliary hydraulic power ports, a Category 1 vertical quick hitch, a hydrostatic transmission, on a 40 foot track with a ball type trailer hitch and a removable axle. CREO Parametric was used to model designs in order to evaluate their effectiveness and manufacturability while developing the design. Several iterations and designs were modelled and discussed in order to get a machine that would meet the specified criteria.

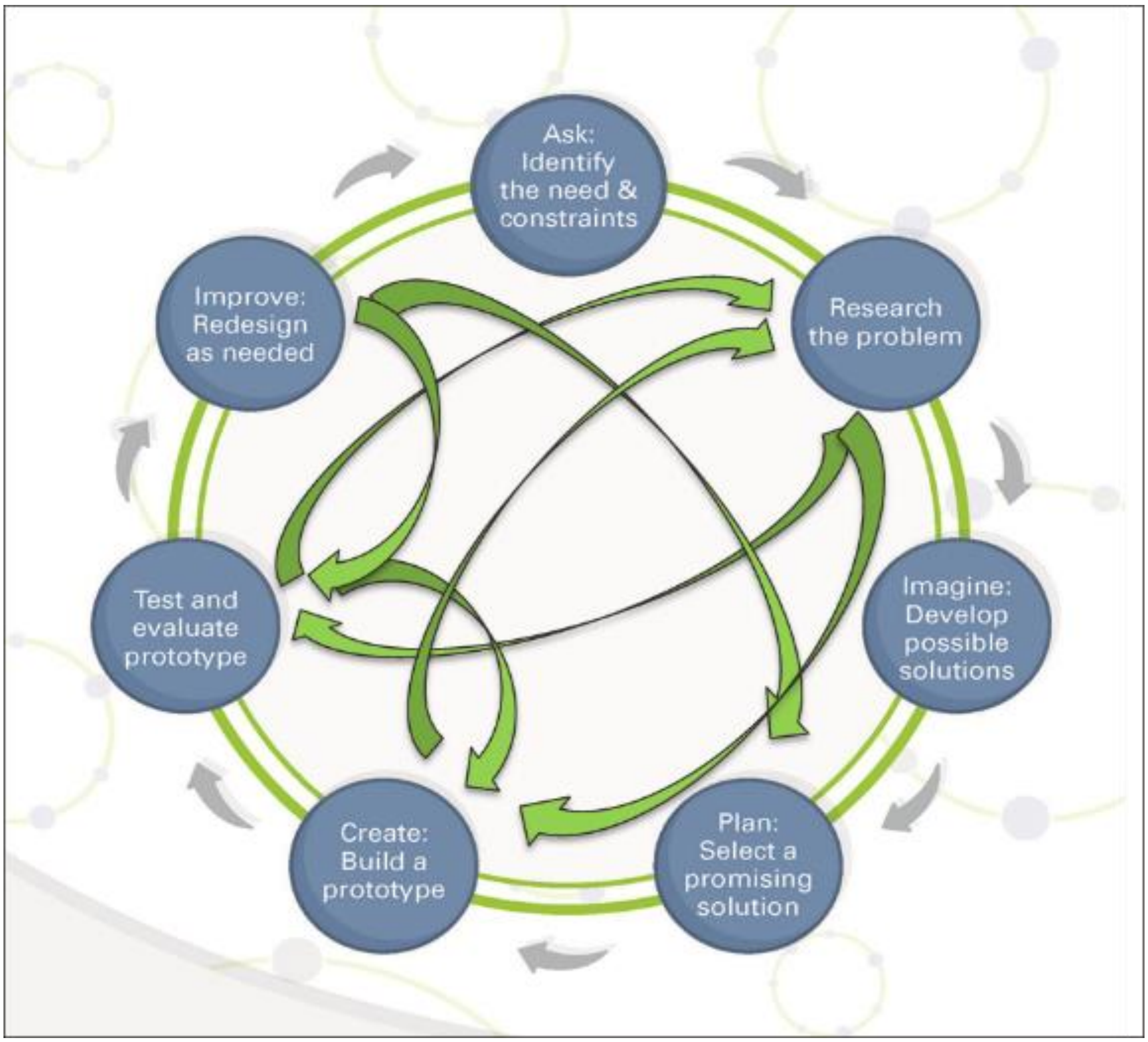

Figure 3: Engineering design process

Identify Constraints

The first step in this process was defining the scope of the project by creating the list of design criteria to focus the design of the machine to meet the needs of project. The goal of the project was to develop a device that could be used to test tillage and planting tools for draft and downforce variations in order to optimize their geometries to reduce their draft and downforce requirements. To reach this goal the design criteria for what became the CAT App. was as follows:

- Mobility to test in different fields and locations,
- Speed ranges seen by planting and tillage tools in the field (0-10 mph),
- A variable drive to select any speed within its range,
- Ability to accommodate a large variety of tillage and planting tools,
- Precise measurement of: draft, speed, downforce, and position,
- Ability to set tools at all conventional working depths,
- A test length 1/1000 of an acre for a 30 in row (17 feet 5 inches), and
- Repeatability of all testing aspects in real field conditions.

Research the Problem

As soon as the problem was defined research began to learn what other things had been done in this field of study to solve similar problems. Research was also done to learn more about the details of each of the design constraints. Along with researching what had been done in this area of study before, committee members, peers, other faculty, and professor were all consulted at different times throughout the design process. They helped refine the design, and provided opinions and things to consider that helped guide the design of the CAT App. This process of research and consulting took place regularly throughout the design of the machine.

Imagine/Develop Possible Solutions

The first solution proposed to meet the design criteria was a C-channel frame with a carriage much like a trolley for a crane that would be pulled by a winch mounted at the front of the track (Figure 4). After developing this possible solution it became evident that the design problem wasn't as simple as what was first thought. The problems with this first design concept were mostly with the propulsion system of the carriage. It would be difficult to moderate the speed of the winch accurately accounting for the change in the spool diameter as the cable began creating consecutive layers around the spool. Also, higher speeds would be hard for the winch to attain. Returning the carriage to the "home" position would require either, another winch and cable on the other side of the track or someone to manually push it back between tests.

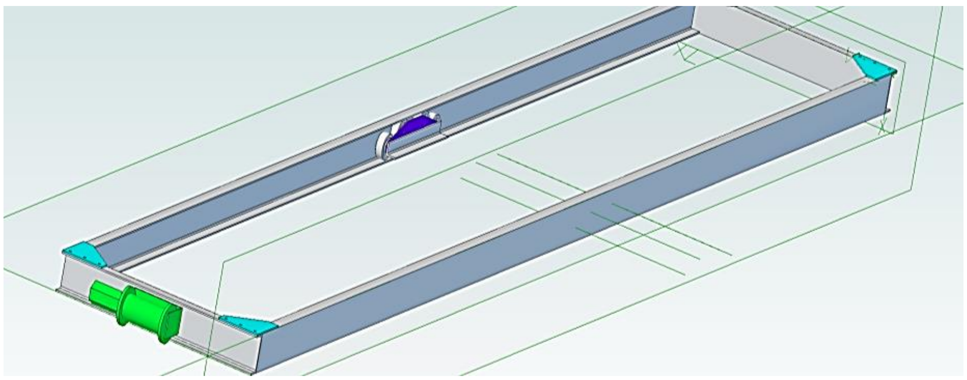

Figure 4: Initial gantry and winch design concept

To address the issues found with the initial concept, other propulsion systems were investigated, though maintaining the track form of the machine. The benefits of the track design are that it eliminates variables such as wheel slip, ground roughness, and topography variations in the field. These benefits give the machine many of the advantages of a soil bin, only mobile. Firstly, an electric drive for the propulsion of the carriage was investigated. Using an electric motor coupled to a gearbox (shown in white in Figure 5) powering output shafts going to the outside of the tracks would provide the power to move the carriage. Drive sprockets would then be mounted to the output shafts. Additional idler sprockets would be mounted to the rear of the track. Roller chain could then be attached to the carriage with the front end of the chain being attached to a load cell to measure draft. Electric motors have the advantages of smooth power delivery to the carriage, less noise, ease of control, and repeatability.

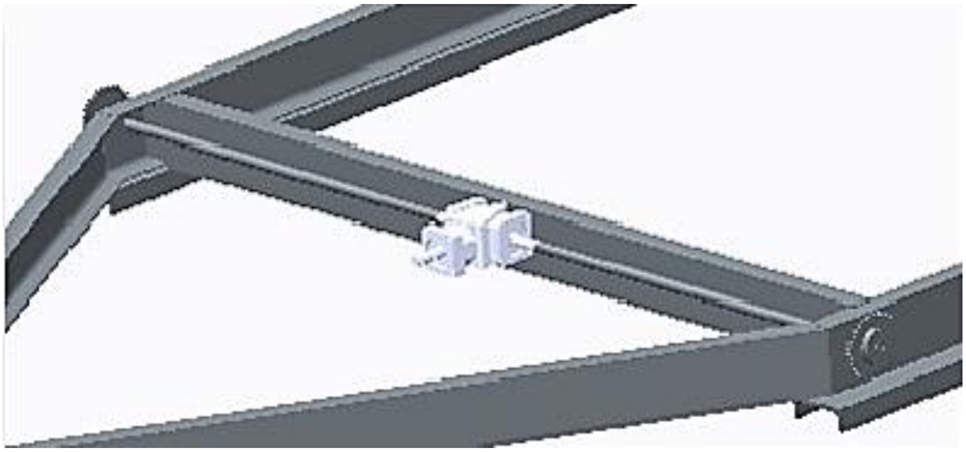

Figure 5: Gear box and output shafts

A problem with this design was that having electric motors with enough power to propel the carriage and tools engaging the soil forward at the speeds desired would require three phase power. Three phase power would be easily available for indoor testing, barring the specific need to test outdoors, in the field. Three phase generators in the field would solve this problem, but the cost of such a generator would have exceeded the budget for the project. Another issue was with the chain pulling the carriage, along with the need to shield that chain, since it would be moving rapidly and in the open. Also, the chain would need to be supported over the length of the track since track lengths were expected to be well over 20 feet long. If not supported, the chain would oscillate vertically and interfere with draft measurements as well as the control of the speed. The greatest concern with the chain was safety and how to shield it appropriately, and still allow for the carriage to move.

Early designs of the track included heavy rail I-beams from PBC Linear. These I-beam rails allowed for combination bearings that were designed for radial loads when engaging the flanges of the I-beam, and also had a roller for going against the web of the I-beam when an axial load was present. Having two bearings on each side of the I-beam would allow the carriage to keep the tracks from spreading apart due to their length. The bearings are shown in Figure 7 in an early rendition of the carriage. The 8 bearings for the carriage were quoted at $810.13, and two I-beams at 19.5 feet each were $975.00. This was a significant cost and other options were looked into for cost savings, especially after the machine length doubled to 40 feet long to allow for acceleration and deceleration distance for higher speed tests.

In order to attach a wide variety of different tools a Category 1 three point (Cat. 1 3-pt) hitch was considered. A 3-pt hitch would enable any currently produced small agricultural implements to be attached to the CAT App. as well as to a tractor if true field tests were desired with the same tool, as seen in Figure 6. This would give a lot of flexibility to the tools that could be used, and the kind of testing that could be done with them. Generic toolbars could be made using square tubing sizes (such as 3 in., 4 in., and 7 in. square tubes) used by most agricultural equipment to mount tools to the frame. This design allows direct fitment of tillage and planting tools to the toolbar used for either testing with the machine or testing with a small tractor.

Figure 6: Great Plains twin row unit hitched via 3-pt to an M9000 Kubota Tractor

Initially a true 3-pt hitch was designed to work exactly like a 3-pt on the back of a tractor, with two lift-arms and a single top-link (see Figure 7). Parts for the top-link and lift arms could be sourced from Tractor Supply Company, a local retailer that carries such parts that are a direct fit to some utility tractors such as an older 8N Ford. Instead of using hydraulics to lift the 3-pt., linear actuators could be used to raise the lift arms in order to be more easily controlled with a program without a lot of additional hardware. Two actuators working in tandem could be used to increase their lift capacity, but it would still be limited since the design of a 3-pt leaves the actuator at a mechanical disadvantage due to the geometry.

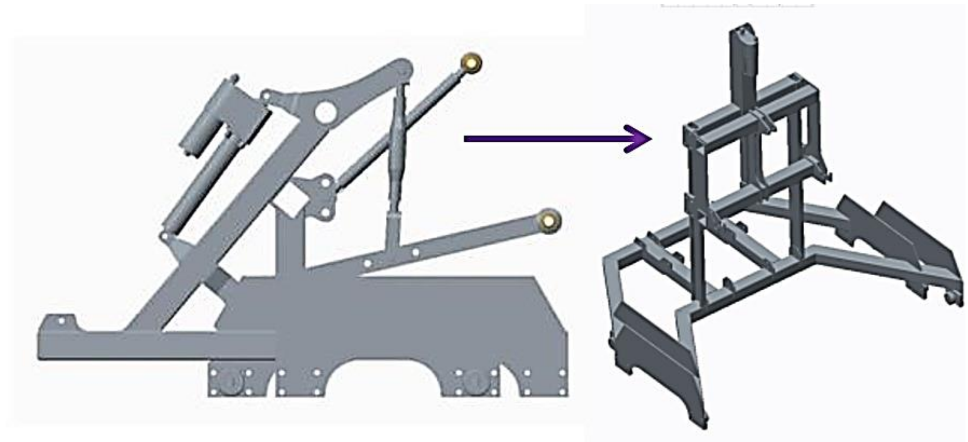

Figure 7: Three point hitch design

A true 3-pt hitch would work to raise and lower implements, and works on a tractor to give more ground clearance with longer implements when raised. However, the depth would be difficult to control for tests without the addition of gauge wheels which would interfere with the ability to measure downforce at the carriage with a single load cell. Also, a true 3-pt hitch would allow the tool to move a little from side to side, and wouldn't hold the tool rigidly, which would affect the data from tests by introducing unknown variabilities from unmeasured tool movement.

Create and Build a Prototype

To test the drive sprocket and fixed chain design and to learn more about the details of a gantry machine that is programmed, a concept of the machine in a scaled version was made (Figure 8). This test version gave a test run of the program, and aided as a stepping stone to get a better idea of what was needed for the design of the machine. The scaled version was a DC motor powered by a 12V battery that sat on a carriage. The DC motor with accompanying gearbox was mounted to a steel frame which mounted to the linear bearings that held the carriage. The 24T-35 sprocket was then mounted to the output shaft of the gearbox. This drive sprocket, along with two 19 tooth idler sprockets, to create sufficient chain-wrap around the drive sprocket, with a 35 roller chain, propelled the carriage of the gantry forward when the motor was turned on. The 35 roller chain was linked solidly to the rear of the gantry frame, and linked to an S-Type load cell that is mounted to the front of the gantry frame. Two constant force strip springs were selected to simulate a tillage tool draft load on the carriage. These springs were hooked to the carriage and to the rear of the gantry frame. The carriage was mounted on four linear bearings that were free to slide on two shafts that acted like the track. The design included the same design of the finished CAT App. of having a sprocket mounted on the motor and an idler sprocket on either side of the drive sprocket. This tested the designed set up of the draft measurement and the propulsion system for the CAT App. A LabVIEW program was developed to control the test machine.

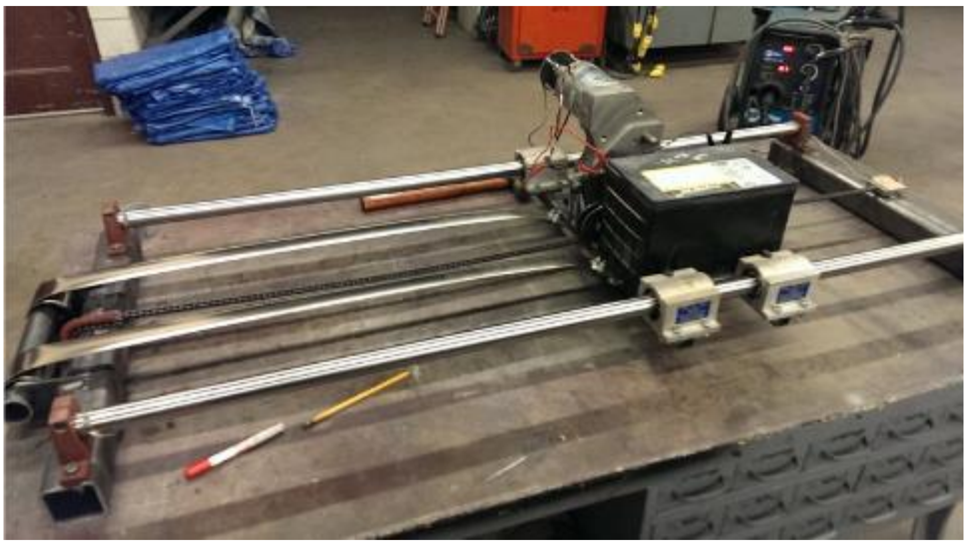

Figure 8: Preliminary model for testing design concepts of the machine

From tests on this initial prototype knowledge was gained about details involved with programming a carriage to move along a fixed track. Learned concepts from creating the code in LabVIEW for this initial prototype gave a better understanding of things that needed to be considered for the selection of components for the final design. Besides being helpful in learning LabVIEW details particular to this type of system, the initial prototype tested the function of the drive sprocket and idler sprocket configuration. From this prototype build it was shown that the drive system could be used in the final design due to its successful outcome in the initial prototype.

Chapter 3 - Final Design

In order to size the components of the final design draft forces of a wide variety of tillage and planting tools were calculated at speeds of zero to ten miles per hour. To calculate draft forces of various tillage and planting tools the ASABE standard for Draft Relationships for Tillage and Seeding Equipment (Harrigan, 1994) was used. All the tabled data from this standard was inserted into Excel, and the width of a single foot of that implement or a single tool was used for calculating the draft requirements of each type of tool. Conventional operating depths were used in the calculations as well. The calculations of the draft for the all the tools (excerpt of spreadsheet in Figure 9 below) were then used to calculate the size of the drive sprockets and the size of the chains used to propel the carriage down the track. Low duty cycles were expected for the chain so tensile strength of the chain was used for selecting the appropriate size of chain based on a Martin Sprocket and Gear, INC. Catalog 60, which had sizing and design information for chains and sprockets. 50 heavy (50H) chain was selected for the drive chains for the CAT App.

	Implement	Draft (lbf/ft)
13	**Implement**	**Draft (lbf/ft)**
47	**MINOR TILLAGE TOOLS**	
48	Rotary hoe	41
49	Coil tine harrow	17
50	Spike tooth harrow	40
51	Spring tooth harrow	135
52	Roller packer	40
53	Roller harrow	180
54	Land plane	550
55	**SEEDING IMPLEMENTS**	
56	Row crop planter, prepared seedbed	
57	Mounted-seeding only	110
58	Drawn-seeding only	200
59	Drawn-seed, fert. and herb.	350
60	Row crop planter, no-till	
61	Seed, Fert, and herb., 1 fluted	410
62	coulter/row	

Figure 9: Excerpt from draft calculations spreadsheet

Variable Drive

To provide a variable drive that was mobile, a hydraulic drive was chosen. To power the CAT App. it was decided to use a 31 Hp Briggs & Stratton engine due to its availability at a significant discount, and for its size. According to the draft calculations and hydraulic pump and motor combination calculations this amount of power would allow for a moderate selection of minor tillage and planting tools to be tested by the machine until a more powerful engine could be purchased with additional funding.

Draft calculations were also used to size hydraulic components for the CAT App. The pump and motor were sized to be able to supply the desired speed range and the most torque possible with the 31 Hp engine available. All the valves, hoses, and other components were sized for a flow capacity of at least 25 gpm and 2500 psi in keeping with the maximum output of the pump motor combination.

A schematic of the hydraulic system is given in Figure 10. Hydraulic flow is created by a 1.654 cubic inch per revolution Prince pump to deliver up to 24.3 gpm flow at 2500 psi to the 1.80 cubic inch per revolution Cross Hydraulic motor when the engine is set to 3500 rpm maintaining the motor below its rated max speed of 3000 rpm. A 30 gallon reservoir was available for use for the project and its capacity was found to be adequate during testing due to the low duty cycle of the machine. Full flow to the motor will allow a speed range of zero to 12.5 mph calculated with no load and no pressure loss through the hoses and other hydraulic components. At full pressure (2500 psi) the draft the motor is capable of pulling by the machine is 938 pounds based solely on the pump and motor's rated outputs. The speed and pull force are reduced to approximately a speed of 10.5 mph, and 795 pounds of pull force, if the machine would have an 85% efficiency of the hydraulic system in accordance with the formulas given by (Trinkel, 2014). It is important to note that the carriage itself puts a draft load on the machine when it is being moved and accelerated. The carriage's weight is approximately 1,200 lbs plus the weight capacity of the linear actuator of 786 lbs, giving a total weight of 1,986 lbs to be accelerated and pulled along the track in addition to the tool being tested.

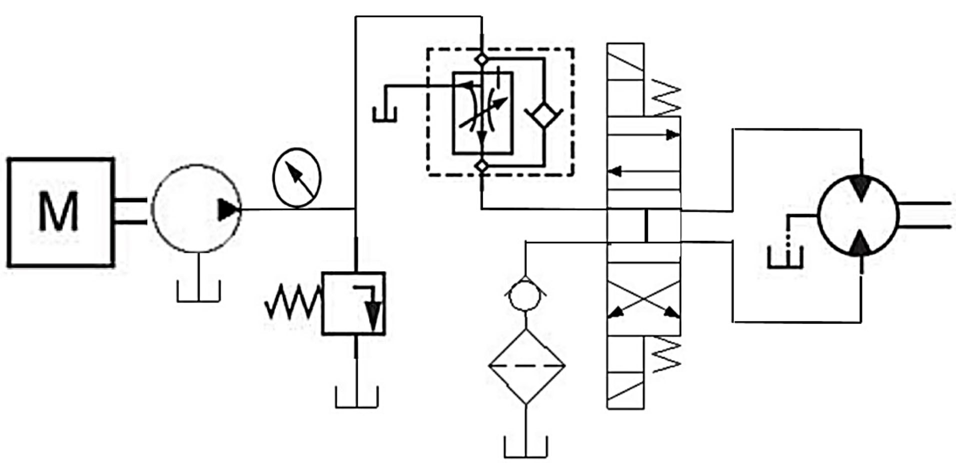

Figure 10: Hydraulic schematic the CAT App. hydraulic system

The hydraulic system's pressure is regulated by a Prince RV-2H pressure relief valve with a range of 1500 to 2500 psi (for component data sheets see Appendix A, for

Component pricing see Appendix B). The system uses a Brand Hydraulics flow control valve that can moderate the flow from 0-30 gpm. This flow control valve is electronically controlled by varying the amperage input to the valve. An Axiomatic solenoid driver (model number RSD-PCB-5V-1.2A) is used to either accept a voltage input from the potentiometer on the control panel, or a pulse width modulated (PWM) voltage input from the program. The direction of the carriage is controlled by a Northman Fluid Power directional control valve. This valve is a three position, double solenoid, open center direction control valve that switches between positions by supplying 12V to either solenoid. The direction control valve is mounted on a Northman Fluid Power single-station subplate (model number M03-06-S-2) to allow easy plumbing to the motor with hydraulic hose with ¾ in NPT ends. The open center position of the direction control valve allows for the pressure to be removed from the system in the center or neutral position of the valve. This free flow of fluid through the system in the neutral position reduces component wear and reduces the amount of heat added to the oil while the machine is between tests. A summary of the specifications for the CAT App. can be seen in Table 1 below.

CAT App. Specifications	
Overall Track Length:	42 ft.
Overall Height:	81.5 in.
Overall Width:	80.5 in.
Available Test Length:	36 ft. 6 in.
Available Test Width:	60 in.
Rated Engine Power:	31 hp
Hydraulic Reservoir Capacity:	30 gal.
Operating Pressure:	1500 - 2000 psi
Speed Range:	0-8 mph
Maximum Draft:	700 lbs

Table 1: CAT App. specifications

Track

The track type was inspired by a roller coaster track design and was a cost reduction from the earlier I-beam design giving a track and bearing material cost savings of $1611.53. This cost savings is only the difference in material costs; differences in fabrication costs were not part of the calculated budget since the labor wasn't outsourced. There are three parts to the track; the track support frame made from four inch square tubing with ¼ inch wall thickness, a three inch schedule 80 pipe for the carriage to follow, and bracing supports that tie these two pieces together. Increased wall thicknesses were chosen to provide frame strength during transportation and to weigh down the track so the machine could apply adequate downforce to keep tools at the desired depth without picking up the track or sliding the track with the pull force of the carriage instead of moving the tool in the ground. The track is made of 4 pieces of track that are 20 feet long (the three inch pipe sticks out an additional foot in each corner of the track). Each of these pieces weighs approximately 500 lbs. The front and back halves of the track are held together with a three foot piece of 3.5 inch square tube with a ¼ inch wall thickness that slides into the mating 4 inch square tubes on each side. Four ¾ inch bolts on each side of the track are used to hold the two halves together.

Since the track was the component of the machine that was most critical to be able to withstand the loads it would see during transportation, a Finite Element Analysis (FEA) study was done on the track. To make sure the track could withstand the loads it would experience a worst case scenario was assumed during the study. This scenario would be supporting the weight of a fully loaded carriage (1200 lbs) with the dynamic weight limit of the linear actuator (786 lbs) on the hitch. For the study one side of the track was isolated. It was then supported at both ends and loaded with half the load of the carriage and half the linear actuator dynamic load limit. Originally the supports between the four inch square tubing and the pipe were set at 24 inches on center. After analysis the span between the supports was reduced to 10 inches on center to reduce the stress on the welded joints of the supports to the pipe and the square tube. With this spacing the stress on the joints was reduced to approximately 30,500 psi (Figure 11). The material that was used for the construction of the CAT App. is ASTM A36 structural steel. This material has a yield stress of 36,000 psi. This gives a factor of safety for 1.18 for the tracks before yielding occurs. The worst case scenario loading should rarely be seen, if at all, since the track is on the ground during testing, and the axle is mounted below the carriage during transport, so none of the carriage weight is on the suspended area of the track during transport.

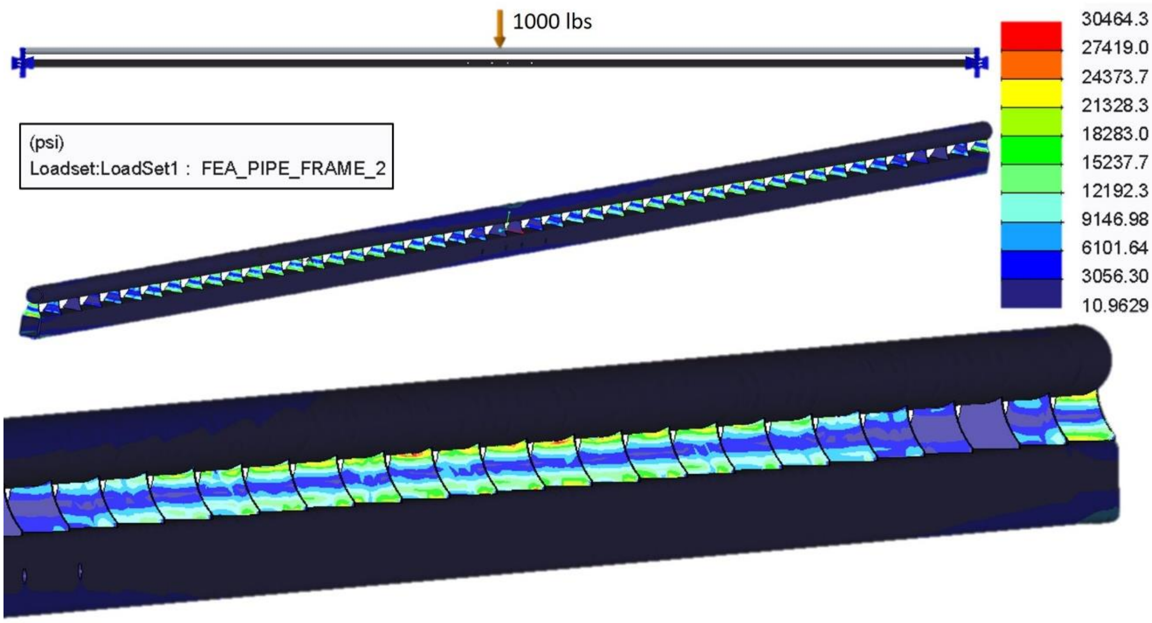

Figure 11: FEA static analysis

The carriage runs along the track via four “tri-caster” wheel units. These units are removable from the carriage while the carriage is still on the track. The topmost wheel of each unit supports the weight of the carriage and the tool being tested. The two side caster wheels of each unit, located 120 degrees from the top wheel, keep the carriage aligned while going down the track. At either end of the track these units act as a carriage stop with the end track pieces that hold the two sides of the track together. A ¾ inch bolt on each side is used to mount these end of track pieces to the frame, which can be seen in Figure 13.

Carriage and Hitch

The carriage was made to house the hydraulic system and keep all the components together with the toolbar and hitch as the carriage moves along the track. This design of the carriage simplifies getting the power to the toolbar and allows for the chains used to propel the carriage to be stationary, eliminating safety hazards of long chains moving at fast speeds. The design also reduces the number of cables or hoses that need to be hooked to the carriage from the track to only the two cables for the two draft measuring load cells at the end of the track. This reduces the weight and complexity of having multiple long hoses and cables span the entire length of the 42 foot track. The carriage is built around a rear axle out of 2001 Ford Explorer which allowed for a simpler design. This axle provides a gear box for necessary reduction of 3.73:1 from the hydraulic motor, and a means by which to get that power to the drive sprockets that engage the chain along the track. The axle is also the main structural component between the two sides of the track, supporting the hitch and hydraulic system as seen in Figure 12. In addition, the axle comes with outboard disc brakes that can be used for slowing the carriage at the end of a test at a higher speed.

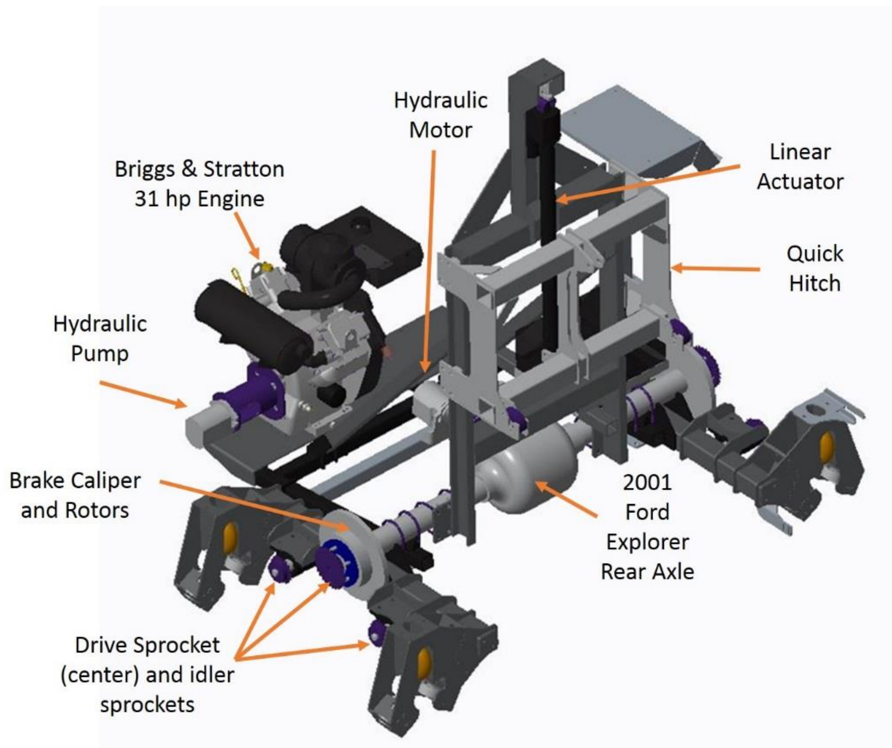

Figure 12: Carriage of the CAT App.

The hitch, as shown in Figure 12, is a vertical hitch that acts much like a mast on a forklift. A type of quick hitch was made to accept Cat. 1 3-pt toolbars. Dimensions for the quick hitch were pulled from the ISO 730 Standard for 3-pt hitches (Clark, 1968). Category 1 3-pt was chosen in order for the CAT App. to accept small utility implements built for utility tractors under 50 Hp. The quick hitch allows for easy hook up of different tools that can also be hooked up easily to a tractor, and prevents the tool from moving in any direction except up or down when controlled by the operator.

To move the hitch up and down a Nook (model number ND8-24-10-B-610-LT-POT-IP65) ball bearing linear actuator is used. The actuator has 24 inches of travel and a dynamic weight capacity of 786 lbs in either direction. The built-in potentiometer in the actuator allows hitch height to be read directly from the actuator's position. The hitch is mounted to a 1200 lbs S-type load cell that allows the weight of the tool to be measured and any reduction in that weight or additional force applied to put the tool in the ground and maintain that tool depth giving the downforce requirement of the tool. A complete model of the CAT App. track and carriage can be seen in Figure 13.

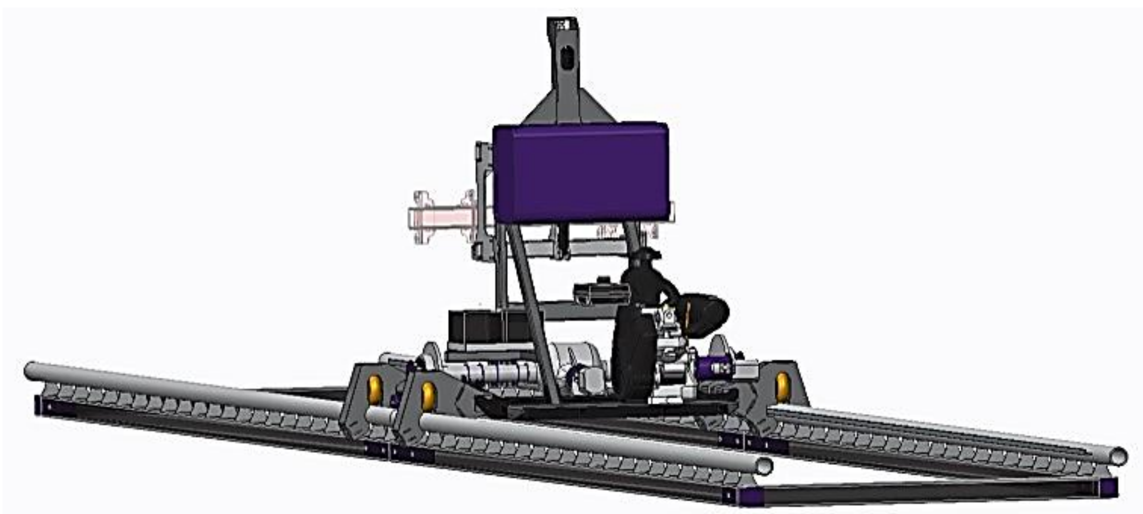

Figure 13: Full view of the track and carriage

Mobility

To make the CAT App. mobile a 2-5/16 inch ball bumper hitch was attached to the front of the track using two by four inch rectangular tubing with a 3/16 inch wall thickness in an A-frame configuration. A telescoping jack was installed in the hitch for safety and ease of unhooking the CAT App. from a tow vehicle, whether in trailer or testing mode. A used 10,000 pound trailer axle was available to mount under the CAT App. for transporting it. To attach the axle, angle iron pieces are inserted into the track between the square tube and the pipe and below the square tube. These angle iron pieces are then clamped around the square tube using a ½ inch bolt as seen in Figure 14. The pipe support pieces of the track act as a means to prevent the axle from sliding forward or backward during transport. In the last stages of the project two 6,000 pound axles replaced the 10,000 pound axle to lower the center of gravity and make axle removal easier and safer.

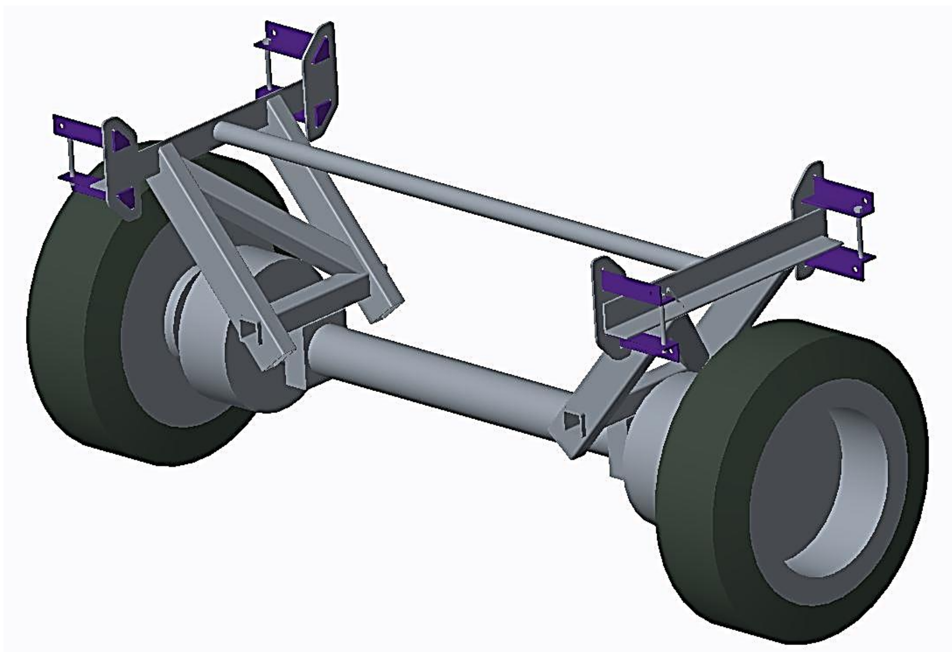

Figure 14: 10,000 pound axle with hardware used for transporting the CAT App.

To put the CAT App. into trailer mode, the carriage is moved into position 10 feet in front of the back end of the track. Here the carriage is bolted to the track to lock it into position. This positioning puts the carriage in the middle of the back section of the track and puts the carriage directly above the axle location. The back of the machine is then raised with a forklift or a front end loader. While raised, the axle is put into position under the carriage to reduce the weight carried by the track, limit the weight on the hitch of the tow vehicle, and allow the machine to follow the tow vehicle better around sharp turns. Once the weight is fully on the axle, the angle iron brackets are put into place and tightened together to securely attach the axle to the track. The CAT App. is now in trailer mode as depicted by Figure 15. The process to change between testing mode and trailer mode of the machine for transporting takes 20 minutes with one person.

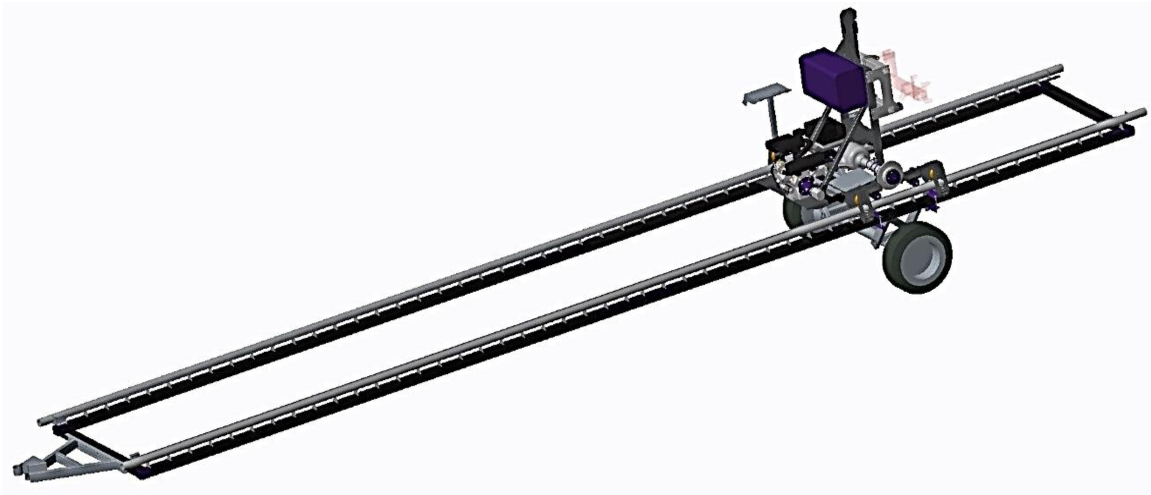

Figure 15: CAT App. in trailer mode - on axle with bumper pull hitch installed

Fabrication and Design Details

All the fabrication of the CAT App. took place in the Kansas State University's Biological and Agricultural Engineering Department shop. Major tools that were utilized for the fabrication of the CAT App. included the following:

- PlasmaCAM CNC plasma table with Hypertherm Performax 65
- Torchmate CNC plasma table with Hypertherm Performax 65
- Haas TM 3P CNC mill
- Harrison M400 lathe
- Miller 251 and 200 MIG welders
- Drake 50 ton Press

After the designs for the track and most of the carriage were completed, materials were acquired to begin fabrication. The tracks were the first things to be made. This gave a framework for the rest of the project to be built around. To ensure equal spacing and accurate placement of each track support a jig was made that could be clamped to the previous support and straddle the square tube the necessary distance, and then the next support to be welded to the square tube could be clamped in place to the jig, and welded. After the supports were all welded in place, the pipe was laid on top of the supports and clamped firmly in place. One edge of the pipe was aligned flush with the square tube.

This pipe end would be the middle of the track. The other end of the pipe was allowed to stick over the edge to provide for a mounting location for the either end of the chains that would be used to propel the carriage forward.

Once the four track sections were built, the joining 3.5 inch square tubing piece was made and the tracks were joined together in the middle to form two 42 foot halves of the track. The end track pieces were made after the base of the carriage was installed on the track. This ensured that if the final dimensions of the fabricated carriage had any variance from the model, the carriage would still fit without complex alterations.

After the track was built, work began on the heart of the machine, the carriage. The pieces for the carriage were formed as needed. Then the tab-and-slot design was utilized for fitting the parts together along with using the casters to bolt pieces together to ensure proper alignment. All four of the “tri-caster” units were welded together as separate units, then the formed parts that made up the interface where these units could be bolted or unbolted from the carriage assembly were bolted together to ensure proper alignment. Sections of square tubing and pipe were then used as depicted in Figure 16. This process was used to ensure that all four of the “tri-caster” units would be uniform and aligned when welded in their proper place as part of the carriage assembly.

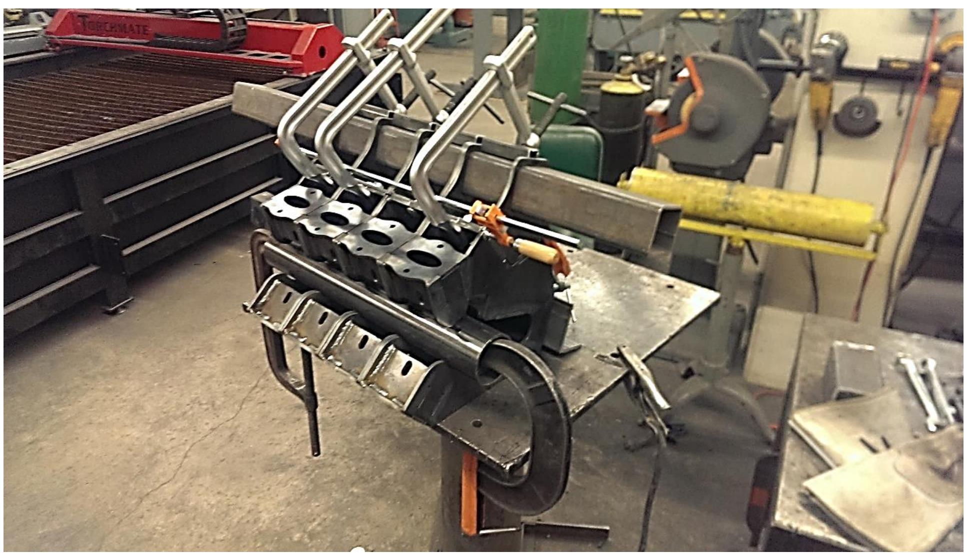

Figure 16: Alignment clamping of the four "tri-caster" assemblies

The idler sprocket bearing mounts and the “tri-caster” assemblies were then welded onto the two 3 inch square tubes that bolted to the axle via two 3/8 inch plates that were welded to the axle itself. After these few items were in place the axle assembly was beginning to take the shape of what would be the carriage. This assembly, seen in Figure 17 with some additional parts clamped to it, was installed on the track and tested for fitment and for how it would run up and down the track. During these tests the base carriage ran smoothly along the track only catching a little in the middle of the track. This catching was developed by the track pieces “smiling” due to the top side being the only side that was welded on the square tube. With all the welds on the top side of the tube, the top of the tube contracted, pulling the ends up. This causes a slight rise in the track ends and the middle of the track.

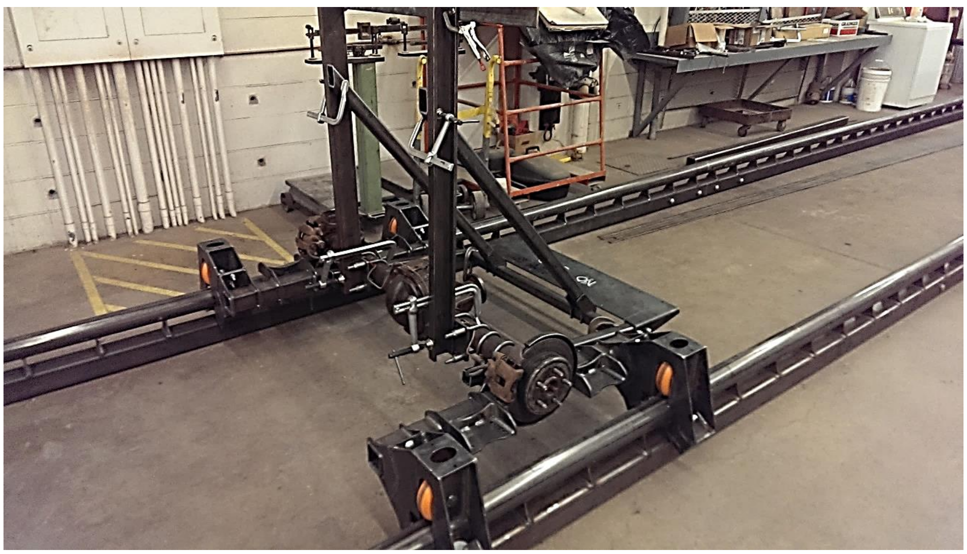

Figure 17: Carriage taking shape

After the axle was installed on the track, the engine mounting plate was installed. It was U-bolted on to the rear axle where the leaf springs would normally be attached. At this time it was observed that the engine mounting plate was only attached at the axle, and that additional support could be easily gained by tying the square tube of the engine mounting plate to the front of the 3 inch square tube used to hold the “tri-caster” assemblies on. This tie-in supported the hitch and the engine plate more rigidly to reduce vibrations and strain on the U-bolts holding things to the axle, by supplying a true node for the front hitch mast brace instead of it being braced only by a moment about the axle. The hitch mast was then clamped in place, and the supports for the mast were clamped to it to make the mast perpendicular to the ground as seen in Figure 17. The supports were then welded in place and the hitch mast was welded to its mounting plates.

The quick hitch was then fabricated. The combination bearings were welded to their mounting plates and then temporarily installed for fitment of the parts to the mast while things were only tacked together. After everything was aligned the hitch was welded to completion and used for final measurements for the design of the mounting of the linear actuator.

The next thing that was fabricated was the mounting for the linear actuator on top of the mast. This mounting was designed in conjunction with the mounting for the hydraulic reservoir during fabrication, as it wasn't sure how things would fit or line up until things were installed, since the reservoir mounting bracket and straps were used from a previous use of the reservoir, and the time wasn't taken to reverse engineer this bracket. The actuator was then mounted to the S-type load cell that would measure draft and the load cell amplifier was mounted nearby. The actuator could then be used to hold the quick hitch.

While the carriage was on the track, the carriage was used to hold the tracks where they needed to be. The track ends were then cut to length and welded in place. To set the square of the track, the track end was clamped to the flat sides of the "tri-caster" assemblies facing the track end. The carriage was then positioned in place to set the length of the track then clamped in place. This ensured the track was square to the carriage and that there was no pinching or pulling of the carriage by the track. The joints of the four inch square tube that made the track end and the two 3.5 inch square tubes that slid in the end of the track segments were then welded together. The holes were then drilled for the ¾ inch bolts to hold the track ends to the track.

The carriage was also used as a jig when welding on the angle-iron pieces that hold the drive chains in place and the flat strap that holds the cable chain along the track frame. To make sure the pieces fit properly through the carriage, two jigs were made to clamp to either side of one of the "tri-caster" assemblies. Next the material being welded in place was clamped to the jigs. This jig set the placement of the piece so it could be welded to the track. Once welded, the piece was simply unclamped from the jig, then the carriage was rolled forward, then the piece was clamped to the jig in the new location and welded there. This process, and use of the carriage as a jig along with other jigs sped up the fabrication of the machine in a safe way, and ensured everything fit together according to the model.

The placement of the hydraulic components came next. The engine was mounted to the engine subplate, then the pump and motor mounts were made. After these were mounted, the routing of everything else had to be solved. It was decided to put a plate down that could be U-bolted to the engine mounting support frame, and all the hydraulic components could be bolted to this plate. As seen in Figure 18, the steel mounting plate U-bolted in place with paper taped to it--used to mark the locations of each hydraulic component. The plate was then taken off and the marked mounting holes were drilled. Then each component was installed with corresponding hardware. Once each component's place was known the required fittings were ordered. During installation of all the fittings and hoses Loctite 545 hydraulic thread sealant was used on all pipe thread (NPT) connections.

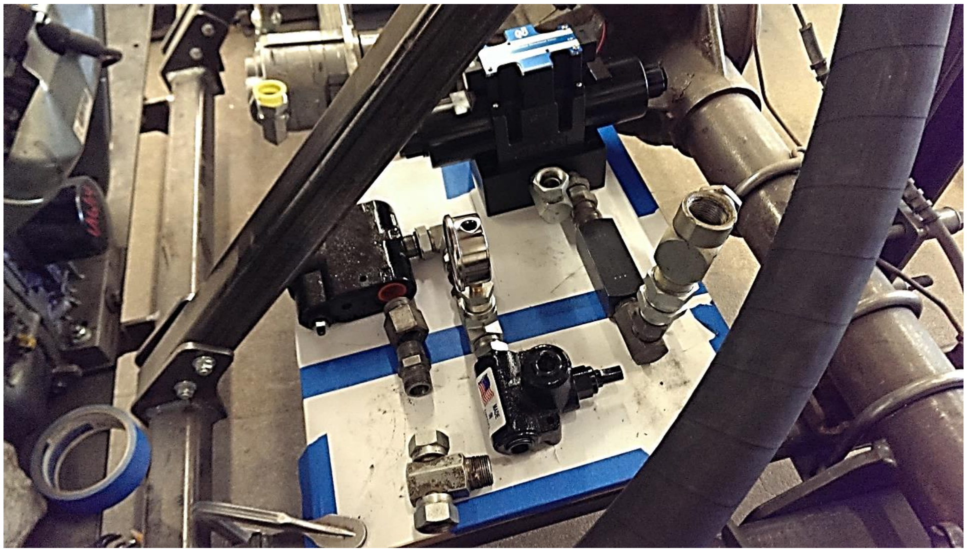

Figure 18: Layout of the hydraulic components

After the hydraulic system was plumbed, assembled and filled with fluid, the wiring was done to hook up all the controls. To house the controls for the manual control of the CAT App. a control panel was made (Figure 19). The control panel is mounted to the top of the front right "tri-caster" assembly. The stand of the control panel is a piece of 1/8 inch wall two inch square tubing. Holes were cut on the top and bottom of the control panel upright to allow the wiring to be ran inside the tube to keep it organized and safe from getting caught in moving parts, as well as out of sight as much as possible. The controls on the control panel include:

- Hitch (raise, stop, lower) – rocker switch
- Direction control valve (forward, neutral, reverse) – rocker switch
- 12V power to controls – safety toggle switch
- Engine start – Briggs ignition switch
- Flow control valve – potentiometer wired to solenoid driver behind panel
- Digital engine tachometer
- Fuse block – behind the panel out of sight, fuses for each component

As part of the control panel, the top was designed to hold a laptop that would be the user interface to run the machine in automatic mode.

Figure 19: First time the CAT App. was operated with all the manual controls

When everything was wired up the machine was started for the first time. It was run under its own power the entire length of the track. At this time a few safety and design concerns were noted. First, the track seemed a little on the short side for high speed testing, which was a concern from the beginning--thus the modular track design to allow expansion of the track. Second, the carriage was prone to slam into the end of the track when coasting without a load. Limit switches were added to kill power in the event either end of the track is reached. For further development the caliper brakes of the rear axle could be integrated into the control of the machine to aid in test sequences to slow the carriage after a test, and to allow for a parking brake on the machine to enhance safety. Another observation from these initial machine runs is that it's important to keep the ball valves open on either end of the reservoir unless the system needs to be opened for service. During a follow up test of the function of the hydraulic system the valves were unknowingly closed prior to the test. When the engine turned over a couple times, before the engine even started, the oil filter popped off the threads, making the mess shown in Figure 20.

Figure 20: Oil spill from popping threads on oil filter

When the filter was replaced and all the hydraulics were back together,the system acquired a perpetual drip. The cause of this has been concluded to be overtightening of the NPT fittings. To address this the fittings should have been torqued correctly, or a different style of fittings chosen such as SAE or JIC fittings.

After function of the machine was tested, the machine was disassembled and prepared for paint. Hecht Interior Painting donated time, equipment and expertise to paint the track and the larger components of the carriage. After the paint cured, the machine was reassembled.

Once reassembled the program was tested on the machine in the location shown in Figure 21. After the program was proven to be functioning, with no load, it needed to go to the field to be tested with a load. In order to get the machine to the field the mobility aspect of the machine needed to be made. First the hitch was made then the axle was built. Before the machine could be raised to place the axle in position the carriage needed a way to lock it in place. The locking device designed to hold the carriage in place during transport are tabs bolted to each of the "tri-caster" assemblies which are then bolted to the pipe of the track.

Figure 21: Assembled CAT App. after painted

Chapter 4 - Control

The CAT App. is a closed-loop controlled machine using sensors for feedback, hardware that could be controlled electronically, and a microcontroller to process all the inputs and outputs. From the experience gained with the initial prototype, LabVIEW was used as the programming language, and a National Instruments (NI) myRIO-1900 was used for the microcontroller. As already mentioned, hydraulic components requiring control were selected with the capability of controlling them with Proportional, Integral, Derivative (PID) control, Pulse Width Modulated (PWM) or simply 0 or 12 volts for on or off controls respectively.

LabVIEW 2013

LabVIEW 2013 was used to create a program that would control the CAT App. (see Appendix C for pictures of the LabVIEW block diagram to see the code). The speed was controlled through the use of a PID control. A PWM signal was used to control the linear actuator in conjunction with the SyRen motor controller (see Appendix A for component data sheets, and Appendix B for prices and sources). A relay board was used to handle all of the higher load switching for the direction control valve and the linear actuator.

The front panel of the LabVIEW program (Figure 22) was designed to show the PID control graph, which shows the desired speed, the actual speed, and the PID output. The front panel also displays the left and right draft forces via a gauge, as well as the weight on the hitch. Also displayed on the front panel are the speed output, the carriage position, the hitch position, and an error message that alerts the operator if the files are not saving to the flash drive after each test. The controls on the front panel include the proportional and integral gains, the set speed for the test, and the direction of the carriage. The hitch was controlled by rocker switch on the control panel but could be added to the front panel for more automated tests. The last control on the front panel is the “stop” button which ends the program and saves the txt file to the flash drive.

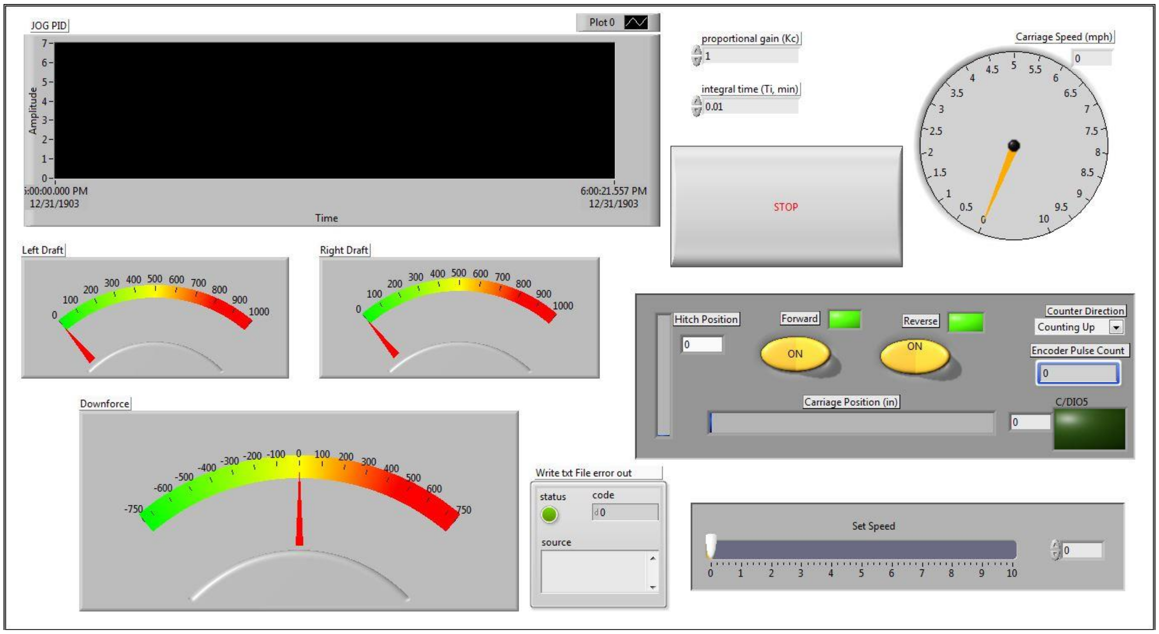

Figure 22: Front panel of LabVIEW program used to control the CAT App.

NI myRIO-1900

As seen in Figure 23, a sealed toolbox was used to house the NI myRIO-1900 microcontroller and the rest of the hardware to control the CAT App. and to collect data. All the power and sensor connections were made at two connectors at the back of the box, making the hardware easy to remove for diagnosis of the program in the lab. A laptop running the LabVIEW program was placed above the control panel and strapped down to secure it. This location of the laptop allowed everything to be monitored and controlled by the operator at one spot.

Figure 23: CAT App. with laptop running LabVIEW and the control box housing a National Instruments MyRio microcontroller and the hardware to control the CAT App.

Sensors

The CAT App. measures and records: the carriage speed, the downforce being put on the tool to keep it at the desired depth, and the draft of the tool as it is pulled during the test. The speed of the carriage is measured by an ACCU-CODER quadrature optical encoder (part number 260-N-T-10-S-1024-Q-PP-1-S-FA-1-N) with a 1024 pulse count per revolution mounted on the front right idler sprocket shaft. This encoder was available for use from a different project, so it is not included in Appendix B. To measure the draft of the tool being tested, two chains lay inside the track and were attached to the front of the track via two Phidgets 1,210 lbs (550 kg) S-type load cells (part number RB_PHI-204). An identical load cell was mounted to the top of the mast of the carriage to support the linear actuator and the quick hitch that the actuator raises and lowers. This load cell was used to measure the downforce of the tools being tested. Next to each load cell a SMOWO RW-STO1A load cell amplifier was mounted and wired in-line to ensure signal noise reduction to the myRIO for cleaner data.

The hitch height was measured from the voltage output of the built-in potentiometer of the Nook Industries N08-24-10-B-610-LT-POTIP165 ball bearing linear actuator. The actuator was controlled by a SyRen 25A regenerative motor driver, from

Dimension Engineering, by a set duty cycle (one for raise, one for off, and another for lower) and frequency in the LabVIEW program for either the raise, off, or lower. The power to the actuator was turned on and off via the Progressive Automations' LC-202 8-channel relay module that was controlled by the myRIO's output signal. The relay module was also used to actuate the solenoids on the direction control valve.

The speed of the carriage was controlled by the flow of the system to the hydraulic motor. This flow was regulated by the Brand 0-30 gpm flow control valve. This valve was controlled by the current output of the Axiomatic solenoid driver. The solenoid driver takes a PID output signal from the myRIO.

PID Control

The output of the PID controls the flow control valve output flow to the hydraulic motor on the pinion of the gearbox driving the CAT App. forward or backward. Having this control over the flow enables the carriage to move at a specified speed in either direction of travel. The PID increases its output until the speed, calculated by the encoder signal, is matching the desired or set speed. During a test the operator can select from the front panel the set speed for the test, and the desired direction of the carriage. The selection of the direction begins the test.

Tuning the PID Control

Initial tuning of the PID control was done by taking the chain off the drive sprocket on the right side of the track. The differential of the rear axle allowed the power to be directly transferred to the one side, and the other side being locked at a stop would allow true speed measurement of the free side. A short chain was then made to wrap around the drive sprocket and the idler sprocket with the encoder attached to it. This arrangement allowed the machine to be operated without movement of the carriage to define the range of the hydraulic system PID gains more closely to make the tuning of the machine safer for tuning the system with the entire carriage moving. After this was done, the mass of the carriage was taken into consideration. The small chain was removed and the drive chain was reinstalled. While running the machine on the track alone, the tendency for the machine to coast became evident, especially since the area where the machine was parked had a slight grade due to a nearby drain. With the coasting, the control of the machine had to be changed to not reverse the direction of the motor if the speed was too far above the desired speed. The control algorithm was changed to approach the desired speed and then letting the PID control the speed instead of the hydraulic valves. This change resulted in much smoother results. From these tests with the carriage the proportional gain was set at 0.1 and the integral gain was set at 0.01.

The next phase of tuning the PID control of the carriage speed was adding a load. During the first experiment, tests were run at lower speeds obtaining a 0.4 to 0.6 mph threshold for the 0.5 mph desired speed. Higher speeds noticed more fluctuation as well as the machine struggling to get to the desired speed. A higher proportional gain was found to bring the machine to the desired speed faster, but would soon exceed the desired speed giving an erratic behavior of the speed creating a lot of periods of accelerating and decelerating during the tests as seen in Figures 24.

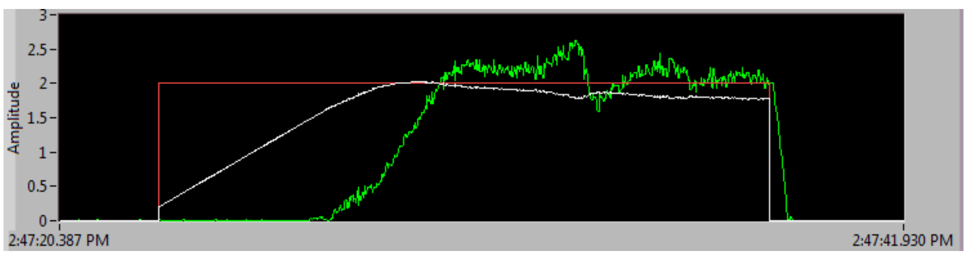

Figure 24: PID speed control high P value, Desired speed 2.0 mph (red), PID output (white), Actual Speed (green)

To do an analysis of the speed fluctuations from experiment one, all the data points--from the time the carriage reached the desired speed until it started its final deceleration--were compiled. The average of the draft and of the carriage speed was then calculated for each test at each set speed, getting a total average of actual carriage speed at all three tests done at each set speed. These results indicated that the machine was underpowered, since changing the gains made the problems worse, and that the engine was struggling to reach the higher speeds.

To verify this conclusion, a controlled load testing device was constructed (Figure 25). Originally, the device was hooked to a tractor via a 3-pt hitch, and the two hoses from the motor were connected to the tractor's hydraulics. The motor, a Sauer Danfoss

OMT 250, and tire assembly were mounted on a frame that was free to slide forward and backward on linear bearings. A load cell was then connected between the sliding frame and the frame hooked to the tractor. The tractor hydraulics were used to drive the tire, then the operator could lower the spinning tire down to the ground to measure the traction or pull force of different tire types or tread patterns.

Figure 25: Wheel apparatus for applying controlled load to CAT App.

To alter this device to be a controlled load for the CAT App. the hydraulic hoses were removed and replaced with a small closed system. A one-gallon reservoir was made and the supply hose was plumbed to the hydraulic motor. The return of the hydraulic motor was plumbed to a pressure relief valve, which is connected to a "T" fitting with a pressure gauge. On the other side of the "T" fitting a needle valve was connected, and finally a hose connected the needle valve back to the tank. This system allowed the wheel to build pressure in the system, to an amount specified by the setting of the needle valve, while the wheel turned as it was being pulled by the CAT App. Weight for more traction could be added on the weight rack to force the tire to spin under the system pressure instead of skid along the surface of the ground.

The drive sprocket ratios were manipulated to allow the device to build adequate pressure to load the machine, and to also get a high enough pressure reading to be able to adjust it for different load settings. Four different ratios were tried, ranging from 1:4 to 4:1. The optimum ratio was found to be at a 2:1 reduction from the wheel to the hydraulic motor. This ratio, along with 270 pounds of ballast allowed the CAT App. to pull a draft load of 425 pounds, similar to that seen by the Horsch single row unit, with the system pressure of the wheel device at 400 psi. At 800 psi the device can stall the CAT App. if sufficient weight is added to maintain traction by the wheel. Figure 26 shows the data from the CAT App. pulling the wheel device with the 270 pounds of ballast and the pressure set at 400 psi with the needle valve. The desired speed was set at 0.5 mph depicted by the light blue line.

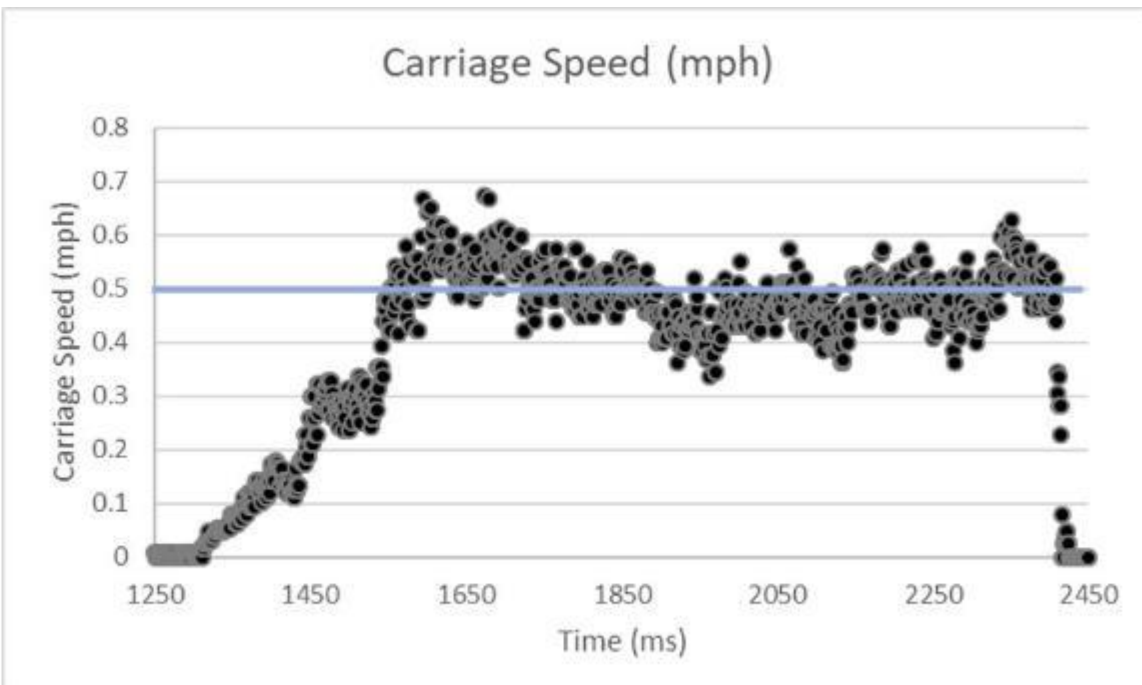

Figure 26: Test data from constant load on CAT App.

The fluctuation in speed from 0.3 to 0.7 mph during the pull is evident from the data. The speed makes a sine wave as it tries to hit and maintain the set speed. In higher speed tests this fluctuation is amplified, and the machine runs out of test length before the speed stabilizes, preventing the collection of consistent data. At higher speeds a lower proportional gain does not allow the carriage to ever reach the desired speed within the length of the track.

After testing in the two experiments it was noted that the potentiometer gain sets on the solenoid driver may be limiting the PID output. Also, Figure 24 shows that the PID output is not ramping up quickly to its 5V maximum to get the carriage to the set speed. This limits the acceleration of the machine. The ramp setting on the solenoid driver needs to be modified to see if the PID output can be more responsive to the speed. By the time this discovery was made there wasn't enough time available for further, investigation of the PID tuning and the solenoid driver settings. Changes in these settings should yield a machine that is better controlled for comparative and repeatable tests with much cleaner data.

Chapter 5 - Experiment One

To determine the relationship between planter draft and planting speed, a study was done at the Kansas State University North Agronomy farm. Tests were completed with use of the CAT App. These tests included the use of a Horsch planter row unit (Figure 27). Tests were completed in a no-till field at the North Farm after soybean harvest in early December 2017 (see Figure 28). Information was collected by the MyRio microcontroller through the LabVIEW program then imported into Excel for analysis.

Draft of a single planter row unit was compared to the planting speed of that row unit using data from these tests. The relationship between planter draft and planting speed indicates if a reduction in power requirements should be investigated to optimize row unit design for different planting speeds.

Equipment

In order to determine the presence of a relationship between planter draft and planting speed, tests were done that recorded the draft of the row unit at different speeds. A Horsch Maestro planter row unit (Figure 27) was used for the testing tool. To control the active downforce system of the row unit, hydraulic pressure was supplied to the row unit's downforce control system by the CAT App. The row unit was equipped with gauge wheels, opening discs, and closing wheels. The firming wheel was not installed for these tests. Neither were trash cleaners installed on the row unit. Seed was not planted during tests, which is independent of the row unit to ground interaction since the Horsch seed meters are electronically driven and not ground driven.

Figure 27: Horsch planter row unit with Yetter row cleaner

Planter Settings

For this study the planter row unit was set at a depth of two inches, at the number "7" pin location. The active downforce was set at 180 pounds on the gauge wheels by the Horsch control screen. The closing wheels of the Horsch row unit were set in the second notch back away from the gauge wheels. The firming wheel was removed to allow the test to deal with those components most common to various planter manufacturer's row units: gauge wheels, double disc openers, and closing wheels. The parallel linkages of the row unit were set to be parallel with the surface of the ground during the experiment. During the tests no seed was planted, nor was there any vacuum provided to the seed meters.

Field Conditions

Tests were done in a no-till field at the Kansas State University North Agronomy farm. Soybeans were harvested from the field the year of the tests. All testing was done in the area depicted by Figure 28, below the first terrace of the field. The GPS location of this site is 39°12'46.1"N 96°35'49.5"W

Figure 28: Google maps picture of the field where testing was completed. Area in red encompasses the area of the field that was tested

During the tests the soil VMC (volumetric moisture contact) reading measured on an average of 3 probes near the soil sample collection areas: 21.2% on the East end of the site, 12.9% in the middle, and 16.4% on the West end of the site. The soil data from the Kansas State Soil Testing Lab is summarized in Table 2. From these results the area tested ranges from a Silty Clay to a Silty Clay Loam.

Lab # (s)	Sample Name	pH	SMP pH	OM LOI %	P-M ppm	K ppm	Sand %	Silt %	Clay %
305327	East	6.3	6.4	3.4	7	246	12	48	40
305328	Middle North	7.5		2.8	14	206	18	46	36
305329	West	7.3		2.8	5	153	16	52	32

Table 2: Soil data from the Kansas State Soil Testing Lab as of December 20, 2017

Procedure

Tests to acquire data of the draft and speed the row unit was being pulled at were set up as follows: three tests were conducted at every speed with speeds in the range of 0.5 mph to 6.0 mph at 0.5 mph increments. Faster testing speeds were desired, but during testing, the CAT App. was limited by power and rail length to achieve those speeds for a long enough duration for the acceleration to transition to a constant speed. The CAT App. was pulled forward by a tractor after each test, so each test could be done in a new location in the field that was undisturbed.

During a test the carriage was moved to the "Home" position of the track, where the encoder was reset to zero. Then the carriage was moved forward to where the closing wheels of the row unit would just clear the frame of the CAT App. track. Here the linear actuator was extended to lower the row unit until the parallel arms were level to the ground. The 24 inch linear actuator was extended until it was 2 inches from the limit of its travel. This position was denoted as 2 inches above the lowest possible hitch point of the CAT App. on the LabVIEW front panel where it could be monitored. This was the hitch height setting for all tests as shown in Figure 29. After the hitch height was set the engine of the CAT App. was set to full throttle, which was 3400 rpm. The hydraulic system was then pressurized by screwing down a built-in needle valve that is before the return to tank. The needle valve was screwed down until the system was at 1500 psi. This pressure was enough for the hydraulic cylinder, supplying the active downforce to the row unit, to push the opening discs into the ground far enough to put pressure on the depth setting pin. After everything was set and ready, the set speed was chosen. Then the "Forward" button on the front panel was clicked to direct oil flow to move the carriage forward. The PID then ramped up its output until the set speed was reached by the carriage. Towards the end of the track the operator then had to click the "Forward" button again to shut flow off to the hydraulic motor powering the carriage to allow the carriage to coast to a stop by the end of the track.

Figure 29: Side view of the CAT App. carriage as it is performing a test at 0.5 mph with the Horsch Row unit

The proportional gain was set at 0.09 for the 0.5 mph tests, 0.25 for tests in the 1.0 to 4.5 mph range, and at 1.0 for the speeds 5.5 mph and above. During the 5.5 mph tests different proportional gains were tried (0.25, 0.3, and 0.5). During testing it was found that higher proportional gains allowed for increased acceleration of the carriage, but this increase was limited by the power of the 31 Hp Briggs & Stratton of the CAT App. The integral time was held constant at 0.01 throughout the study. The derivative time was set at the default of zero.

Chapter 6 - Experiment Two

To better understand what the relationship is between planter draft and planting speed, and the performance of the CAT App., a second experiment was done at the Kansas State University North Agronomy farm. Tests were completed with use of the CAT App. These tests included the use of a Great Plains twin row units (Figure 39). A National Instruments' MyRio was used, and the same LabView program was used for this experiment as was used for experiment one. Tests were completed in the same no-till field at the North Farm, but a year later after corn harvest in late October 2018 (Figure 28). Information was collected by the MyRio microcontroller through the LabVIEW program, then imported into Excel for analysis.

Draft of the twin row units was compared to the planting speed of those row units using data from these tests. The relationship between planter draft and planting speed will support the previous experiment's findings as to if a reduction in power requirements should be investigated to optimize row unit design for different planting speeds, as well as to help determine the power requirements of the CAT App.

Equipment

In order to determine the relationship between planter draft and planting speed, tests were done that recorded the draft of the row units at different speeds. A pair of Great Plains twin row units (Figure 30) were used for the testing tool. The downforce springs were set at their maximum setting for the duration of the experiment. The row units were equipped with gauge wheels, opening discs, and closing wheels. No trash cleaners were installed on either row unit. Seed was not planted during tests, and the drive mechanism for regulating the seed rate was not installed or functional during the experiment.

Figure 30: Great Plains twin row units mounted on a 3-pt toolbar

Planter Settings

For this study the planter row units were set at a depth of two inches, with the selection levers in the third hole forward from the back most holes on both sides of the slot. The downforce springs were set at their most aggressive setting. The closing wheels of the Great Plains twin row units were set in the second notch back away from the gauge wheels. The parallel linkages of the row unit were set to be parallel with the surface of the ground during the experiment. During the tests no seed was planted, nor was there any vacuum provided to the seed meters.

Field Conditions

Tests were done in the same no-till field at the Kansas State University North Agronomy farm as experiment one. Corn was harvested from the field the year of the tests as seen in Figure 31. All testing was done in the area depicted by Figure 28, below the first terrace of the field. The GPS location of this site is 39°12'46.1"N 96°35'49.5"W

Figure 31: CAT App. on the test field ready for testing

During the tests the soil VMC (volumetric moisture contact) reading was neglected to be measured at the time of the tests. The soil data from the Kansas State Soil Testing Lab is summarized in Table 3. From these results the area tested ranges from a Silty Clay to a Silty Clay Loam.

Lab # (s)	Sample Name	pH	SMP pH	OM LOI %	P-M ppm	K ppm	Texture	Sand %	Silt %	Clay %
3469	North West	6.2	6.3	4.6	14	289	silty clay loam	12	52	36
3470	Middle South	6.2	6.5	3.2	7	252	silty clay loam	14	52	34
3471	North East	7.4		2.9	5	219	silty clay loam	18	48	34

Table 3: Soil data from the Kansas State Soil Testing Lab as of October 29, 2018

Procedure

Tests to acquire data of the draft of the row units and the speed that the row units were being pulled at were set up as follows: three tests were conducted at every speed with speeds in the range of 0.5 mph to 3.5 mph at 0.5 mph increments. Faster testing speeds were desired, but during testing, the CAT App. was limited by power, unable to reach speeds above 3.5 mph with the twin row units. The CAT App. was pulled forward after each test with a tractor, so each test could be done in a new location in the field that was undisturbed.

During a test the carriage was moved to the "Home" position of the track where the closing wheels of the row unit would just clear the frame of the CAT App. track, as seen in Figure 32. Here the linear actuator was extended to lower the row unit to the ground. The 24 inch linear actuator was extended until the opening discs were fully pushed into the soil-usually when the actuator was at the limit of its travel. Then the hitch was raised until the parallel arms were parallel with the surface of the ground. This position was denoted as 7 inches above the lowest possible hitch point of the CAT App. on the LabVIEW front panel where it could be monitored. This was the hitch height setting for all tests. After the hitch height was set, the engine of the CAT App. was set to full throttle, which was 3400 rpm. After everything was set and ready, the set speed was chosen. Then the “Forward” button on the front panel was clicked to direct oil flow to move the carriage forward. The PID then ramped up its output until the set speed was reached by the carriage. Towards the end of the track the operator then had to click the “Forward” button again to shut flow off to the hydraulic motor powering the carriage to allow the carriage to coast to a stop by the end of the track.

Figure 32: Side view of the CAT App. carriage as it is performing a test with the Great Plains twin row units

The proportional gain was set at 0.1 for all tests since it was found that this setting gave the best results, and that the machine being underpowered was largely responsible for the inability to maintain the set speed at higher speeds rather than the PID gains. The integral time was held constant at 0.01 throughout the study. The derivative time was set at the default of zero.

Chapter 7 - Results

Data was recorded every 20 milliseconds throughout the duration of the tests. After completion of the tests the data was then imported to Excel and analyzed. The raw data from each test was then copied into a single spreadsheet to put all the data in order of increasing test speeds. A graph was made of all the speed values. For the x-axis of this graph a new time column was made that counted up in 20 millisecond intervals for each row of data, in keeping with the data collection rate of the program

Experiment 1 Results

The speed vs. time graph of the data from Experiment 1 was used to give a visual picture of when the machine was pulling the tool around the desired speed consistently – not accelerating or decelerating. From this graph the time periods of erratic behavior were noted and used to crop out those sections of data that were of no value. The total draft force was then graphed against the speed to show whether or not a relationship existed, this graph is shown in Figure 33. It is important to note that the total draft shown from the data includes the draft of the carriage of the CAT App.

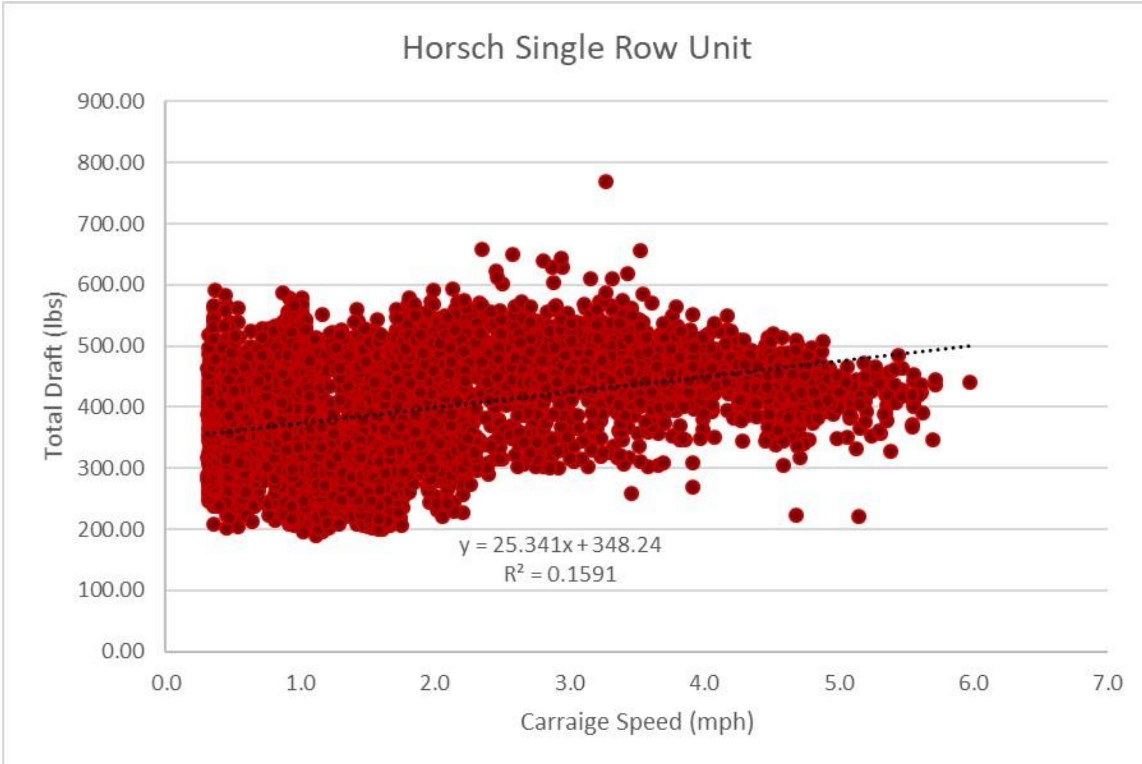

Figure 33: Total Draft vs. Speed when testing the Horsch row unit

Experiment 2 Results

The speed vs. time graph of the data from Experiment 2 was used to give a visual picture of when the machine was pulling the tool around the desired speed consistently – not accelerating or decelerating. From this graph the time periods of erratic behavior were noted and used to crop out those sections of data that were of no value. The total draft force was then graphed against the speed to show whether or not a relationship existed, this graph is shown in Figure 34. It is important to note that the total draft shown from the data includes the draft of the carriage of the CAT App.

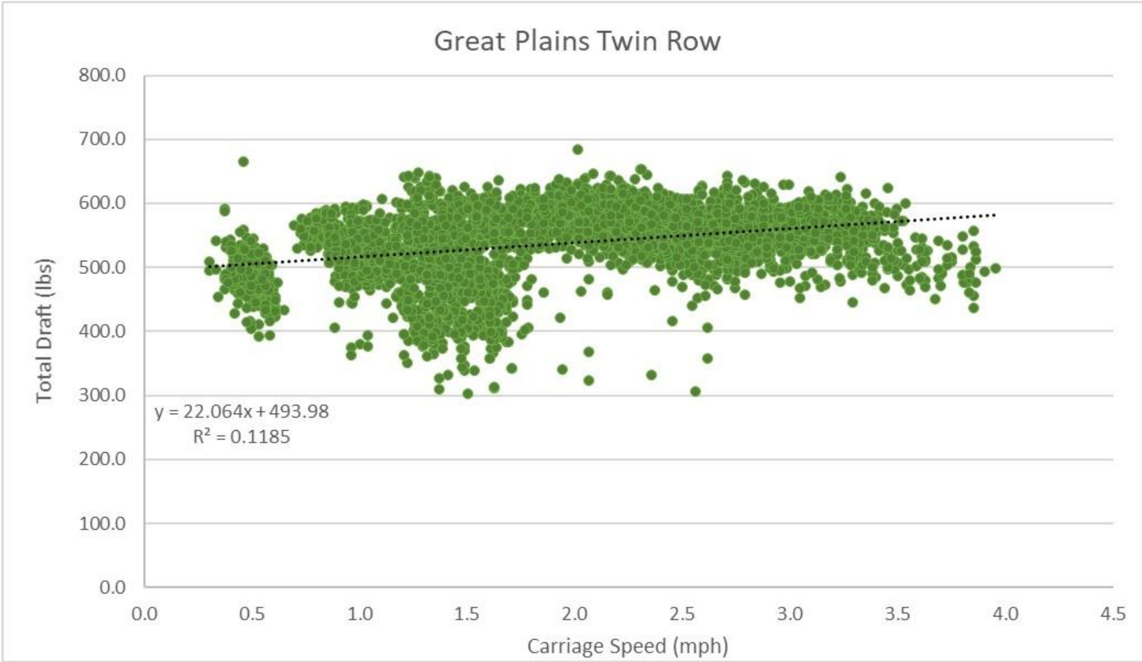

Figure 34: Total draft vs. Carriage speed for tests with Great Plains twin row units

Program Results

Looking at these results shows a lot of fluctuation in the draft force at any set speed during the test. The root cause of these fluctuations is the limited power for the machine. More power would enable the machine to accelerate faster and meet desired speeds in less time allowing the PID control to be further tuned to work better. The data indicate fluctuations in speed versus distance. For example, in Figure 35, the speed fluctuates greatly on both the 0.5 MPH and the 4.0 MPH test shown.

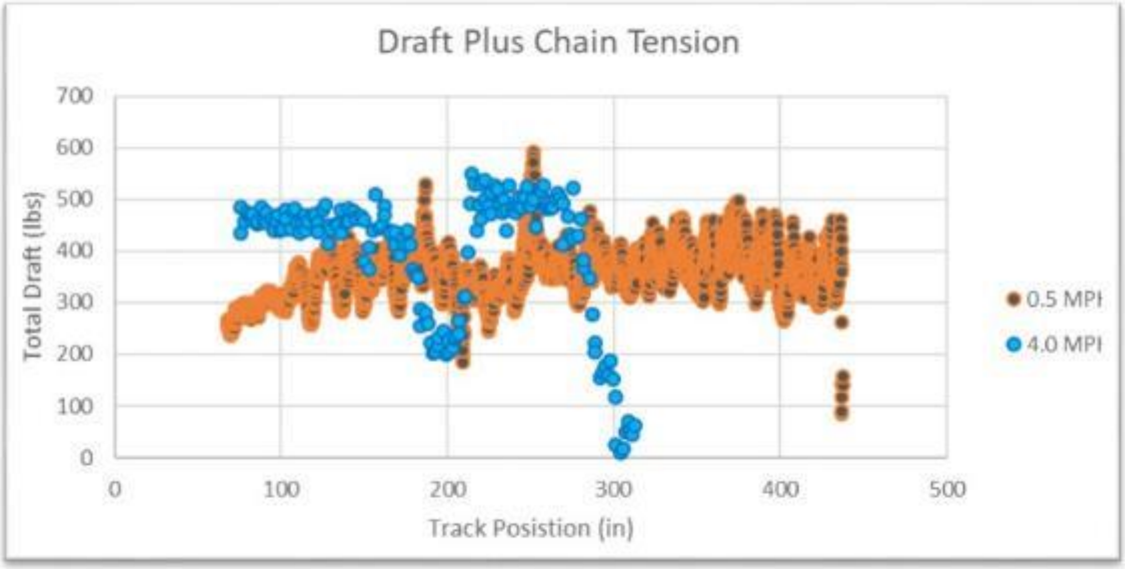

Figure 35: Data from experiment 1 testing the Horsch row unit

Rises in draft occur during acceleration of the carriage to reach speed. After reaching the set speed the carriage decelerates, reducing the draft. These spikes in the data can be removed to clean the data and give more definitive results, as was done for the graph in Figure 36. However, this process is tedious, and introduces effects to the data that are difficult to replicate consistently and exactly for all data in every test. Although the machine needs to be further tuned to get cleaner data for more definitive results, looking at the data in Figure 36 shows a positive correlation between draft forces and the speed at which row units are pulled, thus affirming our hypothesis that there is a relationship between planter draft and planting speed.

Figure 36 also shows a difference in the draft of the two different kinds of row units. The higher draft forces from the Great Plains twin row units were expected as there was two row units instead of the one in the Horsch row unit test. It's also interesting to note the slopes of both sets of data are similar. However, the data was taken on different days and the soil was wetter on the day of the Great Plains test than on the day of the Horsch tests, though the moisture of the soil wasn't measured. Therefore, the data cannot be quantitatively compared, but the data does support that the machine can effectively acquire draft data of different tools and at different speeds. This ability validates that the CAT App. design is able to perform according to the design criteria, which was the purpose of these tests. These tests have also shown areas for design changes or additions that can be made to make the machine perform better and more efficiently.

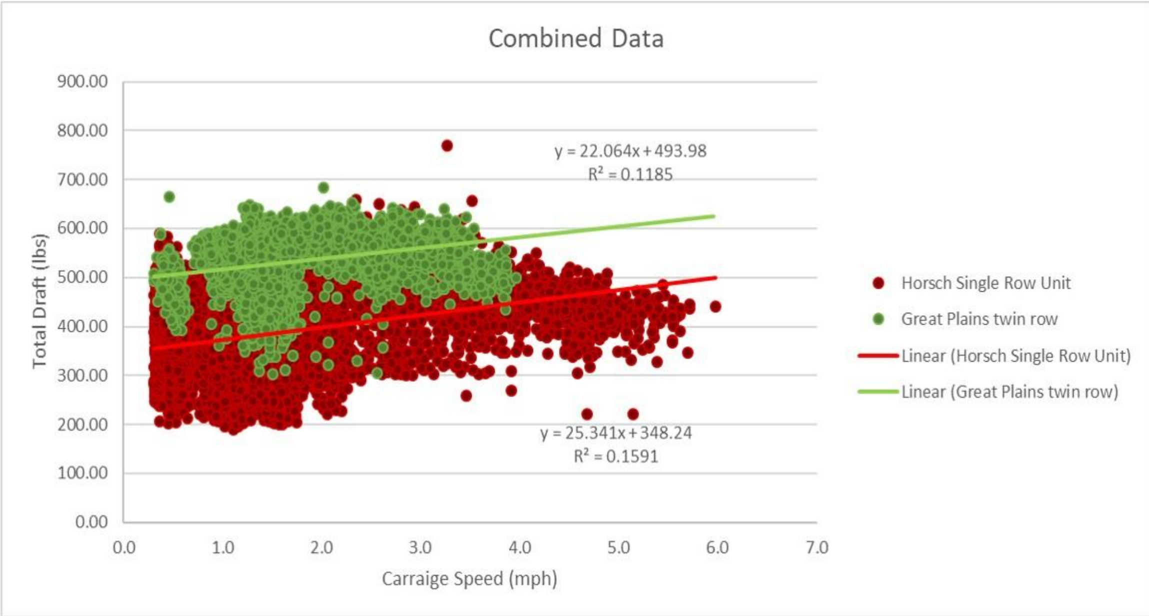

Figure 36: Combined results from experiment 1 and 2

Machine Results

From these results and from experience operating the machine it is apparent that the machine needs a larger power source. Having a larger engine that will be able to provide full flow at max pressure will allow the machine to operate more smoothly and consistently, eliminating the PID control trying to compensate for an engine operating outside its designed performance parameters. A larger displacement hydraulic motor would also give the machine more pulling capacity by allowing the system pressure to produce more torque. This increase in torque will reduce the speed capabilities of the machine. A decrease of up to 4 mph would still allow the machine to test in the high speed planting range at speeds of 8 mph, since the machine can currently theoretically reach 12 mph when not pulling a tool. Having more torque will aid in providing more draft pulling capacity to the machine, allowing the machine to test a wider variety of tools.

After the machine was running, other uses were thought of for it in addition to testing tillage and planting tools. The machine has been used for taking seed images as planted by a row unit it at specific depths and speeds as seen in Figure 37. During the tests a high speed camera took footage of the corn seed placement and location at varying speeds. The CAT App. provided a means to run the active downforce of the row unit, a depth control, and a set speed to do these tests.

Figure 37: Furrow made with Horsch row unit on the CAT App. to take pictures of the seed in the furrow as planted in real time

Another test the CAT App. has been used for was an experiment that tested silage compaction needs. As seen in Figure 38, a bin of silage was placed under the controlled load device used for testing the PID control of the CAT App. Varied amounts of downforce were supplied to the silage via the linear actuator. The downforce data was used to draw conclusion from the different amounts of compaction on the storability of the silage after it was packed.

Figure 38: Silage compaction testing

As displayed by these tests, a machine that is mobile, has a hitch that can raise and lower, can travel at a desired speed in range of most farming operations, and can record draft, speed and downforce data is a very useful piece of equipment that can be used for a wide variety of experiments. The design of the machine has potential to be further refined, and then used for testing in multiple experiments when more power and torque are provided for the carriage. This machine can be used to research draft relationships in tillage and planting tools to optimize their function and draft requirements as well as many other uses.

Chapter 8 - Conclusion

The CAT App. is a test machine that has many uses and can be adapted for testing with tillage and planting tools, wheel to ground interactions, and silage compaction testing, just to name a few. Further development of this machine will provide a test bed for multiple in-field conditions of different tools, as well as different areas of focus. The CAT App. has proven to be a useful test bed for multiple areas of research within the Biological and Agricultural Engineering department at Kansas State University. After testing the machine, it proved to meet the design criteria sufficiently to various degrees. The CAT App. has the following capabilities:

- Mobility to test in different fields and locations,
- Speed ranges up to 6 mph,
- A variable drive to select any speed within this range,
- Accommodates a large variety of tillage and planting tools,
- Acquires data of: draft, speed, downforce, and position, and
- Ability to set tools at conventional working depths.

Finally, the data collected from tests with the CAT App. can be compiled then graphed to show useful relationships between tools and different field conditions as shown in the two experiments. Areas to further improve the design of the machine were discovered during these tests as well. Further improvements to better meet the criteria are discussed in the next chapter.

Chapter 9 - Further Work

During development of the CAT App. several items were discovered that would improve the usefulness of the machine. These items include: mobility, power, control, and length of track of the machine. Each of these improvements that can be made to further the use and ability of the CAT App. are discussed in further detail below.

Mobility

Currently the CAT App. is transported by installing an axle underneath the carriage when it is bolted down to the track in its transport position, and then angle-iron pieces are used to go through the track and clamp it in place. This is a lengthy process and involves working around a suspended load. A forklift or tractor with a front-end loader is needed to raise the back of the machine off the ground to install and uninstall the axle. While this allows for the machine to be transported, it is too lengthy of a process to use the axle in between tests. For consecutive tests the machine is dragged forward with the hitch raised a bit. The best device found to maneuver the CAT App. in the field is a tractor with a front-end loader, that is ballasted in the rear (for installing and uninstalling the axle) with a trailer ball hitch mounted on the 3-pt of the tractor.

In order to reduce the amount of equipment needed to support the CAT App. for changing between testing and transporting modes, a self-raising axle could be used. The axles will need to be separate since any axle tube would hit the track and interfere with the testing area unless it were in the rear-most position of the track, but then it would make the turning radius too large to be able to maneuver it in urban areas. The proposed design is to attach an axle assembly to each side of the track, as seen in Figure 39.

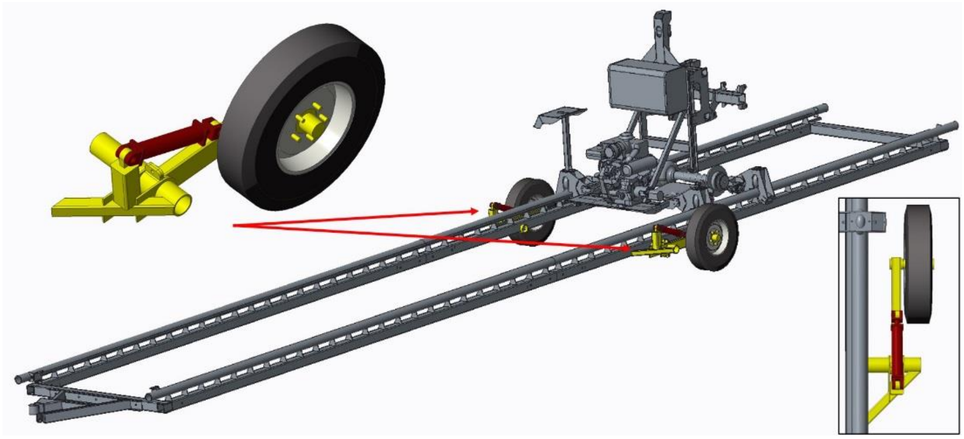

Figure 39: Better mobility concept model

The axle assemblies would be welded to the track with a pivot point and a point for a cylinder to raise and lower the axle. The hoses from the cylinder on the right axle assembly can be routed through the square tubing of the track to connect to the hoses on the left axle assembly. The two hoses from the left axle assembly can then be routed through the square tubing of the left track to connect to the tractor's hydraulic valves via quick couplers. The operator could then raise and lower the machine from the tractor cab like any other agricultural implement. During transport, cylinder stops could be placed on the cylinders to prevent them from seeping down if there is a leak in the system. These stops will also be used when working around or on the machine when it is up in the air. Use of hydraulically operated axles will allow for increased mobility between test sites and better maneuverability in the field.

Power

Besides an increase in mobility, more power to operate the carriage is needed. Initial tests were tried with two Horsch row units; however, one unit had to be removed since the CAT App. was unable to pull both row units in the ground at depths greater than 1.25 inches. More power would also enable faster acceleration times giving longer effective test lengths. The current engine was selected to stay within budget of the machine and to get the machine going. This engine is a 31 Hp Briggs & Stratton V-Twin carbureted engine. The K-State Quarter Scale Tractor Team has determined this engine to have 28 Hp peak output calculated from a prony brake dynamometer. Preliminary calculations done during the design of the CAT App. showed that this engine could pull an adequate variety of minor tillage and planting tools that would fit within the tracks of the machine. These calculations, however, did not include the acceleration, and powering of the carriage the tool would be pulled by.

More power would allow for a larger displacement hydraulic motor to be selected to provide more torque to the pinion of the rear axle and thus more pull force. A more powerful engine would also be able to produce the needed flow by maintaining higher engine speeds to create that flow at the maximum system pressure to produce the full amount of torque from the hydraulic motor to give more pull force at the higher speeds that the tests require. The hydraulic system was designed for a flow of 25 gpm which the current pump can output at its max rpm of 3500. The majority of the system is rated for a flowrate of 30 gpm with the exception of the pump, motor, and the direction control valve, and its corresponding subplate. These three components can be directly replaced with a different component of a max flowrate of 30 gpm to maximize the systems power output. These changes will better utilize the CAT App. and allow the machine to include major tillage operations its scope of testing.

The proposed solution to maximize the power of the current system with as little money as possible is to get a larger displacement motor and run the machine at the rated 25 gpm using a diesel engine between 50 and 60 Hp which would provide the low end torque for pulling and not over speed the pump that is rated for 3500 RPM. A gasoline engine would have to run at higher RPM to provide its best power, and the pump would need to be replaced with one that could operate at higher speeds. Putting a larger engine with more torque would maintain the maximum flowrate of the pump, since it would not lug the engine down to maintain the system pressure of 2500 psi. at the full flowrate of the pump.

In-Cab or Tablet Control

The controls of the CAT App. are currently mounted on a control panel which is mounted to the carriage. This requires the operator to walk with the carriage while a test is being performed. When the machine is able to do tests at speeds above 4 mph this will create a safety issue. A braking mechanism could also be installed using the disc brakes of the axle the carriage is propelled by to stop the carriage from coasting when the operator shuts the test down.

In order to control the CAT App. more easily and safely, putting the controls inside the tractor would eliminate the need to enter and exit the tractor cab multiple times. This improved control could be accomplished by mounting a laptop with LabVIEW program on a RAM mount in the cab and hard wiring controls to a control box in the cab. To do this the wires would need to be routed through the cable chain on the left side track and then through the frame to the cab. Another option would be to simply use wireless connections and use a tablet in the cab of the tractor to operate the machine. Moving the controls would allow a lot more tests to be conducted during a day, and would make running the tests safer and less fatiguing for the operator.

Track Length

In order to test speeds greater than 4 mph, which the machine could do once it has more power, the track will need to be longer to give enough time for the carriage to maintain its desired test speed for an adequate test. Two additional 20 foot sections of track can be made and easily inserted on each side of the track to make the machine another 20 feet longer. With this addition supports will need to be made to prevent the track from sagging excessively when the track is off the ground. To make the track joints stronger, the pipes above the four inch square tubes should be tied together as well. The jointing method for the individual track lengths will also need to be easy to assemble and disassemble, as the center track piece on both sides of the track will need to be removed when the machine is transported in order for turns on the road to be made. Also, without adequate supports between the tracks, the back of the track will tend to wander from side-to-side in relation to the hitch because of the length.

Machine Translation

During the conception of the mobile soil bin, it was intended that the current tracked machine would only be the X-axis of the final machine. The final gantry system

would include a Y-axis as well. On this axis the current machine would translate sideways after each test so multiple test strips could be run in a single test.
Several different methods of translating the machine were discussed, including another track for the machine to follow. This idea, however, proves to counter the efforts for the machine to be mobile and easily transported to different field conditions and down the road. A more favorable idea is to install trailer tires at either end of the track (end and home positions) that could be raised and lowered by the machine's own hydraulic power using the auxiliary power outlets. Figure 40 is a conceptual model of this design.

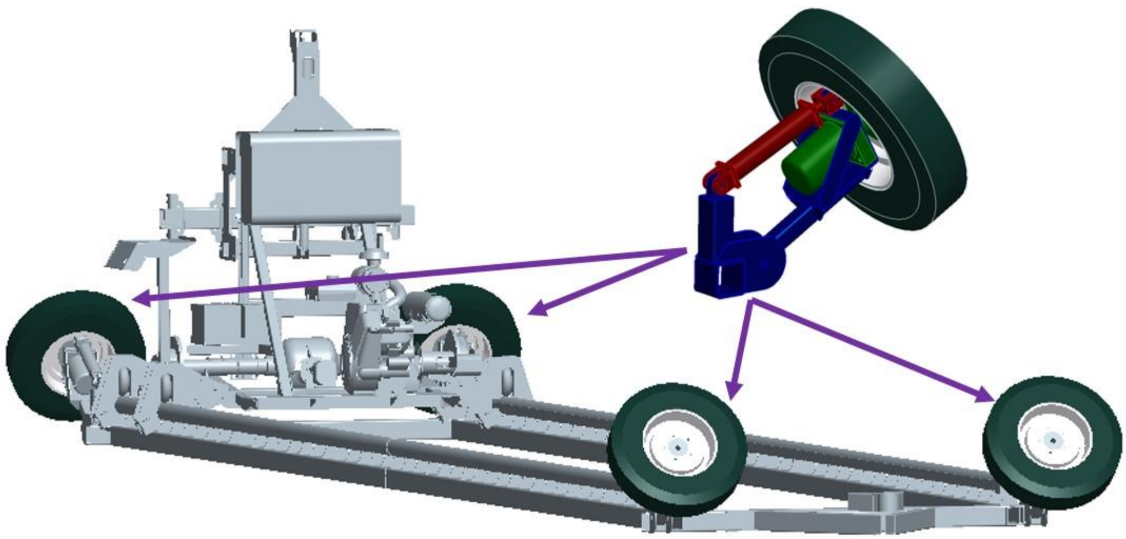

Figure 40: Conceptual model for machine translation

The wheels used for translating the machine would also be hydraulically driven. The four wheel assemblies would include a hydraulic motor; a tire, wheel and hub that would mount onto the hydraulic motor, and the mounting frame that would pivot on the end of the track. The End and Home driven wheels could be controlled at different rates to allow the machine to turn as it translates to follow a specific path. A single hydraulic cylinder would also be used to rotate the wheel assemblies on either end of the track (Figure 40). Rotating up during a test to set the machine on the ground or for transporting on the road, or rotated down to pick up the machine for translating to either side between tests.

The machine could also run tests while the track is off the ground, and the translating wheels could be controlled at different rates to simulate turning conditions on the tool being tested. This ability opens up more variety of tests and would allow for more inclusive tests of types of movement that the tool will be subjected to in use in the field.

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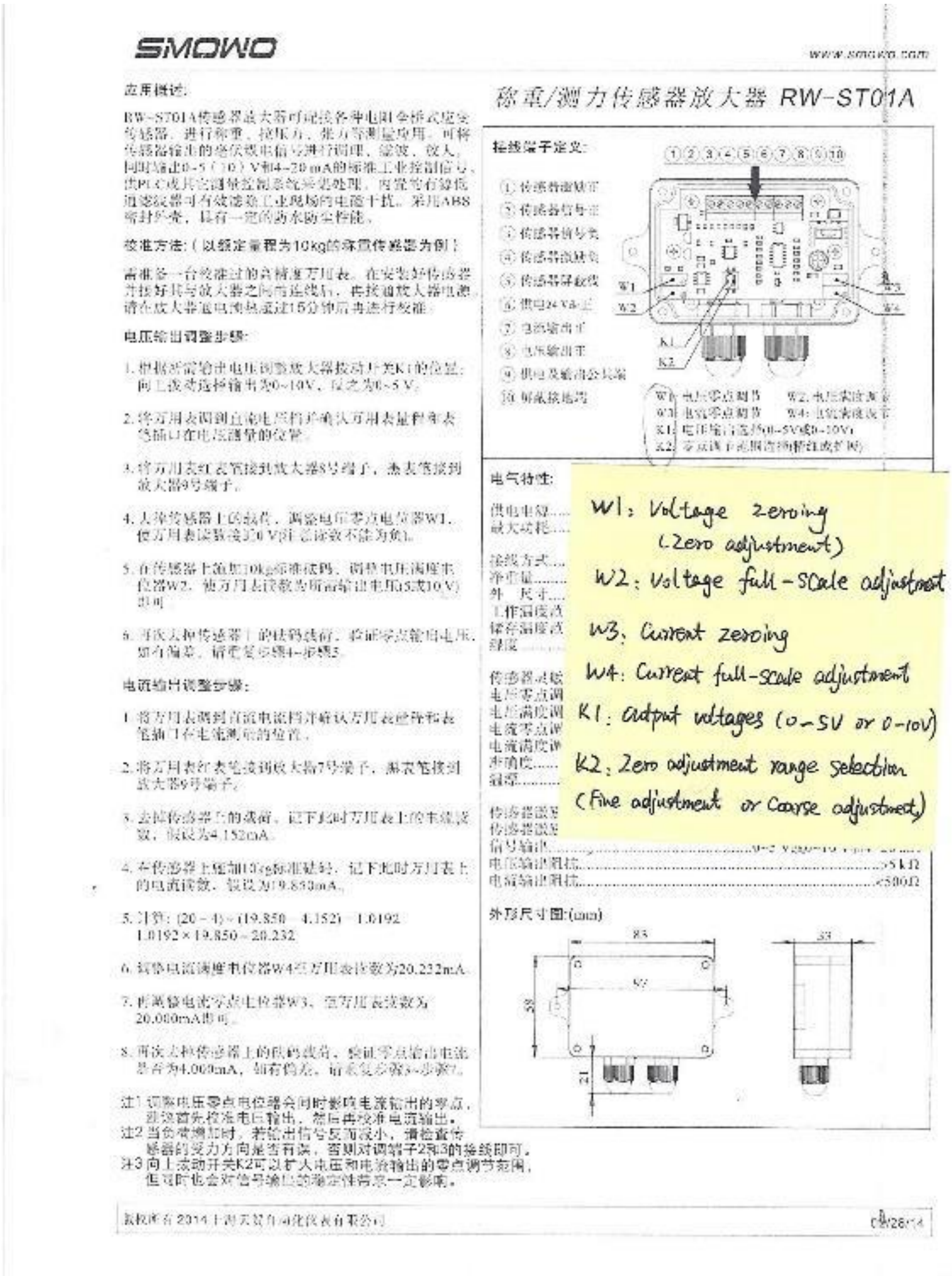
Appendix A - Component Data Sheets

SMOWO Standard One Channel Load Cell Amplifier RW-ST01A



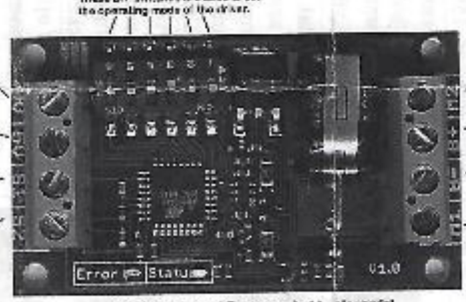
Dimension Engineering SyRen 25 Regenerative Motor Driver

SyRen 25 Quick Start Guide

July 2007

DimensionEngineering

Congratulations on your purchase of a Syren 25 regenerative motor driver. SyRen 25 is one of the most flexible and configurable motor drivers on the market. As a result, it must be set to the correct operating mode before use. Below is a generalized hookup diagram of a Syren 25. On the reverse side is a chart of some of the most commonly used operating modes.



Don't get B+ and B- connected backwards!
Make sure you have the DIP switches configured correctly for the mode you are using!

SyRen 25

Input voltage:
6V-24V

Output current:
25A

Peak Output current:
45A

Operating modes:
Analog, R/C, Serial

For full product documentation and manual, please visit
http://www.dimensionengineering.com/SyRen25.htm

LC-202 8 Channel Relay Module

8 Channel Relay Module -- LC-202

Product Details
in: Relay Boards

Get More Info on Supplier's Site | E-mail Supplier

Product Overview

Enlarge

The LC-202 is an 8 channel relay interface board for controlling our actuators. Combine it with one of our Arduino microcontrollers for even more control options.

- Voltage - 5V
- High Current Relay - AC250V 10A, DC30V 10A
- LEDs for relay output status

Share Via Email

Print This Page

Save Product

Specifications

Product Category	Relay Boards
Signal Type	AC, DC
Channels	8
Input Specifications	
Input Voltage	5 volts
Output Specifications	
Output Current	10 amps
Output Voltage	30 to 250 volts

Resettable Tach/Hour Meter

RESETTABLE TACH/HOUR METER

Operating

1 Push "SELECT" button several times until display shows 1P1r. "DO NOT RELEASE BUTTON" until "SET" appears in the upper right corner of display. Once "SET" appears release and press "SELECT" button to toggle through all degree settings.

2 Stop at correct degree setting for your engine (i.e. 1P1r, 3P1r, 4P1r etc.) see figure 1.

3 Wait for 30 seconds and the display will return to "TOT" Total Hours.

4 TACH/HOUR METER is now ready to use.

1P 1r
Default setting

To Decrease RPM Reading

8P1r=8 SP ARK PER REVOLUTION

4P1r=4 SP ARK PER REVOLUTION

2P1r=2 SP ARK PER REVOLUTION

1P2r=1 SP ARK PER 2 REVOLUTION

6P1r=6 SP ARK PER REVOLUTION

3P1r=3 SP ARK PER REVOLUTION

1P1r=1 SP ARK PER REVOLUTION

TOTAL TIME

TOT=Total Hours of operation

This is always displayed when the engine is off.

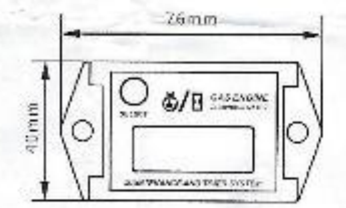
JOB TIMER

JOB=Hours of operation since the timer was reset.

To view "JOB" time push the "SELECT" button once.

To reset "JOB" time: Push and Hold "SELECT" button display shows "RESET" and show hours that have accumulated on the current job.

When you RELEASE the "SELECT" button the "JOB" display will reset to "00:00" You will begin to record the next job interval.



RPM&MAX RPM

1. Typical RPM display when engine is running.

2. When the engine is shut down, the display will show MAX RPM for 8 seconds.

3. Push "SELECT" button three times the display will show MAX RPM for 8 seconds.

SVC&SVC2

1. Push "SELECT" button three times, the display will show "SVC", do not release button until "SET" appears "5:00" is flash, than can to set. The "SVC" degree is 5 to 50 hours

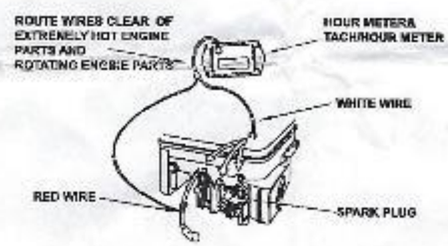
2. Push "SELECT" button three times, the display will show "SVC2", do not release button until "SET" appears "5:00" is flash, then can to set. The "SVC" degree is 10 to 250 hours

Installation

1. Wire damage (cuts or burns) will cause the wire to short and the TACH/HOUR METER will stop working. Wire damage us not covered under warranty.

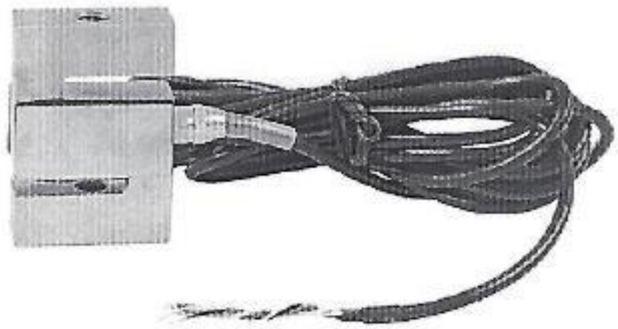
2. [illegible] wire using about 5" turns. PLEASE BE CERTAIN YOU DO NOT WRAP THE RED WIRE TOO CLOSE TO THE SPARK PLUG THAT ENGINE VIBRATION WILL ALLOW IT TO COME INTO DIRECT CONTACT WITH THE METAL PORTION OF THE SPARK PLUG. Most engines have a spark plug cap and will prevent this from happening. After the connections are made, any excess wire can be coiled up and taped to a convenient area.

3. "If the signal is not strong enough, you can add one wrap at a time until your signal is clear. The signal strength is controlled by the number of wraps (too many wraps will pick up electronic noise and give a faulty reading.)



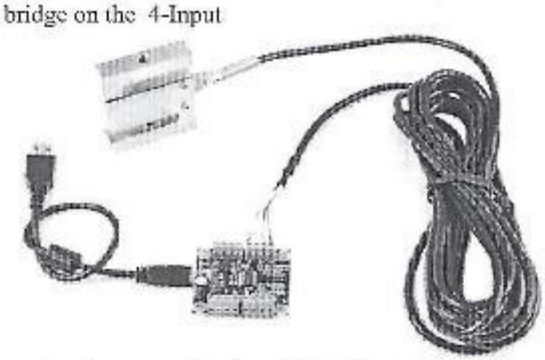
RB-Phi-204 500Kg S-type Load Cell

RB-Phi-204
500Kg S Type Load Cell



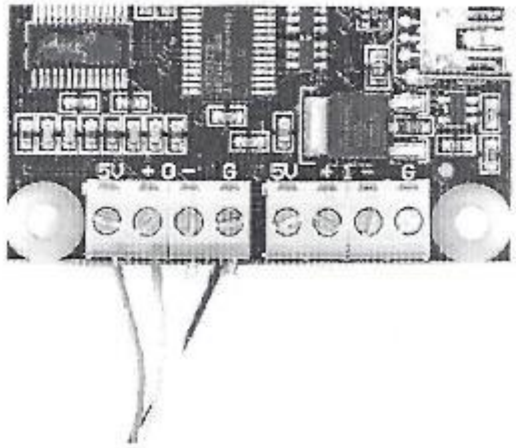
A load cell is a force sensing module - a carefully designed metal structure, with small elements called strain gauges mounted in precise locations on the structure. Load cells are designed to measure a specific type of force, and ignore other forces being applied. This S-Type load cell can be operated in compression or tension with up to 500 kilograms of force. The electrical signal output by the load cell is very small and requires specialized amplification. Fortunately, the 1046 PhidgetBridge will perform all the amplification and measurement of the electrical output.

Connection
The 3140 connects to a bridge on the 4-Input



The following table shows how to connect the Load Cell Wires to the bridge connectors.

Wire Color	Red	Green	White	Black/Yellow
Bridge Connector	5V	+	-	GND



Features

Maximum Load Capacity: 500 kg
Wheatstone Bridge Sensor
Measures compressive or tensile force
Plugs into the 4-Input

Specifications

Sensor Properties

Sensor Type	Compression/Tension Load Cell
Weight Capacity Max	500 kg
Maximum Overload	750 kg

Electrical Properties

Output Impedance	350 Ω
Supply Voltage Min	9 V DC
Supply Voltage Max	12 V DC

Physical Properties

Compensated Temperature Min	-10 °C
Compensated Temperature Max	40 °C
Operating Temperature Min	-20 °C
Operating Temperature Max	55 °C
Cable Length	3 m
Cable Gauge	5x 22 AWG
Material	Alloy Steel
IP Rating	IP66
Weight	603 g

Cross 1.80 cu in Hydraulic Gear Motor model 40MH18DACSC

PRINT PAGE EMAIL FRIEND

1.80 cu in CROSS HYD MOTOR 40MH18DACSC

ITEM NUMBER: 9-7073-180

PRICE: $227.95

12 In Stock

REGULAR STOCK ITEM

QTY: 1

ADD TO CART

ADD TO WISHLIST

CALCULATE SHIPPING

This item is on page 73 of our current catalog

YOU MAY ALSO CONSIDER:

SEAL KIT FOR CROSS 40 SERIES PUMP/MOTOR

DESCRIPTION ASK A QUESTION

CROSS HIGH SPEED HYDRAULIC MOTOR

Brand new, Cross hydraulic gear motor. Model 40MH18DACSC. Pressure balanced loading plates for high efficiency. Aluminum body for good heat dissipation. Pressure lubricated Teflon impregnated sleeve bearings. Internal check valves eliminate need for case drain at shaft seal pressures under 250 PSI.

SPECIFICATIONS

- 1.8 cu in disp
- Max Pressure 3000 PSI
- Max speed 3000 rpm
- 16.5 GPM for 1800 RPM
- 20 HP at 1800 RPM, 2500 PSI
- 700 in-lbs. torque at 2500 PSI
- Reversible Rotation

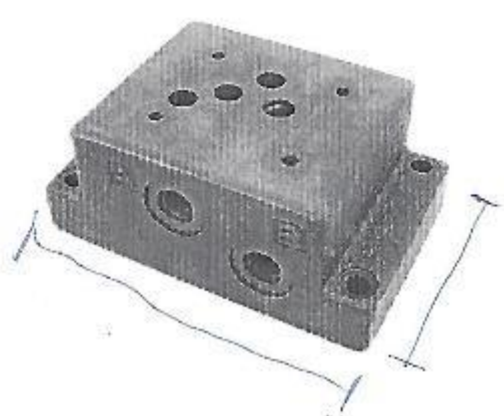
*****

- SAE A 2 bolt mount
- 5/8" dia x 1-1/4" keyed shaft
- SAE 12 ports
- 1/4" NPT drain port
- 5-1/8" x 5-1/4" x 5"
- Shpg 9 lbs

$\frac{1.8 \times 2500}{2\pi} = 716$ in-lbs

Northman Fluid Power Single-Station Subplate

NORTHERN®
TOOL + EQUIPMENT



Northman Fluid Power Single-Station Subplate — NFPA D05 Pattern, 3/4in. NPT Side Ports, Model# M03-06-S-2

Item# 203361

Only $59.99

In Stock Online

Not Available in Stores

4 / 5

1 of 1 would recommend this product to a friend

Product Summary

This Northman Fluid Power single-station subplate for mounting an industrial hydraulic directional control valve conforms to the National Fluid Power Association (NFPA) D05 mounting pattern. It accepts Northern Tool valves in the 20150 and 20250 Series. The 3/4in. NPT female ports are side mounted for the Pressure, Tank, A and B ports.

What's Included

(1) Single-station subplate

Features + Benefits

- Single Station Subplate
- NFPA D05 Mounting Pattern
- 3/4in. NPT Female Ports
- Side Port Location
- Port Connections for Pressure, Tank, A and B Ports

Key Specs

Item#	203361
Ship Weight	10.0 lbs
Accessory Type	Subplate

Prince 1.654 cu in Hydraulic Pump Rear Port Model SP20B27D9H2R

1.654 cu in PRINCE SP20B27D9H2R HYD PUMP REAR PORT

ITEM NUMBER: 9-1901-B-R

PRICE: $209.95

1 In Stock

REGULAR STOCK ITEM

QTY: 1

ADD TO CART

ADD TO WISHLIST

CALCULATE SHIPPING

This item is on page 47 of our current catalog

PRINT PAGE EMAIL FRIEND

YOU MAY ALSO CONSIDER:

SEAL KIT FOR SP20 PRINCE PUMP

DESCRIPTION ASK A QUESTION

PRINCE GEAR PUMP

Brand new, Prince, special non-symmetrical gears give higher efficiency than conventional pumps. Aluminum body. Ideal replacement for many brands on tractors, other implements

SPECIFICATIONS

- 1.654 cu in displ
- 13.50 GPM at 2000 RPM
- 2500 PSI
- 3000 RPM max
- IN SAE 16 rear
- OUT SAE 12 rear
- SAE A 2 bolt mount
- CW rotation
- 5/8" dia x 1-1/4" keyed shaft
- 5"x5-3/8"x4-5/8"
- Shpg 10 lbs

Prince Inline Relief Valve Model RV-2H

3/4" NPT 30 GPM 1500-3000 PSI RELIEF VALVE RV-2H

ITEM NUMBER: 9-6135-75-H

PRICE: $43.65

75 In Stock

REGULAR STOCK ITEM

QTY: 1

ADD TO CART

ADD TO WISHLIST

CALCULATE SHIPPING

DESCRIPTION   ASK A QUESTION

3/4 NPT HYD RELIEF VALVE
Brand new, PRINCE model RV-2H inline relief valve. Differential piston design provides smooth and quiet performance with a minimum variation between cracking and full pressure.

SPECIFICATIONS

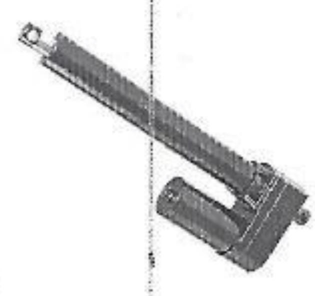
- Flow Rating 30 GPM max
- Pressure Relief Range 1500-3000 PSI
- Factory Setting 2000 PSI
- Ports 3/4" NPT
- Size 5-1/4" x 2-7/8" x 3"
- Shpg. 5 lbs.

Nook DC Ball Screw Linear Actuator Model ND8-24-10-B

NOOK

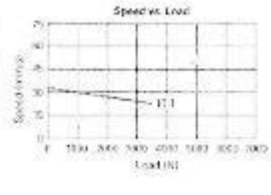
ND8-24-10-B

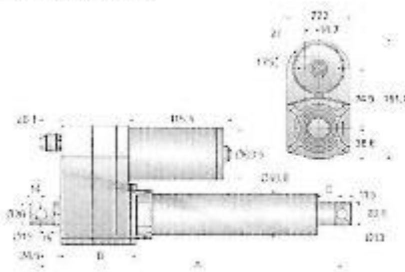
Call 800-321-7800 or visit us online at www.nookindustries.com to configure and order your ND8-24-10-B today!

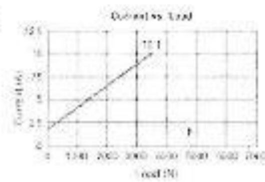


2D/3D CAD ONLINE

	Retracted Length A [±3.8mm]							B	C
Travel [in]	4	6	8	10	12	18	24	—	—
Travel [mm]	102	152	203	254	305	457	610	—	—
Standard	[illegible]	[illegible]	[illegible]	[illegible]	506	[illegible]	[illegible]	[illegible]	115
With Potentiometer	[illegible]	[illegible]	444	[illegible]	548	[illegible]	[illegible]	1245	115
With Limit Switch*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1015	[illegible]







Product Info

Screw Type	Ball Screw
Details	
Voltage [VDC]	24
Gear Ratio	10:1
Speed At No Load [mm/s]	33.5
Speed At Full Load [mm/s]	26.7
Load Capacity Dynamic Load [N]	3500
Load Capacity Static Load [N]	13600
Amps	10
Performance Specifications	
Duty Cycle [% of 5 Minutes]	25
Protection Class	IP65

$50Hz = \frac{50\ cycles}{1\ sec}\ x$

$\frac{1}{50} = \frac{sec}{cycle} = 0.02sec = 20000\ \mu s$ (1 period)

R/C Standard
1000 μs = Full Reverse
1500 μs = STOP
2000 μs = Full Forward

$20{,}000\mu s\,(x) = 1{,}500$

$x = 0.075$

$20{,}000\mu s\,(x) = 1000$

$x = 0.05$

$20{,}000\mu s\,(x) = 2000$

$x = 0.1$

Rev 0.05 —

STOP 0.075 —

F 0.1 —

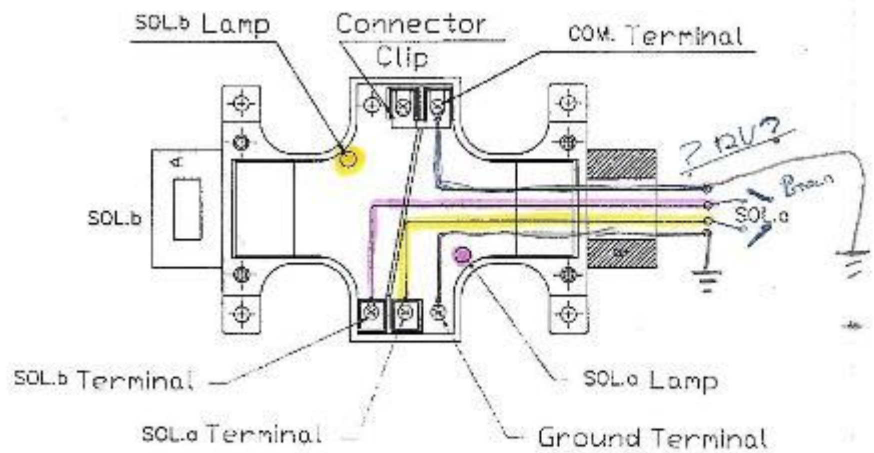
→ Duty Cycle (0 - 1)

Northman Junction Box

Northman

Reliability & Satisfaction

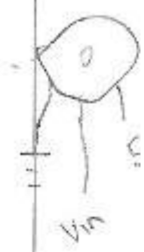
Wiring Diagram Junction Box Style (Type -10)



Note: Removing the Connector Clip will re-configure the box for two separate terminals.

Northman (Asia) Pte Ltd
#07-14 196 Pandan Loop
Singapore 12384

Phone: + 65 6866 1609
Fax: +65 6872 0437
www.northman.com.sg



Northman Fluid Power Solenoid-Operated Directional Valve Model SWH-G03-C3-D12-10

SOLENOID OPERATED DIRECTIONAL VALVE
SWH-G03 SERIES

12V 2.6A

26.4 gpm
4500 psi

3 position
Double Solenoid
Open center Spool
12VDC Solenoids

SWH-G03-C3-D12-10

FEATURES

- Indicating lights and bolt kits are standard.
- Coil screws are especially designed to prevent shocks.
- Electrical connections are joint box type or Hirschman DIN type plug-in connector.
- Joint box is waterproof and dust-resistance.
- Space for electrical connections is large enough for connection layout.
- Electrical connection points are aligned with the axial direction to be compatible with modular system.
- The valve mounting screws are on the outside of the body for ease of installation and repair.
- High pressure up to 310 BAR (4500 PSI), allows for large flow rates up to 120 LPM (32 GPM).
- Ideal design of flow passages to minimize pressure drop.
- High back pressure up to 160 BAR (2350 PSI)
- Manufactured with specifications that allows for parts and accessories interchangeability.

Model Code

SWH – G 03 – C2 – A120 – 10 – LS

1 2 3 4 5 6 7

1 Series

SWH: High Pressure, High Flow Solenoid Directional Control Valve

2 Mounting Style

G: Subplate Mounted

3 Mounting Size

03: Interface 03
NFPA D05 Size / ISO 4401-05 / CETOP 5 / NG 10

4 Spool Type

(See Spool Chart)

C3

5 Coil Voltage

A24: AC24V 60Hz
A110: AC110V, 60HZ; AC100V, 50Hz
A120: AC120V, 60HZ; AC110V, 50Hz
A220: AC220V, 60HZ; AC200V, 50Hz
A240: AC240V, 60HZ; AC220V, 50Hz
R110: AC110V, 50/60Hz
R120: AC120V, 50/60Hz
R220: AC220V, 50/60Hz
R240: AC240V, 50/60Hz
D12: DC12V
D24 : DC24V

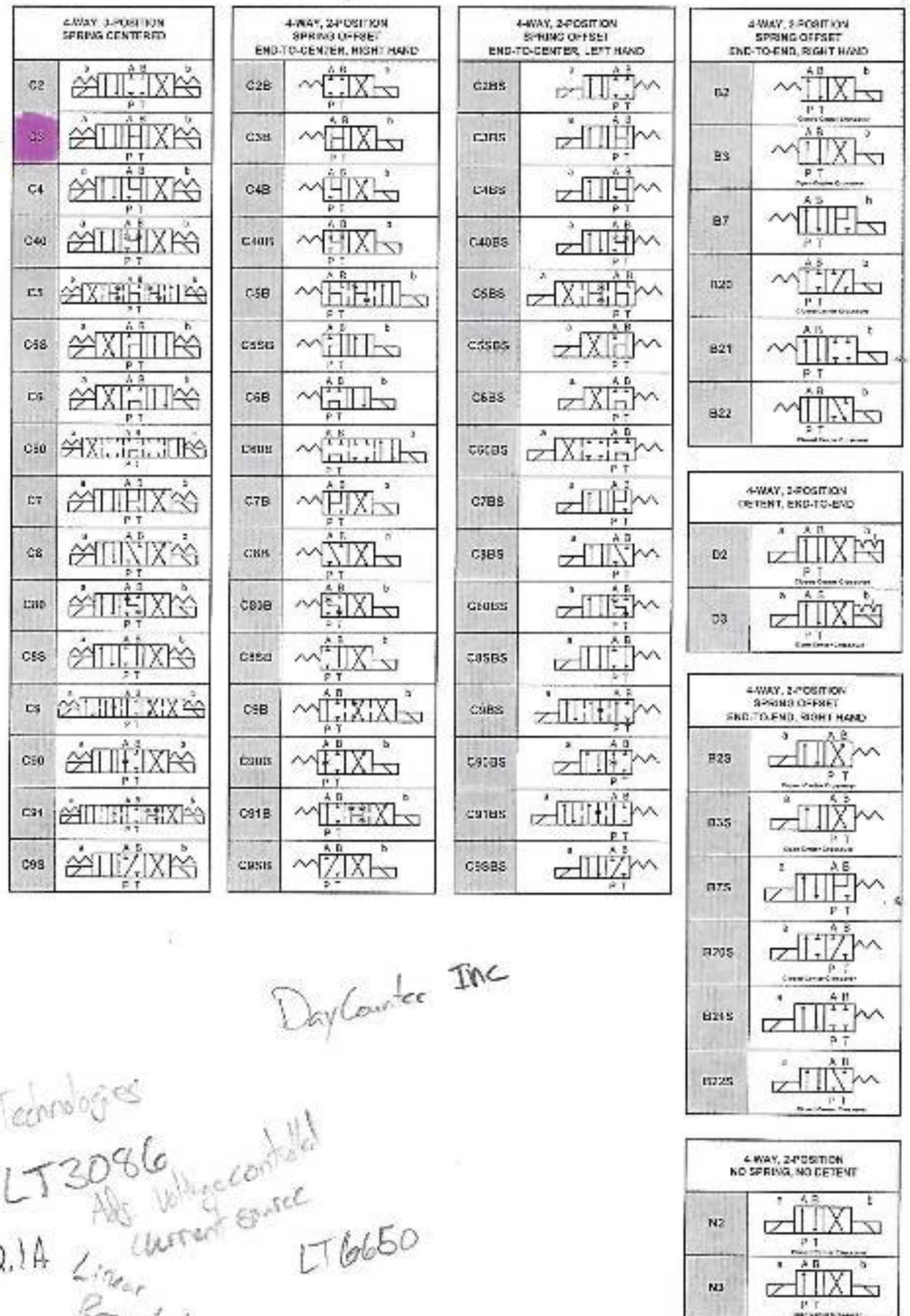
6 Wiring Type

10: Junction Box with Indicator Light
20: DIN43650 Connector with Indicator Light
31: Lead Wire (DC Only)
41: Dual Spade (DC Only) SAE J858A)

7 Option

No Code: Standard
LS: Low Surge Voltage

Northman www.northmanfp.com 20



AB
PT

DayCounter Inc

Linear Technologies
LT3086
Adj. Voltage controlled current source
2.1A Linear Regulator
LT6650

SOLENOID OPERATED DIRECTIONAL VALVE
SWH-G03 SERIES

SPECIFICATIONS

Maximum operating pressure	310 BAR (4500 PSI)
Maximum flow capacity	120 LPM (32 GPM)
Maximum tank line back pressure	160 BAR (2350 PSI)
Maximum frequencies of operation	240 CPM
Recommended filtration	25 MICRON
Hydraulic fluids	Mineral Oil, Viscosity 10 - 400 Cst
Temperature range	-25° C to +90° C (-13° F to +194° F)

SOLENOID RATINGS

ELECTRIC	COIL	VOLTAGE (V)			CURRENT & POWER		
		Hz	SOURCE RATED	RANGE (±10%)	IN-RUSH CURRENT (A)	HOLDING CURRENT (A)	WATTAGE
AC	A110	50	AC100V	90-110	4.79	0.86	
		60	AC100V	90-110	3.71	0.62	
			AC110V	99-121	4.20	0.74	
	A120	50	AC110V	99-121	4.29	0.78	
		60	AC120V	108-132	3.99	0.70	
	A220	50	AC200V	180-220	2.31	0.42	
		60	AC200V	180-220	1.87	0.31	
			AC220V	198-252	2.05	0.36	
	A240	50	AC220V	198-242	2.04	0.37	
		60	AC240V	216-264	1.88	0.33	
	R110	50	AC100V	90-110	0.47	0.47	42
		60	AC110V	99-121	0.47	0.47	
	R220	50	AC200V	180-220	0.24	0.24	
		60	AC220V	198-252	0.24	0.24	
DC	D12		DC 12V	10.8-13.2	2.58	2.58	32
	D24		DC 24V	21.6-26.4	1.33	1.33	

TECHNICAL DATA

- Solenoid can be used within - 10% to + 10% of the rated voltage of the coil.
- Withstand voltage 1500 v/sec.
- Insulation resistance over 100MΩ.

ACCESSORIES

- Mounting bolt kits are supplied with valve socket head cap screws M6x35L 4 pcs (1/4"-20UNCx1-3/8" 4 pcs) for tightening torque 120-150 kgf-cm (104-130 lbs-in).
- O-Ring AS568-014 5 pcs.

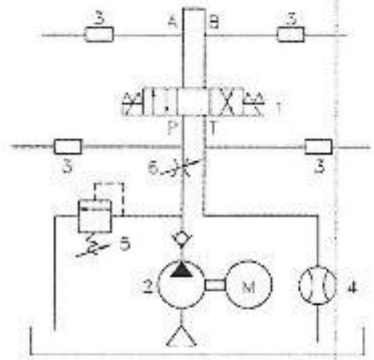
PRESSURE DROP AND PERFORMANCE CURVES

TEST SYSTEMS

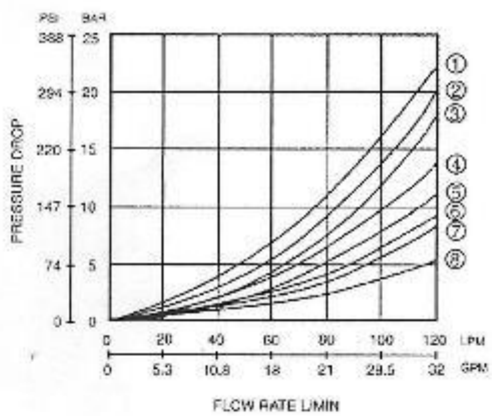
1. Testing Valve
2. Pump
3. Pressure Sensor
4. Flow Sensor
5. Relief Valve
6. Throttle Valve

TEST CONDITIONS
Pressure: 69 BAR (1000PSI)
Flow Rate: 140 LPM(37 GPM)
Viscosity: 35 cSt (175SSU)

TEST CIRCUIT



PERFORMANCE CURVES



MODEL NO.	PRESSURE DROP CURVE NUMBER P—A	B—T	P—B	A—T	P—T
C2	6	6	6	6	-
C3	7	7	7	7	5
C4	6	7	6	7	-
C40	6	7	6	7	-
C5	5	2	2	5	8
C6	2	2	2	2	5
C60	1	1	1	1	4
C7	7	6	7	6	-
C8	6	6	6	7	-
C9	7	6	6	6	-
B2	2	2	6	6	-
B3	3	3	6	6	-
B20	5	-	5	-	-
B2S	6	6	2	2	-
B3S	6	6	3	3	-
B20S	5	-	5	-	-

CONTRAST CHART BETWEEN FACTORS AND VISCOSITIES

VISCOSITY	cSt	15	20	30	40	50	60	70	80	90	100
	SSU	77	98	141	186	232	278	324	371	417	464
FACTOR (G')		0.81	0.87	0.96	1.03	1.09	1.14	1.19	1.23	1.27	1.30

The pressure drop (AP') can be obtained from the formula
AP'=AP (G'/0.85) for other specific gravity (G').

SOLENOID OPERATED DIRECTIONAL VALVE
SWH-G03 SERIES

THE MAXIMUM FLOW RATE LPM(GPM) UNDER DIFFERENT PRESSURE BAR (PSI) SWH G03 AC TYPE

SPOOL TYPE NORMAL POSITION	50 BAR (735 PSI)	100 BAR (1470 PSI)	150 BAR (2200 PSI)	207 BAR (3000 PSI)	250 BAR (3675 PSI)	310 BAR (4500 PSI)	50 BAR (735 PSI)	100 BAR (1470 PSI)
C2	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	54(14.3) 38(10.0)
C3	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)
C4	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	54(14.3) 42(11.1)
C40	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4) 75(19.8)
C5	88(23.2) 82(21.7)	88(23.2) 82(21.7)	88(23.2) 82(21.7)	88(23.2) 82(21.7)	88(23.2) 82(21.7)	-	100(26.4)	100(26.4)
C6	84(22.2) 75(19.8)	84(22.2) 75(19.8)	84(22.2) 75(19.8)	84(22.2) 75(19.8)	84(22.2) 75(19.8)	-	100(26.4) 95(25.1)	100(26.4) 95(25.1)
C7	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	63(16.6)	63(16.6)
C8	100(26.4)	100(26.4)	100(26.4) 76(20.1)	44(11.6) 28(7.4)	30(7.9) 21(5.5)	19(5.0) 14(3.7)	100(26.4)	100(26.4) 53(14)
C9	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	57(15.1)	57(15.1)
B2	90(23.8) 72(19.0)	90(23.8) 72(19.0)	90(23.8) 72(19.0)	90(23.8) 72(19.0)	90(23.8) 72(19.0)	90(23.8) 72(19.0)	63(16.6)	63(16.6)
B3	89(23.5) 81(21.4)	89(23.5) 81(21.4)	89(23.5) 81(21.4)	89(23.5) 81(21.4)	89(23.5) 81(21.4)	89(23.5) 81(21.4)	100(26.4)	100(26.4)
B20	-	-	-	-	-	-	81(21.4)	29(7.7)
D2	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	60(15.9)	40(10.6)
D3	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	70(18.5)	60(15.9)

NOTE: 1.The figures in the square shows the parameter among voltage & flow under saturated temperature and 90% applied voltage.

2.The upper number in table describes the maximum flow under 100%.

3.The lower number in table describes the maximum flow under saturated temperature and 90% applied voltage.

SOLENOID OPERATED DIRECTIONAL VALVE
SWH-G03 SERIES

THE MAXIMUM FLOW RATE LPM(GPM) UNDER DIFFERENT PRESSURE BAR (PSI) SWH G03 AC TYPE										
SPOOL TYPE NORMAL POSITION	150 BAR (2200 PSI)	207 BAR (3000 PSI)	250 BAR (3675 PSI)	310 BAR (4500 PSI)	50 BAR (735 PSI)	100 BAR (1470 PSI)	150 BAR (2200 PSI)	207 BAR (3000 PSI)	250 BAR (3675 PSI)	310 BAR (4500 PSI)
C2	40(10.6)	28(7.4)	25(5.6)	20(5.3)	100(26.4)	54(14.3)	40(10.6)	28(7.4)	25(6.6)	20(5.3)
	27(7.1)	17(4.5)	13(3.4)	10(2.6)		38(10.0)	27(7.1)	17(4.5)	13(3.4)	10(2.6)
C3	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)
C4	30(7.9)	23(6.1)	18(4.8)	14(3.7)	100(26.4)	54(14.3)	30(7.9)	23(6.1)	18(4.8)	14(3.7)
	27(7.1)	16(4.2)	11(2.9)	8(2.1)		42(11.1)	27(7.1)	16(4.2)	11(2.9)	8(2.1)
C40	33(8.7)	28(7.4)	22(5.8)	18(4.8)	100(26.4)	100(26.4)	33(8.7)	28(7.4)	22(5.8)	18(4.8)
	23(6.1)	21(5.5)	15(4)	12(3.2)		75(19.8)	23(6.1)	21(5.5)	15(4)	12(3.2)
C5	100(26.4)	100(26.4)	100(26.4)	-	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)
C6	100(26.4)	100(26.4)	100(26.4)	-	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	-
	95(25.1)	95(25.1)	95(25.1)		95(25.1)	95(25.1)	95(25.1)	95(25.1)	95(25.1)	
C7	63(15.6)	63(16.6)	63(16.6)	63(16.6)	63(16.6)	63(16.6)	63(16.6)	63(16.5)	63(16.6)	63(16.6)
C8	37(9.8)	34(9.0)	28(7.4)	20(5.3)	100(26.4)	61(16.1)	33(8.7)	27(7.1)	20(5.3)	16(4.2)
	32(8.5)	28(7.4)	21(5.5)	15(4)		48(12.7)	27(7.1)	21(5.5)	15(4)	9(2.4)
C9	57(15.1)	57(15.1)	57(15.1)	57(15.1)	100(26.4)	53(14)	47(12.4)	45(11.9)	40(10.6)	34(9.0)
						40(10.6)	37(9.8)	34(9.0)	29(7.7)	25(6.6)
B2	63(16.6)	63(16.6)	63(16.6)	63(16.6)	100(26.4)	78(20.6)	45(11.9)	43(11.4)	38(10.0)	32(8.5)
						74(19.6)	38(10.0)	36(9.5)	31(8.2)	27(7.1)
B3	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	95(25.1)	82(21.7)	75(19.8)	65(17.2)
						89(23.5)	84(22.2)	77(20.3)	70(18.5)	62(16.4)
B20	19(5.0)	12(3.2)	9(2.4)	7(1.8)	100(26.4)	80(21.1)	32(8.5)	25(6.6)	20(5.3)	14(3.7)
						42(11.1)	28(7.4)	22(5.8)	17(4.5)	12(3.2)
D2	40(10.6)	40(10.5)	30(7.9)	28(7.4)	60(15.9)	40(10.6)	40(10.6)	40(10.6)	30(7.9)	28(7.4)
D3	60(15.9)	60(15.9)	42(11.1)	36(9.5)	70(18.5)	60(15.9)	60(15.9)	60(15.9)	47(11.1)	36(9.5)

SOLENOID OPERATED DIRECTIONAL VALVE
SWH-G03 SERIES

THE MAXIMUM FLOW RATE LPM(GPM) UNDER DIFFERENT PRESSURE BAR (PSI) SWH G03 DC TYPE								
SPOOL TYPE NORMAL POSITION	50 BAR (735 PSI)	100 BAR (1470 PSI)	150 BAR (2200 PSI)	207 BAR (3000 PSI)	250 BAR (3675 PSI)	310 BAR (4500 PSI)	50 BAR (735 PSI)	100 BAR (1470 PSI)
C2	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7) 100(26.4)
C3	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)
C4	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7) 100(26.4)
C40	120(31.7)	120(31.7)	120(31.7) 100(26.4)	97(25.6) 75(19.8)	78(20.6) 54(14.3)	60(15.9) 41(10.8)	120(31.7)	120(31.7) 115(30.4)
C5	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)
C6	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)
C7	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	65(17.2)	65(17.2)
C8	120(31.7)	120(31.7)	120(31.7) 100(26.4)	97(25.6) 85(22.5)	78(20.6) 54(14.3)	66(17.4) 41(10.8)	120(31.7)	120(31.7)
C9	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	65(17.2)	65(17.2)
B2	95(25.1)	95(25.1)	95(25.1)	95(25.1)	95(25.1)	95(25.10)	69(18.2)	69(18.2)
B3	89(23.5)	89(23.5)	89(23.5)	89(23.5)	89(23.5)	89(23.5)	120(31.7)*	120(31.7)
B20	-	-	-	-	-	-	85(22.5)	35(9.2)
D2	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	60(15.9)	40(10.6)
D3	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	70(18.5)	60(15.9)

SOLENOID OPERATED DIRECTIONAL VALVE
SWH-G03 SERIES

THE MAXIMUM FLOW RATE LPM(GPM) UNDER DIFFERENT PRESSURE BAR (PSI) SWH G03 DC TYPE										
SPOOL TYPE NORMAL POSITION										
	150 bar (2200 psi)	207 bar (3000 psi)	250 bar (3675 psi)	310 bar (4500 psi)	50 bar (735 psi)	100 bar (1470 psi)	150 bar (2200 psi)	207 bar (3000 psi)	250 bar (3675 psi)	310 bar (4500 psi)
C2	73(19.3)	63(16.6)	54(14.3)	37(9.8)	120(31.7)	120(31.7)	73(19.3)	63(16.6)	54(14.3)	37(9.8)
	55(14.5)	48(12.7)	38(10.0)	29(7.7)		100(26.4)	55(14.5)	48(12.7)	38(10.0)	29(7.7)
C3	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)	120(31.7)
C4	90(23.8)	73(19.3)	60(15.9)	47(12.4)	120(31.7)	120(31.7)	90(23.8)	73(19.3)	60(15.9)	47(12.4)
	78(20.6)	64(16.9)	51(13.5)	39(10.3)		100(26.4)	78(20.6)	64(16.9)	51(13.5)	39(10.3)
C40	75(19.8)	54(14.3)	42(11.1)	37(9.8)	120(31.7)	120(31.7)	75(19.8)	54(14.3)	42(11.1)	37(9.8)
	50(13.2)	39(10.3)	30(7.9)	21(5.5)		115(30.4)	50(13.2)	39(10.3)	30(7.9)	21(5.5)
C5	100(26.4)	100(26.4)	100(26.4)	-	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	-
C6	100(26.4)	100(26.4)	100(26.4)	-	100(26.4)	100(26.4)	100(26.4)	100(26.4)	100(26.4)	-
C7	65(17.2)	65(17.2)	65(17.2)	65(17.2)	65(17.2)	65(17.2)	65(17.2)	65(17.2)	65(17.2)	65(17.2)
C8	68(18.0)	51(13.5)	37(9.8)	27(7.1)	120(31.7)	85(22.5)	50(13.2)	36(9.5)	25(6.6)	19(5.0)
	52(13.7)	39(10.3)	28(7.4)	18(4.8)		65(17.2)	40(10.6)	28(7.4)	15(4)	12(3.2)
C9	65(17.2)	65(17.2)	65(17.2)	65(17.2)	120(31.7)	100(26.4)	94(24.8)	85(22.5)	76(20.1)	70(18.5)
						85(22.5)	80(21.1)	74(19.6)	54(14.3)	49(12.9)
B2	69(18.2)	69(18.2)	69(18.2)	69(18.2)	120(31.7)	120(31.7)	77(20.3)	63(16.6)	57(15.1)	45(11.9)
							66(17.4)	55(14.5)	44(11.6)	38(10.0)
B3	120(31.7)	120(31.7)	120(31.7)	120(31.7)	100(26.4)	100(26.4)	95(25.1)	82(21.7)	75(19.8)	65(17.2)
						89(23.5)	84(22.2)	77(20.3)	70(18.5)	62(16.4)
B20	28(7.4)	19(5.0)	15(4)	10(2.6)	120(31.7)	120(31.7)	95(25.1)	74(19.6)	61(16.1)	43(11.4)
						95(25.1)	84(22.2)	63(16.6)	50(13.2)	34(9.0)
D2	40(10.6)	40(10.6)	30(7.9)	28(7.4)	60(15.9)	40(10.6)	40(10.6)	40(10.6)	30(7.9)	28(7.4)
D3	60(15.9)	60(15.9)	42(11.1)	36(9.5)	70(18.5)	60(15.9)	60(15.9)	60(15.9)	42(11.1)	36(9.5)

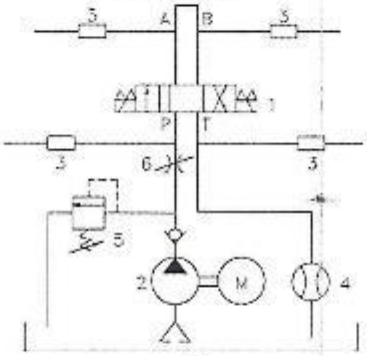
SOLENOID OPERATED DIRECTIONAL VALVE
SWH-G03 SERIES

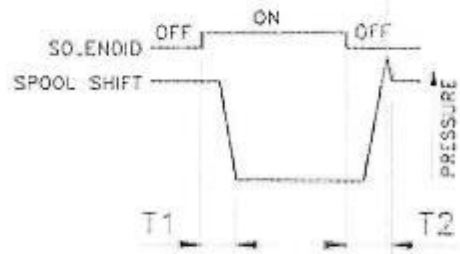
TEST SYSTEMS

1. Testing Valve
2. Pump
3. Pressure Sensor
4. Flow Sensor
5. Relief Valve
6. Throttle Valve

TEST CONDITIONS
Pressure: 138 BAR (2000PSI)
Flow Rate: 30 LPM(8 GPM)
Viscosity: 35 cSt(175 SSU)

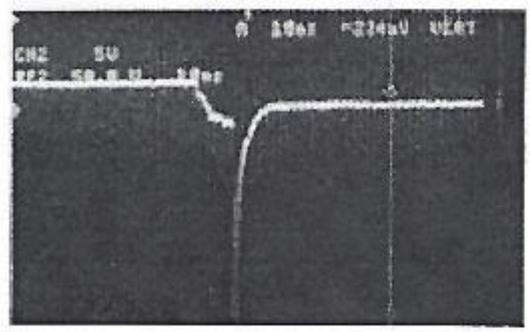
TEST CIRCUIT





MODEL	CHANGE OVER TIME (sec)	
	T1	T2
SWH-G03-AC SERIES	0.02	0.02
SWH-G03-DC SERIES	0.07	0.07

Electrical surge waveform standard DC solenoid



OPTION LS N/A

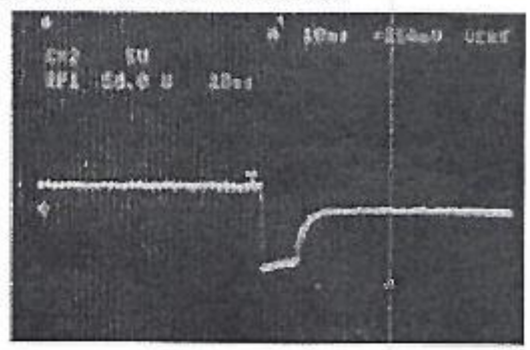
ELECTRICAL SURGE CONTROL MODEL SWH - G03 - *** - D ** - ** - LS

FEATURES
- Suppresses the surge voltage.
- Eliminates sparks between relay contacts.
- Extends the life of the relay contact.

EFFECTS

- Improves the reliability of the control relay.
- Extends the life of conventional relays.
- Can be operated with a miniature relay.
- The RAC rectifier built in DC model eliminates sparks at the control relay contact. It can be directly operated with a PLC (programmable logic controller).

Electrical surge control DC solenoid



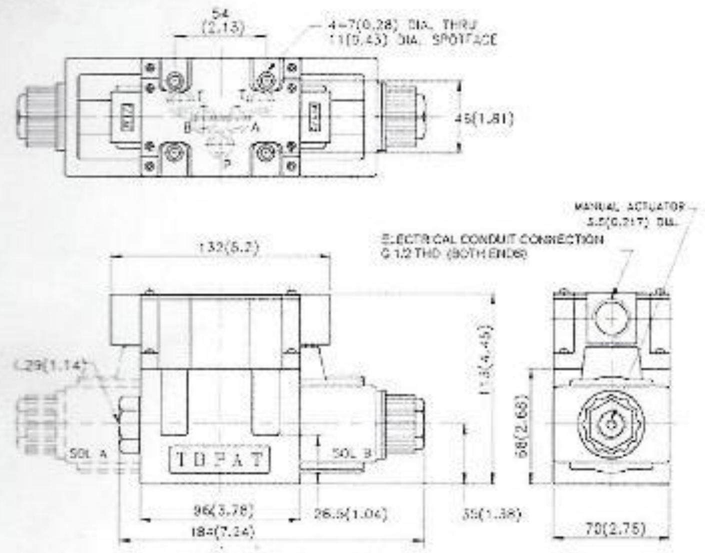
SOLENOID OPERATED DIRECTIONAL VALVE
SWH-G03 SERIES

Dimensions

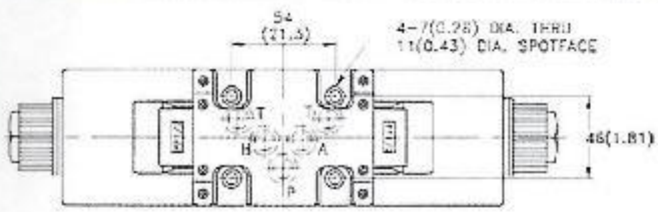
MOUNTING SURFACE: ISO 4401-AB-03-4-A
UNIT: mm(inch)

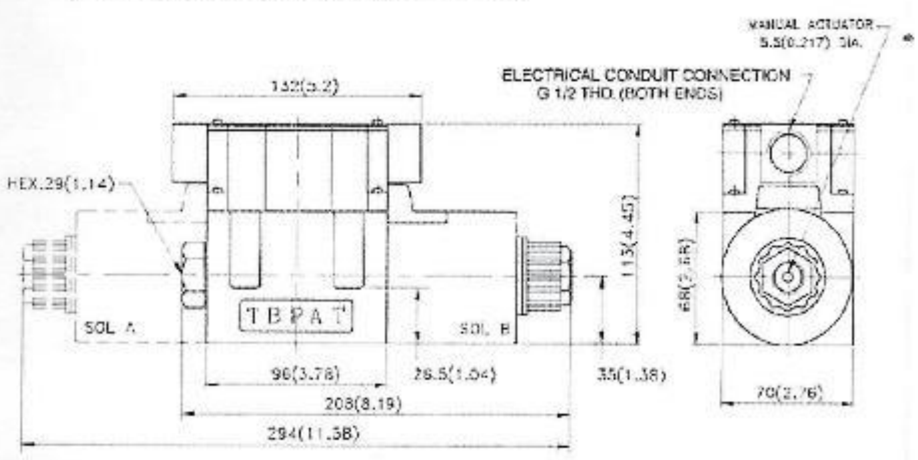
SWH - G03 - A ** - **** - 10 - **
with AC/DC/RF solenoids

MODEL	WEIGHT KGS (LBS)
SWH-G03-C**-A***	4.1(9.02)
SWH-G03-B**-A***-	3.4(7.48)



MODEL	WEIGHT KGS (LBS)
SWH-G03-C**-D **	5.5(12.1)
SWH-G03-C**-R ***	
SWH-G03-B**-D **	4(9.68)
SWH-G03-B**-R ***	



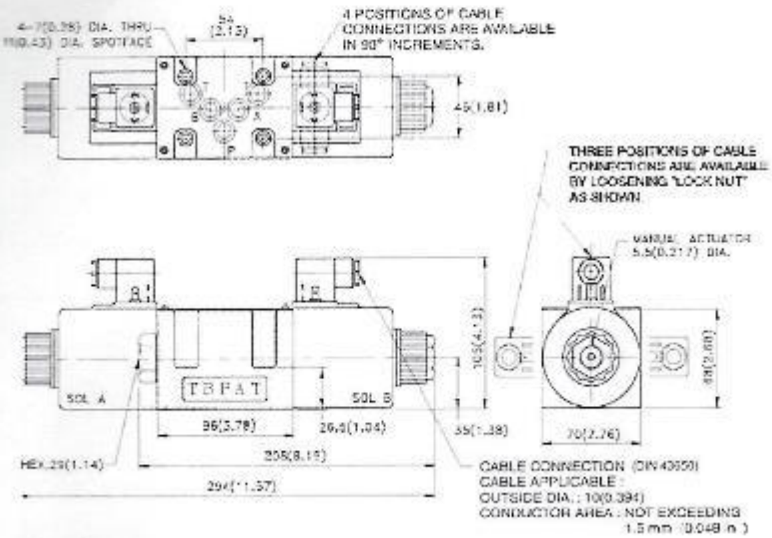


SOLENOID OPERATED DIRECTIONAL VALVE
SWH-G03 SERIES

Dimensions

MOUNTING SURFACE: ISO 4401-AB-03-4-A
UNIT: mm(inch)

SWH - G03 - *** - **** - 20 - **
with AC solenoids

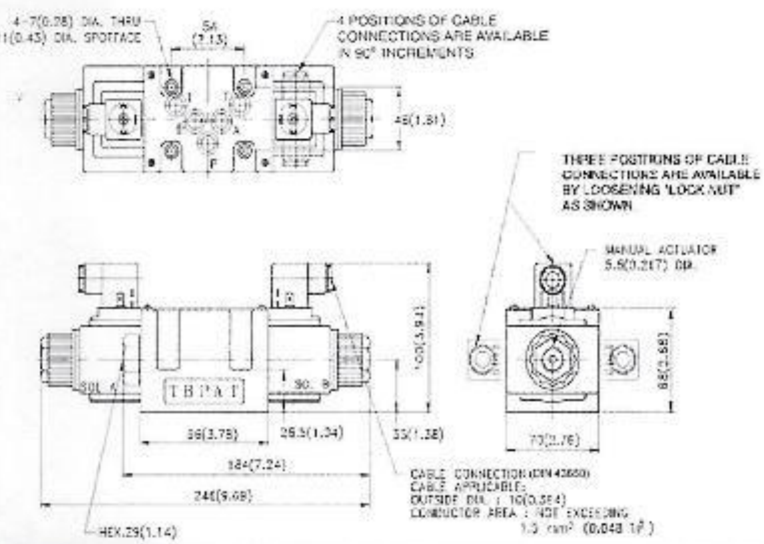


MODEL	WEIGHT KGS (LBS)
SWH-G03 -C**-A***	4.1(9.02)
SWH-G03 -B**-A***	3.4(7.48)

Dimensions

MOUNTING SURFACE: ISO 4401-AB-03-4-A
UNIT: mm(inch)

SWH - G03 - *** - **** - 20 - **
with DC,RF solenoids

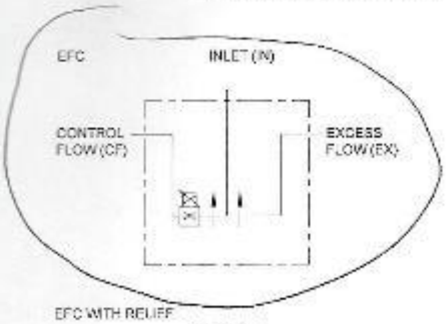


MODEL	WEIGHT KGS (LBS)
SWH-G03-C**-D **	5.5(12.1)
SWH-G03-C**-R ***	
SWH-G03-B**-D **	4(9.68)
SWH-G03-B**-R ***	

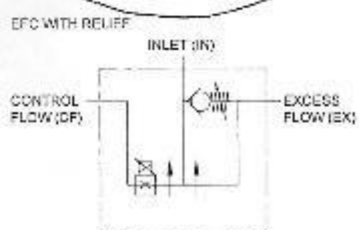
Brand Hydraulics Co. Electronically Adjustable Proportional Pressure Compensated Flow Control "EFC" Model PEFC12-30-12

Shipping: 2332 S 25th St (Zip 68105)
Mailing: P.O. Box #6069 (Zip 68106)
Omaha NE
Phone: (402) 344.4434
Fax: (402) 341.5419
www.BRAND-HYD.COM

ELECTRONICALLY ADJUSTABLE PROPORTIONAL PRESSURE COMPENSATED FLOW CONTROL "EFC"



EFC12-10-12



EFC12-15-12R22

Model # PEFC12-30-12 pressure compensated.

Pressure Compensated:
Same flow regardless of pressure
∴ at set flow rate carriage will travel at same speed up to system pressure in which case a stall will occur.

FEATURES:

- DIAMOND HONED SPOOL BORE provides consistent spool fit with low leakage.
- O'RING PORTS to eliminate leakage.
- EVERY EFC IS TESTED for shutoff, linearity, max. flow, crack open and pressure compensation.
- STANDARD 3-PORT allows for pressure compensated flow out of the CF and EX ports.
- MANUAL OVERRIDE when electrical power is lost.
- OPTIONAL 2-PORT allows for pressure compensated flow out of CF port.
- OPTIONAL FREE REVERSE FLOW allows fluid to move from the CF port to the inlet.
- OPTIONAL HIGH LIFT RELIEF.

SPECIFICATIONS:

- **See flow chart for capacity.**
- **3000 psi (207 bar) rating.**
- **Weighs 8-1/2 lbs. (3.9 kg).**
- **Standard Port size #12SAE (1-1/16 – 12).**
- **10-Micron Filtration Recommended.**
- **Pulse Frequency (90 to 115 hz).**
- **Coil**
  - **-12 VDC standard (24 VDC).**
  - **-9.6 ohms (48 ohms).**
  - **-15 watts (15 watts).**
  - **-1.0 amp max (0.5 amp max.).**
- **Response Time**
  - **-0.035" Standard dash pot (375 ms).**
  - **-0.020" Dash pot (900 ms).**
  - **-0.093 Dash pot (175 ms to 350 ms depending on flow).**
- **Spool leakage (3.05 in^3/min. @ 1000 psi ((50 ml/min. @ 68.9 bar) on EX port).**

MATERIALS:

- **Ductile Cast Iron Body**
- **Heat Treated Steel Spools**
- **Buna N O'Rings**
- **Heat Treated Free Reverse Check Seat**

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EFC – GENERAL INFORMATION

The Brand, electronically adjustable proportional pressure compensated flow control is an electronically controlled version of the original FC51 style flow control valve. The EFC performance as a flow control is very similar to the FC51 because they both use the same spring and compensator spool. Thus, the control flow port (CF) and the excess flow port (EX) remain usable and pressure compensated.

The main advantage of the EFC over the FC51 is that the flow can be adjusted proportionally with a solenoid instead of manually. As the current to the solenoid increases the variable orifice moves proportionally similar to positioning the rotary side lever on the manual FC's. The solenoid is connected to our EC – series controls which can be sold with the EFC. We also give the choice of a dashpot size, which allows the customer to select a valve that responds to the control box at different rates. Other options are 2-port, free reverse flow and high lift ball spring relief.

2-PORT- The 2-port (2P) option is a modified version of the standard 3-port EFC. This option lets the customer use the control flow port while the excess port is plugged. A special compensator spool was designed to eliminate hunting that can occur between pressure compensated valves and pumps. To use the EFC 2-port a pressure compensated pump is required. The 2-port can be converted to a 3-port (by removing the EX plug), but it will not have the same characteristics as the standard 3-port. (See chart on next page for 2-port EFC)

FREE REVERSE FLOW- The free reverse flow option was designed to be used primarily where cylinders and motors are needed to go in reverse. The flow can only go in reverse from controlled flow (CF) to the inlet (IN). Flow is not metered when it goes in reverse. The steel ball seat inside the compensator spool is heat treated to assure a long life.

HIGH LIFT BALL SPRING RELIEF – The high lift ball spring relief (R) reduces plumbing and provides relief protection. Once the pressure on the inlet port increases above the relief setting the relief valve opens and diverts flow to the EX port while maintaining pressure on the IN port. The EX port must be plumbed back to tank for this relief to work. This relief does not chatter and the cracking pressure from low to high flow is virtually the same. The relief is easily adjustable by simply loosening the lock nut and turning the adjusting fitting. (See relief chart on next page)

EFC – EXAMPLES OF COMMON MODEL CODES:

EFC12-10-12........................ 10 gpm (37.9 lpm) 3-port with 12 volt coil
EFC12-15-12R15...................... 15 gpm (56.8 lpm) 3-port, 12 volt coil with 1500 psi (103.4 bar) relief
EFC12-10-122P..................... 10 gpm (37.9 lpm) 2-port with 12 volt coil
CEP1000............................. 10 gpm (37.9 lpm) 3-port with EC-12-01 control

EFC – CREATING A MODEL CODE FOR EFC'S:

EFC _ _-_-_ _

REVERSE FLOW:
C – Free reverse flow
Omit – No reverse flow

PORT SIZE:
12 - #12SAE (1-1/16 – 12)
** - Contact factory for others

FLOW SETTING:
05 – 0-5 gpm (18.9 lpm)
10 – 0-10 gpm (37.8 lpm)
15 – 0-15 gpm (56.8 lpm)
20 – 0-20 gpm (75.7 lpm)
25 – 0-25 gpm (94.6 lpm)*
30 – 0-30 gpm (113.6 lpm)*

OPTIONS:
2P – 2 port
R15 – Relief set at 1500 psi (103.4 bar) (specify pressure in 100 psi increments)*
.093 – 0.093 dashpot orifice
.020 – 0.020 dashpot orifice

COIL VOLTAGE & TERMINAL:
12 – 12 volt DC
24 – 24 volt DC
PF – Weather pack, female shroud with male pin
PM – Weather pack, male tower with female pin

* - 3 port only

EFC WITH ELECTRONIC CONTROL:

CEP _ _ _ 00 _

REVERSE FLOW:
C – Free reverse flow
Omit – No reverse flow

CONTROLS:
D – EC-12-02 (Dashmount)
Omit – EC -12-01 (Weather proof box)

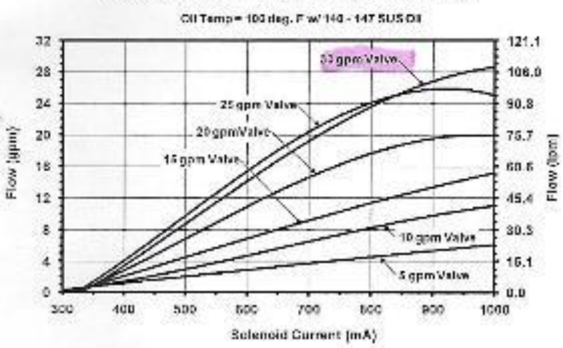
FLOW SETTING:
05 – 0-5 gpm (18.9 lpm)
10 – 0-10 gpm (37.8 lpm)
15 – 0-15 gpm (56.8 lpm)
20 – 0-20 gpm (75.7 lpm)
25 – 0-25 gpm (94.6 lpm)*
30 – 0-30 gpm (113.6 lpm)*

OPTIONS:
2P – 2 port
R15 – Relief set at 1500 psi (103.4 bar) (specify pressure in 100 psi increments)*
.093 – 0.093 dashpot orifice
.020 – 0.020 dashpot orifice
Omit – No options

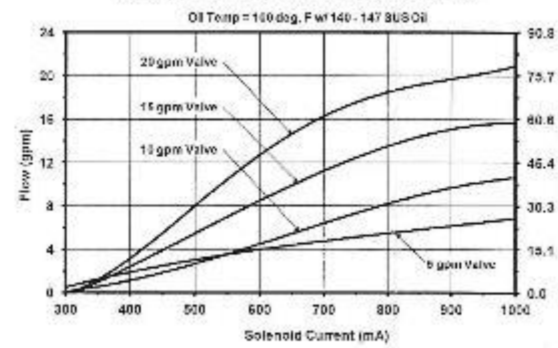
* - 3 port only

EFC FLOW & SOLENOID CURRENT INFO FOR 2-PORT AND 3-PORT:

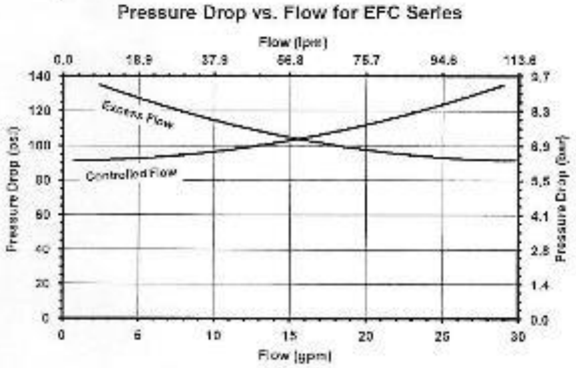
Flow vs. Solenoid Current for EFC 3-Port



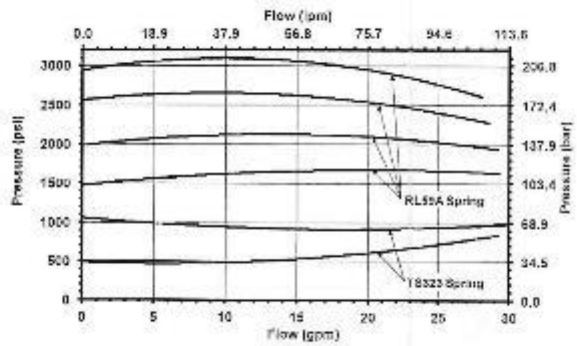
Flow vs. Solenoid Current for EFC 2-Port



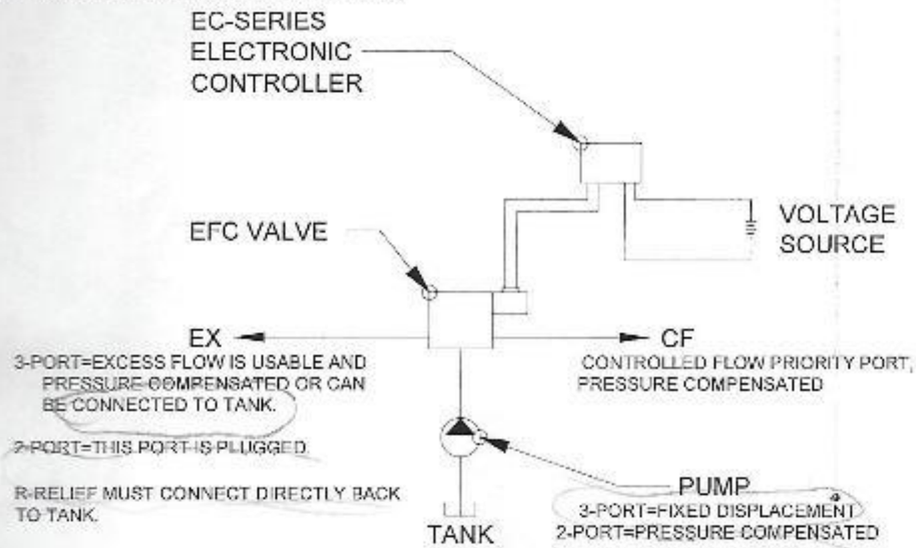
Pressure Drop vs. Flow for EFC Series



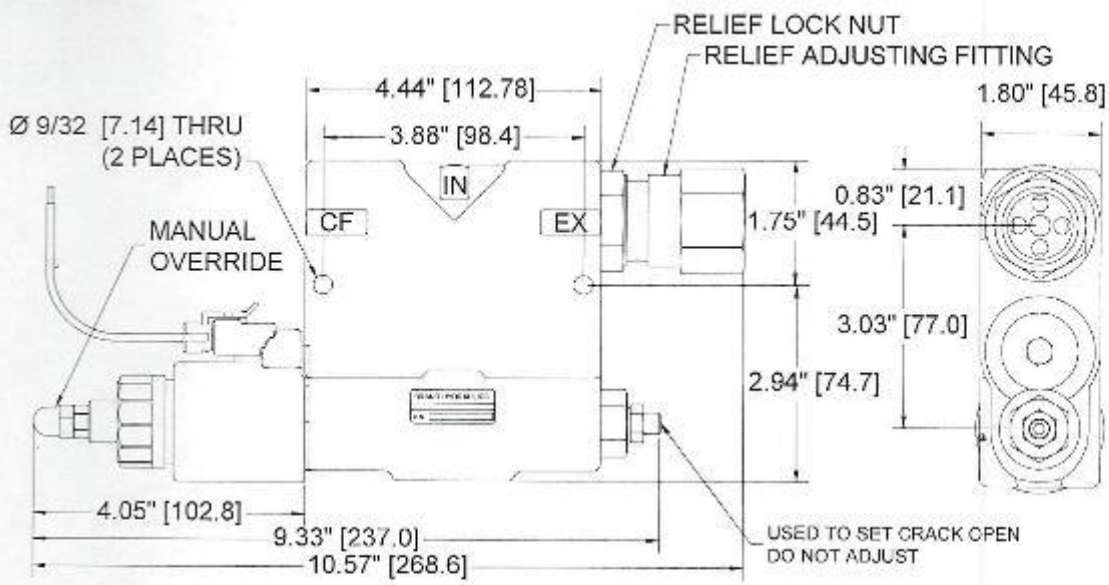
Pressure vs. Flow for EFC with Relief



2 & 3 PORT SCHEMATIC DRAWING:



DIMENSIONAL DATA (EFC WITH RELIEF SHOWN):



Page B-12

BRAND HYDRAULICS

Shipping: 2332 So 25th St (Zip 68105)
Mailing: P.O. Box #6069 (Zip 68106)
Omaha NE
Phone: (402) 344-4434
Fax: (402) 341-5419
HTTP://WWW.BRAND-HYD.COM

ISO 9001:2008 WITH DESIGN
Certificate #02.002.1

INSTALLATION SHEET FOR EFC STYLE FLOW CONTROLS

KEEP WITH PRODUCT UNTIL INSTALLED

ADDITIONAL SHEETS MAY BE PRINTED OUT FROM OUR WEBSITE WWW.BRAND-HYD.COM UNDER PRODUCT CATALOG SECTION

CF port (Controlled Flow) - flow coming from the CF port is pressure compensated and proportional to the current received by the coil. Flow can vary from closed to wide open.

EX port (Excess Flow) - Flow coming from the EX port is also pressure compensated.

WHAT IF I?
Block the CF port – Compensator spool will shift over and close off the EX port. Do not block the CF port.

Block the EX port – to do this a pressure compensated or load sense pump must be used. We also offer a special compensator spool (C9A-2P) to help reduce instability issues.

Mounting Surface – The valve must be mounted on a flat surface. It is important not to bend or twist the casting when mounting because this may cause the comp spool to bind. On rigid surfaces we recommend washers between casting and mounting surface.

Have Instability Issues – Most instability issues can be resolved by using a different compensator spool or spring. The following parts can be substituted for the C9A compensator spool: C9AS, C9A-093, C9A-2P and XDC609, spring: P1652.

Instability generally occurs when a motor is turning something that can free wheel (fan) or has a shaking force (vibration). When this occurs the EFC compensator spool tries to compensate for all the changes in load. The reaction to each other becomes unstable and leads to chatter & noises.

Manual Override Adjustment – First, remove the 7/16" acorn nut. Next, loosen the 7/16" jam nut. Finally, turn the override screw clockwise with a flat head screwdriver to manually adjust the flow out of the CF port until the motor, or cylinder, begins to move. Then, turn the screw counterclockwise until the motor, or cylinder, stops. Turn the override screw counterclockwise an additional ½ turn, secure the jam nut and reinstall the acorn nut.

Relief Adjustment –The relief pressure will be preset to customer specifications. In order for the relief to work, the EX port must be plumbed back to tank. To adjust the relief, simply loosen the relief lock nut and then turn the relief adjustment fitting clockwise to increase the pressure setting, see Figure 1 for more information. Both the relief lock nut and relief adjustment fitting accept a 1.375" wrench.

Other Information – EFC valves come standard in #12 SAE. Consult the factory for other possible port sizes, we do, however, recommend SAE porting.

Revision 11-09

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INSTALLATION SHEET FOR EFC STYLE FLOW CONTROLS

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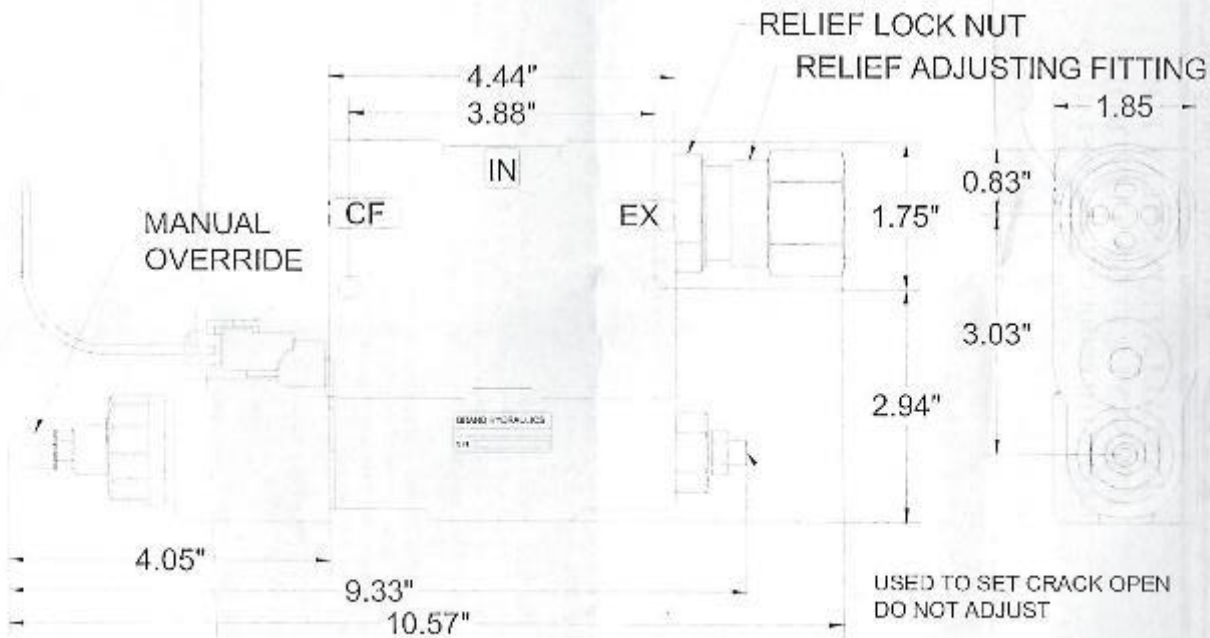


Figure 1: Dimensional Data for EFC valves (EFC with relief shown).

Revision 11-09

Axiomatic Remote Mount Solenoid Driver RSD-PCB-5V-1.2A

AXIOMATIC
Global Electronic Solutions

Dakota Fluid Power
micheal:

TECHNICAL DATASHEET #TD1500AX

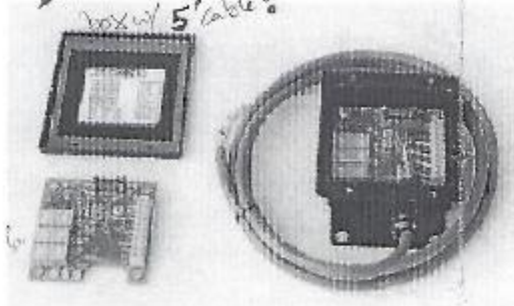
REMOTE MOUNT SOLENOID DRIVER

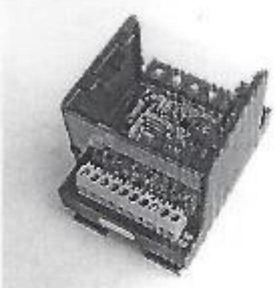
(0-5 VDC/0-20 mA/10K Potentiometer Input)

PCB only: $155.00 approx
box w/ 5' cable:

Part No.: RSD-PCB-5V-1.2A

PCB Board - RSD-PCB-5V-x
DIN Rail Mount – RSD-DR-5V-x
Packaged Driver (board installed in metal box)
Available with no cable - RSD-SMB-5V-x-00
Available with 3 connectors – RSD-SMB-5V-x-01
IP65 rated, with cable - 5 ft. (1.5m)
- RSD-SMB-5V-x-IP5-yM
IP67 rated, with solid round cable - 5 ft. (1.5m) -
RSD-SMB-5V-x-IP7-yM
Clear cover, 1.5 m cable, 2A output –
AXRSDSMB5V2A1C
Where x = maximum current output
(2A, 1.2A, 800 MA, 600MA or 400MA)
y = 1.5 or custom lengths (meters)





Description: The Remote Mount Solenoid Driver simplifies control of proportional solenoids by supplying a current proportional to an input control (0-5 VDC, 0-20 mA, potentiometer or pre-set level). It accepts power supply voltages from 9 to 28 VDC. This linear solenoid driver utilizes high frequency switching output (PWM) to provide a DC current output. A current sensing circuit maintains output current regardless of changes in input voltage and coil resistance. The options for maximum current output include 2 A, 1.2 A, 800 MA, 600 mA or 400 mA. The user can adjust maximum and minimum current. Ramp time, dither frequency and amplitude can also be adjusted to match the application. A system of LED's indicates output power level, input level and power on/off. The unit is available as a stand alone PCB Board, DIN rail mount version or as a Packaged Driver enclosed in an IP65 or IP67 rated metal housing with cable or connectors provided. It is designed for remote mounting. Other versions are available including 4-20 mA signal input, 0-10 VDC signal input and DIN 43650 coil mount versions.

Application: Accurate control of hydraulic or pneumatic proportional solenoid valves in mobile equipment or industrial processes

Features:

- Stand alone PCB Board, DIN rail mount version or enclosed in a metal housing with cable (3 connectors or no cable optional)
- Maximum current adjustment does not affect minimum current setting
- Current sensing circuit maintains output current regardless of changes in input voltage and coil resistance
- Broad range of supply voltages (9 to 28 VDC) with no degradation in performance
- Modern technology utilizing high frequency switching output (PWM)
- Energy efficient design (no heat sink is required)
- Accepts a 10K Potentiometer, 0-5 VDC or 0-20 mA inputs (0-10 V or 4-20 mA input versions available)
- Options for maximum current output include 2 A, 1.2 A, 800 mA, 600 mA or 400 mA
- LED indication of output power level, input level and power on/off
- Simple implementation of "soft shift" control with minimal external components
- Electronic limiting circuit means no internal fuses
- Short circuit proof (in case of solenoid failure or miswiring)
- CE certified for EMC
- UL and cUL versions available on request
- Metal box version carries IP67 rating
- Reverse polarity protected
- Filter eliminates electrical noise

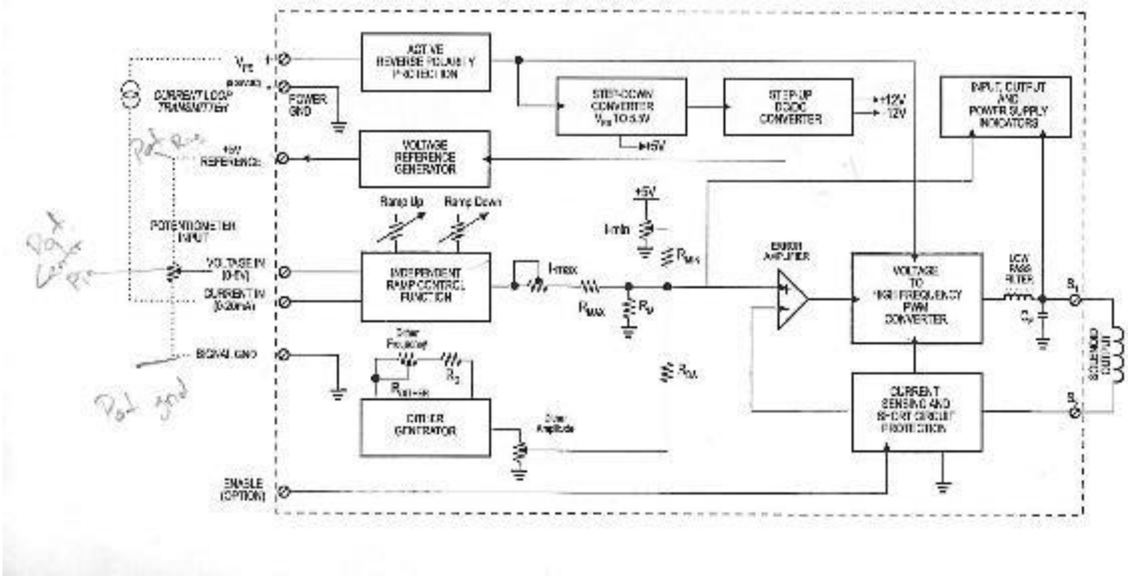
module

In Europe:
Axiomatic Technologies Oy
Höytämöntie 6
33880 LEMPÄÄLÄ - Finland
Tel. +358 3 3595 600
Fax. +358 3 3595 660
www.axiomatic.fi

Valve Driver $300
8 inputs
16 inputs

In North America:
Axiomatic Technologies Corporation
5915 Wallace Street
Mississauga, ON Canada L4Z 1Z8
Tel. 1 905 602 9270
Fax. 1 905 602 9279
www.axiomatic.com

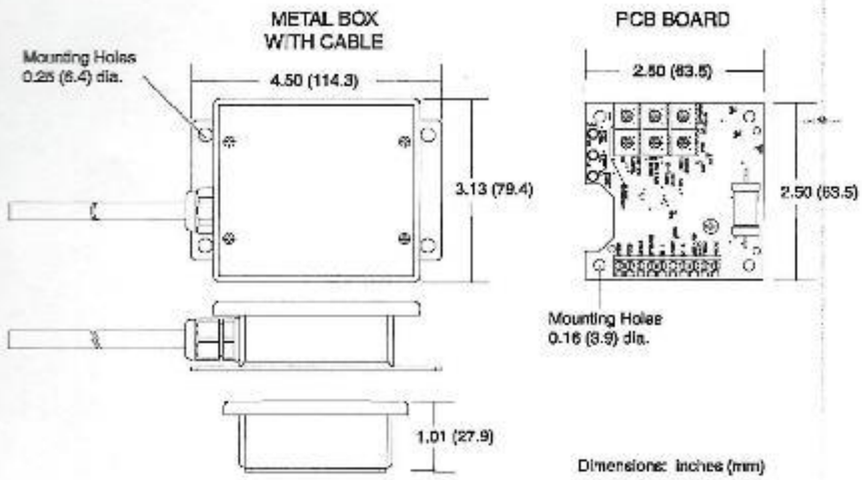
BLOCK DIAGRAM (0-5VDC Remote Mount Solenoid Driver)



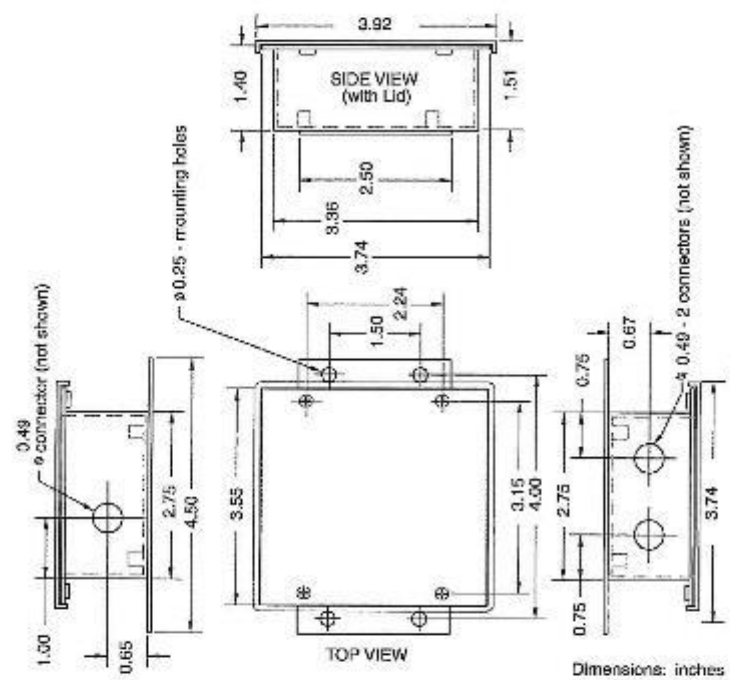
Technical Specifications: All specifications typical at nominal input voltage and 25°C unless otherwise specified.

General Specifications

Quiescent current	13.7 mA @ 12VDC 10 mA @ 24VDC
Operating conditions Storage temperature	-40 to +85 degrees C (-40 to 185°F) 0 to 85% relative humidity -60 to +125 degrees C (-58 to 257°F)
Electromagnetic compatibility (EMC)	Emission EN 50081-2; Immunity EN 50082-2
Approvals	CE (Packaged Driver version only) *The PCB Board and DIN rail mount versions are sold as components.*
Protection - Packaged Driver	IP65 with nitrile lid gasket and cable installed IP67 with nitrile lid gasket and cable installed
Protection – DIN Rail Mount	IP00 Circuit board is conformally coated.
Electrical connection - PCB Board, DIN Rail Mount or Packaged Driver (no cable)	10 screw terminals accept 16-20 AWG wire for the power conductors and 18-24 AWG wire for the signal conductors
Electrical connection - Packaged Driver with cable	Unterminated cable 5 ft. (1.5m) standard length *(A DIN 43650 coil mount version is also available.)*
Electrical connection - Packaged Driver with connectors	*Solenoid* - Brad Harrison 45360-001 nano-change receptacle (3-pole male) *Signal input* - Brad Harrison 45360-001 nano-change receptacle (3-pole male) *Power Input* – Brad Harrison 8R4E06A18A120 micro-change single keyway receptacle (4-pole male) *Mating plug with cable assemblies are available. Contact manufacturer.*
Cable clamp (grommet) size Max. cable diameter Wire size - cable in IP65 rated Packaged Driver Wire size - cable in IP67 rated Packaged Driver	PG9 screw type 5.00 to 7.92 mm (0.200 to 0.312 in.) 9 insulated wires AWG 20 plus drain wire 1 twisted quad AWG 18 (1.0 mm²) and 5 insulated wires AWG 24 (0.25 mm²) plus drain wire
Dimensions - PCB Board	63.5 x 20.3 x 63.5 mm (W x D x H) 2.5 x 0.8 x 2.5 inches
Dimensions – DIN Rail Mount	90.0 x 68.0 x 70.0 mm 3.54 x 2.67 x 2.75 inches (W x L x H excluding DIN rail foot)
Dimensions - Packaged Driver with cable	114.3 x 27.9 x 79.4 mm 4.50 x 1.01 x 3.13 inches (W x D x H excluding grommet and cable)
Dimensions - Packaged Driver with connectors	114.3 x 39.0 x 110.64 mm 4.50 x 1.53 x 4.36 inches (W x D x H including mounting plate and connectors)
Weight	PCB Board 0.10 lbs. (0.045 kg) DIN Rail Mount 0.30 lbs. (0.136 kg) Packaged Driver with Cables (1.5m) 1.25 lbs. (0.567 kg) Packaged Driver with Connectors 1.10 lbs. (0.499 kg)



METAL BOX WITH 3 CONNECTORS



Electrical Specifications

Operating voltage (power supply requirement)	9 to 28 VDC power supply range
Control input signal options	0-5 VDC voltage signal or 0-20 mA current signal (max. 30 mA) or 10K Potentiometer (accepts 10K to 50K pots) or for soft shift control, pre-set the solenoid driver by connecting +5VDC to input and use the I-max. adjustment (0-10 VDC and 4-20 mA input versions available) Refer to Notes below for proper installation.
Input resistance	Voltage mode: 250K Ohms Current mode: 33 Ohms
Range of maximum output current	2 A (1.2 A, 800 mA, 600 mA and 400 mA versions)
Solenoid resistance selection (nominal)	Nominal resistance of solenoid coil should comply with: Rcoil ≤ (Vpowersupply - 1.5 V)/Imax
Internal supply for setpoint potentiometer	+5 VDC (See Note 4.)

Imax = 1amp

9.6 ohm coil

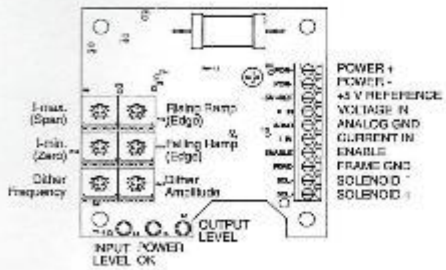
$9.6 \le \frac{12-1.5}{1}$

Note 1: For proper operation, match the power supply voltage with rating of solenoid coil. Operating the driver with a supply voltage lower than the solenoid rated voltage may result in reduced maximum current output.
Note 2: Since the output is filtered (not switched), no external protection diodes are necessary.
Note 3: The maximum current output of the driver should not exceed the current rating of the solenoid coil.
Note 4: WARNING: The control input and the +5V reference lines should never be connected to the power supply input line. This will damage the controller.

Adjustments

Minimum current setting	0 to 500 mA (for 2 A output model) 0 to 300 mA (for 1.2 A output model) 0 to 150 mA (for 800 mA output model) 0 to 150 mA (for 600 mA output model) 0 to 100 mA (for 400 mA output model)
Maximum current setting	0.6 to 2.0 A (for 2 A output model) 0.36 to 1.2 A (for 1.2 A output model) 300 to 800 mA (for 800 mA output model) 180 to 600 mA (for 600 mA output model) 120 to 400 mA (for 400 mA output model)
Current ramp time	0.01 - 5 sec. independent
Dither amplitude Dither waveform Current dither frequency	0 to 10% of rated maximum current Triangular 70 to 350 Hz (±10% of full scale)

Mounting Instructions and Wiring Connections:
For stand alone PCB Boards:



Mounting the PCB board

- The board will accommodate #6 size mounting screws (not supplied).

Connecting to the screw terminals on the board

- Use a cable to connect to the PCB board with each wire stripped to 6.5 mm (1/4 inch) and the shield (jacket) stripped to permit splaying of the wires in the screw terminals without tension. The exposed ground shield wire should have a heat shrink placed around the wire as a precautionary measure.
- Reference the label (included with the board) for the pin out connections of the screw terminals.
- To connect the cable to the board, loosen each screw terminal, insert the pre-tinned wire and tighten with a jeweller's sized screwdriver. **Take care to position the ground shield wire away from the PCB Board.**

For Packaged Drivers with/without cable (Metal Box):

Mounting the housing

Mount the housing using four #10-32 bolts or screws.

Connecting to the screw terminals on the board

For models where no cable is provided connect a cable as follows. For a cable specification, refer to the technical specification section.

- To access the screw terminals, loosen the four screws on the lid using a Phillips #1 screwdriver. Remove the lid.
- Use a 0.200 to 0.312 inch diameter solid round shielded cable to connect to the remote mount solenoid driver. Each wire should be stripped to 6.5 mm (1/4 inch) and the shield (jacket) stripped to a minimum of 57 mm (2-1/4 inches). Exposed ground shield wire should have a heat shrink placed around the wire as a precautionary measure.
- Remove the clamp nut on the Heyco PG9 grommet using an adjustable wrench.
- Slide the clamp nut over the cable. Insert the cable into the grommet, allowing for the stripped minimum of 2 1/4 inches to be available inside the housing. Tighten the clamp nut securely attaching the cable to the housing assembly.
- Reference the label (found on the inside of the lid) for the pin out connections of the screw terminals.
- To connect the cable to the board, loosen each screw terminal, insert the pre-tinned wire and tighten with a jeweller's sized screwdriver. **Take care to position the ground shield wire away from the PCB Board.**
- Replace the lid and gasket. Replace and tighten the four 4-40 Phillips flat head screws.

Connecting the cable

For models where the cable is supplied, connect the cable to the load, power supply and input signal or potentiometer, as follows.

For Potentiometer, 0-20 mA or 0-5 VDC Control:

Turn ramp screws fully counterclockwise to eliminate ramping.

Use I-Min. screw to set up minimum speed with minimum control input.

Use I-Max. screw to set maximum speed with 100% of control input.

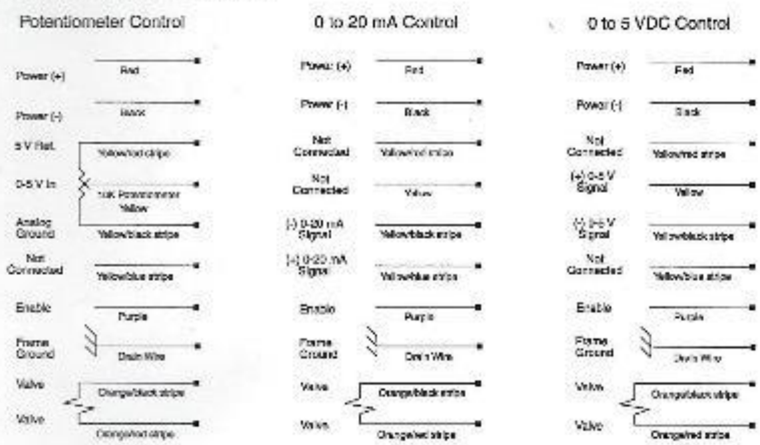
WARNING: The control input and the +5V reference lines should never be connected to the power supply input line. This will damage the controller.

Enable:

When Enable is connected to the -ve power supply, the unit will be disabled. When Enable is left open or connected to the +ve power supply, the unit is enabled.

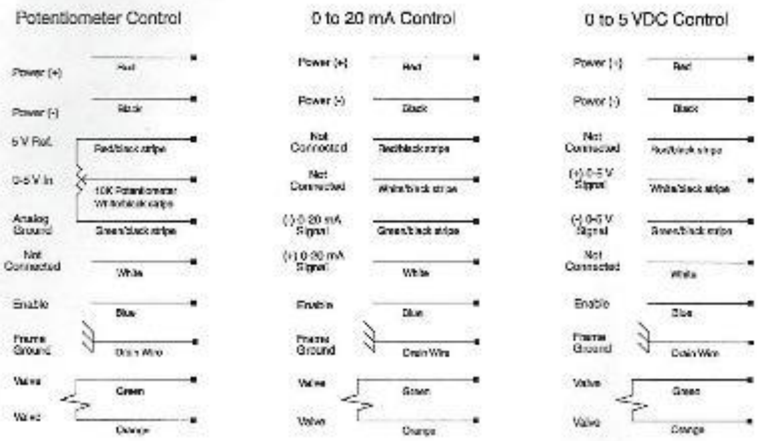
IP67 Rated Driver with Cable – Wiring Diagram

WARNING: The control input and the +5V reference lines should never be connected to the power supply input line. This will damage the controller.



IP65 Rated Driver with Cable – Wiring Diagram

WARNING: The control input and the +5V reference lines should never be connected to the power supply input line. This will damage the controller.



Refer to page 2 (block diagram) for an alternative method of connecting a current loop transmitter to provide a current control signal input. In this method, the current loop transmitter receives power from the power supply powering the amplifier. The transmitter is connected to the driver's +power supply input wire and the +0 to 20 mA input wire. This method does not use the –0 to 20 mA signal wire connection.

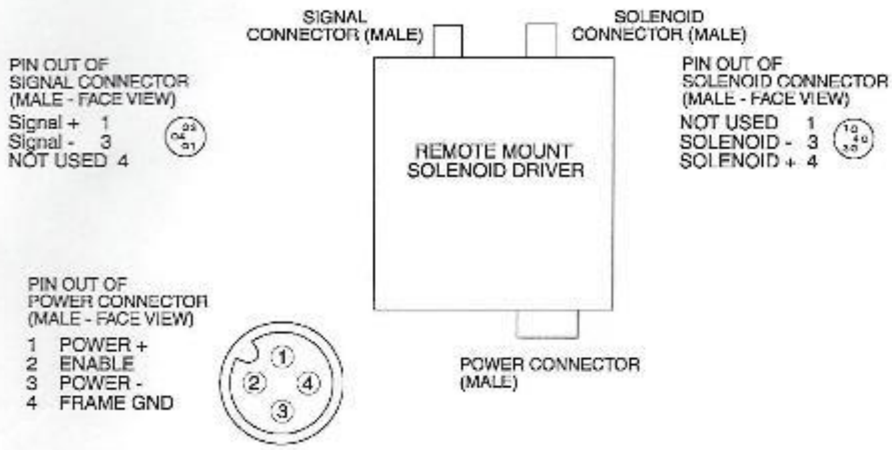
For Packaged Drivers with three connectors (Metal Box):

Mounting the housing
Mount the housing using four #10-32 bolts or screws.

Connector Pin Out:

For Either Potentiometer, 0-5 VDC or 0-20 mA Control:
Turn ramp trim pot fully counterclockwise to eliminate ramping.
Use I-Min. trim pot to set minimum speed with minimum control input.
Use I-Max. trim pot to set maximum speed with 100% of control input.
Enable:
When Enable is connected to the -ve power supply or Analog GND screw terminal, the unit will be disabled.
When Enable is left open or connected to the +ve power supply, the unit is enabled.

Mating plug and cable assemblies are available. Contact the manufacturer. The pin out shown below is for the three male connectors mounted in the metal box.



For DIN Rail Mount Drivers:

Mounting the housing
The DIN Rail Mount Driver has a universal foot for mounting on the DIN rail.

Connecting to the screw terminals on the board

- Use 16-20 AWG wire for the power conductors and 18-24 AWG wire for the signal conductors in a solid round shielded cable to connect to the remote mount solenoid driver. Each wire should be stripped to 6.5 mm (1/4 inch) and the shield (jacket) stripped to a minimum of 57 mm (2-1/4 inches). Exposed ground shield wire should have a heat shrink placed around the wire as a precautionary measure.
- Reference the label for the pin out connections of the screw terminals.
- To connect the cable, loosen each screw terminal, insert the pre-tinned wire and tighten with a jeweller's sized screwdriver. **Take care to position the ground shield wire away from the PCB Board.**

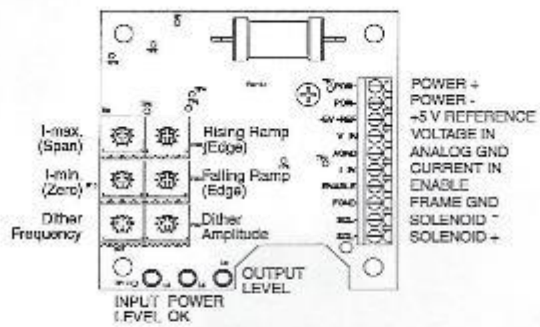
Enable: When Enable is connected to the -ve power supply, the unit will be disabled. When Enable is left open or connected to the +ve power supply, the unit is enabled.

Adjustment Details:

Ensure that the unit is connected to an operating proportional valve. Use a Phillips #1 screwdriver to make adjustments to the trim pots. The torque rating for the trim pots is 5.0 oz-in. max.

The following settings represent a typical set up for a voltage or current signal input. Conditions will vary for other set up scenarios. Trim pots are single turn. Use a Phillips #1 screwdriver to adjust the single turn trim pots.

PCB Board and Packaged Driver versions



In the Packaged Driver, adjustments are accessible by loosening the four screws on the lid of the housing and removing the lid.

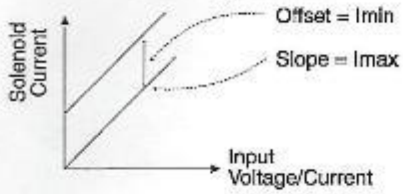
DIN Rail Mount version

Trim Pot Adjustments	Range of Adjustment	Factory Setting
Zero - Minimum Current Setting (I-min.)	0 to 0.5 A (for 2 A output model) 0 to 0.3 A (for 1.2 A output model) 0 to 150 mA (for 800 mA output model) 0 to 150 mA (for 600 mA output model) 0 to 100 mA (for 400 mA output model)	0% (CCW)
Span - Maximum Current Setting (I-max.)	0.6 to 2.0 A* (for 2 A output model) 0.36 to 1.2 A (for 1.2 A output model) 300 to 800 mA (for 800 mA output model) 180 to 600 mA (for 600 mA output model) 120 to 400 mA (for 400 mA output model)	100% (CW)
Ramp Time (Rising and Falling Edge)	0.01 to 5 seconds independent	minimum (0.01 sec.) (CCW)**
Dither Level (Amplitude)	0 to 10% of rated maximum current	0% (CCW)
Dither Frequency	70 to 350 Hz (±10%)	minimum (CCW)

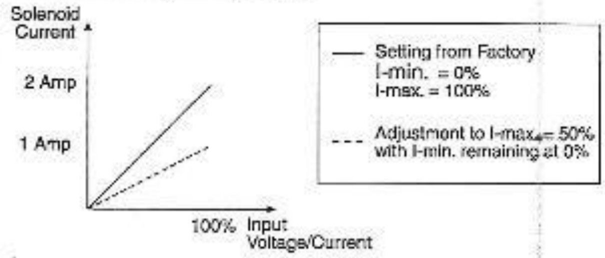
CW = clockwise, CCW = counterclockwise

*NOTE 1: Range of maximum output current is 2A (maximum output current = minimum current setting + maximum current setting).
**NOTE 2: To eliminate ramping, turn the trim pots fully counterclockwise.

Adjusting the minimum current will shift the maximum current setting, as shown.



Adjusting the maximum current (I-max.) does not affect the minimum current (I-min.) setting.



Setting the Minimum Current (I-min.)

The minimum current setting can be used to take into account the mechanical valve deadband and provide desired offsets from zero to allow full control within the functional range of the specific valve.

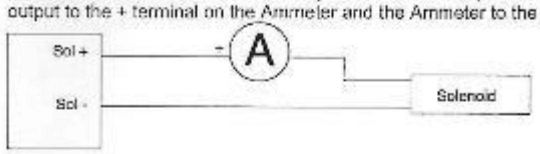
- **Set the minimum current before setting the maximum current.**
- Apply minimum input (control potentiometer at minimum or 0 V or 0 mA).
- The factory setting for the I-min. trim pot is set at 0 or fully counterclockwise (CCW).
- If the desired minimum current is greater than 0, adjust the trim pot clockwise (CW) until the desired current is achieved.

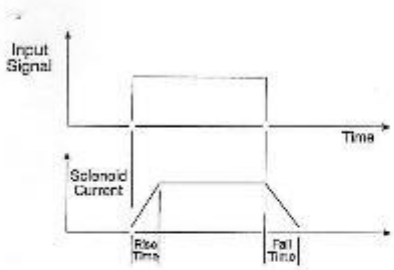
Setting the Maximum Current (I-max.)

- Apply maximum control (control pot at maximum or 5 V or 20 mA).
- The factory setting for the I-max. trim pot is 100% or fully CW.
- Turn the trim pot CCW to adjust the current setting downwards to the desired maximum.

The maximum current setting is adjusted to meet the customer's working pressure or flow range to the full scale signal input range. This provides maximum control for a specific application. *For example, a 5 VDC input can represent a 500 mA output (versus a 2 A output) if the valve requires this maximum current for its control function application.*

Current output should be measured by an ammeter set up in series with the driver and the load. Connect the Solenoid + output to the + terminal on the Ammeter and the Ammeter to the Solenoid. Connect the Solenoid - output to the Solenoid.





Ramp Times

Setting the Ramp Times

- The factory setting for ramp times is the minimum (0.01 seconds) or fully CCW.
- **If the ramp time settings are not needed, leave the setting at the minimum value.**
- To change the ramp times, adjust the trim pot CW to increase the time.
- Note that rising and falling ramp times are independent.

Ramp times are application dependent. They limit the rate of change or how fast the operation happens. Note that if the input signal is not applied long enough for the ramp time set, the desired solenoid current will not be reached.

Setting the Dither Amplitude

- The factory setting for dither amplitude is 0% (CCW).
- To adjust dither amplitude, turn the trim pot CW until small changes in the input signal register similar changes in current output.
- Choose the smallest effective dither amplitude.

Dither amplitude is adjustable from 0 to 10% of the rated maximum current. Dither amplitude and frequency are dependent on the specific valve. The effects of static friction on the operation of the solenoid are reduced by the application of a small AC current. The hysteresis and repeatability of the valve are improved by this practice. The optimum dither amplitude is attained when small input signal changes register similar changes in current output (pressure or flow through the valve).

Setting the Dither Frequency

- The factory setting for dither frequency is the minimum or 0% (CCW).
- To adjust dither frequency, turn the trim pot CW until the desired frequency is set.
- The valve manufacturer will provide the desired dither frequency rating for their product.

Measure the superimposed dither by attaching a digital multimeter (with a frequency setting) to the Test Point located next to the INPUT LEVEL LED and to the Analog GND screw terminal (for PCB and Packaged Driver versions).

Ordering Part Number:

PCB Board - RSD-PCB-5V-x

DIN Rail Mount - RSD-DR-5V-x

Packaged Driver (board installed in housing assembly)

Available with no cable - RSD-SMB-5V-x-00

Available with 3 connectors – RSD-SMB-5V-x-01
Contact the manufacturer for mating plug and cable assemblies.

IP65 rated and available with cable - 5 ft. (1.5m) - RSD-SMB-5V-x-IP5-1.5M
IP67 rated and available with solid round cable - 5 ft. (1.5m) - RSD-SMB-5V-x-IP7-1.5M

Clear cover, 1.5 m cable, 2A output – AXRSDSMB5V2A1C

Where x = maximum current output (2A, 1.2A, 800MA, 600MA or 400MA) and y = 1.5 or custom lengths (meters)

Specifications are indicative and subject to change. Actual performance will vary depending on the application and operating conditions. Users should satisfy themselves that the product is suitable for use in the intended application. All our products carry a limited warranty against defects in material and workmanship. Please refer to our Warranty, Application Approvals/Limitations and Return Materials Process as described on www.axiomatic.com/service.html.

Form: TD1500AX-02/22/11

Appendix B - Materials and Cost

CAT App Materials Cost List

Supplier abbreviations:

BSW	Built-So-Well
FAS	Fastenal
ORS	Orscheln's
SUR	Surplus Center
NOR	Northern Tool
MEN	Menard's
GRA	Grainger
DFP	Dakota Fluid Power
NAP	Napa Auto Parts
EQP	Equipatron
RAD	Radio Shack
JET	Jet Ski Plus, LLC
MOT	Motron Industries
MOU	Mouser
MIN	Mini In The Box
QST	Kansas State Quarter Scale Tractor Team
TYK	TYKB Buy
WTA	Wamego Truck and Auto Recycling

Building Materials

Supplier	Quantity	Description	Price	Amount
BSW	80 ft	1/4" x 1-1/4" flat	0.9	72
BSW	12 ft	4" x 1/4" square tubing	10.54	126.48
BSW	80 ft	1-1/2" x 3/16" angle iron	1.28	102.4
BSW	80 ft	4" x 1/4" steel square tubing	5.38	430.4

ORS		touchup paint		31.74
ORS		Purple and black paint		13.76
ORS	3 gal	Paint	30.99	92.97
ORS	6 ea	spray paint	5.29	31.74
ORS	4 ea	Rustoleum	3.44	13.76
		Total Paint Materials		**$ 336.01**
BSW	24 ft	2" x 3/16" steel square tubing	1.76	42.24
BSW	20 ft	3.5" x 1/4" steel square tubing	8.63	172.6
BSW	84 ft	3" steel sched 80 pipe	9.3	781.2
BSW	56 sq ft	1/4" steel plate	6.85	383.6
BSW	8 sq ft	3/8" steel plate	10.28	82.24
BSW	8 ea	074200 1/2" U-bolts	13.22	105.76
BSW	40 ft	3/16" x 1-1/4" flat	0.6	24
BSW	2.5 ft	3" x 3/16" square tubing	5.52	13.8
BSW	1 ft	4" sched 40 pipe	3.65	3.65
MOT	2 ea	45" u-rods	73.33	146.66
MOT	4 ea	HUB-054 axial bearings	64.4	257.6
FAS	4 ea	bolt, HCS 3/4 - 10 x 5 Z5	1.9307	7.72
FAS		misc fasteners		82.46
		Total Building Materials		**$ 2,834.81**

Paint Materials

Supplier	Quantity	Description	Price	Amount
ORS Painting supplies		120 ORS plastic sheeting		
32.04				

Hydraulic & Power Transmission

Supplier	Quantity	Description	Price	Amount
WTA	1 ea	3.73:1 rear axle from '01 Ford Explorer	250	250
SUR	4 ea	18T 1 bore 50P sprocket	8.5	34
SUR	9 ea	#50-10 H 10ft box of #50 roller chain	22.95	206.55
SUR	12 ea	#50H heavy duty connecting link	0.6	7.2

SUR	1 ea	1" x 36" keyed shafting	26.95	26.95
SUR	1 ea	1-1/8" L-110 jaw coupling half	22.95	45.9
SUR	2 ea	Buna-N insert for L-110 jaw coupling	10.15	20.3
SUR	2 ea	5/8" L-110 jaw coupling half	22.95	45.9
SUR	1 ea	1" L-110 jaw coupling half	22.95	22.95
SUR	2 ea	28T unfinished 3/4" bore 50P sprocket	8.25	16.5
SUR	1 ea	1.80 cu in cross hyd motor 40MH18DACSC	227.95	227.95
SUR	1 ea	1.654 cu in Prince SP20B27D9H2R hyd pump	209.95	209.95
SUR	1 ea	4 qt plastic fuel tank	9.95	9.95
SUR	1 ea	4 position ignitino key switch	6.99	6.99
SUR	1 ea	steel fuel tank	14.95	14.95
SUR	1 ea	swivel tee	11.5	11.5
SUR		shipping and handling	90	90
NOR	1 ea	flow control valve	369.99	369.99
NOR	1 ea	directional control valve	139.99	139.99
NOR	1 ea	single-station subplate	59.99	59.99
NOR		shipping and handling	21.99	21.99
MEN	1 ea	1-1/4" brass ball valve	23.99	23.99
MEN	1 ea	1-1/2" brass ball valve	30.59	30.59
SUR	1 ea	1-1/2" npt hex nipple	9.9	9.9
SUR	3 ea	SAE 10 plug	1.3	3.9
SUR	1 ea	1-1/4" nptm x 1-1/4" nptf 90 elbow	10.95	10.95
SUR	1 ea	SAE 20M x 1-1/4" nptm 90 elbow	11.95	11.95
SUR	1 ea	SAE 10M x 1/2" nptf 90 elbow	4.8	4.8
SUR	1 ea	3/4" nptm x 3/4" nptf swivel 90 long elbow	9.1	9.1
SUR	2 ea	3/4" nptm x 3/4" nptf 90 swivel	6.9	13.8
SUR	1 ea	SAE 12M x 3/4" nptf 90 swivel	7	7
SUR	4 ea	3/4" x 24" hose	15.95	63.8
SUR	2 ea	3/4" x 30" hose	17.95	35.9
SUR	1 ea	1" x 30" 1 nptm x 1 nptm 2750 psi hyd hose	26.95	26.95
SUR	1 ea	1/4" nptm x 3/8" nptf 90 swivel	2.4	2.4

SUR	1 ea	1/2" npt to 3/8" npt bushing	1.65	1.65
SUR	1 ea	3/8" x 72" hose		14.95
14.95				
QST	1 ea	Briggs & Stratton 31HP engine	1800	1800
NOR	1 ea	flow control valve, 0-30 gpm	369.99	369.99
NOR	1 ea	single-station subplate, 3/4" npt side ports	59.99	59.99
NOR	1 ea	directional control valve	139.99	139.99
GRA	8 ea	caster wheel 660 lb 3 D x 1-1/4"	17.7	141.6
GRA	3 ea	surge protector 15A 8 outlet	32	96
NAP	1 ea	barricade hose	1.22	1.22
MEN	1 ea	1/4" barb 90 deg elbow	1.74	1.74
		Total Hydraulic & Power Transmission	**$**	**4,721.66**

Experiment 2 Materials

Supplier	Quantity	Description	Price	Amount
SUR	1 ea	1/2" npt 15 GPM Prince WNV-800 needle valve	33.95	33.95
SUR	1 ea	1/2" npt 30 GPM 500-1500 psi relief valve	45.9	45.9
SUR	1 ea	2000 psi 2.5 bm dry guage 50 psi graduation	5.95	5.95
SUR	1 ea	reservoir filler breather w/ 4" strainer basket	15.9	15.9
SUR	4 ea	1/2" npt stamped weld-in tank flange	2.25	9
SUR	8 ea	1/2" nptm x 1/2" nptf 90 swivel	3.4	27.2
SUR	2 ea	4.00-6 pneumatic tire & wheel assmb	5.95	11.9
SUR	1 ea	1/2" x 36" 1/2 nptm x 1/2 nptm SAE 100R17 hyd hose assmb 3000 psi	10.95	10.95
SUR	1 ea	1/2" x 48" 1/2 nptm x 1/2 nptm SAE 100R17 hyd hose assmb 3000 psi	12.95	12.95
SUR	2 ea	1/2" x 12" 1/2 nptm x 1/2 nptm SAE 100R17 hyd hose assmb 3000 psi	5.85	11.7

SUR	1 ea	1/2" x 1/2" x 1/2" nptf tee	4.7	4.7
SUR	1 ea	1/2" npt to 1/4" npt bushing	1.65	1.65
		Total Experiment 2 Materials		**$ 191.75**

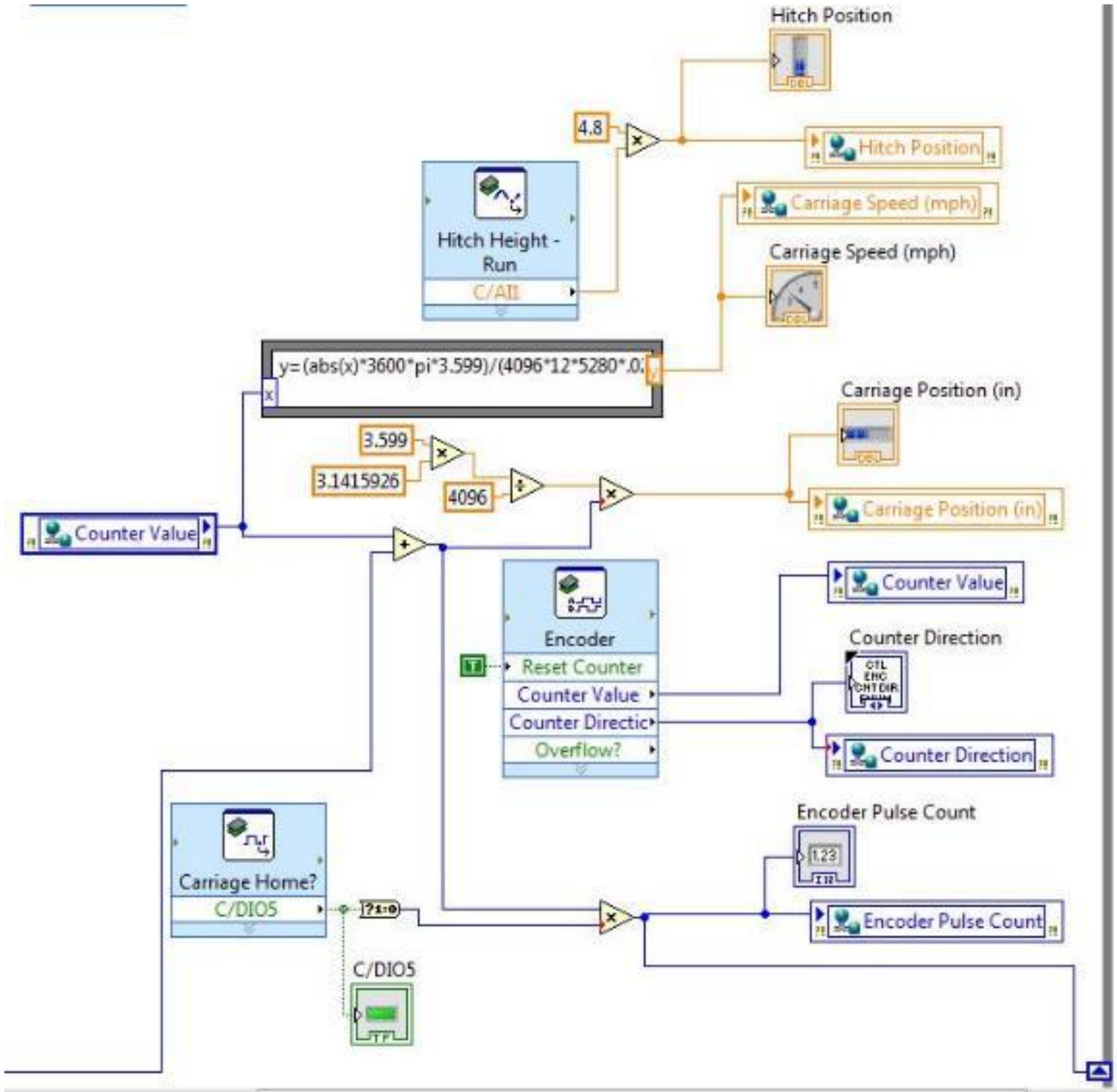
Electrical & Control Materials				
Supplier	Quantity	Description	Price	Amount
NAP	2 ea	battery cable terminal	5.69	11.38
NAP	1 ea	pkg 8 ea clip-on nuts	4.56	4.56
DFP	1 ea	PCB board solenoid driver	155	155
MOU	40 ea	female connector pins	0.48	19.2
MOU	40 ea	male connector pins	0.39	15.6
MOU	1 ea	cable clamp	4.76	4.76
MOU	1 ea	receptacle	4.35	4.35
MOU	1 ea	plug	4.17	4.17
MOU	1 ea	hall effect sensor	26.43	26.43
NAP	2 ea	battery	80.75	161.5
NAP	1 ea	battery m c specialty	89.09	89.09
NAP	1 ea	battery cable terminal	5.69	5.69
JET	1 ea	digital tachometer	28.95	28.95
MOT	1 ea	N08-24-10-B-610-LT-POTIP165 actuator	703.4	703.4
EQP	1 ea	Briggs & Stratton 809967 wiring harness	22.28	22.28
EQP	1 ea	Briggs & Stratton 692318 key switch assmb	20.12	20.12
EQP	1 ea	Briggs & Stratton 692541 control lever	19.85	19.85
EQP		shipping & handling		8.87

TYK	1 ea	0-5V (10V) 4-20mA load cell sensor amplifier transmitter strain gauge transducer	19.99	19.99
MIN	1 ea	relay board	14.9	14.9
RAD	2 ea	switch rocker SP/10A	1.92	3.84
RAD	2 ea	12V dc toggle switch w/ safety cover	1.99	3.98
RAD	1 ea	NTE HS-ASST-9 HS-4 in asstd sizes and colors	13.63	13.63
RAD	1 ea	NTE HS-ASST-2 HS-2-1/2 in asstd sizes	9.69	9.69
RAD	1 ea	compact butane torch	19.99	19.99
RAD	1 ea	butane cartridge 2 pk	5.99	5.99
		Total Electrical & Control Materials		**$ 1,397.21**
Miscelaneous Expenses			**$750.00**	
		GRAND Total Materials		**$ 10,231.44**

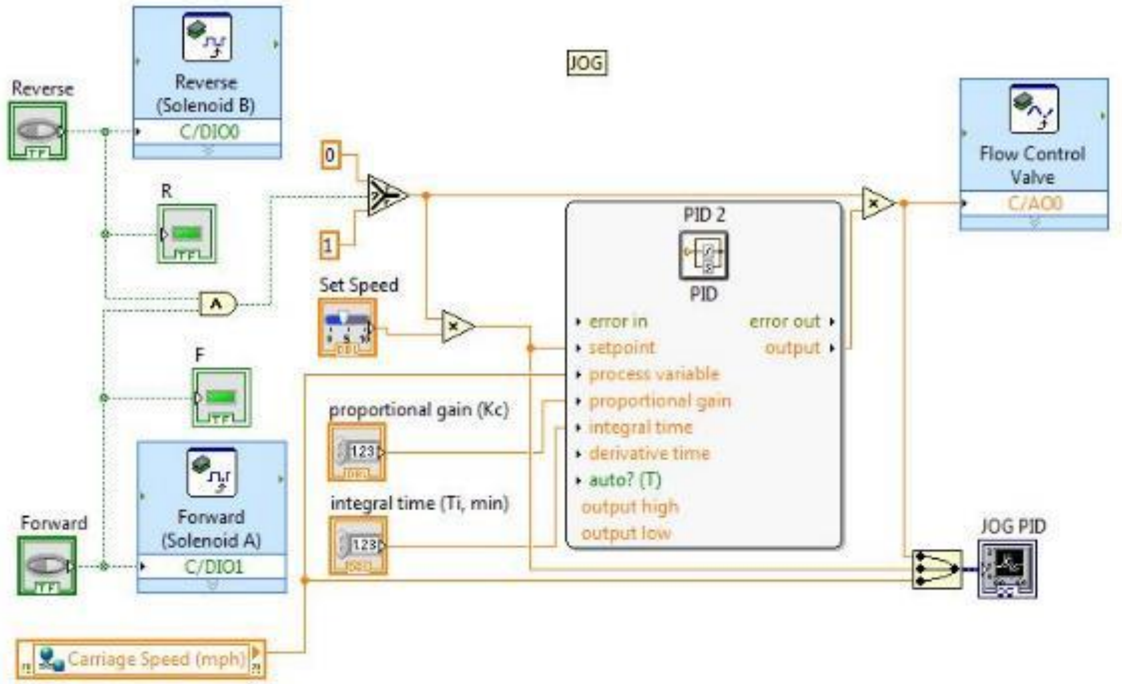
NOTE: Other materials were used that were not purchased; such as the trailer axles, the hydraulic reservoir, optical encoder, miscellaneous hardware and some materials. These materials are not included in the total cost of materials given above.

Appendix C - Code

Variable production

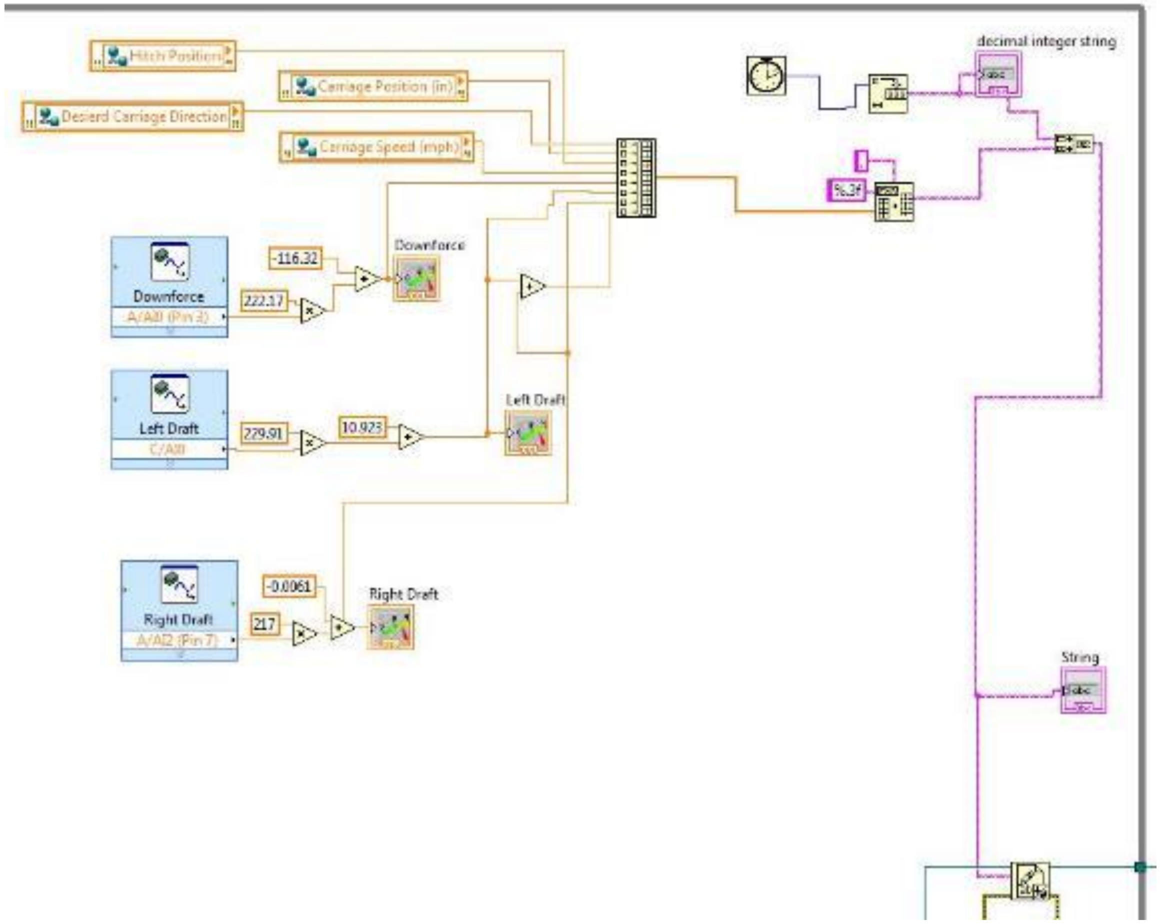


PID Control

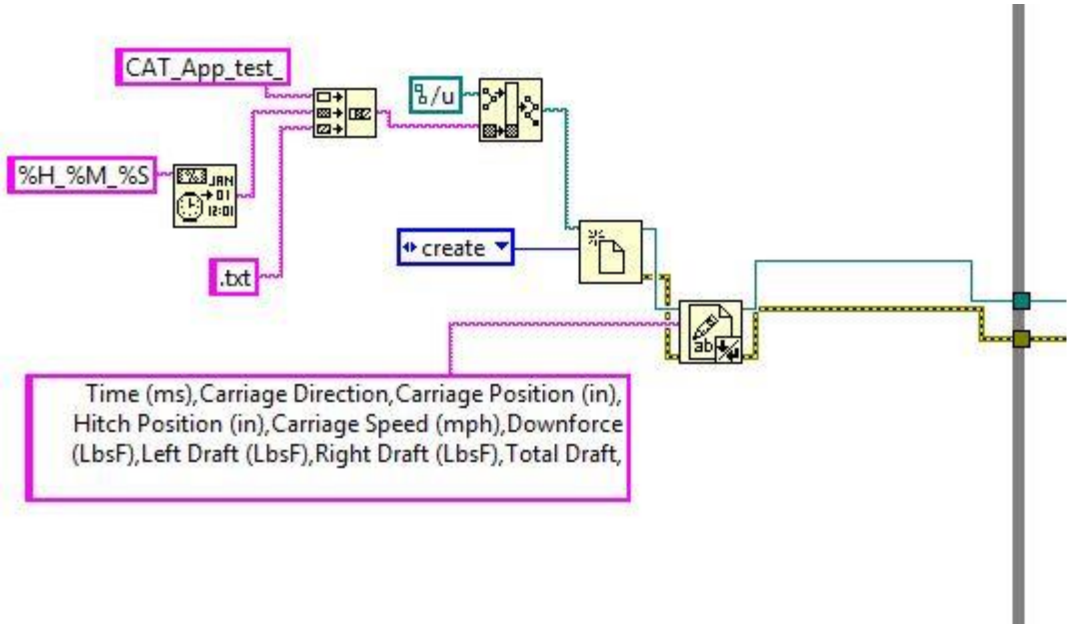


Reverse
Reverse (Solenoid B)
C/DIO0
JOG
R
0
1
Flow Control Valve
C/AO0
PID 2
PID
Set Speed
error in
setpoint
process variable
proportional gain
integral time
derivative time
auto? (T)
output high
output low
error out
output
F
proportional gain (Kc)
integral time (Ti, min)
Forward
Forward (Solenoid A)
C/DIO1
JOG PID
Carriage Speed (mph)

Data Recording



Write to File



Appendix D - Pin and Wire Connections

Toolbox 37 pin connector			
Component	Wire Color	Pin Number	Pin Assignment
Home Limit Switch	red	1	
	white	2	
End Limit Switch	red	3	
	blue	4	
Linear Actuator	black	5	
	white	6	
Direction Control Valve	green/brown	7	Forward
	yellow/brown	8	Reverse
Flow Control Valve	white/green stripes	9	PWM signal to Solenoid driver
	green	10	AGND for solenoid driver
	-	11	
	-	12	
Hitch Height	yellow	13	0V reference
	blue	14	Signal
	white	15	5 V Reference
Pinion Speed Sensor (not used)	black	16	output signal
	brown	17	+ 5V
	blue	18	GND
Downforce load cell	shield/clear	19	GND/Shield
	black/black	20	GND
	green/brown	21	Signal
	white/red/red	22	+ 24V
Left Draft Load Cell	shield/clear	23	GND/Shield
	black/black	24	GND
	clear/purple	25	Signal
	red/red	26	+ 24V
Right Draft Load Cell	shield/clear	27	GND/Shield
	black/black	28	GND
	clear/orange	29	Signal
	red/red	30	+ 24V
Optical Encoder	red	31	5 V
	black	32	GND
	green	33	Signal A
	-	34	
	-	35	
	-	36	
Optical Encoder (continued)	white	37	Signal B

Load Cell Amplifier										
	1	2	3	4	5	6	7	8	9	10
Connection Description	EXC +	SIG +	SIG-	EXC -	SHIELD	24 v +	+ mA	V +	GND	Shield
Wire Color Downforce	Red	green	white	black	shield	red	N/A	clear	Black	Shield
Wire Color Draft	Red	green	white	black	shield	red/clear	N/A	green	Black	Shield
	To Load Cell					From Box to Load Cell Amplifier				

myRio **Connector C**		
Pin Number	Primary/Secondary Signals	Connection/Use
1	+15 V	-
2	- 15 V	-
3	AGND	Solenoid Driver groud
4	AO0	Solenoid Driver output signal
5	AO1	-
6	AGND	Hitch Height Reference
7	AI0+	Left Draft signal
8	AI0-	To Machine Ground for Reference
9	AI1+	Hitch Height
10	AI1-	To Machine Ground for Reference
11	DIO0/ENC0.A	Forward DCV - Relay 2
12	DIO1	Reverse DCV - Relay 1
13	DIO2/ENC0.B	Power to linear actuator - Realy 3
14	DIO3/PWM0	Syren 25 Motor controller - Actuator
15	DIO4/ENC1	Speed/postion - Encoder A
16	DIO5	Limit Switch "home"
17	DIO6/ENC1.B	Speed/postion - Encoder B
18	DIO7/PWM1	Pinion Speed Sensor (not used)
19	DGND	GND to motor controller and Relay module
20	5 V	5V to relay module

myRio		
Connector A		
Pin Number	Primary/Secondary Signals	Connection/Use
1	+ 5 v	-
2	AO0	-
3	AIO	Downforce signal (brown)
4	AO1	-
5	AI1	-
6	AGND	-
7	AI2	Right Draft signal (orange)
8	DGND	-
9	AI2	-
10	DGND	-
11	AI3	-
12	UART.RX	-
13	DIO0	-
14	DGND	-
15	DIO1	-
16	UART.TX	-
17	DIO2	-
18	DGND	-
19	DIO3	-
20	DIO11/ENC.A	-
21	DIO4	-
22	DGND	-
23	DIO5/SPI.CLK	-
24	DIO12/ENC.B	-
25	DIO6/SPI.MOSI	-
26	DIO13	-
27	DIO8/PWM0	-
28	DGND	-
29	DIO9/PWM1	-
30	DGND	-
31	DIO10/PWM2	-
32	DIO4/12C.SCL	-
33	+ 3.3 V	-
34	DIO15/12C.SDA	-