NEXUS

Final Design Report

Oklahoma State University

NEXUS Controls Members

David Bevill
E. Evans Chambers
Lee Eldridge
Adam Gossen

Case New Holland

May 1, 2007

Table of Contents

Introduction

Case New Holland (CNH) is considered a leader in the agricultural and construction equipment industry with more than 11,000 dealers stretched throughout 160 countries. The combination of heritage Case and New Holland designs coupled with the innovative needs of the future has led CNH to strive to develop new products on the cutting edge of technology. CNH has come to the Biosystems and Agricultural Engineering (BAE) department at Oklahoma State University (OSU) to further produce ground-breaking solutions for their unique engineering design challenges.

Problem Statement

Design and employ a three point hitch controller in order to maintain user defined implement position with reference to the machine. The design should involve minimal change to the existing unit while functioning in an ergonomic manner. Addition to machine cost must be kept considerably lower than the current optional laser guided control system.

Statement of Work

Students in the OSU BAE Department are required to complete a two semester senior design course/project to fulfill degree requirements. Four students in the 2006-2007 senior design class have been selected to assist CNH with a design task submitted by the company. These four BAE students comprise Nexus Controls. Team Nexus will attempt to **solve the problem by selecting a controlling mechanism to regulate position of the three point hitch in order to further the capabilities and performance of the Case 570 MXT Loader Landscaper**.

Nexus Controls has acquired the assistance and guidance of Dr. Marvin Stone, a renowned sensors and controls expert from the BAE department at OSU, to serve as an advisor to the team.

CNH has also indicated that the solution created by Nexus controls must be able to be easily added to the machine; furthermore, they do not want Team Nexus to engage in heavy redesign of the existing three point hitch. CNH would like to maintain the current ability of their industrial three point hitch to have down pressure.

The 570 MXT Loader/Tool Carrier currently hosts a laser control module capable of sensing box blade position relative to a fixed plane of reference. Sensors mounted on the

machines receive input signals from a rotary laser plane mounted in a stationary position. The laser control module constantly monitors the box blade position and computes the error in height from the plane of reference created by the rotary laser. Based upon the magnitude and direction of the observed error, the controller opens the appropriate solenoid valve to correct the error in height. Though extremely accurate, this method of control brings an additional cost of approximately nine thousand dollars to the base price machine.

The approach of NEXUS Controls is to create a less expensive control system that employs a different method of box blade height control. This method will utilize the machine as the position reference while incorporating an adjustable set point function.

The position reference is the most critical difference between the laser plane module and the controlling method devised by NEXUS. Sensing position of the box blade relative to the machine is to be achieved using a rotational sensor placed on the rock shaft of the three point assembly. The three point hitch height is adjusted by one hydraulic cylinder capable of applying force upward and downward. This cylinder applies force to the main lift arm which converts the linear actuation of the cylinder into rotational motion about the rock shaft axis. In order for the rotational sensor to indicate height, the housing of the device must be fixed to the frame of the machine while an external member of the sensor rotates with the rock shaft.

One suitable electrical device is a potentiometer that incorporates three connections into a resistor. The center connection, known as a wiper, is translated along the resistor by the rotation of a dial. Alterations in position along the resistor cause the voltage output at the wiper to change. Connected in the circuit will be an electronic controller monitoring the voltage magnitude. The set point height value will correspond to a specific value of electric potential observed by the controller. Likewise, the error in box height will be received by the controller as a deviation in voltage magnitude. The controller will then activate the appropriate solenoid valve to correct the error in voltage and thus, hitch position.
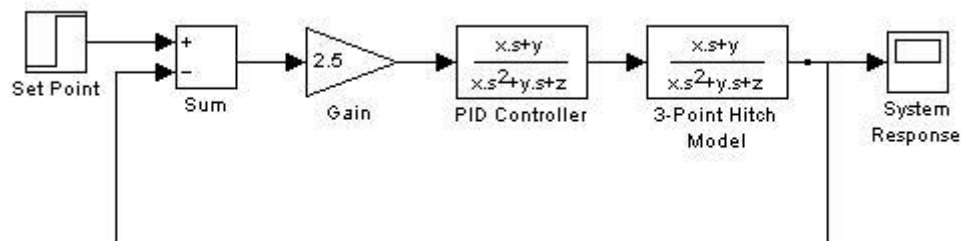
Figure 1: Block Diagram of Control Process

The voltage measurement at the specified node in the circuit is referred to as the feedback in the controlling system. Proportional Integral Derivative (PID) is a common type of feedback controller. This device incorporates three mathematical operations that are a function of the error in the feedback measurement as illustrated below.

$$\text{Output(t)} = K_p \left(e(t) + K_{ip} \int_0^t e(\tau) \, d\tau + K_{dp} \frac{de}{dt} \right)$$

When tuned properly, the combination of each term in the equation yields stable and functional control of the system. That is, once the box blade height differs from the set point, the controller operates to quickly adjust the three point hitch to the correct position without oscillating around the prescribed height or violently accelerating. The proportional term results in an output of a magnitude equal to the error multiplied by the constant K_p. The integral term sums the error on a time scale (milliseconds) so the larger the error in height, the greater response of the hydraulic system to correct that error. The derivative term will result in controller output based upon the rate of change in error with respect to time. This will decrease the amount which the controller moves the hitch beyond the prescribed set point (overshoot). By adjusting the constant value in each term of the output equation, one can tune the controller. The controller may be utilized with proportional control plus either, both, or neither integral or derivative action. Using the integral action without the derivative can result in large overshoot, while adding the derivative action results in quick response while minimizing overshoot.

A spring in the valve assembly applies force to a spool blocking the flow of hydraulic oil and maintaining cylinder position. The coil of the solenoid creates a magnetic field while current is flowing through the coil. The metallic spool responds to the magnetic field by sliding past the valve orifice allowing fluid flow. The output from the controller will come in the form of pulse width modulation (PWM). The width of pulse refers to the ratio of the amount of time the solenoid circuit is closed to the amount of time the circuit is broken. This pulse schedule will occur at approximately 100 hertz. The ratio of on/off time translates to a position of the spool in the valve. Due to the mass of the spool and the force of the restricting spring, the spool does not

oscillate at the PWM frequency. The effect on the spool is a stable position determining fluid flow through the valve.

The safety of those present during machine operation is held paramount by NEXUS Controls. When considering electrical devices, it is required that all connections be completely insulated from personnel. Though the power source on the machine is only twelve volts, a short circuit current is potentially dangerous and thus considered in design. In addition, the possibility of an automated mechanism becoming instable and behaving violently is inherent with computerized machinery. Multiple steps are to be taken when programming such a device to ensure that irregular operating conditions will at worst terminate implement motion. No significant mechanical changes are to be made on the three point hitch. The safety of this apparatus has been determined by Case New Holland.

In summary, our statement of work is to produce a safe, cost-effective controller, capable of automatically maintaining the position of the 3 point hitch on the 570 MXT Loader Tractor. The design shall include sensors to measure position of the hitch, a controller to interface between the sensors and existing laser system, and all of the necessary wiring, manuals, and inner workings of the aforementioned parts. CNH will be solely responsible for safety and liability of this product and derivatives of this product.

Patent and Background Research

The team has discovered four patents making claims of design and function that are associated with initial ideas of NEXUS controls. Each of the four patents implements distinctly different methods of hydraulic control for a three point hitch on a tractor. Though dissimilar, the abstract of each patent provides cause for further reading and detailed research. However similar, NEXUS concludes ideas generated by the team currently present no direct threat of patent infringement.

Patent 1: Towable Box Grader with Multi-Variable Axis #6672401

The invention is a towable scraper system designed for contour surface grading. The device includes a rigid chassis member configured for attachment to a conventional three-point hitch. A scraper blade is suspended from the above mentioned member and is equipped with a blade motivator capable of blade rotation about an axis oriented in the direction of towing. The inventor claims that the said blade motivator and the lift assembly are responsive to a controller

output. This yields control of tilt angle and height relative to the work surface. Specific devices achieving this type of control are left undefined.

The critical phrase in the above patent description is the height control "relative to the work surface". NEXUS has generated several ideas of control with respect to a predetermined set point utilizing a rotational sensor on the lift arm hinge. This method controls the height of the implement relative to the machine – not the work surface. In addition, the tilt function is negligible because NEXUS currently has no plans of tilt control.

Patent 2: Apparatus for Counteracting Vehicle Pitch Variation #20030085042

The apparatus and method to be described are designed to counteract vehicle pitch variation with three possible adjustments: implement position, rear suspension, and front suspension. The claims refer to currently implemented electronic draft control (EDC) systems. These devices are capable of adjusting implement height in response to changes in draft force. The patent of discussion includes the idea of adjusting the vehicle suspension in addition to the implement height. In doing so, the possibility of vehicle oscillation is developed. This is counteracted by a second control function responsible for monitoring suspension behavior and making hydraulic valve adjustments to prevent unwanted resonant motion of the machine.

NEXUS sees no issue of infringement on the above patent for several reasons. The three point hitch of the agricultural machine described in the patent is not capable of exerting a downward force on the implement. Construction machinery utilizes the capability of downward force. In addition, the system previously explained operates with signals generated from draft force alterations. The intentions of NEXUS are to control a box blade with a rotational sensor; disregarding draft force.

Patent 3: Dynamic Controller of Excess Down Pressure #6389999

The patent of consideration describes a system for controlling the depth of an agricultural implement with respect to soil surface. Seeding is the primary application of such technology. The system is comprised of a depth sensor in collaboration with a pressure sensor of the depth regulation member. The depth sensor communicates the position of the implement to a controller. In order to prevent damage to the surface penetrating member, the controller will also respond to the sensed pressure experienced by the lowered member. The implement will be

adjusted if the depth is inaccurate or forces experienced by surface penetrating members are unacceptable.

This design presents no obstacle to the future plans of NEXUS Controls. The above patent describes the control of a seeding implement based upon a depth and forces experienced below the surface. The designs of NEXUS pertain to three point hitch control based upon relative position to the tractor. There is no consideration of forces experienced by the implement when devising controlling methods.

Patent 4: Hitch Control System with Spring Centered Lever #6935434

The subject of concern is a control system involving incremental alterations of hydraulic valve positioning in response to various inputs. Specifically, this design incorporates a lever, that when moved any distance, the controller responds with a preset magnitude of valve manipulation. Essentially, the operator will communicate the desired direction of motion of the three point hitch. The controller does not consider the level as to which the lever is rotated.

This documentation is of a response operation of a hydraulic valve to be entered into a controller. The agenda of NEXUS is centered on sensing methods of a three point hitch. However, programming controller output into the device will pertain to NEXUS design. This concept is essential to total system function; for a controller must have a program of position alteration in order to perform. The plans of NEXUS deviate from those previously described in that a controller will operate to correct an error in voltage that it will calculate.

Patent Summary

Though several of the previously mentioned patents pertain to three point hitch control, not one defines solutions conceived by NEXUS. Details of future plans of work devised by NEXUS are original so as not to infringe upon exclusive rights of past inventors.

Competitors

Team Nexus would like to acknowledge the machines that are direct competitors of Case New Holland. In the following section, we will distinguish how our intended design will not infringe upon the current models of competing companies. Some machines do not have the features which we are attempting to design and thus do not require discussion. Team Nexus currently wants to incorporate a user friendly controller to maintain a constant box blade position.

John Deere features a landscape loader model 210 LE that has levers mounted inside the cab of the machine which control the position and tilt of the three point hitch. The levers are controlled manually by the operator. This design does not make use of a controller.

The Kubota M6800 Series utility agricultural tractor features two levers to control the hydraulics for the three point hitch. These levers are mounted to the right of the cab and are controlled manually by the driver of the machine.

Massey Ferguson makes a utility tractor, the MF 400 Series, which is used for landscaping applications and grading with a box blade. This design also uses levers to control the three point hitch position. The current design for MF does not include any form of electronic controlling and should not affect our design plans.

Caterpillar has a machine that performs the task that is required by utilizing their Accu-Grade Laser Grade Control System, but does so in a manner that is different from the current design that Team Nexus is pursuing. The machine used by Caterpillar is a track type tractor which is different from the CNH model. The Cat design features a laser receiver mounted on a mast extending upward from the top of the bucket mounted on the front of the machine. The receiver detects a laser beam emitted from an off board tripod mounted laser traditionally used in surveying work.

As the blade moves above or below the finished grade level information is sent to the in-cab display to show the cut or fill requirements. Based on the signal received the automatic blade control system lifts or tilts the cutting edge. A dual hydraulic control valve is used to raise and lower the machine's cutting edge.

Team Nexus has been informed by CNH to pursue a solution that does not include lasers, i.e. a cheaper solution. While this solution is for the same desired outcome we feel that it will not be infringed upon by Team Nexus since we are currently looking at a controller instead of a laser solution.

We have checked out other competitors such as JCB (Models 212SL, 212SU, and 3C LL) and Terex (Models 640-660B and TX 640-660) and have not been able to find any form of automated controlling of three point hitch tilt and position. A newly formed company, Montana Tractors, has a method of control that uses dials mounted on the dash inside of the cab to control the hitch position. It will be discussed further below.

Montana Tractor Review

Team Nexus reviewed the Montana tractor controller system that is used for draft control. The sensors are located on the rear of the tractor with the height sensor attached to the lift arm via a simple linkage system. This sensor is attached by a tab that is welded to the lift arm, and the lift arm is attached to the tractor by a spline shaft

The center link has an attached sensor for measuring force. The force is measured by a large spring located behind the center link. With a known spring constant and a link arm that reads change in distance, the change in force can be determined to ensure that the draft control is functioning correctly.

The controller functions make the operation of the machine easier on the operator by creating a "hands free" operating environment. The depth is controlled by a manual knob that is similar to a depth lever on most common agricultural tractors.

The controller has various functions which allow the machine to be operated easier. One of the options is setting the controller so that turning the steering wheel a certain distance will automatically raise the three point hitch. The Montana controller has a diagnostic test feature to ensure that it is functioning properly. When the machine is shifted into reverse, a controlling mechanism can be set to automatically raise the hitch up. The draft control has a minimum and maximum setting which the operator can select depending on his normal operating conditions. The operator can set the upper position limit so that the controller will only raise the implement to a set point as opposed to the implement rising to the top of the lift distance each time.

Instrument Review

The three point hitch controller must be able to hook up to the existing wire connections already on the machine. In a conceptual sense the controller is a "plug-n-play" device used to automatically control position of the three point hitch. The operator will need the ability to manually override the system while still in "auto-control" mode. This will allow the user to set a predetermined position of the three point hitch, but also return control to the user if desired.

The system will be comprised of three main components: the remote sensors on the three point hitch, the controller, and the user interface. The interface will be where the operator sets the predetermined position of the three point hitch. The sensors will provide data from the hitch, and the controller will interface the main electro-hydraulic system to control the hitch. A closed loop system will provide this type of control.

With a closed loop system, the remote sensors will provide the controller with data of the position of the three point hitch. Once the predetermined position is set the operator can use the machine without constantly adjusting the three point position. If the operator wanted to manually change the position, an override could be activated allowing manual control to the operator. The controller would return the three point hitch to the set position after the operator reactivates automatic control.

Customer Requirements

The customer requirements can be grouped into three categories: means and modes of operation, production, and integration.

The first set of requirements deals with means and modes of operation. First and foremost, the controller must have two modes of operation: automatic and manual. The automatic controller must be able to maintain a position set by the operator. The automatic controller will maintain or reach a desired position unless it is unattainable due to ground conditions

The second set of requirements deals with production. Cost is a major factor for this design, because it is meant to add features and controllability while keeping cost to a minimum. A laser-leveling system is available that maintains a constant grade at a cost of nine thousand dollars. This system is meant to provide the operator a method of returning to a previously achieved position. Once this position is achieved, the system will monitor and maintain that position

The last set of requirements deals with controller integration into the 570MXT. The controller must interface with the existing hydraulics system. By utilizing the existing hydraulics system, all of the existing controllers, such as the laser-leveling controller, will not have to be redesigned.

Engineering Specifications

Potentiometer

In order to use any electrical device to measure rotational position, the electrical resistance must be sized properly so that appropriate current is achieved in the control circuit.

Due to resistance heating of conducting elements, it is necessary to attain a current flow in the range of milliamps. Heating is quantified using the following relationship:

Power = (Current) ^2 * (Resistance) (P=I^2*R)

Current = Voltage/Resistance (I=V/R)

With a known voltage source of 12 volts, one is able to determine a suitable resistance range of the potentiometer. For example:

I = 12 volts / 10000 ohms = 0.0012 amps = 1.2 milliamps

I = 12 volts / 5000 ohms   = 0.0024 amps = 2.4 milliamps

P = (0.0012) ^2 * 10000 = 0.0144 Watts

P = (0.0024) ^2 * 5000   = 0.0288 Watts

Using low conductance resistors yields a minute current, which can be safely carried in light, inexpensive wire. An additional resistor may be added in series with the potentiometer to lower the current flow. The resistance of the controller element in circuit with the potentiometer is extremely high so as to produce a minimal current flow.   Electrical load and power requirement must also be considered due to the finite power supply from the alternator driven by the engine of the machine. The example calculations above are of electrical loads suitable for machinery as the 570 MXT Loader/Tool Carrier.

In addition to circuit overload, one must consider the sensitivity of the controller. The voltage change induced by rotation of the sensor must be large enough to be recognized by the controller. For example, consider a potentiometer with a circular resistor that completes a rotation of 150 degrees. The voltage reading at the wiper terminal ranges from 0 to 12 volts as rotation angle ranges from 0 to 150 degrees. Therefore, assuming resistance per length of material is uniform; one degree of rotation corresponds to a voltage change of 12/150. Consider the following:

$$V_w = \Theta\left(\frac{12v}{150°}\right) = \Theta\left(0.08\frac{v}{deg}\right)$$

Common controllers sense DC voltage from 0 to 12 volts at an accuracy of approximately 3 milliVolts. Meaning, the controller can discern the voltage at the center terminal of the potentiometer to a magnitude of 3 mV. Therefore, a controller response is achieved from angle error of less than one degree. Specifically:

$$Accuracy = (.003v) \div \left(0.08 \frac{v}{\text{deg}} \right) = .06$$

The Case machine of interest is configured so that the scraper of the box blade is approximately 3 feet from the axis of rotation. The orientation of the lower lift arms supporting the box blade is so that the specified three feet equals the radius of curvature of the implement travel path. The ratio of the rockshaft lever arm distance to that of lower lift arms is approximately 1/3. Therefore, the angle of rotation of the rockshaft is three times that of the lower lift arms.

$$\frac{1}{3}\Theta_{measured} = \Theta_{box}$$

The change in height relative to rotation angle is then governed by the following relationship.

$$\Delta H_{box} = 3\,ft \times \sin(\Delta\Theta_{box}) = 3\,ft \times \sin(\frac{1}{3}\Delta\Theta_{measured})$$

Using the above equation, the change in height from a measured angle change of one degree is about ¼ in. The described calculation process allows one to calibrate the controller for the desired output. Deviations from theoretical accuracy and achievable accuracy will be discussed later.

NEXUS Controls considers a potentiometer as a suitable instrument for measuring rotation. The most accurate definition of the "potentiometer" is a device used to measure an unknown electric potential by comparing that unknown voltage to a quantified potential. The measurement can be achieved by means of either a voltmeter or a galvanometer. Typically, constant current potentiometers are used for the measurement previously described. However, constant resistance devices are utilized in a similar fashion to measure electric potential in the microvolt range. Industry has accepted "potentiometer" as a term for a device incorporating operator adjusted variable resistance output. Generally, potentiometers have three terminals: positive, ground, and a connector or wiper that translates across the solid resistor contained in the device housing. The effective circuit diagram is shown below.
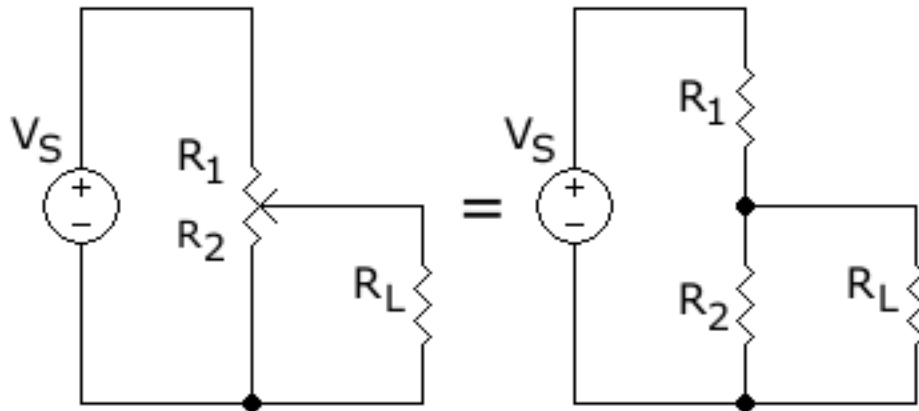
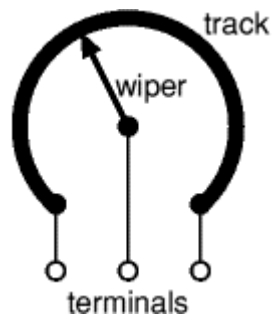Figure 2: Effective Potentiometer Circuit

Figure 3: Actual Potentiometer

Controller

The controller has three main functions:

      1. Determine position

      2. Compute error in position relative to set point

      3. Send signal to solenoid valve to correct error

This device requires a power source of 12-26 volts DC provided by a power supply that maintains constant output voltage. The referred power source is simply to operate the controller and is not necessarily equivalent to the signal voltage. The constant voltage output power supply maintains a specific voltage output while the input voltage may fluctuate within a certain range.

It has been established that the controller sensor input will be an analog DC quantity ranging from 0 to 12 volts

The programming language of the controller is Ladder Logic. The controller will make the circuit connection to activate the solenoid with 12 volts DC, preferably pulse width modulation (PWM). It should be made clear that this voltage does not vary in magnitude, but it does vary in time on/off. A percentage of on/off time is executed on the order of 100 times per second. The circuit closure is accomplished using transistors in the controller. The nature of the transistor allows for the required frequency of switching. Standard relay outputs are incapable of effectively switching at such a frequency due to the mass of the contact. Pulse width modulation is practical because it allows for a valve to be partially opened. The precise control of fluid flow, and thus implement velocity, is desired especially when using automated control. Stability is more easily achieved with PWM. The capability of relay output is also desired in the controller.

User Interface

The simplest user input device is that similar to the standard cruise control in automobiles. The necessary controls are as follows:

Set - the operator actuates a "set" input when implement is in desired position

Resume - if the operator has manually overridden the control function, this input resumes control based upon the previous set point. Manual control would be achieved once the operator moves the hitch lift control lever.

This refers to the method of analog set point input. The three previously described functions would be accessible through buttons/switches located in the operator station.

Design Concepts

When looking at this project and the possible solutions the team came up with several ideas to supplement the ideas and needs that CNH conveyed to the group. CNH recommended the placement for the height sensor to be on the rocker arm. This would work with a special pin that would have a hole drilled in the end to accept the potentiometer arm. The rocker shaft rotates about the pin so the housing for the potentiometer will have a boss welded to the rocker arm. The potentiometer will be bolted to the boss with the potentiometer arm in the hole on the pin and then the cover plate would be put in place by bolting it to the boss.

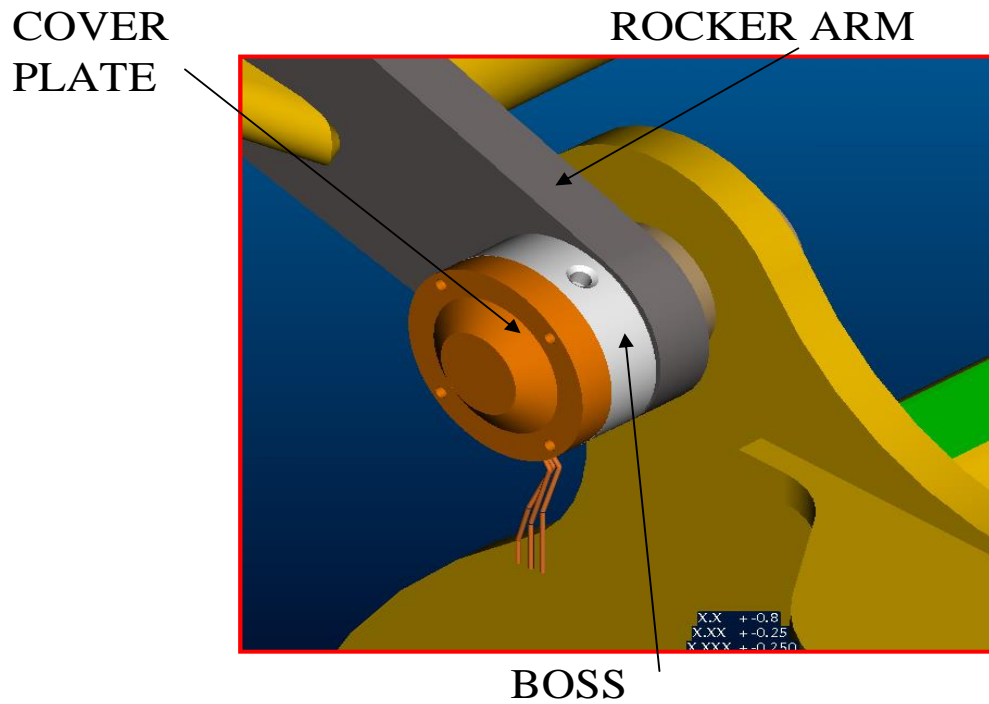COVER PLATE

ROCKER ARM

BOSS

Figure 4: CAD Drawing of Sensor Housing

Another possibility for placement of the potentiometer would be placing one on each side of the machine where the lift arms attach to the machine. By placing the sensors there the operator can sense height as well as see the difference in roll between the two lift arms. This feature would be for the determination of roll and could be used in conjunction with the previous mentioned possibility as an added feature that would be a convenience to the operator.
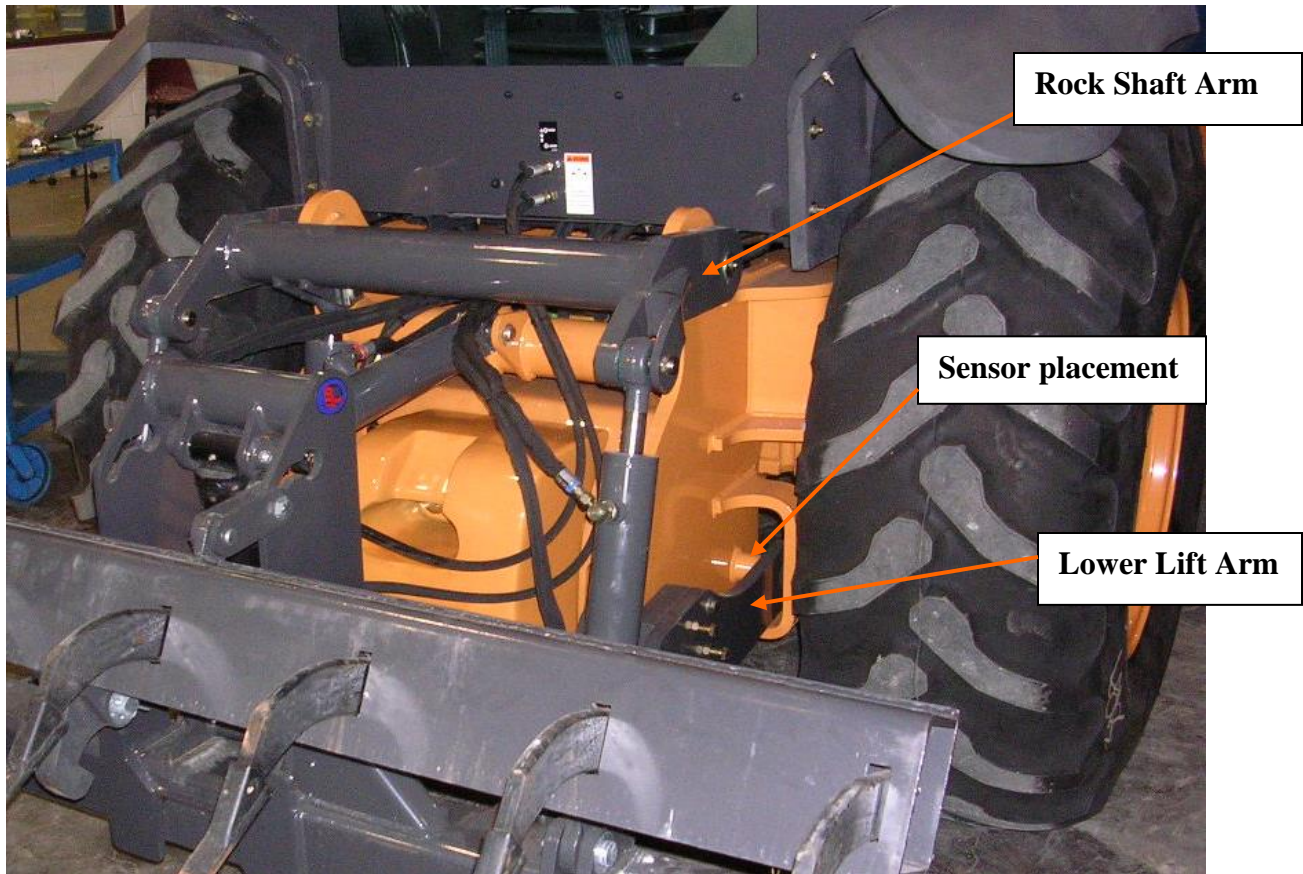
Figure 5: Picture of 570 MXT 3-Point Hitch

Start Up

Safety is the most important consideration of NEXUS Controls. The control system will always be inactive upon start up of the machine, regardless of the status when the machine was shut down. Automatic control is active only after the user has engaged the controller once the machine is running.

Laser and potentiometer on the same machine

Individuals operating with the control of the laser module may also wish to utilize the potentiometer capability momentarily. This could only be effective if the change in control modes is effortless. This can be achieved by simply providing the user the both wire harness connectors so that 2 control modules may be connected at once. The operator could then choose the desired control method with a switch. It is important to note that only one type of control would be active at one time. This decision would then be conveyed to the operator with an indicator lamp.

The laser control solenoid valve is plumbed with restrictor ports to limit the flow rate to the three point implement. When considering convenience of changing control modes, the restrictors would remain in the valve for the set point control system. The restrictor ports limit the speed of implement travel. Stability in control is more easily achieved at decreased speeds. In addition to the restrictor ports, a flow regulator allowing 3 to 8 gallons per minute of oil flow is built into the system for additional speed control.

Unachievable set point
1. Disable control after 3 seconds of relief flow

It has been established that passing oil through the relief valve for a long period of time has multiple negative consequences. Once the pressure in the lift cylinder line is high enough to open the relief valve, the controller would be notified by a pressure transducer. If this pressure is sustained for 3 seconds, the controller would deactivate, returning the machine to manual control. The operator would be notified of the status of the machine by means of an indicator lamp. Upon deactivation, the implement would remain in the current position until the operator interferes.

2. Disable control immediately after the relief is opened

In order to prevent any unnecessary heating of oil whatsoever, the controller would deactivate once the pressure was sufficient to open the relief. The following process would be similar to that of the previous design concept in that the controller would cease to execute valve control in the event of an unachievable set point. Upon controller deactivation, the hitch would become stationary. The three point hitch would then be in manual control mode.

3. Allow 7 seconds to reach set point – then shift to manual control

(No pressure transducer)

In order to eliminate the pressure transducer, one could allow a given period of time for the rocker arm to reach the set position. Once this time is expired, the controller would deactivate the automatic control mode and the hitch would remain stationary. For example, from the time the operator instructs the controller to seek the set point, seven seconds would be allowed for the hitch to reach the desired position. This is based on the expectation of no more than seven seconds for the hitch to travel the maximum rotational distance possible. There is the inherent

possibility of passing fluid through the relief for a short time and thus, heating the oil. However, the pressure transducer would be unnecessary.

4. Solenoid Flow Divider

Addition of a solenoid valve to the down force side of the lift cylinder line would eliminate the possibility of passing fluid through the relief. The solenoid valve would open when the machine is in automatic control mode. Being plumbed parallel to what becomes the high pressure line when down force is exerted would limit the maximum achievable pressure thus, preventing relief flow. The solenoid would divert a portion of flow to the oil reservoir while still allowing fluid to exert a decreased force on the lift cylinder. There would still be a time limit for achievement of instructed position. Once the operator engages the manual control lever, the solenoid would close and full down force would be returned to the lift cylinder.

5. Modification to all previously discussed methods of control

In modification to the previous four control sequences, rather than immobilizing the box blade once control is disengaged, the implement would be raised to the highest achievable position. This would serve as a physical indication that the set point is unachievable. This would be obvious to the operator who could then make the appropriate system modifications. Indicator lights would supplement this notification of control disengagement.

6. Temporary manual operation

It is possible that the operator would temporarily wish to manually control the box blade while automatic control is engaged. The controller could be programmed allowing for a short period of manual operation. Once manual mode is engaged, the controller would definitely cease modification of the three point hitch position. In addition, the controller would remain alert for a period of one minute so that once the manual operation lever returns to the neutral position for three seconds, the controller returns the implement to the previously chosen set point. At any moment the operator would be able to terminate automatic control with a simple switch. This allows hands free return to the set point after a brief period of manual adjustment.

7. Transport mode

The above sequence could be modified so the hitch must be within a certain range of the set point before control is resumed. In addition, one could eliminate the timing function so the

operator has an unlimited time period to maneuver the tractor. The operator would raise the implement to the maximum height and control would end once the set point was exceeded by a certain distance.

It is unlikely but, possible that the operator has chosen a set point near the maximum height of the three point hitch. In this instance, it would not be practical to terminate control simply to move the machine. The sequence described is geared towards the more common box blade operation near the horizontal traction plane of the tractor.

8. Incremental Increase

In the event of an unattainable set point, the controller could adjust the set point after a certain period of time. For example, if the desired depth is not reached after seven seconds, the controller then seeks the next lowest set point. Another seven seconds is allowed for height adjustment. The process would be repeated until the controller seeks the lowest attainable position. The operator would be notified of the process by an indicator lamp reading similar to "incremental increase".

Suitable Design Requirements

Nexus has determined that the requirements for suitable design are as follows:

- Attempt to eliminate operator constantly looking over shoulder to manually adjust box blade position
- Maintain box blade position accuracy within 0.25 inches
- Maintain box blade stability
- Allow for easy installation onto machine without having to overhaul or significantly change existing design
- Unachievable set point time out control
- Create user friendly control panel setup
- Follow CNH FMEA policy as well as OSU FPST safety procedures

Selection of Suitable Design

Nexus reviewed the possible designs listed above as well as these design requirements and determined that a system which operates similar to the cruise control in an automobile would be the best solution. With this system the operator can manually adjust the box blade to a desired

height. The operator will then push the set button mounted on the control panel. This will maintain the box blade at the desired height within 0.25 inches. If the operator needs to temporarily adjust the box blade position, he can simply manually maneuver the box blade and then hit the resume button to return the box to the original height position. If the operator decides to use another function of the machine (not the box blade), a kill switch that will deactivate the control program is located on the control panel. The control system must be switched to on and the tractor must be in laser mode for this to work. Both of these buttons are located on the control panel as well.

Program Logic

Once the controller is energized, the operator is then ready to utilize the three-point hitch controller. As a safety feature, the controller is inactive upon power up. The attached flowchart describes the essential components of the control algorithm; however, several mathematical operations are excluded from the figure for clarity. At any moment during operation, the operator may end electronic control of the three-point hitch through the following:

- Key Switch
- Laser/Normal/Float Rocker Switch
- Actuation of the Manual Control Valve Lever

The default set point is approximately the middle of the range of motion of the hitch assembly. The operator may select a new set point at any time by pressing a momentary "SET" button. With the controller energized, pressing the momentary "RESUME" button will instruct the controller to actuate the laser control valve as necessary to achieve an error in position of zero (error refers to the difference in current position and the set point). Movement of the hitch is not achieved until the error is greater than approximately 10 degrees. However, the controller will seek the set point until the error returns to zero. The dead band of ten degrees is in place to prevent needless movement of the three-point hitch. With the rock shaft in a fixed position relative to the machine, the signal to the controller representing position does vary for reasons later discussed in this document. With no dead band, the box blade will oscillate at a frequency high enough to render the system counter productive.

To reduce the effect of the noisy hitch position input, a moving average variable was created. The moving average function returns the average of the of most recent 100 data points

of position value. Taking the average reduces the variance of the sensed value and stabilizes the system. The moving average must differ from the set point by a magnitude greater than the dead band before the valve is activated. Upon a change in position, the noisy position input responds instantly while the moving average accuracy in position is delayed. Time is required to accumulate 100 new values of position near the new actual position. Therefore, valve actuation ceases when the noisy error reaches zero. To rely only upon the averaged error results causes significant overshoot of the set point position. Furthermore, controlling position using only the noisy input causes unnecessary oscillatory movements of the three-point hitch.
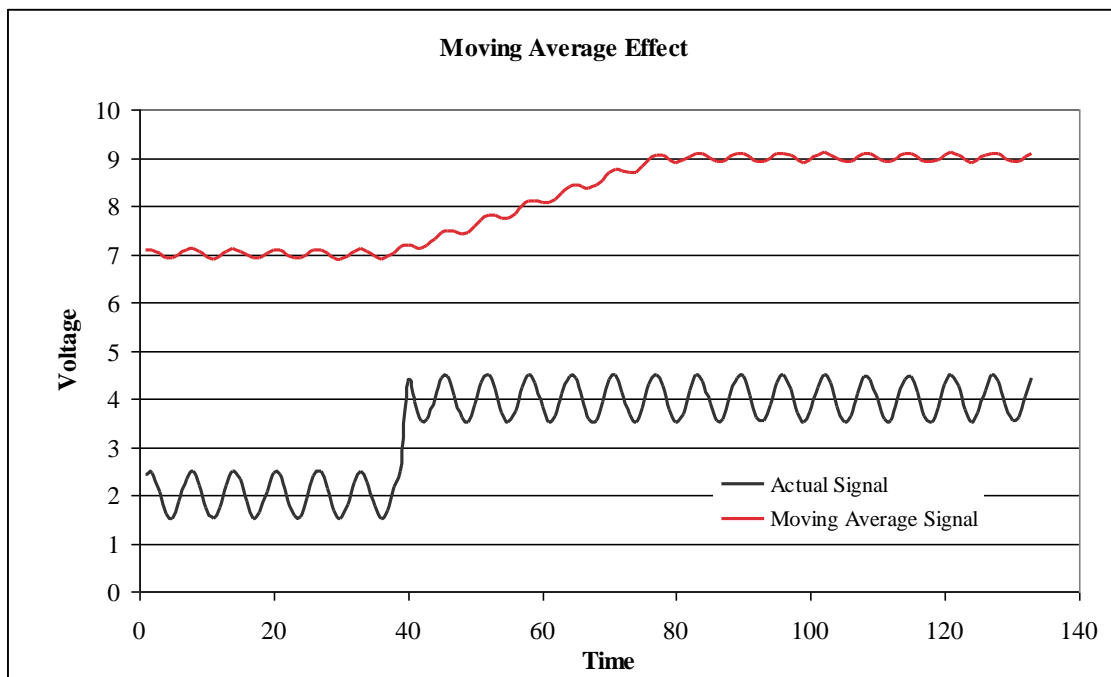
Figure 6. Moving Average Effect

-Note that the time and voltage values are not representative of actual data.

Once a sufficient error in position is achieved, the PID control algorithm generates output to be converted into a duty cycle of pulse width modulation (PWM). The response time of the PID function depends upon the gain values for the P I and D components of control. With consistent error in position, the duty cycle of PWM increases and eventually causes the valve to open. A duty cycle of 60% is required to achieve motion. Ideally, PWM allows one to vary flow

rates. However, this ability is missing from this system for reasons discussed later.

Nevertheless, control is achieved with "ON/OFF" valve behavior.

Once the control valve has been actuated, a time of 7 seconds is allowed for the hitch to reach a position of zero error. The time limit is in place to prevent needless flow of oil through the relief valve in the event of an unachievable set point. After 7 seconds, the operator must push the resume button to return to control mode. The control process described here is an infinite loop. Meaning, the controller will loop through the program as long as it is energized.

Noise

After assembling the complete control system, it was evident that there was an error in the signal perceived by the controller. The EZ Ladder software display allows one to view, in real time, the value of all variables used in computation throughout the running program. From the beginning, a signal from the potentiometer is used as a sensor that fluctuates when the device is in a fixed position. Therefore, when the box blade is in a stationary position, the controller behaved as though it was moving and attempted to compensate for error in position. Several sources of the undesired signal variation were investigated. The first question concerned the stability of the voltage input to the potentiometer; it would be nearly impossible to achieve a stable signal out of the sensor with a poor input signal. Using a digital oscilloscope, the team found that the voltage input to the potentiometer varied $\pm$ 50 mV. In order to stabilize the input signal, a voltage regulator was connected in circuit before the input to the potentiometer. A steady voltage of 10.4 $\pm$ 0.010 V was achieved. Even though improvement in signal from the sensor was achieved, the sensed position was still instable. Upon connecting to the output of the potentiometer, a reduced variation in signal was observed.
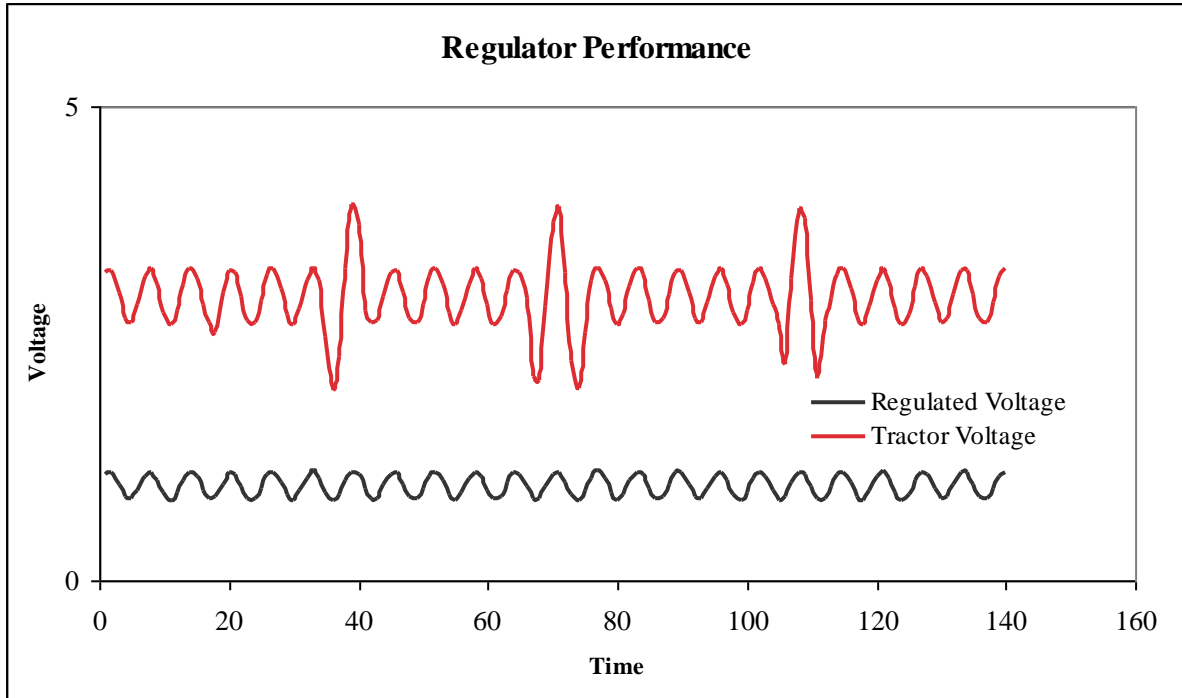
Regulator Performance

Figure 7. Regulator Performance

-Note that the time and voltage values are not representative of actual data.

In order to minimize the effect of the remaining noise in the system, an amplifier was constructed so that the signal would cover the entire digital range of the A/D converter. The signal from the voltage regulator alone ranges from approximately 150 to 700 digital. With a 10 bit A/D converter, one may obtain a digital value from 0 to 1024. Using an amplifier, the signal may be increased to the maximum value of 1024 at the highest position; 1024 corresponds to 20 mA, the maximum amperage specified by the controller manufacturer. With the amplifier in circuit, there was no significant increase in unwanted signal variance. Therefore, the variance corresponds to a lower value of angular rotation of the hitch. As a result, the system increases in accuracy.

Test Stand Simulation

Figure 8. Test stand simulation setup

The above picture is of the hydraulic test stand fabricated by the Oklahoma State University BAE Laboratory staff. The purpose of the test apparatus was to safely test software and hydraulic system modifications before installing new components on the 570 MXT tractor. Using the exact lift cylinder, potentiometer and controller as on the machine, the test stand effectively represented the behavior of the actual tractor. This similarity between the test stand and full size tractor aided NEXUS throughout the software generation process.

Test Data
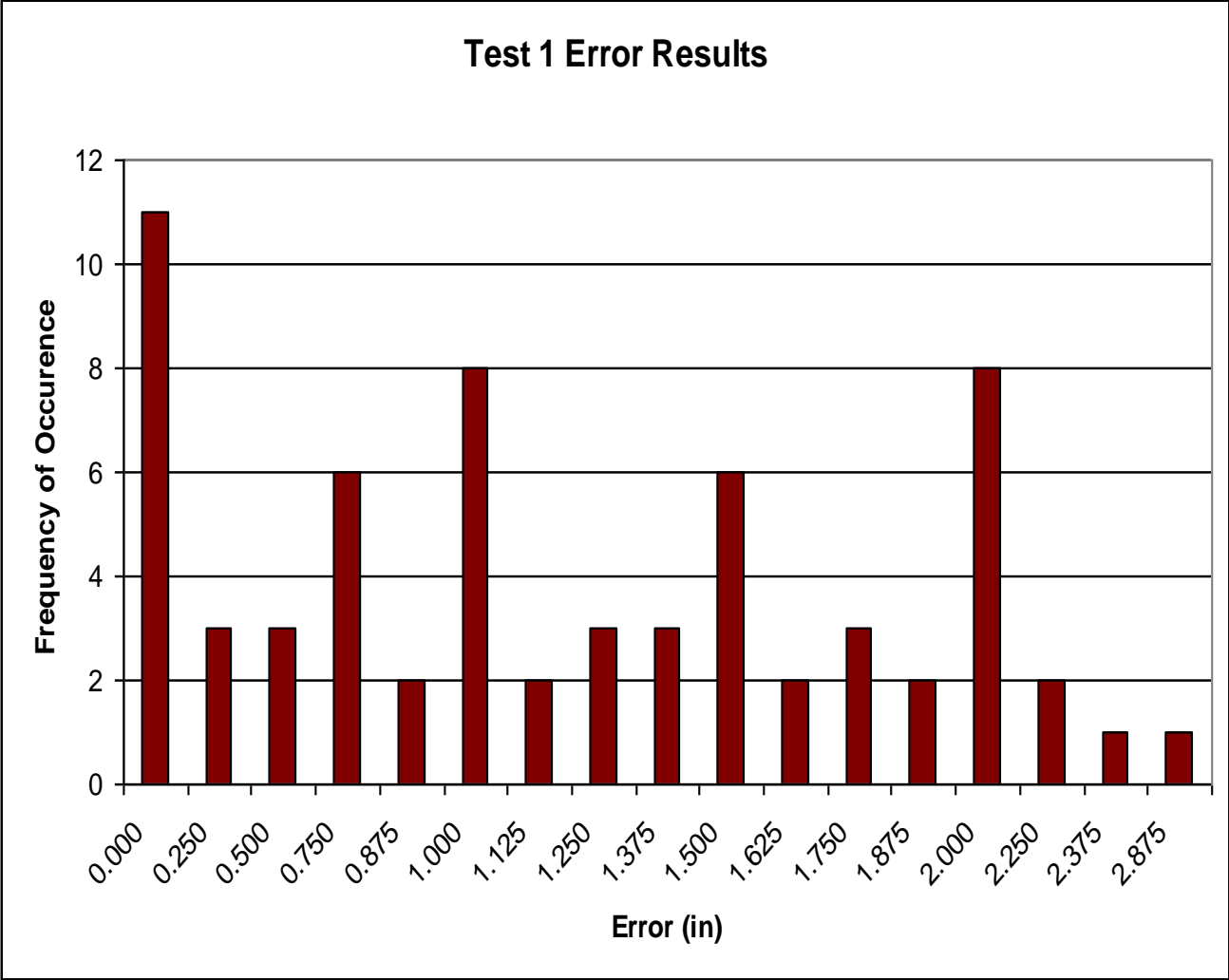
Figure 9. Test 1 data

Test 1 Error Results
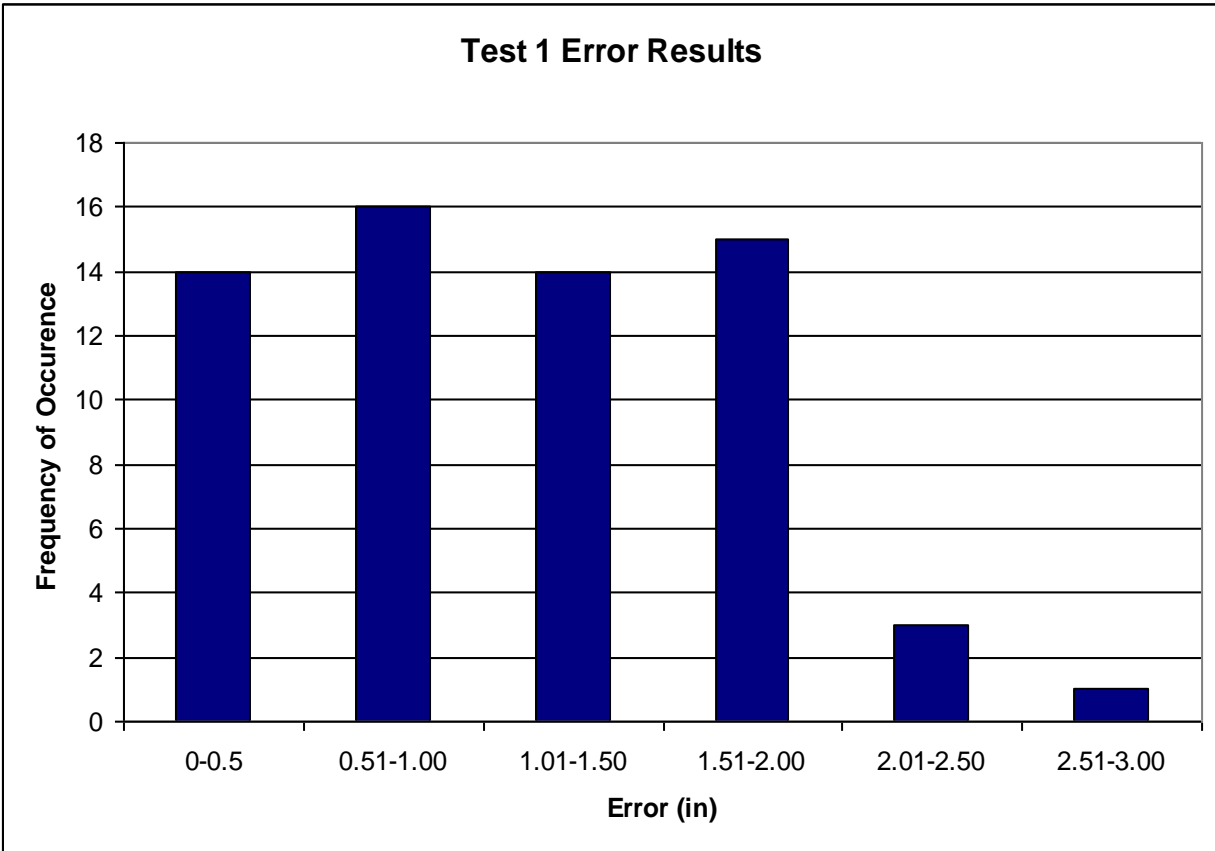
Figure 10. Test 1 error results

Proportional Valve

To improve controlling capabilities, Team Nexus removed the main solenoid valve from the machine and replaced it with a proportional valve that was ordered from Parker. The proportional valve allows the box blade to move slower while changing height thus allowing a safer, smoother transfer when resuming to a set point. This slower movement is accomplished by pulse width modulation. The valve that was on the tractor previously did not allow for pulse width modulation which made it difficult to achieve a relatively constant set point.

Final Marketable Solution

The previously discussed testing and subsequent resolving of design issues has led Team Nexus to the final solution. The control panel received three new switches: on/off switch, set/resume switch, and a manual relief switch. The operator can move the box blade to a desired height and turn the switch to on to activate the control program. If the operator then pushes set,

the position of the box blade is stored and maintained. If the operator moves the blade manually to a new position, yet later desires to return to the original position, he can do so by simply pushing the resume switch. Immediately before the operator pushes the resume button it is necessary in the current design to push the manual relief switch to avoid blowing relief. This could be removed and performed by the controller when further research is resumed by CNH.

Figure 11. Control panel with 3 new switches added by Nexus Controls.

The existing solenoid valve was replaced with a proportional valve and an additional solenoid valve was added to alleviate the constant blowing of the relief valve. The controller was housed in the console behind the control panel. The voltage regulator mentioned above was placed in a small box and secured under the floor panel. These locations were selected as they were determined to be safe despite the harsh environments that most of these machines are used in.
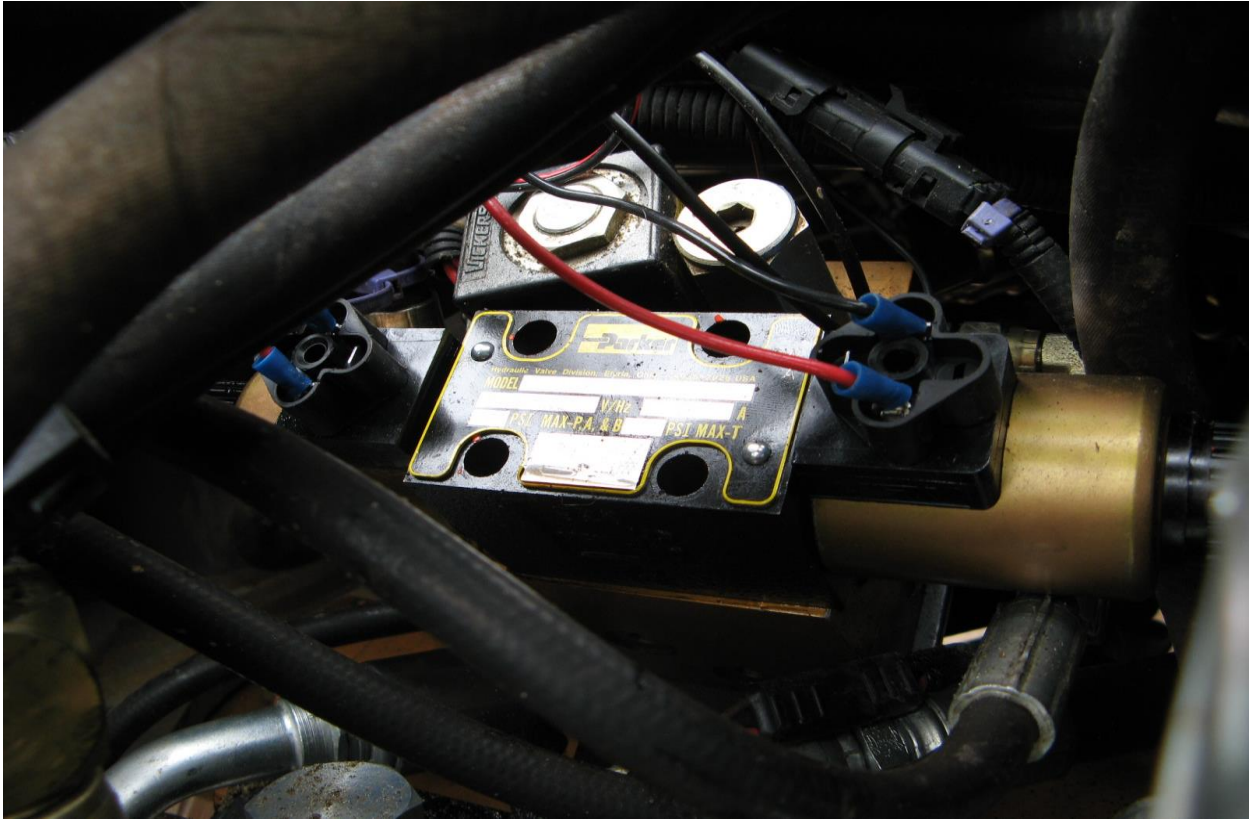
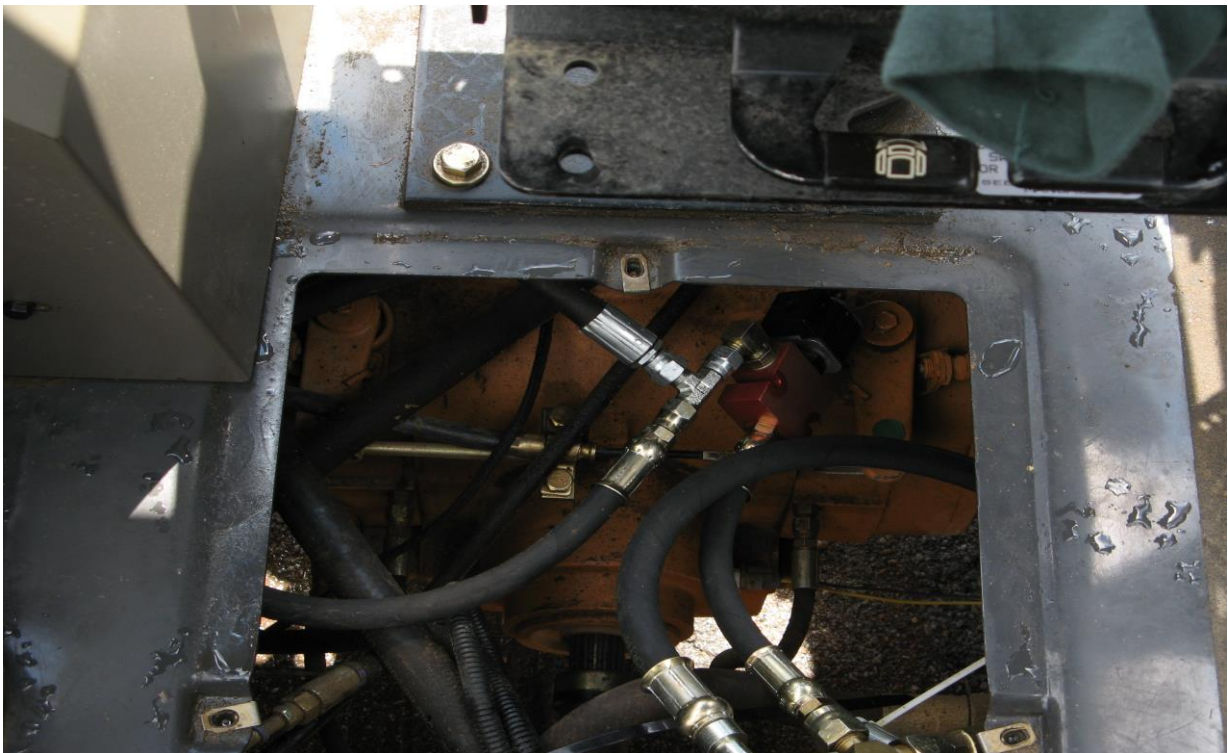Figure 12. New proportional valve

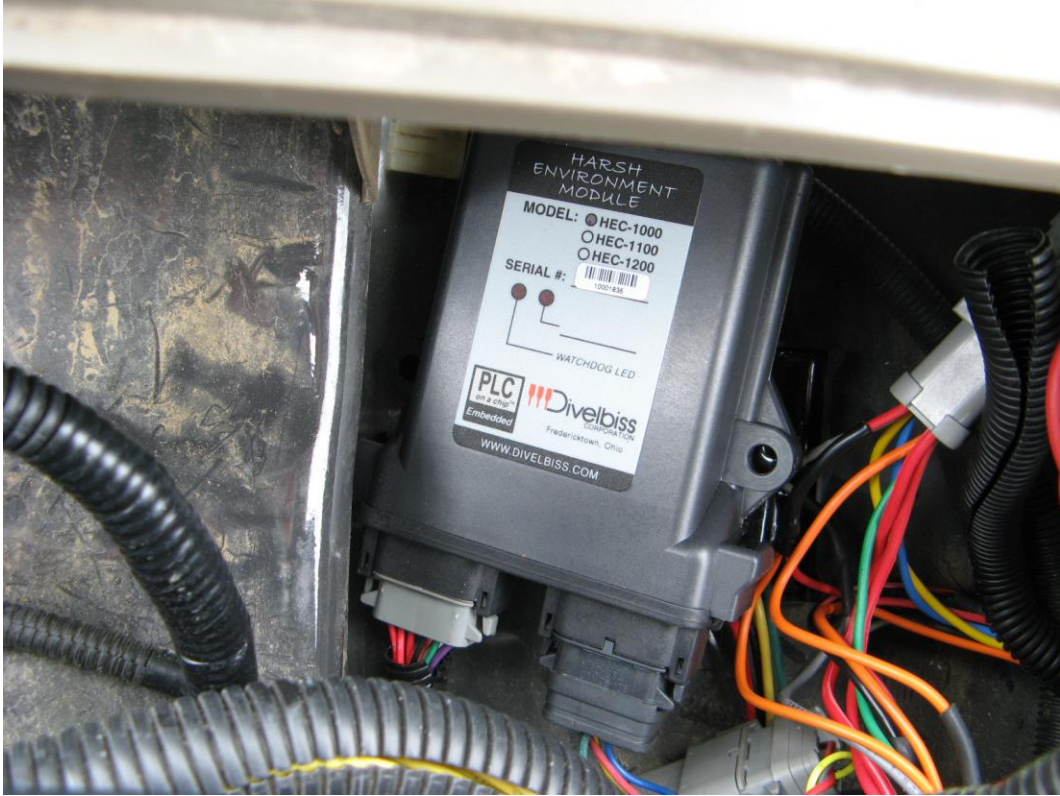Figure 13. New solenoid valve to prevent blowing of relief.
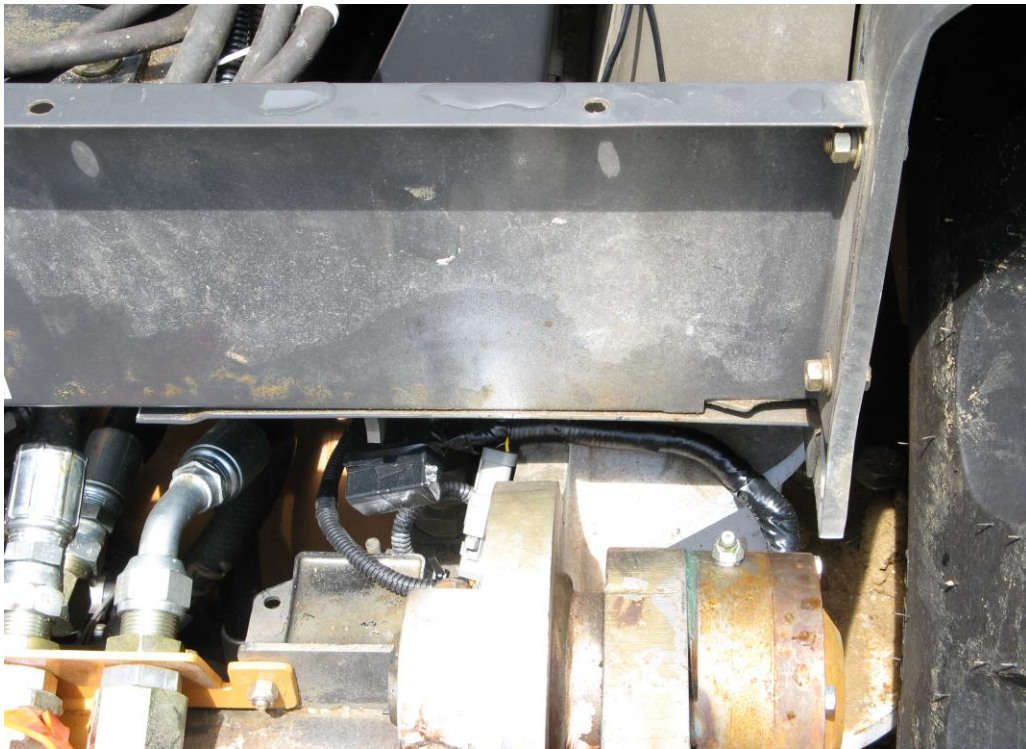
Figure 14. Controller housing

Figure 15. Voltage regulator housing

The new control system performs admirably as it resumes to the set point within 0.25-0.50 inches. Occasionally, the system will cause the box blade to jump or drop 0.75 inches. The system is an accurate solution to the customer requirements determined by Nexus Controls.

Budget

Budget	
Controller	$235.00
Wiring Harness	$75.00
Switches	$15.00
Proportional Valve	$800.00
Potentiometer	$50.00
TOTAL	$1,175.00

User Manual

To supply power the laser control function must be selected. Once the machine is in laser mode then the controller can be powered up using the controller power switch. When the controller is on then you can adjust the box blade height using the manual spool valve lever. After the box is at the desired depth the operator is to press the set side of the rocker switch. The Controller can be stopped by moving the manual lift lever or by pressing the kill switch. Even though this stops control mode, the set point is stored. When the resume side of the rocker switch is selected, the box moves back to the previously selected set height

1.) Select Laser Mode
2.) Power Controller
3.) Move implement to the desired position – Set Point
4.) Select Resume to engage electronic position control
5.) Move implement to new position
6.) Press Resume to return to the previously stored position

Project Schedule

Attached in Appendix

References

Callister, William D. 2000. *Fundamentals of Material Science Engineering*. 5th ed. Wiley.

Crowley, II; Robert W. 2004. Towable Box Grader with Electronically Controlled Continuously Variable Multi-Axis Blade System. U.S. Patent No. 6672401.

Duello, Dennis. 2002. Dynamic Controller of Excess Downpressure for Surface Engaging Implement. U.S. Patent No. 6389999.

Easton, David Joseph, Bruce Craig Newendorp, and Mark Allan Bergene. 2005. Hitch Control System with Spring Centered Control Lever. U.S. Patent No. 6935434.

Montana Tractors. 2006. Montana Tractors and Implements Product Line. MTT-20205. Springdale, Arkansas: Montana Tractors.

Rogala, Jeffrey A. 2003. Apparatus for Counteracting Vehicle Pitch Variation Resulting from the Operation of an Electronic Draft Control System. U.S. Patent Application No. 0030085042.

Smith, Carlos A. and Armando B. Corripio. 1997. *Principles and Practice of Automatic Process Control*. 2nd ed. Wiley.
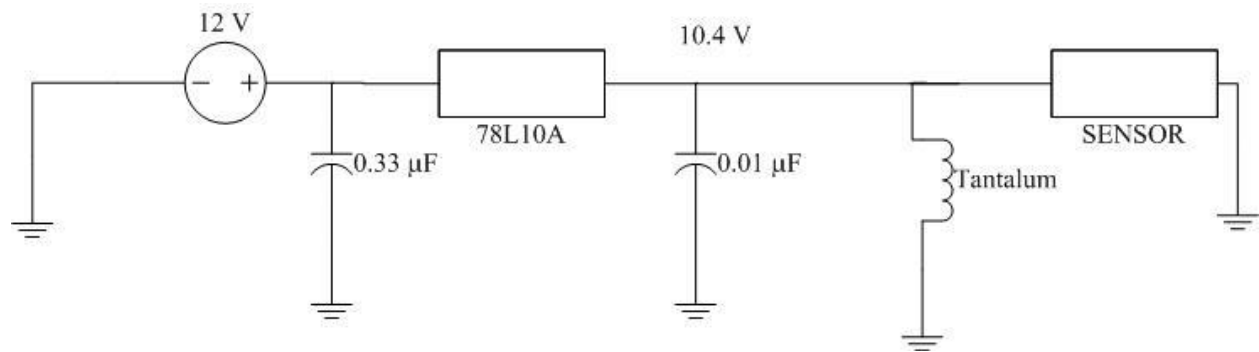
Appendix
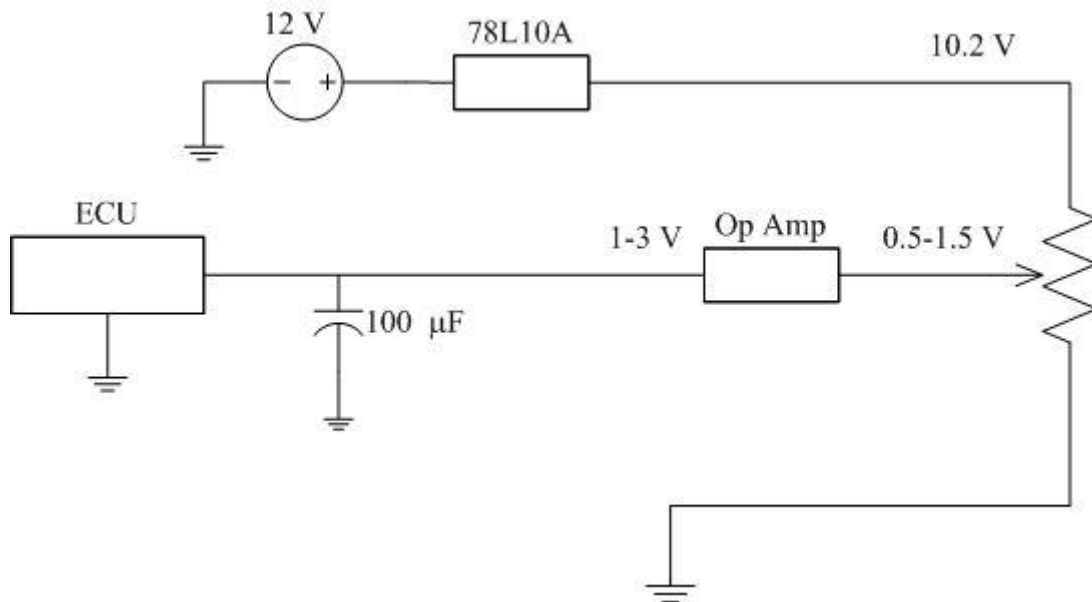
MAIN CIRCUIT COMPONENTS
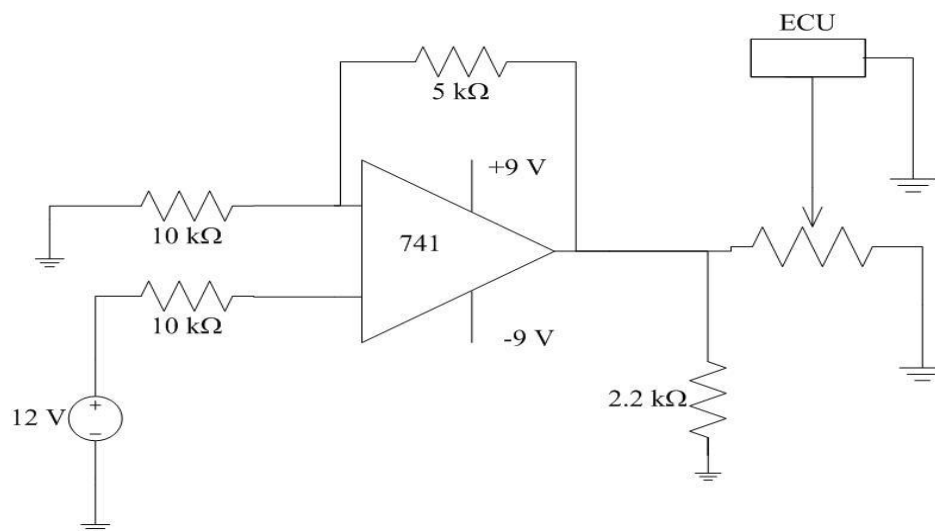
741 OPERATIONAL AMPLIFIER CIRCUITRY

COMPLETE 78L10A VOLTAGE REGULATOR CIRCUITRY

3-Point Hitch Controller

Presentation Overview

- **Background Information**
- **Design Concepts**
- **Engineering Specifications**
- **Final Solution & Recommendations**

Nexus Controls

- **David Bevill, Bio-Mechanical Option**

- **E. Evans Chambers, Bio-Mechanical Option**

- **Lee Eldridge, Bio-Mechanical Option**

- **Adam Gossen, Bio-Mechanical Option**

Problem Statement

- **Design and employ a three point hitch controller in order to set, resume & maintain a user defined implement position**

- **Design should involve minimal change to existing unit while functioning ergonomically**

- **Cost must be considerably lower than current optional laser guided control system**

Statement of Work

- **Select controlling mechanism to regulate 3 point hitch position**

- **Design shall include sensors to measure hitch position, controller to interface between sensors and laser system, program logic, wiring harness, additional parts information, etc.**

Customer Requirements

- Two modes of operation
  - Automatic
    - Set, Resume & Maintain, Stop
  - Manual
    - Manual control can over ride the automatic control function.
- Minimize cost
- Off the shelf or in-house components

NEXUS CONTROLS

CNH
Case New Holland

OKLAHOMA STATE UNIVERSITY

Customer Requirements Cont.

- Interface with existing system
  - Hydraulics
  - Electrical

- Down force capability
  - Controller mode must have down force like manual operation.

NEXUS
CONTROLS

CNH
Case New Holland

OKLAHOMA
STATE
UNIVERSITY
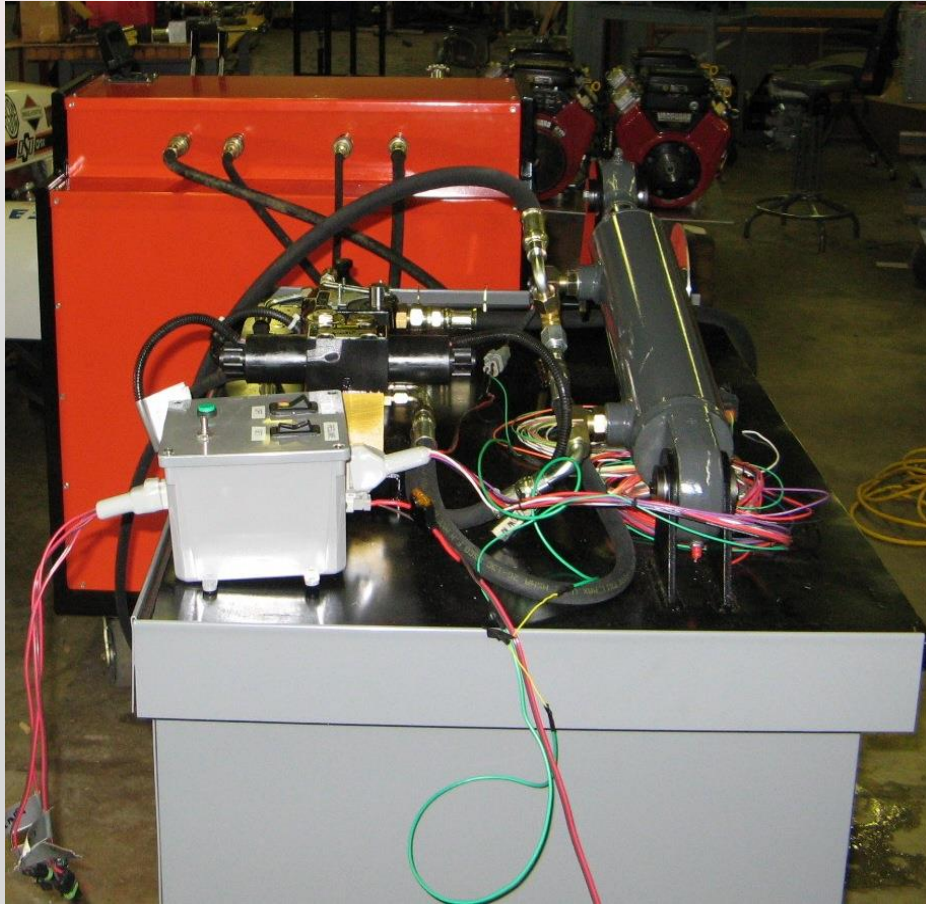
Initial Testing

- Test stand
  - Initial program testing
  - Watch the performance of the valve by the movement of cylinder

User Controls

- Switches insert to the current dash panel
  - On / Off switch
  - Set / Resume

NEXUS
CONTROLS

CNH
Case New Holland

User Controls Cont.

- Easy access to the driver
  - Set / Resume switch finger length away from the manual lift lever
- Power is supplied from the laser switch
- Manual override
  - Manual lift lever breaks control mode
    - Sends signal to controller to interrupt control

Wire Harness

- Connect to current CNH configuration
  - Power from the laser system
- Custom built to fit the needs of the project

NEXUS
CONTROLS

CNH
Case New Holland

OKLAHOMA
STATE
UNIVERSITY

Controller Location

- Concealed in the console behind the control panel

NEXUS CONTROLS

CNH
Case New Holland

OKLAHOMA STATE UNIVERSITY
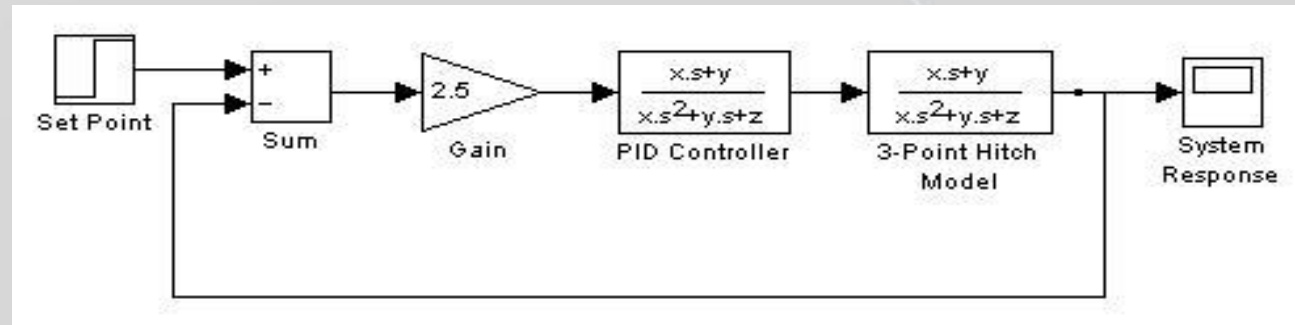
Hydraulic Valve Comparison

- Directional Control Only Valve
  - Open Center Valve
- Proportional Valve
  - Closed Center Valve
    - Requires a bypass to be placed in the hydraulic system in order to avoid heating the oil

NEXUS CONTROLS

CNH Case New Holland

OKLAHOMA STATE UNIVERSITY
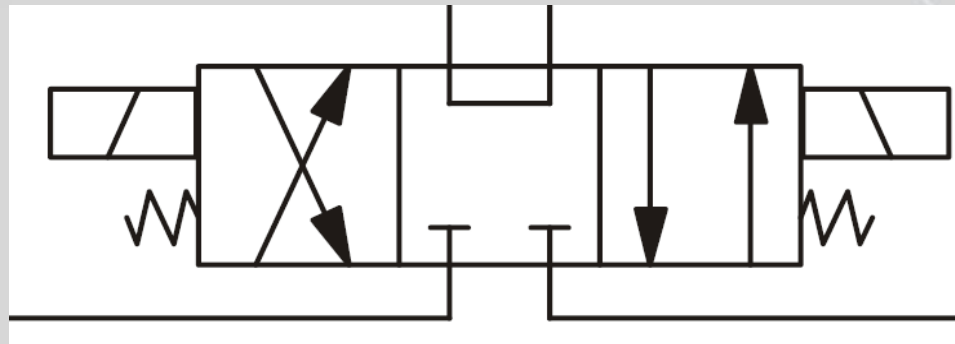
PI CONTROL

➢ Proportional, Integral Terms

➢ Variable PWM

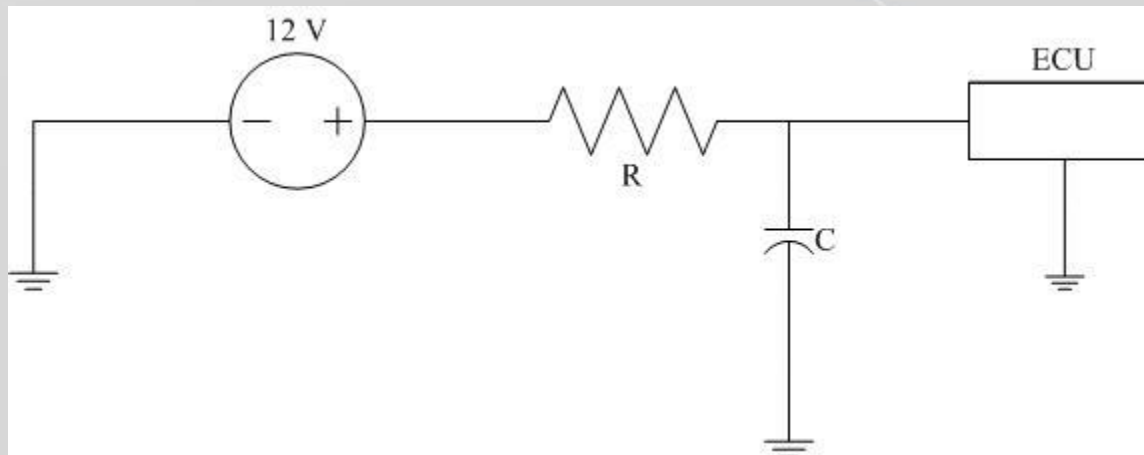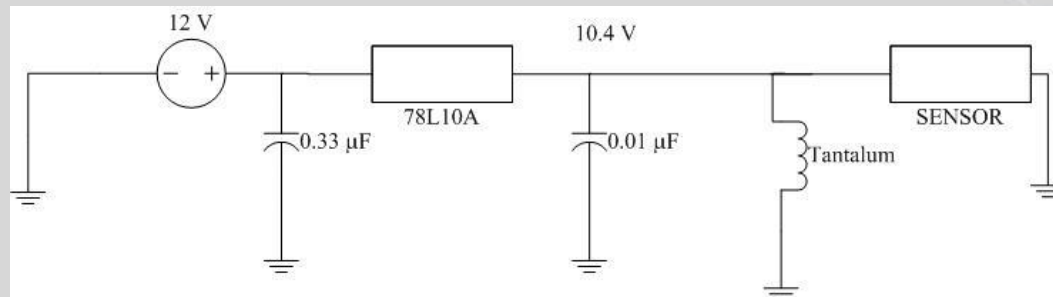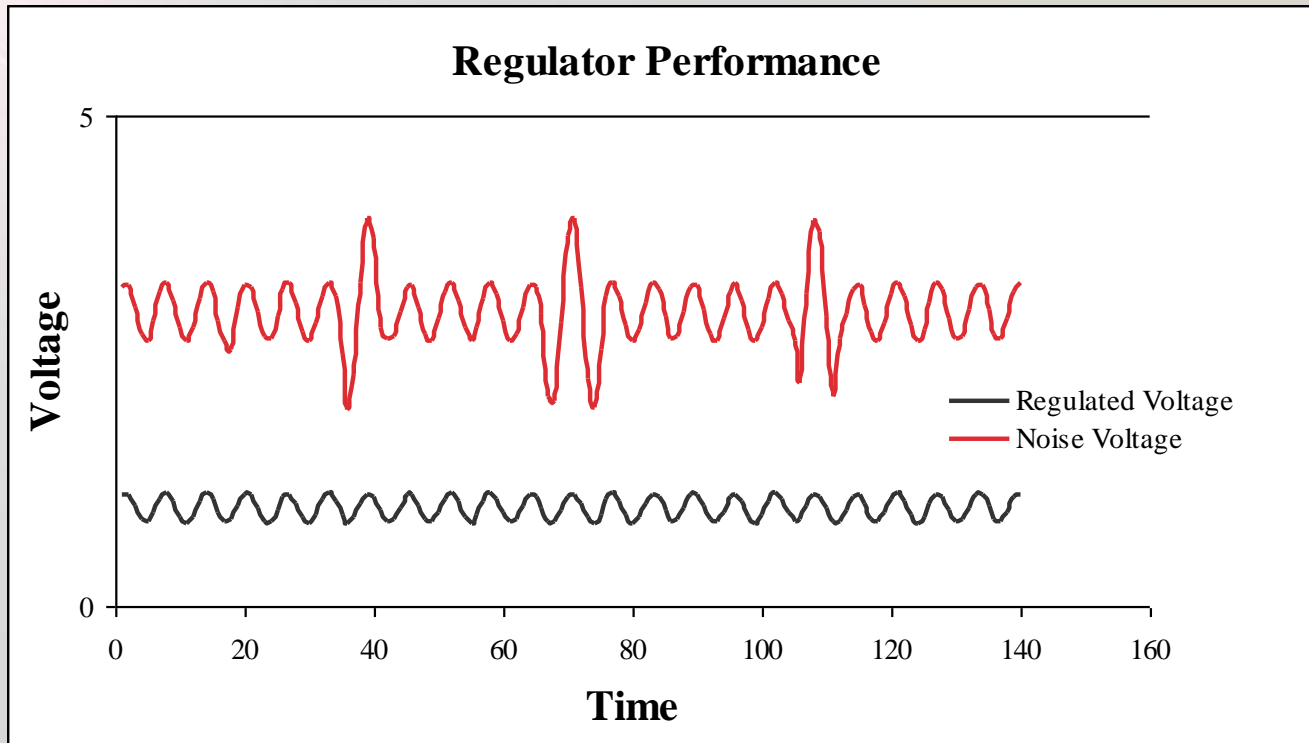$$\mathrm{Output(t)} = K_p \left(e(t) + K_{ip} \int_0^t e(\tau)\, d\tau \right.$$

FILTER

$$f = \frac{1}{2\pi RC} = \frac{1}{2\pi \cdot .01\,\Omega \cdot 100\,\mu F} = 160\,kHz$$

$$f = \frac{1}{2\pi RC} = \frac{1}{2\pi \cdot 150\,\Omega \cdot 100\,\mu F} = 10.6\,Hz$$

VOLTAGE REGULATOR

Regulator Performance

AMPLIFICATION

$$GAIN = 1 + \frac{R_f}{R_b}$$

NEXUS
CONTROLS

CNH
Case New Holland

OKLAHOMA STATE UNIVERSITY
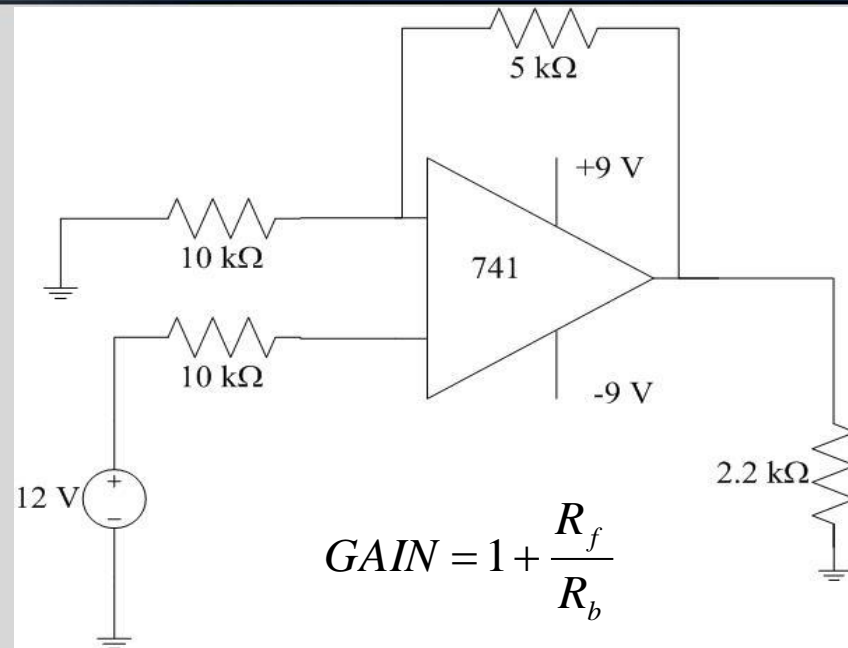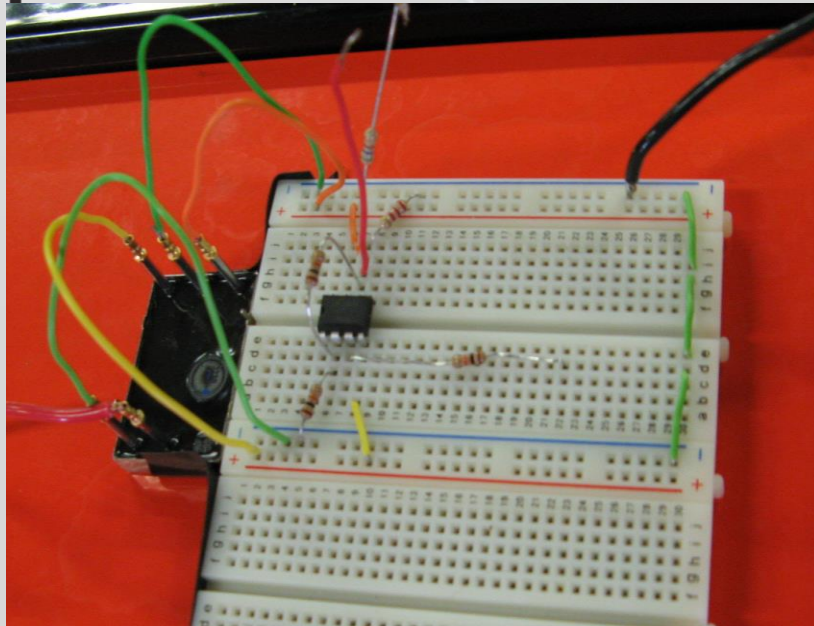
CURRENT DIVIDER

– EQUATION

➢10 BIT
   -1024 Digits
➢0-20 mA

$$\frac{V_{ECU}}{R_{ECU}} + \frac{V_{ECU}}{750} = \frac{12V - V_{ECU}}{1000 + 150}$$

$$\frac{V_{ECU}}{R_{ECU}} = 7mA$$

NEXUS
CONTROLS

CNH
Case New Holland

OKLAHOMA STATE UNIVERSITY

MOVING AVERAGE
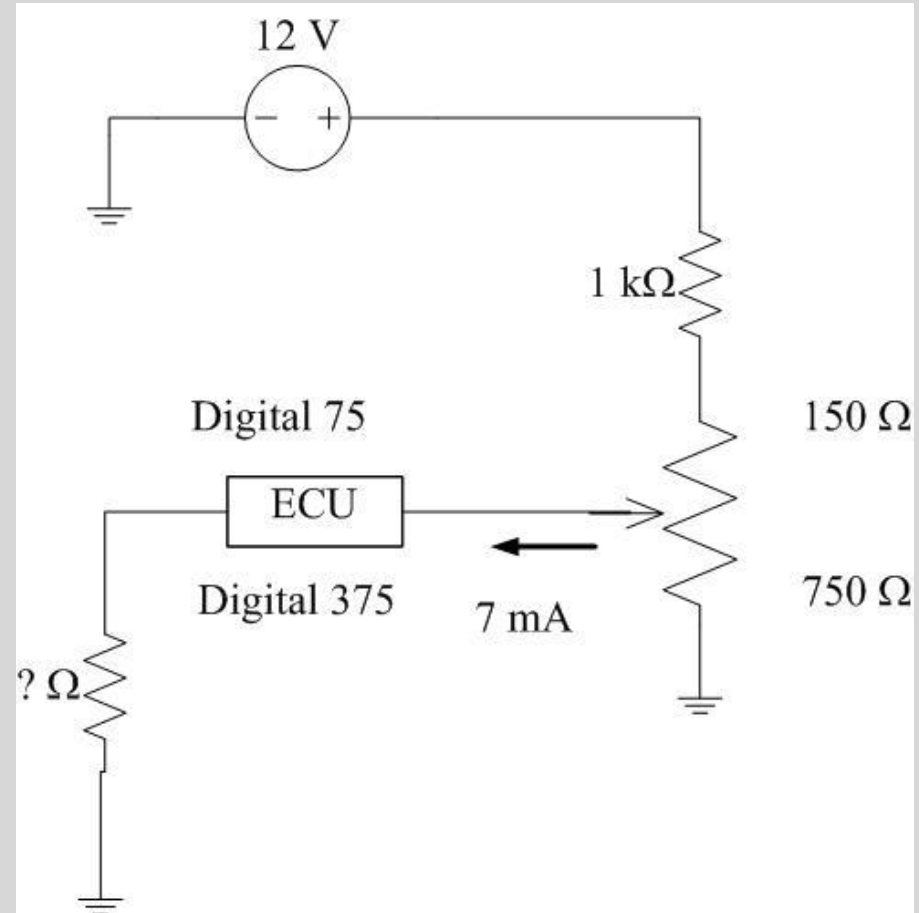
Moving Average Effect
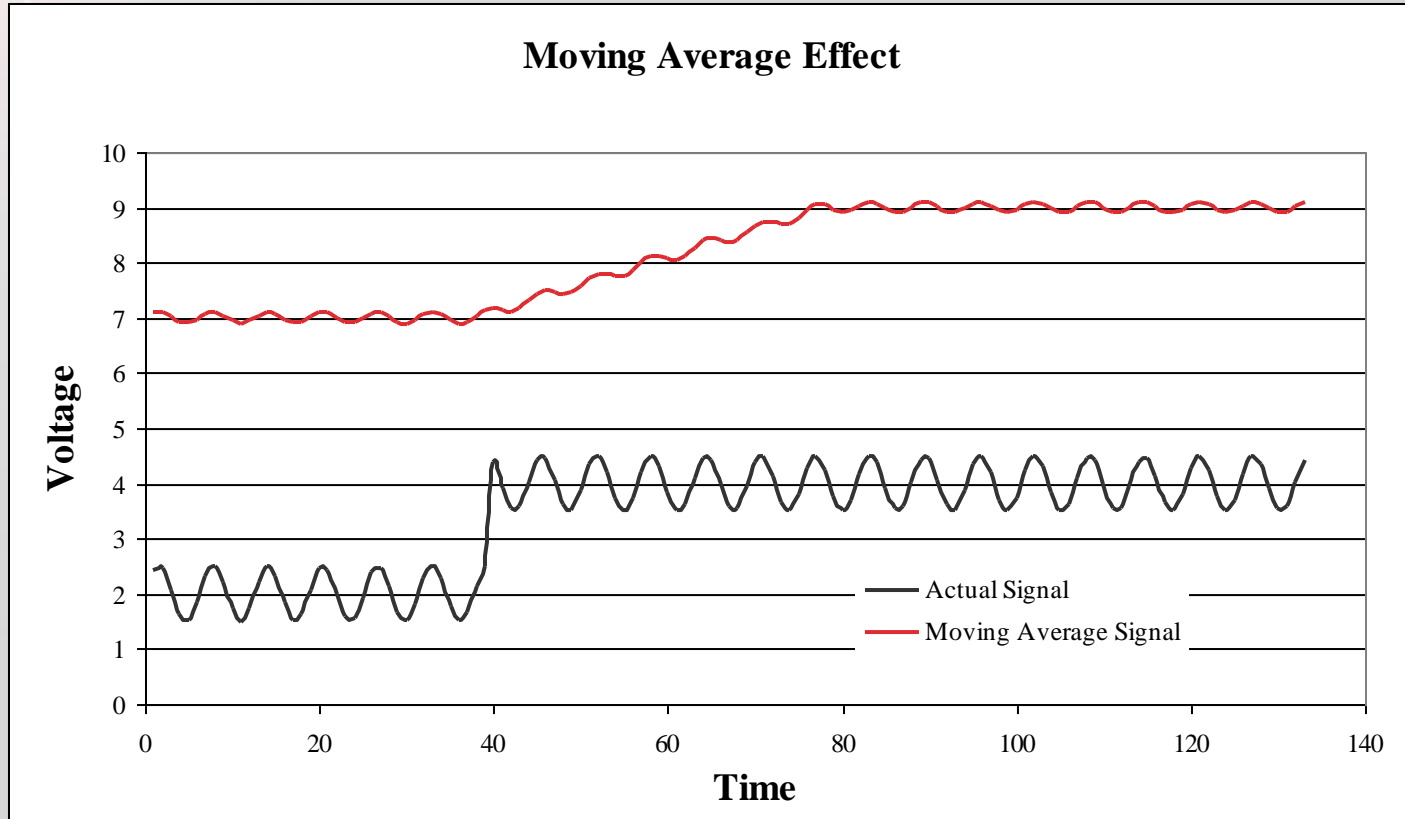
EZ LADDER SOFTWARE

➢ -1.Q#0!

➢ 2 Byte Variables

➢ 4 Byte Storage
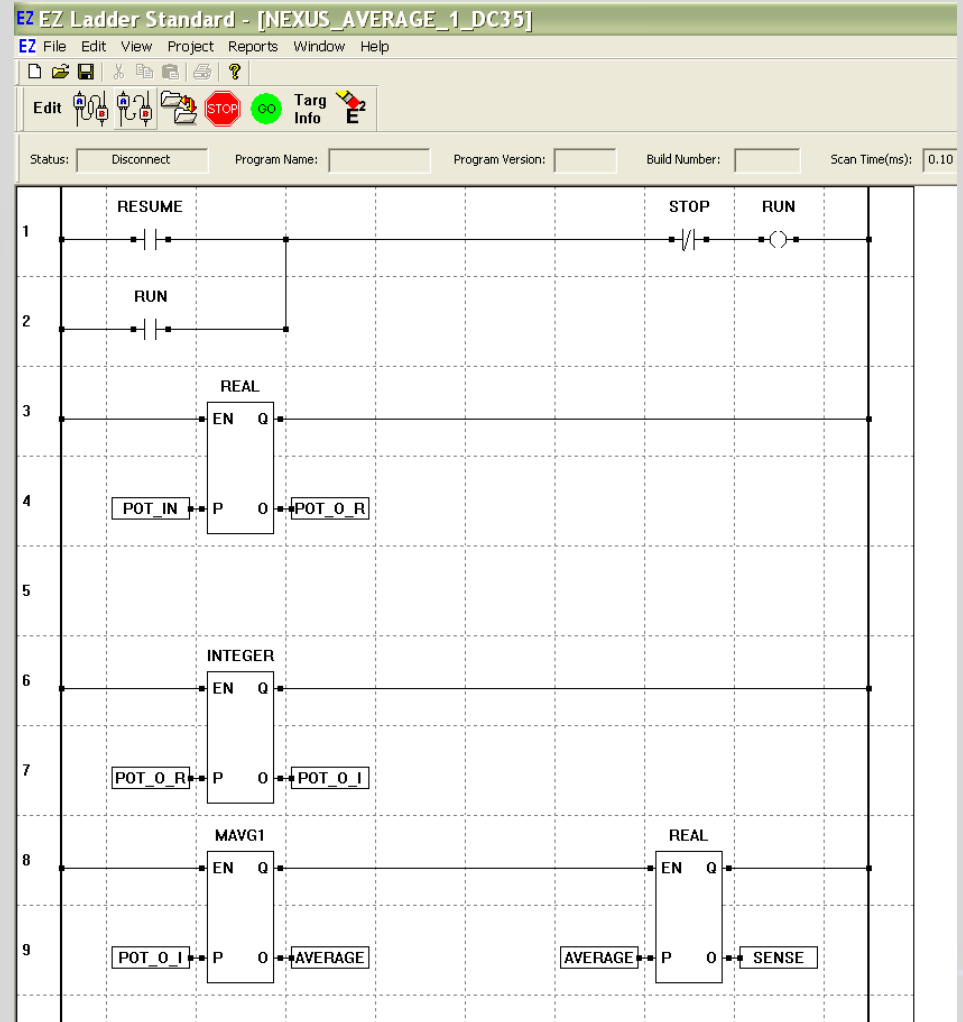
ALTERNATIVE SENSORS

- ➤ Rotary Encoder
  - ❑ Avoid Additional Circuitry
  - ❑ Less Susceptible to Noise
- ➤ Noise on board

NEXUS CONTROLS

CNH Case New Holland

OKLAHOMA STATE UNIVERSITY
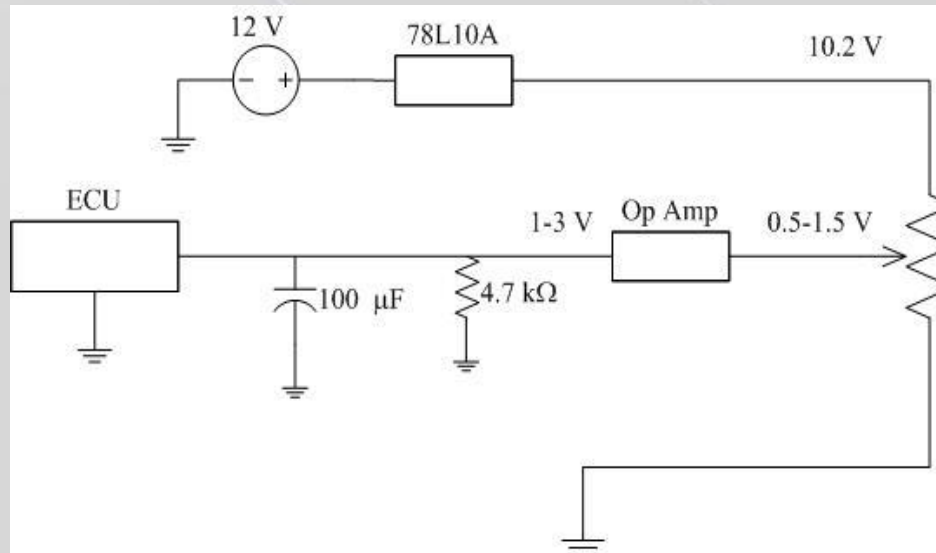
Final Solution

- **Control panel additions:**
  - **On/Off Switch**
  - **Set/Resume Switch**
  - **Manual Relief Switch**

Final Solution

- **Valves**
  - **Proportional valve for better control**
  - **On/off solenoid valve to prevent blowing relief**
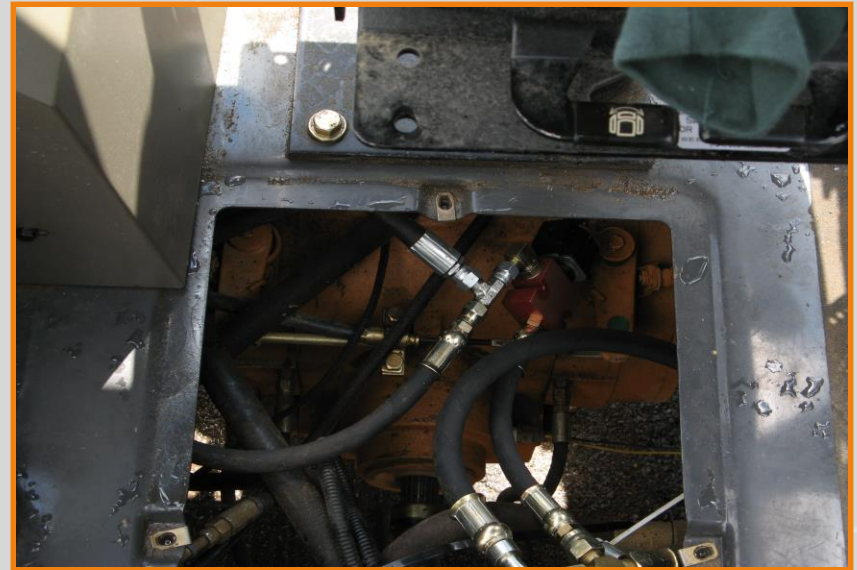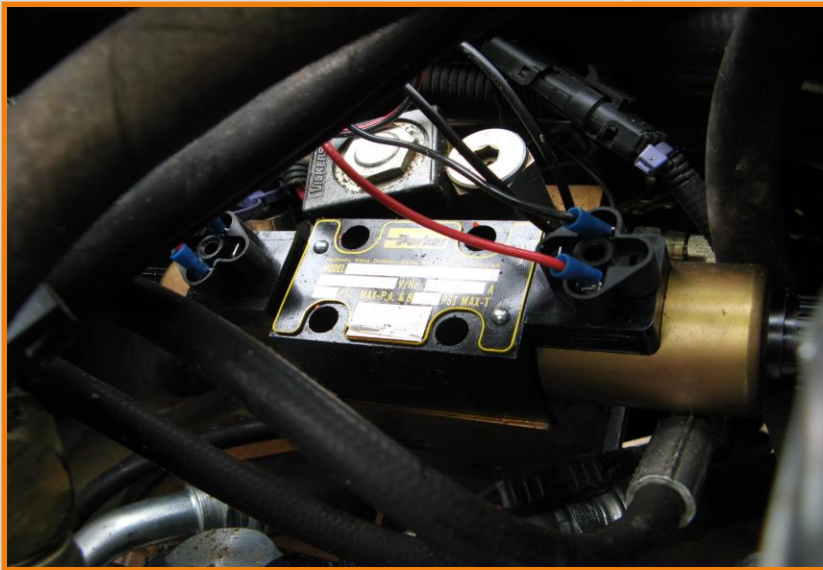
Final Solution

- ## Housing:
  - ### Controller housed in console behind control panel
  - ### Voltage regulator housed under floor panel
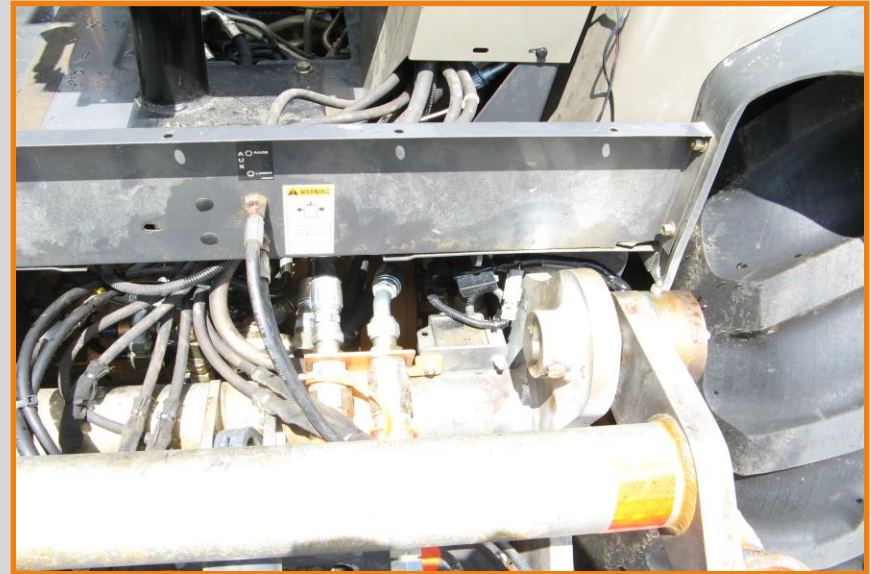
Final Solution

- **Performance**

  – **Accuracy**

  – **1/4"-1/2" range**

  – **Occasional bump or drop of ~ ¾"**

Budget

Budget	
Controller	$235.00
Wiring Harness	$75.00
Switches	$15.00
Proportional Valve	$800.00
Potentiometer	$50.00
TOTAL	$1,175.00

NEXUS
CONTROLS

Acknowledgements

- **Nexus Controls would like to thank the following:**
  - **BAE Faculty**
  - **BAE Lab Staff**
  - **CNH**

NEXUS CONTROLS

CNH
Case New Holland

OKLAHOMA STATE UNIVERSITY

Fall Design Proposal

BAE 4012

NEXUS Controls Members
David Bevill
E. Evans Chambers
Lee Eldridge
Adam Gossen

Case New Holland

Table of Contents

Introduction

Case New Holland (CNH) is considered a leader in the agricultural and construction equipment industry with more than 11,000 dealers stretched throughout 160 countries. The combination of heritage Case and New Holland designs coupled with the innovative needs of the future has led CNH to strive to develop new products on the cutting edge of technology. CNH has come to the Biosystems and Agricultural Engineering (BAE) department at Oklahoma State University (OSU) to further produce ground-breaking solutions for their unique engineering design challenges.

Problem Statement

Design and employ a three point hitch controller in order to maintain user defined implement position with reference to machine. The design should involve minimal change to the existing unit while functioning in an ergonomic fashion. Addition to machine cost must be held considerably lower than currently optional laser guided control system.

Statement of Work

Students in the BAE Department are required to complete a two semester senior design course/project to fulfill degree requirements. Four students in the 2006-2007 senior design class have been selected to assist CNH with a design task submitted by the company. These four BAE students comprise Nexus Controls. Team Nexus will attempt to **solve the problem by selecting a controlling mechanism to regulate position of the three point hitch in order to further the capabilities and performance of the Case 570 MXT Loader Landscaper**.

Nexus Controls has acquired the assistance and guidance of Dr. Marvin Stone, a renowned sensors and controls expert from the BAE department at OSU, to serve as an advisor to the team. The team has expressed that the task can only be completed if a machine is provided by CNH for the team to use for testing our possible solutions. CNH has indicated verbally that this request should be met some time in the near future.

CNH has also indicated that the solution created by Nexus controls must be able to be easily added to the machine; that is, they do not want Team Nexus to engage in heavy redesign of the existing three point hitch. Team Nexus has been advised that the current setup of the laser ready hydraulics could be an ideal starting point. CNH would like to maintain the current ability of their industrial three point hitch to have down pressure.

The 570 MXT Loader/Tool Carrier currently hosts a laser control module capable of sensing box blade position relative to a fixed plane of reference. Sensors mounted on the machines receive input signals from a rotary laser plane mounted in a stationary position. The laser control module constantly monitors the box blade position and computes the error in the height from the plane of reference created by the rotary laser. Based upon the magnitude and direction of the observed error, the controller opens the appropriate solenoid valve to correct the error in height. Though extremely accurate, this method of control brings an additional cost of approximately nine thousand dollars to the base price machine.

The approach of NEXUS Controls is to create a less expensive control system that employs a different method of box blade height control. This method will utilize the machine as the position reference while incorporating an adjustable set point function. The set point function will allow the operator to program predetermined heights of the three point hitch assembly to which the box blade is attached.

The position reference is the most critical difference between the laser plane module and the controlling method devised by NEXUS. Sensing position of the box blade relative to the machine is to be achieved using a rotational sensor placed on the rock shaft of the three point assembly. The three point hitch height is adjusted by one hydraulic cylinder capable of applying force upwards and downwards. This cylinder applies force to the main lift arm which converts the linear actuation of the cylinder into rotational motion about the rock shaft axis. In order for the rotational sensor to indicate height, the housing of the device must be fixed to the frame of the machine while an external member of the sensor rotates with the rock shaft.

One suitable electrical device is a potentiometer that incorporates three connections into a resistor. The center connection, known as a wiper, is translated along the resistor by the rotation of a dial. Alterations in position along the resistor cause the voltage output at the wiper to change. Connected in the circuit will be an electronic controller monitoring the voltage magnitude. The set point height value will correspond to a specific value of electric potential observed by the controller. Likewise, the error in box height will be received by the controller as a deviation in voltage magnitude. The controller will then activate the appropriate solenoid valve to correct the error in voltage and thus, hitch position.
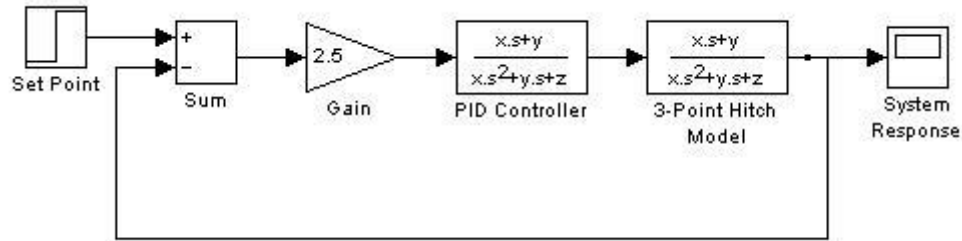
Figure 1: Block Diagram of Control Process

The voltage measurement at the specified node in the circuit is referred to as the feedback in the controlling system. Proportional Integral Derivative (PID) is a common type of feedback controller. This device incorporates three mathematical operations that are a function of the error in the feedback measurement as illustrated below.

$$\text{Output(t)} = K_p \left(e(t) + K_{ip} \int_0^t e(\tau)\, d\tau + K_{dp} \frac{de}{dt} \right)$$

When tuned properly, the combination of each term in the equation yields stable and functional control of the system. That is, once the box blade height differs from the set point, the controller operates to quickly adjust the three point hitch to the correct position without oscillating around the prescribed height or violently accelerating. The proportional term results in an output of a magnitude equal to the error multiplied by the constant K_p. The integral term sums the error on a time scale (milliseconds) so the larger the error in height, the greater response of the hydraulic system to correct that error. The derivative term will result in controller output based upon the rate of change in error with respect to time. This will decrease the amount which the controller moves the hitch passed the prescribed set point (overshoot). By adjusting the constant value in each term of the output equation, one can tune the controller. The controller may be utilized with proportional control plus either, both or neither integral or derivative action. Using the integral action without the derivative can result in large overshoot, while adding the derivative action results in quick response while minimizing overshoot.

A spring in the valve assembly applies force to a spool blocking the flow of hydraulic oil and maintaining cylinder position. The coil of the solenoid creates a magnetic field while current

is flowing through the coil. The metallic spool responds to the magnetic field by sliding past the valve orifice allowing fluid flow. The output from the controller will come in the form of pulse width modulation (PWM). The width of pulse refers to the ratio of the amount of time the solenoid circuit is closed to the amount of time the circuit is broken. This pulse schedule will occur at approximately 1000 hertz. The ratio of on/off time translates to a position of the spool in the valve. Due to the mass of the spool and the force of the restricting spring, the spool does not oscillate at the PWM frequency. The effect on the spool is a stable position determining fluid flow through the valve.

The use of a touch screen as a possible user interface would benefit the operator by allowing the individual to enter in various settings and set points. The screen would also have an output reading of the current height or depth of the box blade. This feature would cost a little more than other possibilities but would allow the user to operate with more pre-determined settings. Another possibility is an output screen with a numerical key pad that would be used to enter a set point. The other possibility would be a dial knob that would be turned to the desired height or depth. The knob setup could have problems with accuracy because the operator is not entering a specific number they are instead lining a mark on the dial up with a number on the controller box. The possibility of bumping the knob during operation and it moving would change the depth at a critical time in operation.

The safety of those present during machine operation is held paramount by NEXUS Controls. When considering electrical devices, it is required that all connections be completely insulated from personnel. Though the power source on the machine is only twelve volts, a short circuit current is potentially dangerous and thus considered in design. In addition, the possibility of an automated mechanism becoming instable and behaving violently is inherent with computerized machinery. Multiple steps are to be taken when programming such a device to ensure that irregular operating conditions will at worst terminate implement motion. No significant mechanical changes are to be made on the three point hitch. The safety of this apparatus has been determined by Case New Holland.

In summary, our statement of work is to produce a safe, cost-effective controller, capable of automatically maintaining the position of the 3 point hitch on the 570 MXT Loader Tractor. The design shall include sensors to measure position of the hitch, a controller to interface between the sensors and existing laser system, and all of the necessary wiring, manuals, and

inner workings of the aforementioned parts. CNH will be solely responsible for safety and liability of this product and derivatives of this product.

Task List
- Confirm exact electrical connection for laser controls
- Determine hydraulic/electrical specifications of lift cylinder valve
- Locate controller with PID function suitable for machinery
- Investigate computer modeling options
- Analyze cost of all additional components
- Acquire machine & laser system
- Obtain housing for controller
- Experiment with pulse width modulation & variable voltage
- Program controller actions
- Testing and modification of the beta version of our controller
- Visit Burlington, Iowa facility

Patent and Background Research

The team has discovered four patents making claims of design and function that are associated with initial ideas of NEXUS controls. Each of the four patents implements distinctly different methods of hydraulic control for a three point hitch on a tractor. Though dissimilar, the abstract of each patent provides cause for further reading and detailed research. However similar, NEXUS concludes ideas generated by the team currently present no direct threat of patent infringement.

Patent 1: Towable Box Grader with Multi-Variable Axis #6672401

The invention is a towable scraper system designed for contour surface grading. The device includes a rigid chassis member configured for attachment to a conventional three-point hitch. A scraper blade is suspended from the above mentioned member and is equipped with a blade motivator capable of blade rotation about an axis oriented in the direction of towing. The inventor claims that the said blade motivator and the lift assembly are responsive to a controller output. This yields control of tilt angle and height relative to the work surface. Specific devices achieving this type of control are left undefined.

The critical phrase in the above patent description is the height control "relative to the work surface". NEXUS has generated several ideas of control with respect to a predetermined set point utilizing a rotational sensor on the lift arm hinge. This method controls the height of the implement relative to the machine – not the work surface. In addition, the tilt function is negligible because NEXUS currently has no plans of tilt control.

Patent 2: Apparatus for Counteracting Vehicle Pitch Variation #20030085042

The apparatus and method to be described are designed to counteract vehicle pitch variation with three possible adjustments: implement position, rear suspension, and front suspension. The claims refer to currently implemented electronic draft control (EDC) systems. These devices are capable of adjusting implement height in response to changes in draft force. The patent of discussion includes the idea of adjusting the vehicle suspension in addition to the implement height. In doing so, the possibility of vehicle oscillation is developed. This is counteracted by a second control function responsible for monitoring suspension behavior and making hydraulic valve adjustments to prevent unwanted resonant motion of the machine.

NEXUS sees no issue of infringement on the above patent for several reasons. The three point hitch of the agricultural machine described in the patent is not capable of exerting a downward force on the implement. Construction machinery utilizes the capability of downward force. In addition, the system previously explained operates with signals generated from draft force alterations. The intentions of NEXUS are to control a box blade with a rotational sensor; disregarding draft force.

Patent 3: Dynamic Controller of Excess Down Pressure #6389999

The patent of consideration describes a system for controlling the depth of an agricultural implement with respect to soil surface. Seeding is the primary application of such technology. The system is comprised of a depth sensor in collaboration with a pressure sensor of the depth regulation member. The depth sensor communicates the position of the implement to a controller. In order to prevent damage to the surface penetrating member, the controller will also respond to the sensed pressure experienced by the lowered member. The implement will be

adjusted if the depth is inaccurate or forces experienced by surface penetrating members are unacceptable.

This design presents no obstacle to the future plans of NEXUS Controls. The above patent describes the control of a seeding implement based upon a depth and forces experienced below the surface. The designs of NEXUS pertain to three point hitch control based upon relative position to the tractor. There is no consideration of forces experienced by the implement when devising controlling methods.

Patent 4: Hitch Control System with Spring Centered Lever #6935434

The subject of concern is a control system involving incremental alterations of hydraulic valve positioning in response to various inputs. Specifically, this design incorporates a lever, that when moved any distance, the controller responds with a preset magnitude of valve manipulation. Essentially, the operator will communicate the desired direction of motion of the three point hitch. The controller does not consider the level as to which the lever is rotated.

This documentation is of a response operation of a hydraulic valve to be entered into a controller. The agenda of NEXUS is centered on sensing methods of a three point hitch. However, programming controller output into the device will pertain to NEXUS design. This concept is essential to total system function; for a controller must have a program of position alteration in order to perform. The plans of NEXUS deviate from those previously described in that a controller will operate to correct an error in voltage that it will calculate.

Patent Summary

Though several of the previously mentioned patents pertain to three point hitch control, not one defines solutions conceived by NEXUS. Details of future plans of work devised by NEXUS are original so as not to infringe upon exclusive rights of past inventors.

Competitors

Team Nexus would like to acknowledge the machines that are direct competitors of Case New Holland. In the following section, we will distinguish how our intended design will not infringe upon the current models of competing companies. Some machines do not have the features which we are attempting to design and thus do not require discussion. Team Nexus currently wants to incorporate a user friendly controller to maintain a constant depth.

John Deere features a landscape loader model 210 LE that has levers mounted inside the cab of the machine which control the position and tilt of the three point hitch. The levers are controlled manually by the operator. This design does not make use of a controller.

The Kubota M6800 Series utility agricultural tractor features two levers to control the hydraulics for the three point hitch. These levers are mounted to the right of the cab and are controlled manually by the driver of the machine.

Massey Ferguson makes a utility tractor, the MF 400 Series, which is used for landscaping applications and grading with a box blade. This design also uses levers to control the three point hitch position. The current design for MF does not include any form of electronic controlling and should not affect our design plans.

Caterpillar has a machine that performs the task that is required by utilizing their Accu-Grade Laser Grade Control System, but does so in a manner that is different from the current design that Team Nexus is pursuing. The machine used by Caterpillar is a track type tractor which is different from the CNH model. The Cat design features a laser receiver mounted on a mast extending upward from the top of the bucket mounted on the front of the machine. The receiver detects a laser beam emitted from an off board tripod mounted laser traditionally used in surveying work.

As the blade moves above or below the finished grade level information is sent to the in-cab display to show the cut or fill requirements. Based on the signal received the automatic blade control system lifts or tilts the cutting edge. A dual hydraulic control valve is used to raise and lower the machine's cutting edge.

Team Nexus has been informed by CNH to pursue a solution that does not include lasers, i.e. a cheaper solution. While this solution is for the same desired outcome we feel that it will not be infringed upon by Team Nexus since we are currently looking at a controller instead of a laser solution.

We have checked out other competitors such as JCB (Models 212SL, 212SU, and 3C LL) and Terex (Models 640-660B and TX 640-660) and have not been able to find any form of automated controlling of three point hitch tilt and position. A newly formed company, Montana Tractors, has a method of control that uses dials mounted on the dash inside of the cab to control the hitch position. It will be discussed further below.

Montana Tractor Review

Team Nexus reviewed the Montana tractor controller system that is used for draft control. The sensors are located on the rear of the tractor with the height sensor attached to the lift arm via a simple linkage system. This sensor is attached by a tab that is welded to the lift arm, and the lift arm is attached to the tractor by a spline shaft

The center link has an attached sensor for measuring force. The force is measured by a large spring located behind the center link. With a known spring constant and a link arm that reads change in distance, the change in force can be determined to ensure that the draft control is functioning correctly.

The controller functions make the operation of the machine easier on the operator by creating a "hands free" operating environment. The depth is controlled by a manual knob that is similar to a depth lever on most common agricultural tractors.

The controller has various functions which allow the machine to be operated easier. One of the options is setting the controller so that turning the steering wheel a certain distance will automatically raise the three point hitch. The Montana controller has a diagnostic test feature to ensure that it is functioning properly. When the machine is shifted into reverse, a controlling mechanism can be set to automatically raise the hitch up. The draft control has a minimum and maximum setting which the operator can select depending on his normal operating conditions. The operator can set the upper position limit so that the controller will only raise the implement to a set point as opposed to the implement rising to the top of the lift distance each time.

After reviewing the hydraulic schematic for the Case 570 MXT Loader Landscaper sent to the team by CNH, Team Nexus has determined a few possible locations for housing the potentiometer. One location, which was recommended by CNH, is on the upper rock shaft. The other position is located where the lower lift arms connect to the machine. The advantage of this location is that the operator can determine the height of the attachment as well as its pitch. The machine has an electronic controlled hydraulic valve in the lift system while the tilt is manually controlled using the laser system.

Instrument Review

The three point hitch controller must be able to hook up to the existing wire connections already on the machine. In a conceptual sense the controller is a "plug-n-play" device used to automatically control position of the three point hitch. The operator will need the ability to

manually override the system while still in "auto-control" mode. This will allow the user to set a predetermined position of the three point hitch, but also return control to the user if desired.

The system will be comprised of three main components: the remote sensors on the three point hitch, the controller, and the user interface. The interface will be where the operator sets the predetermined position of the three point hitch. The sensors will provide data from the hitch, and the controller will interface the main electro-hydraulic system to control the hitch. A closed loop system will provide this type of control.

With a closed loop system, the remote sensors will provide the controller with data of the position of the three point hitch. Once the predetermined position is set the operator can use the machine without constantly adjusting the three point position. If the operator wanted to manually change the position, an override could be activated allowing manual control to the operator. The controller would return the three point hitch to the set position after the operator deactivates manual control.

The electro-hydraulic system will accept analog signal only. The main two types of commercially used signals are variable-voltage and pulse-width modulation and both are acceptable for the current electro-hydraulic system. The range of the variable voltage or the pulse-width frequency suitable for this system is unknown, but the system setup allows for selection from a wide variety of controllers.

One idea for the interface is a touch screen LCD, which shows pertinent information while the hitch position settings are controlled by dials or buttons that interface the controller. By utilizing an LCD screen for readout and/or input, the operator will have a better feel for the system with a much shorter response time. Such improvements come with significant cost increase to the machine.

Customer Requirements

The customer requirements can be grouped into three categories: means and modes of operation, production, and integration.

The first set of requirements deals with means and modes of operation. First and foremost, the controller must have two modes of operation; automatic and manual. The automatic controller must be able to maintain a position set by the operator. The automatic controller will maintain or reach a desired position unless it is unattainable due to ground

conditions. The automatic controller will also allow for brief, minor manual adjustments, after which will return the 3 point hitch back to the set position. If the manual adjustments are made above and beyond a certain point, or while in manual operation and the position is not brought back to neutral within a certain time frame, the automatic control will be suspended until physically re-enabled. While the controller is on and operation is suspended, this will be called the carry/transport mode.

The second set of requirements deals with production requirements. Cost is a major factor for this design, because it is meant to add features and controllability while keeping cost to a minimum. There is already a laser-leveling system available that maintains a precision grade, but the cost is $9000. This system is meant to provide the operator a method of returning to a previously achieved position; once this position is achieved, the system will monitor and maintain that position. To keep the production rate high, the components used in the system must be widely available and/or "off-the-shelf". Generally "off-the-shelf" components are not only widely available, but have had lots of testing, and offer much more support than custom components. The majority of the components should come from or be derived from existing components in use on other CNH machines.

The last set of requirements deals with controller integration into the 570MXT. The controller must interface with the existing hydraulics system. By utilizing the existing hydraulics system, all of the existing controllers, such as the laser-leveling controller, will not have to be redesigned. Also, redesign of the hydraulics system would mean that all of the tractors in production now would need to be retrofitted with new hydraulics, which would add cost and down time for the existing owners.

Engineering Specifications

Potentiometer
In order to use any electrical device to measure rotational position, the electrical resistance must be sized properly so that appropriate current is achieved in the control circuit. Due to resistance heating of conducting elements, it is necessary to attain a current flow in the range of milliamps. Heating is quantified using the following relationship:

Power = (Current) ^2 * (Resistance) (P=I^2*R)

Current = Voltage/Resistance (I=V/R)

With a known voltage source of 12 volts, one is able to determine a suitable resistance range of the potentiometer. For example:

I = 12 volts / 10000 ohms = 0.0012 amps = 1.2 milliamps

I = 12 volts / 5000 ohms   = 0.0024 amps = 2.4 milliamps

P = (0.0012) ^2 * 10000 = 0.0144 Watts

P = (0.0024) ^2 * 5000   = 0.0288 Watts

Using low conductance resistors yields a minute current, which can be safely carried in light, inexpensive wire. An additional resistor may be added in series with the potentiometer to lower current flow. The resistance of the controller element in circuit with the potentiometer is extremely high so as to produce a minute current flow.   Electrical load and power requirement must also be considered due to the finite power supply from the alternator driven by the engine of the machine. The example calculations above are of electrical loads suitable for machinery as the 570 MXT Loader/Tool Carrier.

In addition to circuit overload, one must consider the sensitivity of the controller. The voltage change induced by rotation of the sensor must be large enough to be recognized by the controller. For example, consider a potentiometer with a circular resistor that completes a rotation of 150 degrees. The voltage reading at the wiper terminal ranges from 0 to 12 volts as rotation angle ranges from 0 to 150 degrees. Therefore, assuming resistance per length of material is uniform; one degree of rotation corresponds to a voltage change of 12/150. Consider the following:

$$V_w = \Theta\left(\frac{12v}{150°}\right) = \Theta\left(0.08\frac{v}{°}\right)$$

Common controllers sense DC voltage from 0 to 12 volts at an accuracy of approximately 3 milliVolts. Meaning, the controller can discern the voltage at the center terminal of the potentiometer to a magnitude of 3 mV. Therefore, a controller response is achieved from angle error of less than one degree. Specifically:

$$Accuracy = (.003v) \div \left(0.08\frac{v}{\circ} \right) = .06$$

The Case machine of interest is configured so that the scraper of the box blade is approximately 3 feet from the axis of rotation. The orientation of the lower lift arms supporting the box blade is so that the specified three feet equals the radius of curvature of the implement travel path. The ratio of the rockshaft lever arm distance to that of lower lift arms is approximately 1/3. Therefore, the angle of rotation of the rockshaft is three times that of the lower lift arms.

$$\frac{1}{3}\Theta_{measured} = \Theta_{box}$$

The change in height relative to rotation angle is then governed by the following relationship.

$$\Delta H_{box} = 3\,ft \times \sin(\Delta\Theta_{box}) = 3\,ft \times \sin(\frac{1}{3}\Delta\Theta_{measured})$$

Using the above equation, the change in height from a measured angle change of one degree is about ¼ in. The described calculation process allows one to calibrate the controller for the desired output.

NEXUS Controls considers a potentiometer as a suitable instrument for measuring rotation. The most accurate definition of the "potentiometer" is a device used to measure an unknown electric potential by comparing that unknown voltage to a quantified potential. The measurement can be achieved by means of either a voltmeter or a galvanometer. Typically, constant current potentiometers are used for the measurement previously described. However, constant resistance devices are utilized in a similar fashion to measure electric potential in the microvolt range. Industry has accepted "potentiometer" as a term for a device incorporating operator adjusted variable resistance output. Generally, potentiometers have three terminals: positive, ground, and a connector or wiper that translates across the solid resistor contained in the device housing. The effective circuit diagram is shown below.
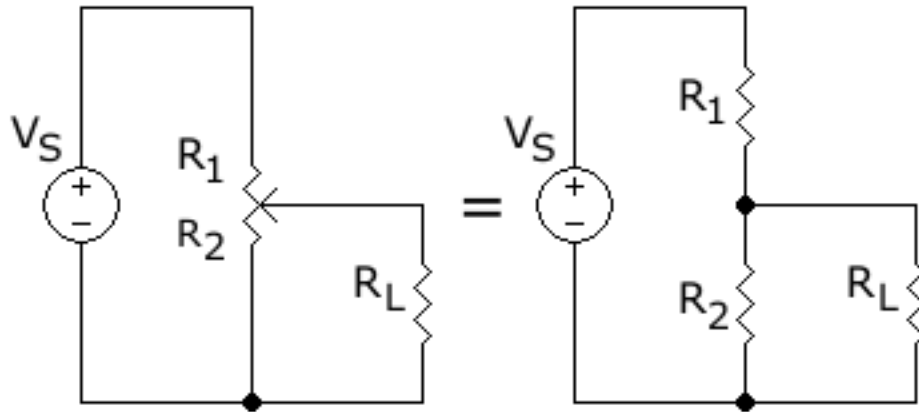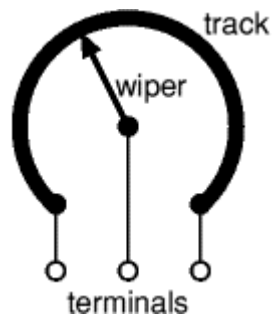
Figure 2: Effective Potentiometer Circuit

Figure 3: Actual Potentiometer

Pressure Transducer

Many foreseeable operating conditions involving inability of the hitch to reach the prescribed set point subsist. The result in this situation is increased hydraulic pressure in the lift cylinder line. The controller continues summing the error in position as time passes. The solenoid valve is then opened to the point of maximum pressure in the system causing actuation of the relief valve. The unnecessary flow through the relief valve increases fluid work of the hydraulic system, thus wasting energy. This energy is transferred to the oil increasing the temperature. Viscosity lessens with the increase in temperature resulting in a greater probability for leakage in the system. The function of a pressure transducer is to communicate with the

controller in the event of an unachievable set point. The controller could compensate in various pre programmed methods.

The device reacts with an analog output when the pressure in the system approaches that of relief valve actuation. One could monitor the output of the device constantly during operation and calibrate for the critical analog value. Another approach is to allow a contact to be closed once the pressure is extreme. Here, the pressure input is either on or off. In either case, the input is again DC voltage.

Controller

The controller has three main functions:

1. Determine position

2. Compute error in position relative to set point

3. Send signal to solenoid valve to correct error

This device requires a power source of 5 to 12 volts DC provided by a power supply that maintains constant output voltage. The referred power source is simply to operate the controller and is not necessarily equivalent to the signal voltage. The constant voltage output power supply maintains a specific voltage output while the input voltage may fluctuate within a certain range. It has been established that the controller sensor input will be an analog DC quantity ranging from 0 to 12 volts. Input can come three sources: potentiometer, pressure transducer, or the operator interface device communicating the set point. The set point communication method is likely digital into the controller. This digital input is then translated to a desired voltage the controller seeks.

It is also possible to use analog signal to communicate set point to the controller. This can be achieved by requiring the implement to be in the set point position upon control engagement.

The programming language of the controller is likely Ladder Logic in combination with Visual Basic or simply Basic. C++ is another likely language used in conjunction with Ladder Logic.

The controller will make the circuit connection to activate the solenoid with 12 volts DC, preferably pulse width modulation (PWM). It should be made clear that this voltage does not vary in magnitude, but it does vary in time on/off. A percentage of on/off time is executed on the order of 1000 times per second. The circuit closure is accomplished using transistors in the controller. The nature of the transistor allows for the required frequency of switching. Standard

relay outputs are incapable of effectively switching at such a frequency due to the mass of the contact. Pulse width modulation is practical because it allows for a valve to be partially opened. The precise control of fluid flow and thus implement velocity is desired, especially when using automated control. Stability is more easily achieved with PWM.

The capability of relay output is also desired in the controller. This function would be utilized in the activation of indicator lamps communicating machine condition to the operator.

User Interface

The simplest user input device is that similar to the standard cruise control in automobiles. The necessary controls are as follows:

Auto - the setting allowing for automated control of the three point hitch

Set - the operator actuates a "set" input when implement is in desired position

Resume - if the operator has manually overridden the control function, this input resumes control based upon the previous set point. Manual control would be achieved once the operator moves the hitch lift control lever.

This refers to the method of analog set point input. The three previously described functions would be accessible through buttons/switches located in the operator station.

Utilizing a digital input screen requires a larger area to house the input module. The module would allow the operator to specify the set point by means of a small keypad. The modes of operation are effectively the same as the described "cruise control" system.

Indicator Lamps

In the event that the prescribed set point is unachievable, the operator should be notified so that the appropriate action can be taken. The operator is then likely to be a short period of manual operation due to irregular ground conditions. It is also possible to program a sequence of set point adjustments. Using this method, the controller raises the set point until it can be achieved in a certain period of time. In either case, the operator should be aware of the controlling mode at all times. Lamps indicating the status of control (for example – "set", "seeking", "incremental increase", or "inactive") could be added readily to the existing machine. The activation of these lamps would be achieved by the closing of a relay on the controller.

Design Concepts

When looking at this project and the possible solutions the team came up with several ideas to supplement the ideas and needs that CNH conveyed to the group. CNH recommended the placement for the height sensor to be on the rocker arm. This would work with a special pin that would have a hole drilled in the end to accept the potentiometer arm. The rocker shaft rotates about the pin so the housing for the potentiometer will have a boss welded to the rocker arm. The potentiometer will be bolted to the boss with the potentiometer arm in the hole on the pin and then the cover plate would be put in place by bolting it to the boss.
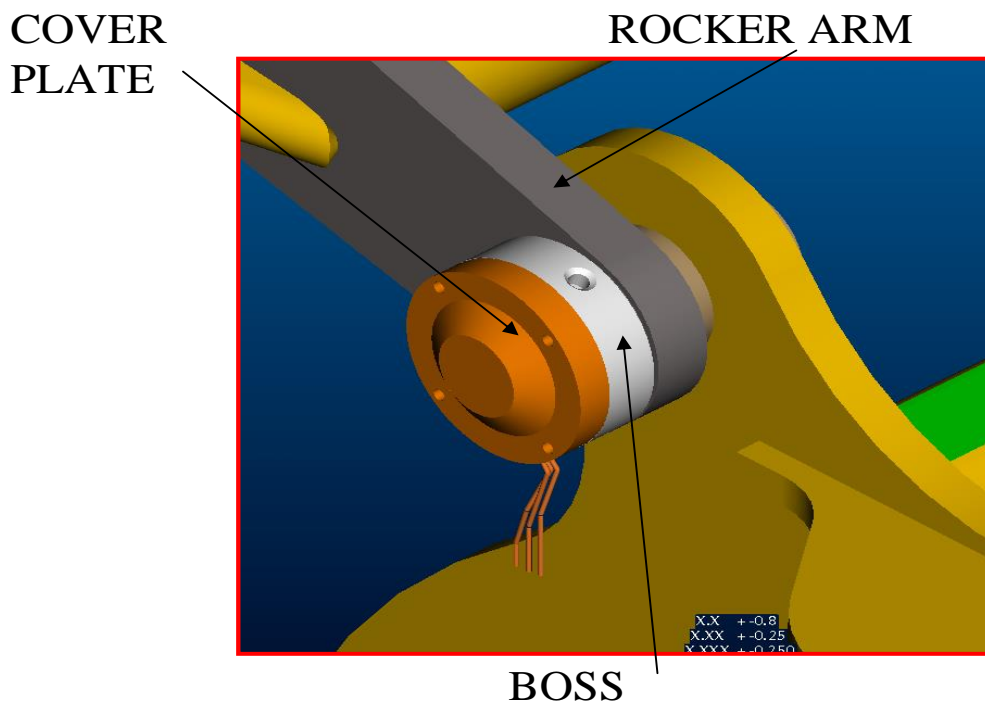
COVER PLATE

ROCKER ARM

BOSS

Figure 4: CAD Drawing of Sensor Housing

Another possibility for placement of the potentiometer would be placing one on each side of the machine where the lift arms attach to the machine. By placing the sensors there the operator can sense height as well as see the difference in roll between the two lift arms. This feature would be for the determination of roll and could be used in conjunction with the previous mentioned possibility as an added feature that would be a convenience to the operator. No control functions would be based on pitch.
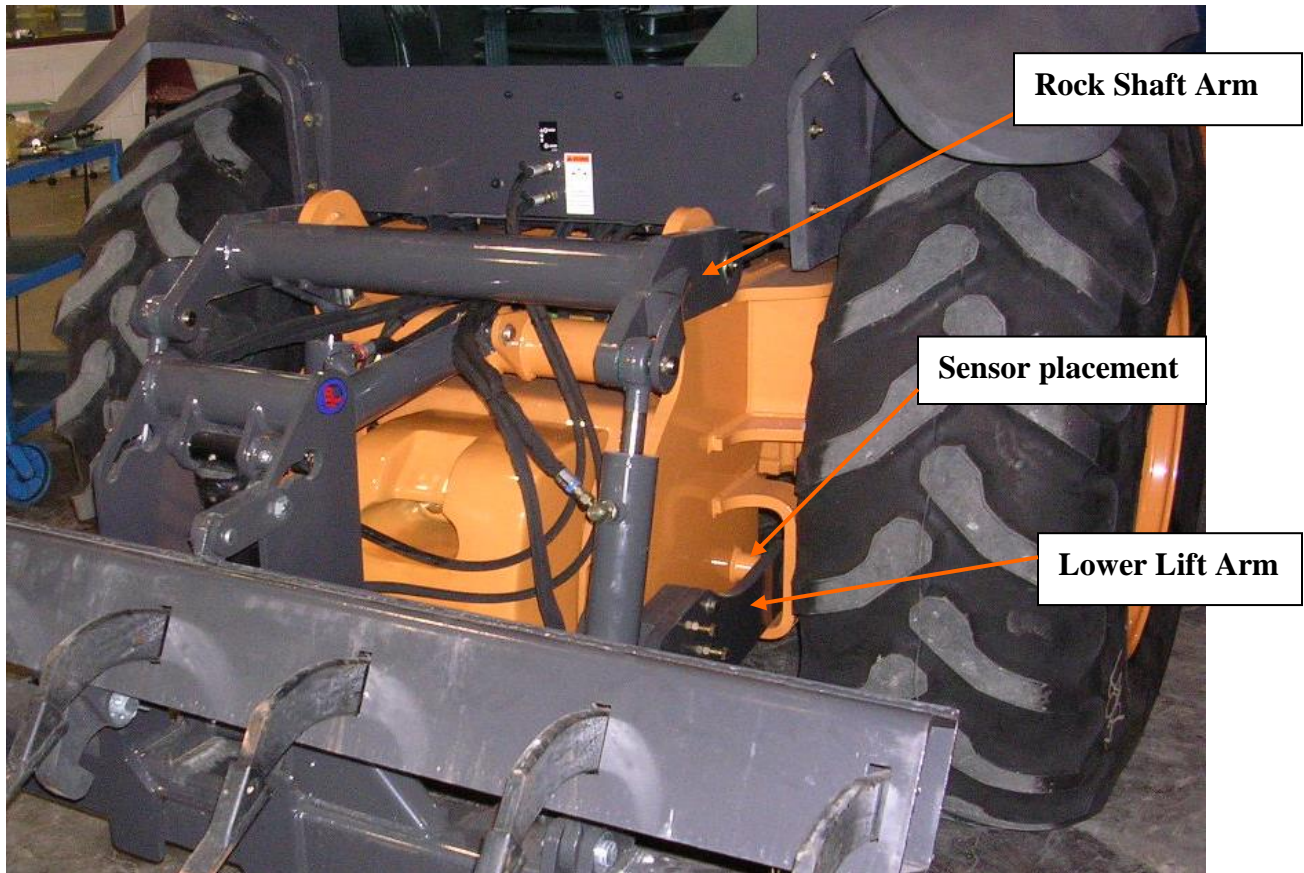
19

Figure 5: Picture of 570 MXT 3-Point Hitch

Controller Location and Housing

The controller should be housed in a safe and dry place on the machine. The possible locations are in a box that is mounted on the ROPS bar or the controller could be located in the console that is currently on the machine. If the controller is located in the console, there would need to be room for the user interface and all the dials, switches and warning lights. The controller, if very small, could be housed in a box that slides into a slot in the console. This box would have all the user interface requirements on it.

Start Up

Safety is the most important consideration of NEXUS Controls. The control system will always be inactive upon start up of the machine, regardless of the status when the machine was

shut down. Automatic control is active only after the user has engaged the controller once the machine is running.

Laser and potentiometer on the same machine

Individuals operating with the control of the laser module may also wish to utilize the potentiometer capability momentarily. This could only be effective if the change in control modes is effortless. This can be achieved by simply providing the user the both wire harness connectors so that 2 control modules may be connected at once. The operator could then choose the desired control method with a switch. It is important to note that only one type of control would be active at one time. This decision would then be conveyed to the operator with an indicator lamp.

The laser control solenoid valve is plumbed with restrictor ports to limit the flow rate to the three point implement. When considering convenience of changing control modes, the restrictors would remain in the valve for the set point control system. The restrictor ports limit the speed of implement travel. Stability in control is more easily achieved at decreased speeds. In addition to the restrictor ports, a flow regulator allowing 3 or 8 gallons per minute of oil flow is built into the system for additional speed control.

Unachievable set point
1. Disable control after 3 seconds of relief flow

It has been established that passing oil through the relief valve for a long period of time has multiple negative consequences. Once the pressure in the lift cylinder line is high enough to open the relief valve, the controller would be notified by a pressure transducer. If this pressure is sustained for 3 seconds, the controller would deactivate, returning the machine to manual control. The operator would be notified of the status of the machine by means of an indicator lamp. Upon deactivation, the implement would remain in the current position until the operator interferes.

2. Disable control immediately after the relief is opened

In order to prevent any unnecessary heating of oil whatsoever, the controller would deactivate once the pressure was sufficient to open the relief. The following process would be similar to that of the previous design concept in that the controller would cease to execute valve

control in the event of an unachievable set point. Upon controller deactivation, the hitch would become stationary. The three point hitch would then be in manual control mode.

3. Allow 7 seconds to reach set point – then shift to manual control

(No pressure transducer)

In order to eliminate the pressure transducer, one could allow a given period of time for the rocker arm to reach the set position. Once this time is expired, the controller would deactivate the automatic control mode and the hitch would remain stationary. For example, from the time the operator instructs the controller to seek the set point, seven seconds would be allowed for the hitch to reach the desired position. This is based on the expectation of no more than seven seconds for the hitch to travel the maximum rotational distance possible. There is the inherent possibility of passing fluid through the relief for a short time and thus, heating the oil. However, the pressure transducer would be unnecessary.

4. Solenoid Flow Divider

Addition of a solenoid valve to the down force side of the lift cylinder line would eliminate the possibility of passing fluid through the relief. The solenoid valve would open when the machine is in automatic control mode. Being plumbed parallel to what becomes the high pressure line when down force is exerted would limit the maximum achievable pressure thus, preventing relief flow. The solenoid would divert a portion of flow to the oil reservoir while still allowing fluid to exert a decreased force on the lift cylinder. There would still be a time limit for achievement of instructed position. Once the operator engages the manual control lever, the solenoid would close and full down force would be returned to the lift cylinder.

5. Modification to all previously discussed methods of control

In modification to the previous four control sequences, rather than immobilizing the box blade once control is disengaged, the implement would be raised to the highest achievable position. This would serve as a physical indication that the set point is unachievable. This would be obvious to the operator who could then make the appropriate system modifications. Indicator lights would supplement this notification of control disengagement.

6. Temporary manual operation

It is possible that the operator would temporarily wish to manually control the box blade while automatic control is engaged. The controller could be programmed allowing for a short period of manual operation. Once manual mode is engaged, the controller would definitely cease modification of the three point hitch position. In addition, the controller would remain alert for a period of one minute so that once the manual operation lever returns to the neutral position for three seconds, the controller returns the implement to the previously chosen set point. At any moment the operator would be able to terminate automatic control with a simple switch. This allows hands free return to the set point after a brief period of manual adjustment.

7. Transport mode

The above sequence could be modified so the hitch must be within a certain range of the set point before control is resumed. In addition, one could eliminate the timing function so the operator has an unlimited time period to maneuver the tractor. The operator would raise the implement to the maximum height and control would end once the set point was exceeded by a certain distance.

It is unlikely but, possible that the operator has chosen a set point near the maximum height of the three point hitch. In this instance, it would not be practical to terminate control simply to move the machine. The sequence described is geared towards the more common box blade operation near the horizontal traction plane of the tractor.

8. Incremental Increase

In the event of an unattainable set point, the controller could adjust the set point after a certain period of time. For example, if the desired depth is not reached after seven seconds, the controller then seeks the next lowest set point. Another seven seconds is allowed for height adjustment. The process would be repeated until the controller seeks the lowest attainable position. The operator would be notified of the process by an indicator lamp reading similar to "incremental increase".

Proposed Budget

Part	Estimated Cost
potentiometer	$50.00
pin kit	$15.00
controller	$125.00
pressure transducer	$35.00
boss & cover	$50.00
Total	$275.00

Project Schedule

The project schedule is attached on the following page.

References

Callister, William D. 2000. *Fundamentals of Material Science Engineering*. 5th ed. Wiley.

Crowley, II; Robert W. 2004. Towable Box Grader with Electronically Controlled Continuously Variable Multi-Axis Blade System. U.S. Patent No. 6672401.

Duello, Dennis. 2002. Dynamic Controller of Excess Downpressure for Surface Engaging Implement. U.S. Patent No. 6389999.

Easton, David Joseph, Bruce Craig Newendorp, and Mark Allan Bergene. 2005. Hitch Control System with Spring Centered Control Lever. U.S. Patent No. 6935434.

Montana Tractors. 2006. Montana Tractors and Implements Product Line. MTT-20205. Springdale, Arkansas: Montana Tractors.

Rogala, Jeffrey A. 2003. Apparatus for Counteracting Vehicle Pitch Variation Resulting from the Operation of an Electronic Draft Control System. U.S. Patent Application No. 0030085042.

Smith, Carlos A. and Armando B. Corripio. 1997. *Principles and Practice of Automatic Process Control*. 2nd ed. Wiley.

3-Point Hitch Controller

December 7

Presentation Overview

- **Background Information**
- **Design Concepts**
- **Engineering Specifications**
- **Future Plans**

Nexus Controls

- **David Bevill, Bio-Mechanical Option**
- **E. Evans Chambers, Bio-Mechanical Option**
- **Lee Eldridge, Bio-Mechanical Option**
- **Adam Gossen, Bio-Mechanical Option**

- **Develop a functional, ergonomic, and innovative three point hitch controller**

NEXUS CONTROLS

CNH Case New Holland

OKLAHOMA STATE UNIVERSITY

Introduction

- **CNH is a leader in the agricultural and construction equipment industry**

- **Innovative needs of the future lead to the development of new products with latest technology**

- **CNH contacted OSU BAE Department to produce ground-breaking solutions for unique design challenges**

NEXUS CONTROLS

CNH Case New Holland

Problem Statement

- **Design and employ a three point hitch controller in order to maintain user defined implement position**

- **Design should involve minimal change to existing unit while functioning ergonomically**

- **Cost must be considerably lower than current optional laser guided control system**

Statement of Work

- **Select controlling mechanism to regulate 3 point hitch position to further the capabilities and performance of the Case 570 MXT**

- **Design shall include sensors to measure hitch position, controller to interface between sensors and laser system, and wiring, additional parts information, etc.**

NEXUS CONTROLS

CNH
Case New Holland

OKLAHOMA STATE UNIVERSITY

Patents & Market Research

- **Patent 1: Towable Box Grader with Multi-Variable Axis**

- **Patent 2: Apparatus for Counteracting Vehicle Pitch Variation**

- **Patent 3: Dynamic Controller of Excess Down Pressure**

- **Patent 4: Hitch Control System with Spring Centered Lever**

- **Determined our intended design will not infringe upon current competitor machines**

NEXUS CONTROLS

CNH
Case New Holland

OKLAHOMA STATE UNIVERSITY

Customer Requirements

- Two modes of operation
  - Automatic
  - Manual
    - Manual control can over ride the automatic control function.

- Cost
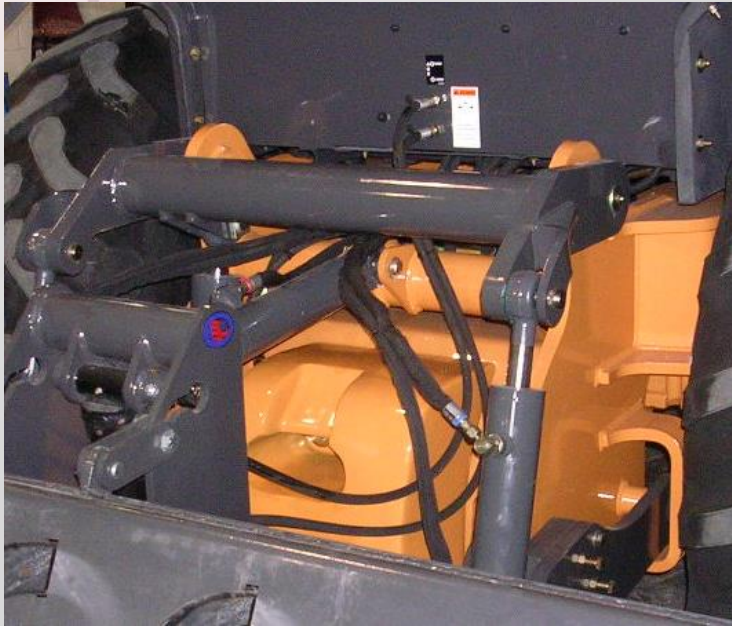 - Minimize
  - Off the shelf or in-house components

Customer Requirements Cont.

- Interface with existing system
  - Hydraulics
  - Electrical

- Down force capability
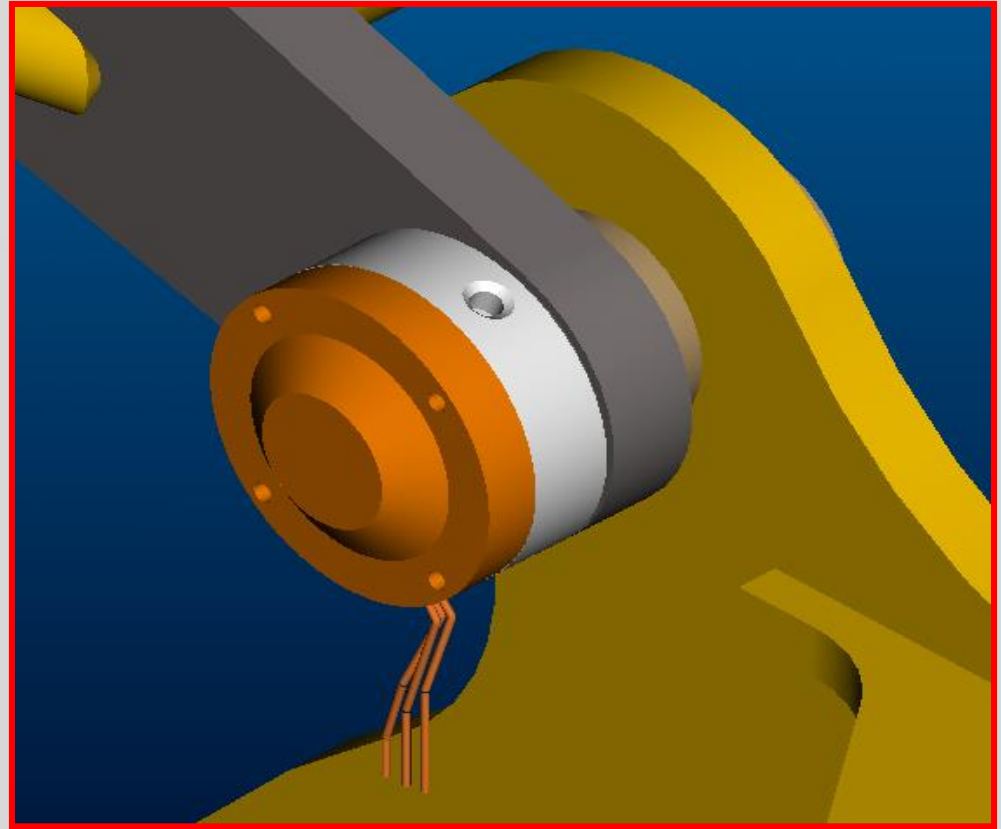 - Controller mode must have down force like manual operation.

Design Concepts

- Potentiometer Location

Above: Picture of Rocker arm
Right: Picture of Rocker arm
pin and Potentiometer location

Pictures From CNH

NEXUS CONTROLS

CNH
Case New Holland

OKLAHOMA STATE UNIVERSITY

Design Concepts Cont.

- Controller location
  - Inside the console
    - User interface on Console
  - Controller in a box hangs on ROPS
    - Pros: Easy to access and connect to machine.
    - Cons: Laser Controller box attaches at same position.

NEXUS CONTROLS

CNH
Case New Holland

OKLAHOMA STATE UNIVERSITY

Design Concepts Cont.

- Safety
  - Controller would be inactive upon start of machine.
  - Set button
    - Must press the button after determining set point.
  - Resume button
    - Must press to return to Controller mode after using manual controls.

NEXUS CONTROLS

CNH Case New Holland

OKLAHOMA STATE UNIVERSITY

Design Concepts Cont.

- User input
  - Dial
    - Potentiometer
  - Cruise control method
    - Set the depth manually then press set button
    - Resume button to return to previous depth

NEXUS
CONTROLS

CNH
Case New Holland

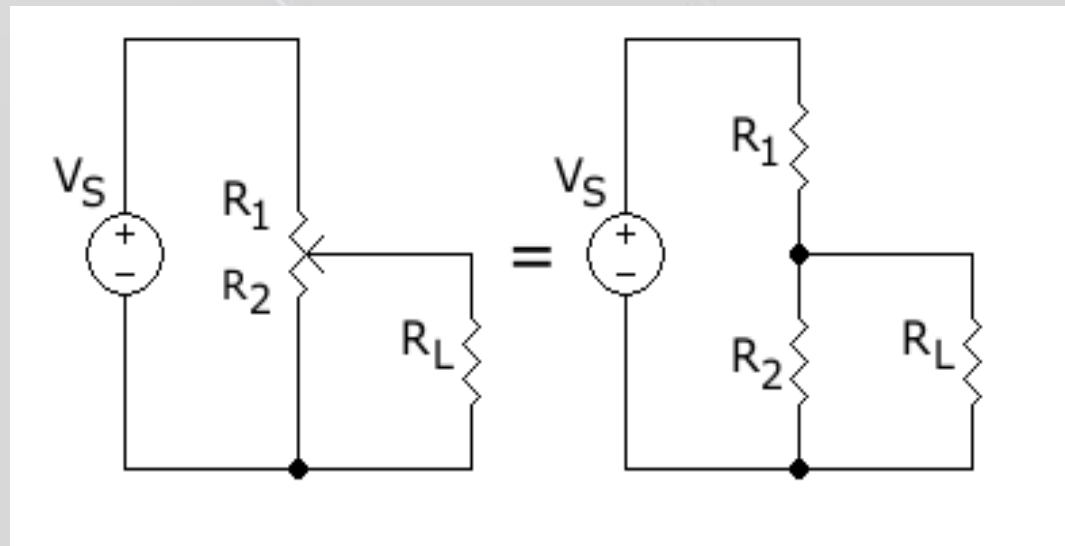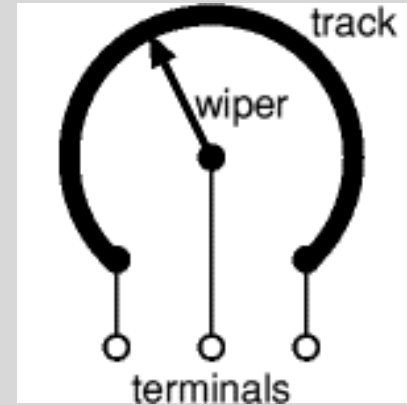OKLAHOMA STATE UNIVERSITY

Design Concepts Cont.

- Unachievable set point
  - Controller depth setting is not reachable due to ground conditions.
    - Pump would go over relief
      - Oil would heat up
    - Rear of machine would lift up
      - Decrease in traction of rear tires

Design Concepts Cont.

- Laser controller and Potentiometer with controller on same machine.
  - Require a special wire harness to connect both options.
  - Would need a switch to select between the two systems.
  - Note: These options can not be used together at the same time!

NEXUS CONTROLS

CNH
Case New Holland

OKLAHOMA STATE UNIVERSITY

Potentiometer

- Actual Device

- Actual Circuit Diagram

- Effective Circuit Diagram

http://en.wikipedia.org/wiki/Potentiometer
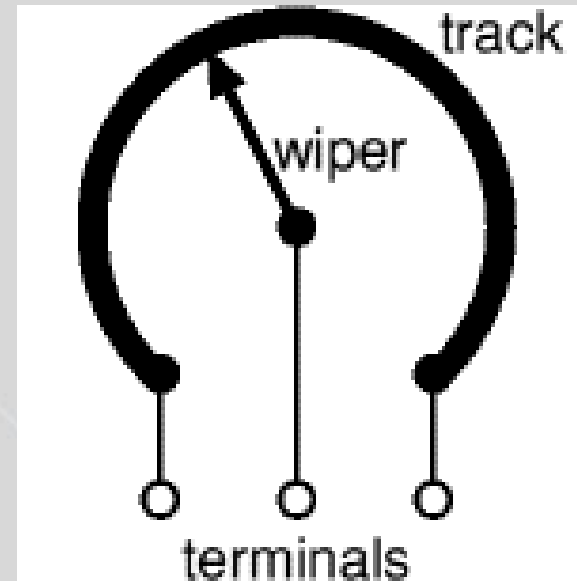
NEXUS CONTROLS

CNH
Case New Holland

OKLAHOMA STATE UNIVERSITY

Potentiometer

• Linear Resistance

• Rate Change Voltage/Degree

$$V_w = \Theta\left(\frac{5V}{150°}\right) = \Theta\left(0.033\frac{V}{°}\right)$$

Controller

- Output

$$\text{Output(t)} = K_p \left(e(t) + K_{ip} \int_0^t e(\tau) \, d\tau + K_{dp} \frac{de}{dt} \right)$$

www.wikipedia.org

- Accuracy – 12 Bit A/D

$$Voltage \ Increment = \frac{5V}{2^{12}} = .0012 \ V \approx 1mV$$

NEXUS
CONTROLS

CNH
Case New Holland

OKLAHOMA STATE UNIVERSITY

Height = f(Voltage)

(Idealized Case)

$$Angle\ Accuracy = (.001v) \div \left(0.0333 \frac{v}{\circ} \right) = .03$$

$$\Delta H_{box} \approx 3\,ft \times \sin(\Delta\Theta_{box}) \approx 3\,ft \times \sin(\frac{1}{3}\Delta\Theta_{measured})$$

Courtesy CNH

Measured Angle

$$\frac{1}{3}\Theta_{measured} = \Theta_{box}$$
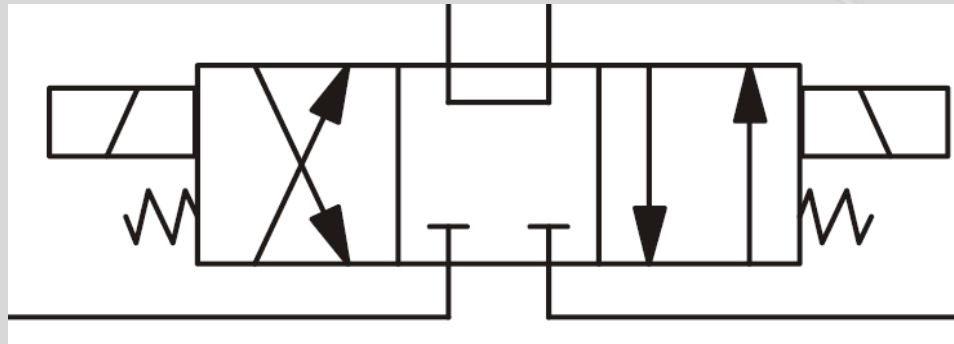
Box Height Angle

NEXUS CONTROLS

CNH Case New Holland

Pulse Width Modulation

- Valve accepts PWM

- %ON/%OFF

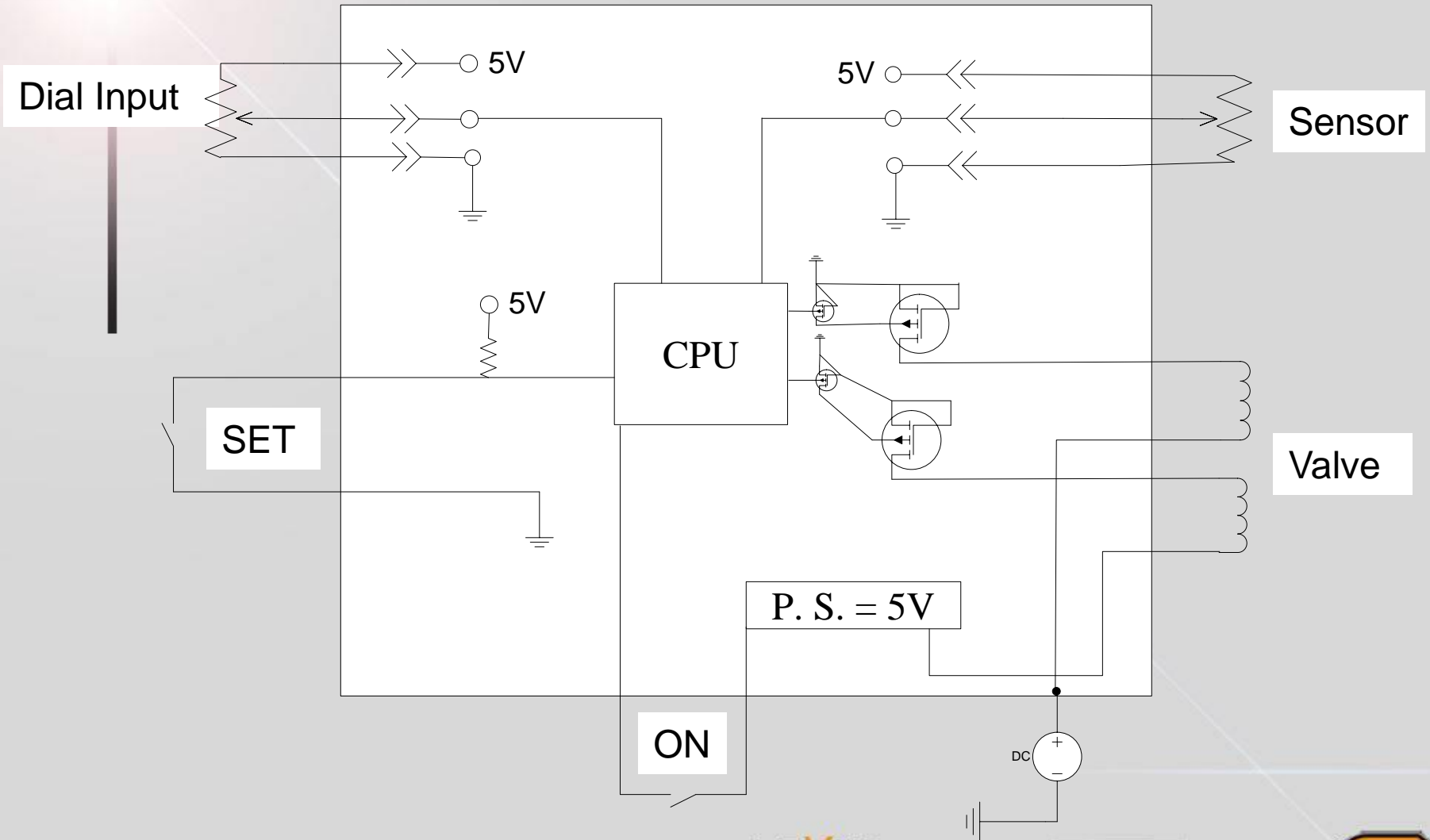- Mass of Spool/Stable Position

- Flow Rate Control

Courtesy CNH

NEXUS CONTROLS

CNH
Case New Holland

OKLAHOMA STATE UNIVERSITY

Solid State Device

- M.O.S.F.E.T
- Additional Drivers - Solenoid Current
- Applicable to "A" and "D"
- Allows for PWM

http://en.wikipedia.org/wiki/Mosfet

NEXUS
CONTROLS

CNH
Case New Holland

OKLAHOMA STATE UNIVERSITY

Circuitry

Dial Input   5V

Sensor

5V

CPU

5V

SET

Valve

P. S. = 5V

ON

DC

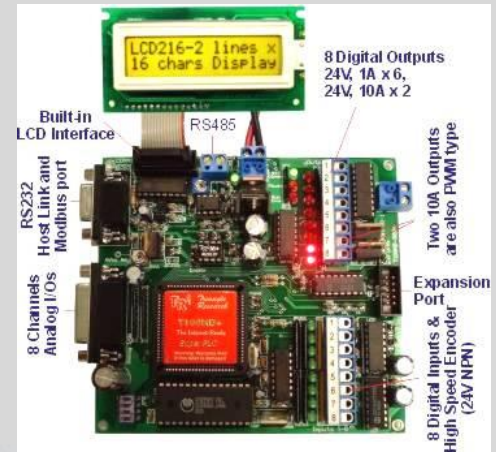NEXUS CONTROLS

CNH Case New Holland
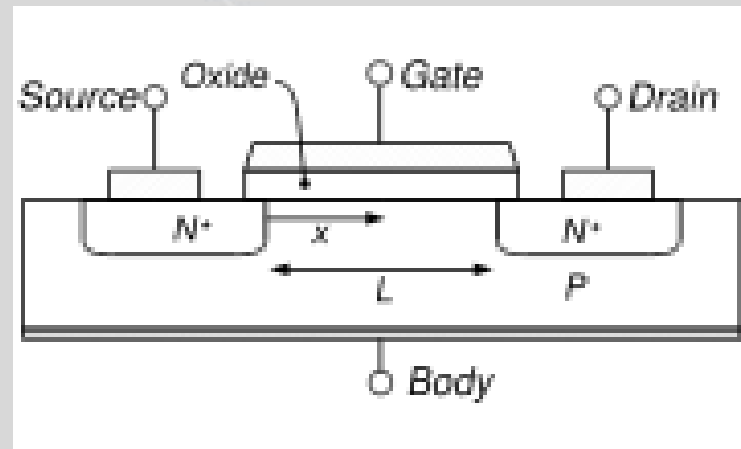
OKLAHOMA STATE UNIVERSITY

Recommended Solution

- Tri-Logic PLC Controller
  - For Testing & Design
  - Built-in PID Function
  - Multiple IO
  - Inexpensive & Robust



Reference Tri-Logic

NE**X**US
CONTROLS

CNH
Case New Holland

Recommended Solution (cont'd)

- Input
  - 1 potentiometer for reading position
  - On/Off, Set, and Resume Functions
  - Manual control input (Already Provided)
- Output
  - PWM to control hydraulic system
  - Possible analog/digital gauge for set point and/or current position

Controller Logic & Simulation

- Controller logic will be very similar to that of an automotive cruise control
  - Logic will be developed in a flow chart
  - Programmed into controller using BASIC
- System will be simulated in Matlab
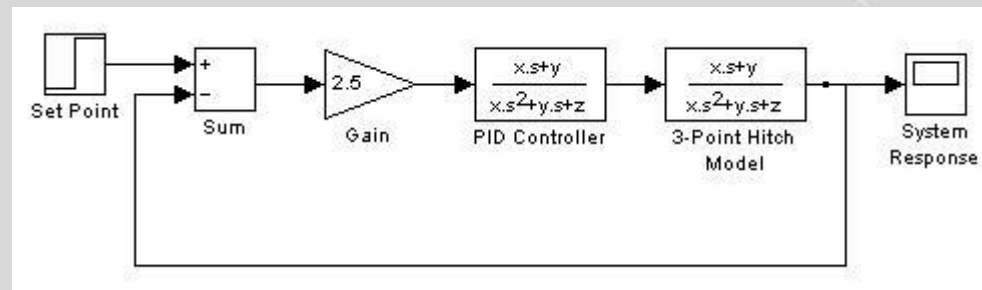
Future Schedule

- 1/1/07-1/30/07: Familiarize with machine & order parts
- 1/30/07-2/30/07: Build and install prototype
- 2/30/07-3/30/07: Implement, test, and debug controller
- 3/30/07-Finished: Finish up testing, make ready for presentation

NEXUS CONTROLS

CNH
Case New Holland

OKLAHOMA STATE UNIVERSITY

Proposed Budget

Part	Estimated Cost
Potentiometer	$50.00
Pin Kit	$15.00
Controller	$125.00
Pressure Transducer	$35.00
Boss & Cover	$50.00
Total	**$275.00**

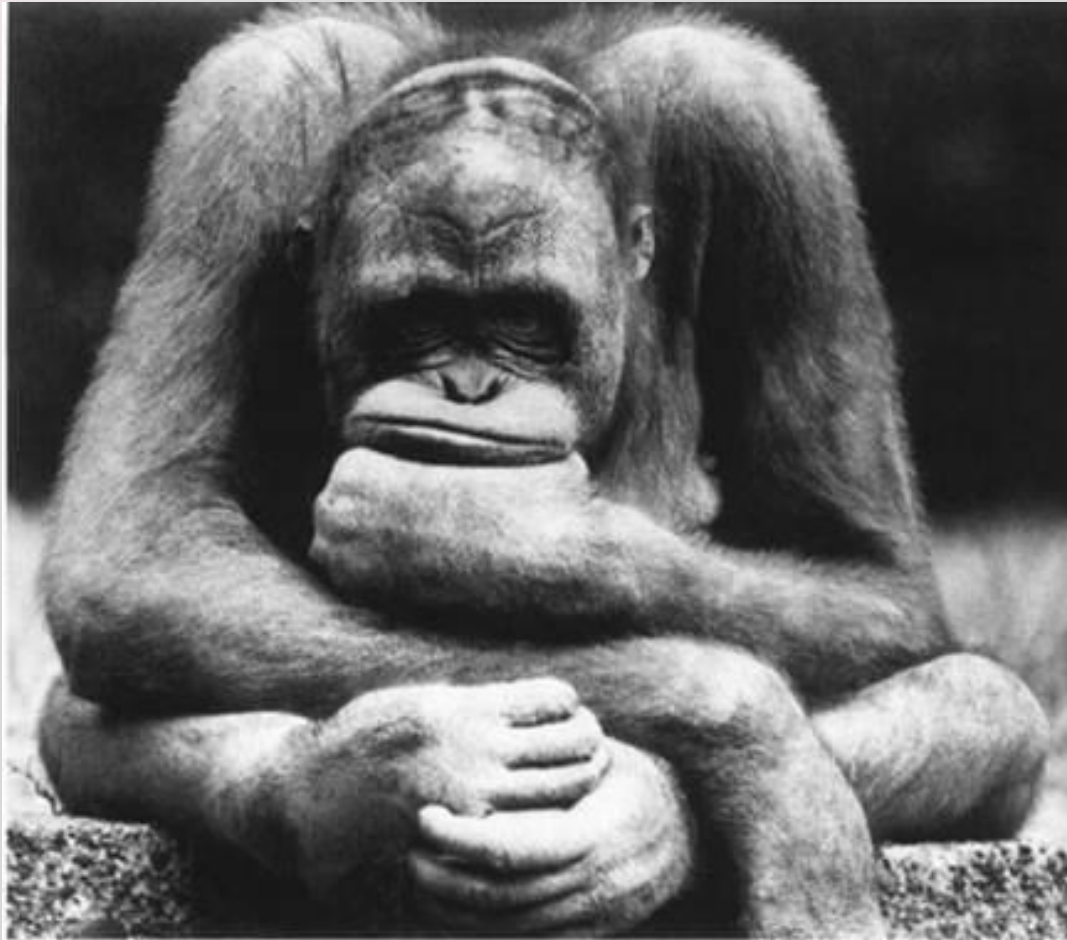NEXUS
CONTROLS

CNH
Case New Holland

Acknowledgements

Mr. Wayne Kiner

Dr. Marvin Stone

Dr. John Solie

Dr. Paul Weckler

Members of CNH

Any Questions?

NE**X**US
CONTROLS

CNH
Case New Holland

OKLAHOMA
STATE
UNIVERSITY