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Analysis of factors causing failure mode for automotive hitch control system calibration in agriculture equipment

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ANALYSIS OF FACTORS CAUSING FAILURE MODE FOR AUTOMOTIVE HITCH CONTROL SYSTEM CALIBRATION IN AGRICULTURE EQUIPMENT

An Abstract of a Thesis
Submitted
In Partial Fulfillment
of the Requirements for the Degree
Master of Science

Setordji Yao Abotsi
University of Northern Iowa
July 2009

ABSTRACT

Traditionally, agricultural tractors have used hydro-mechanical draft control systems to mechanically sense implement draft. Technological development of low cost, reliable microprocessors has contributed to allowing greater flexibility in designing agricultural tractor control systems (Rutkowski & Welchens, 1986). To successfully control the depth of which an implement penetrates the ground, it has become imperative to incorporate a draft control system on agricultural tractors. The control system operates by responding to the draft load or force acting on the tractor. Increasing the draft load or force allows the implement to be raised and decreasing the draft load or force allows the implement to be lowered. In view of this, successful calibration of the implement hitch is very necessary for proper functionality.

The traditional ways of performing system calibration on implement hitch system involves manual processes of assessing a diagnostic address and manually configure the calibration steps in accordance to the hydraulic software installed in the tractor system for operating the hydraulic system. With technological advancement, there have been new and improved ways of facilitating the calibration system for the hitch implement using automated system by interacting with the tractor system through the use of Communication Area Network (CAN) and a computer interface, Roll Test Tool (RTT).

The goal of this research was to explore the calibration process for implement hitch system, and study the various components that contribute to successful calibration of the system. Although good performance of the components will contribute to

successful calibration, there are some other factors that can contribute to the failure mode. Finally, the paramount goal of this research was focused on analyzing the various possible factors causing failure mode in the hitch system calibration. Possible factors causing failure mode of the implement hitch system that were analyzed under this study includes; the hydraulic oil temperature and engine revolution per minutes (rpm) in relation to the tractor voltage system. Analysis of the data set collected during experimentation of the implement hitch system calibration have shown that there were no significant differences in the hydraulic oil temperature prior to, and after calibration that might have contributed to failure mode of the hitch system. In addition, it was also found that changes in engine revolution per minutes did not really affect the calibration processes. However, higher engine revolution per minutes (rpm) contributed to an increase in the hydraulic oil temperature during the calibration process, thereby reducing the viscosity of the hydraulic oil in the hitch valves as well as the cylinders for easy and faster flow.

The software used in the calibration process was found to be highly interactive, easy to use, and provide flexibility to the end-user. The software is built using LabView and JPEG exporter. This has the capability of providing operators with pictorial information as assembly-assist during calibration failures.

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This study by: Setordji Yao Abotsi

Entitled: ANALYSIS OF FACTORS CAUSING FAILURE MODE FOR AUTOMOTIVE HITCH CONTROL SYSTEM CALIBRATION IN AGRICULTURE EQUIPMENT

Has been approved as meeting the thesis requirement for the Degree of Master of Science in Industrial Technology.

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TABLE OF CONTENTS

PAGE

LIST OF TABLES ix

LIST OF FIGURES xi

CHAPTER I. INTRODUCTION 1

- Motivation and Background 1
- Statement of Problem 2
- Purpose of Study 3
- Need and Justification 3
- Hypothesis/Research Questions 4
  - Hypothesis 1 4
  - Hypothesis 2 4
- Assumptions 4
- Limitations/Delimitations 5
- Organization of the Study 5
- Definition of Terms 6

CHAPTER II. REVIEW OF RELATED LITERATURE 9

- Introduction 9
- Theory of Hitch Control System and Functionality 9
- Theory of Hitch System Calibration 11

PAGE

CAN Communication 19

SAE J1939 Network Standard 20

On-Board Diagnostics (OBD)..23

Power Flow Architecture of the Implement Hitch System..........................25

Application of Hitch in Agriculture Equipments..28

CHAPTER III. METHODS AND MATERIALS 29

Introduction..29

Procedure of Study..29

Research Design..29

Sensors Selection 30

Hitch Valve Selection and Functionality 33

Engine Specifications..38

PowerTech™ Plus 6.8L Engine...38

PowerTech™ Plus 9.0L Engine...39

Material Preparation..40

The Experiment..42

Variables of the Study..42

Statistical Analysis..42

CHAPTER IV. ANALYSIS OF THE RESULTS 44

Experimental Data 44

Data Analysis 45

PAGE

Descriptive Statistics....46

Multiple Regression....55

7030 Regression....55

8030 Regression....56

7030 Regression Analysis on Oil Temp Change....57

8030 Regression Analysis on Oil Temp Change....58

t-test Analysis....59

t-test for 7030....59

t-test for 8030....60

CHAPTER V. CONCLUSIONS AND RECOMMENDATIONS....61

Discussion....61

Hypothesis 1....61

Hypothesis 2....62

Conclusions....63

Recommendations....64

REFERENCES....66

APPENDIX A: HALL EFFECT ROTARY SENSOR....68

APPENDIX B: CAN VOLTAGE LIMITS....70

APPENDIX C: ELECTRICAL NETWORK SYSTEMS....72

APPENDIX D: TRACTOR MODELS....75

PAGE

APPENDIX E: LIST OF TABLES..78

APPENDIX F: T-VALUES..96

LIST OF TABLES

TABLE PAGE

1 Calibration Status Description 1 14

2 Calibration Status Description 2 15

3 Calibration Status Description 3 18

4 Diagnostic Trouble Codes (DTCs) 21

5 Hitch position sensor specification 31

6 Draft position sensor specification 31

7 7030 Calibration Data Set 79

8 7030 Calibration Data Set with Engine Speed (1900 – 2000) rpm 80

9 7030 Calibration Data Set with Engine Speed (2200 – 2300) rpm 81

10 8030 Calibration Data Set 82

11 8030 Calibration Data Set with Engine Speed (1900 – 2000) rpm 83

12 8030 Calibration Data Set with Engine Speed (2200 – 2300) rpm 84

13 7030 Descriptive Statistics Results 85

14 8030 Descriptive Statistics Results 86

15 7030 Regression Model Results 87

16 7030 Backward Elimination 1. 88

17 7030 Backward Elimination 2. 89

18 7030 Backward Elimination 3. 90

19 8030 Regression Model Results 91

20 8030 Backward Elimination 1. 92

TABLE PAGE

21 8030 Backward Elimination 2. 93

22 8030 Backward Elimination 3. 94

23 7030 Regression on Oil Temp Change 94

24 8030 Regression on Oil Temp Change 95

25 7030 t-test Analysis Result on Oil Temp Change....................95

26 8030 t-test Analysis Result on Oil Temp Change....................95

27 Table of Critical T-Values 97

LIST OF FIGURES

FIGURE PAGE

1 Implement Hitch 10

2 Information Center 22

3 Corner Post Monitor 22

4 Block Diagram of Subsystems 25

5a 7030 HCU / Valves Communiation 27

5b 8030 HCC / Valves Communication 28

6 Dual Output Hall Effect Rotary Sensor 32

7a Full Hitch Control Valve Set 34

7b Hitch control valve (Electrohydraulic actuator) 35

8 Internal Structure of Hitch Control Valve 35

9 Outlet Section of the Hitch Control Valve 36

10a CAN Valve Set 37

10b Side View of CAN Valve Set 37

11 PowerTech™ Plus 6.8L Engine 39

12 PowerTech™ Plus 9.0L Engine 40

13a Power Quad Transmission (PTQ) Control center 41

13b Infinite Variable Transmission (IVT) Control Center 41

14 Scatter plot of Hydraulic Oil Temperature (7030) 47

15 Scatter plot of Hydraulic Oil Temperature (8030) 48

FIGURE PAGE

16 7030 Scatter plot of System Voltage vs. Sensors Voltage....49

17 8030 Scatter plot of System Voltage vs. Sensors Voltage....50

18 Histogram on Pre-Cal Oil Temperature (7030)....51

19 Histogram on Pre-Cal Oil Temperature (8030)....52

20 Histogram on Post-Cal Oil Temperature (7030)....53

21 Histogram on Post-Cal Oil Temperature (8030)....54

22 Internal Structure of the Hall Effect Rotary Sensor....69

23 CAN Voltage Limits....71

24 Power Flow Architecture of the Implement Hitch System 7030....73

25 Power Flow Architecture of the Implement Hitch System 8030....74

26 7030 Tractor Model....76

27 8030 Tractor Model....77

CHAPTER I

INTRODUCTION

Motivation and Background

Focuses have been shifted to power optimization for many engineering devices as a common objective due to rapid increase of energy cost. In the agricultural sector, tillage has become one of the biggest power consumer, (Arnold, Bentaher, Hamza, Kantchev & Maalej, 2008). In view of that, there are the needs for high productivity and efficiency. Improving productivity in agricultural equipment requires not only detailed information about forces between tractors and implements but also successful calibrations of the implement hitch system.

One of the common methods of attaching an implement to a tractor is through the use of a three-point hitch. The modification of an implement depth is achieved by limiting the variations in the draft load through the use of a draft control system.

Technological advancement has contributed to simplifying the way agricultural as well as industrial equipments are configured and calibrated. In this scope, an automated system is used in conjunction with an end-user to configure and calibrate a vehicle electronic system, (in this case, implement hitch). The implement hitch system is connected to a controller that communicates to a special calibration computer using CAN (Controller Area Network) system to download the configuration, calibration data and algorithm onto the controller. Providing an electronic hitch system with automatic configuration and calibration capabilities that do not require extra equipment or manual adjustment has been the focus in the 21st century. With the automated calibration process, the calibration algorithm functions to establish ranges of all hitch related installed sensors and consequently generate error codes if the related sensors required for proper calibrations are not present. In addition, the algorithm provides a functional test of the control valve system during the calibration process to purge the valve by removing air while filling the valve with heated hydraulic oil. It is recommended to fill the hitch control valves with heated hydraulic oil so as reduce the viscosity of the oil for easy flow.

Although this automated calibration system has been so far efficient in providing companies and customers good products, there are some challenges that hinder successful calibration of the implement hitch system. Some of these challenges are supplier quality related in the sense that some components may be internally defective while others could be related to manufacturing failures where components are not electrically connected for proper configuration. Other factors may be related to engine speed, and hydraulic oil temperature. It is based on these related failure modes that it is really important to analyze the factors contributing to the failure modes of hitch system calibration in agricultural equipment.

Statement of the Problem

The problem of this study is to compare the relationship between the factors (Hydraulic Oil Temperature, and Engine Speed) affecting hitch system calibration in agricultural equipments.

Purpose of the Study

The purpose of this study was to provide an analysis of the factors (Hydraulic Oil Temperature, and Engine Speed) affecting hitch system calibration in agricultural equipments. In view of this, the objectives for this study were as follows:

1. To investigate hitch system calibration under various hydraulic oil Temperature.
2. To study hitch system calibration in relation to tractor engine speed.
3. To analyze any relationship between the factors under study for the hitch system calibration.

Need and Justification

The hitch system operation is based on an electro-hydraulic control system. In order to ensure that implement hitch in tractor system functions properly as expected by the manufacturer and customers, the whole hitch system needs to be successfully calibrated to ensure accuracy and ensure that the hitch system functions within the manufacturer's specifications. As such, the hitch system calibration is aimed at verifying component functionality, determining and recording component characteristics in order to improve performance. The hitch system calibration treats the entire measurement system, sensor and wiring, conditioning hardware, cabling and conversion software as a single entity for proper functionality. There are numerous factors that can affect hitch system calibration thereby causing failures. Some of these factors affecting hitch system calibration include: hitch control valve, hitch solenoid, draft position sensor, and hitch position sensor, hitch control unit (HCU), electrical wiring harness, hydraulic oil temperature, and engine speed. The last three factors have tremendously contributed to hitch system calibration failures and hence the Analysis of Factors (hydraulic oil temperature, and engine speed) affecting the hitch system calibration in Agriculture Equipment.

Hypothesis/Research Questions

Hypothesis 1:

The null hypothesis 1, H_{01} is that there are no significance differences in the hydraulic oil temperature that affects hitch system calibration.

The alternative hypothesis 1, H_{A1} is that there are significance differences in the hydraulic oil temperature that affects hitch system calibration.

Hypothesis 2:

The null hypothesis 2, H_{02} is that there are no significance differences in engine speed during the calibration process thereby providing successful hitch system calibration.

The alternative hypothesis 2, H_{A2} is that there are significance differences in engine speed during the calibration process thereby providing successful hitch system calibration.

Assumptions

The following assumptions were made in pursuit of this study.

1. It was assumed that the measuring equipment was correctly calibrated to provide accuracy of the data collection.
2. It was assumed that the components (draft sensor, hitch position sensor, hitch control valve, and hitch solenoid) were error free and tested by suppliers.

3. It was assumed that all electrical harnesses were good and connections have been properly made to all components involved in the calibration process.

Limitations/Delimitations

The limitations for the development of this study were as follows:

1. This study was to be conducted using the 7030 and 8030 tractors manufactured by John Deere Company.
2. The calibration weight was to be variable according to the tractor model to analyze the impact on calibration process.
3. The testing was to be done at different hydraulic temperatures.

Organization of the Study

The procedures that were employed in this study are listed below:

Research Design

Materials Selection

The Experiment

Data Description

Data Collection

Data Analysis

Data Interpretation

Definition of Terms

Below is a list of terms that might help in understanding the review of the related literature presented.

Algorithm: is a controlling logic or software that provides the output controls of the hitch implement system.

CAN: stands for Controller Area Network that refers to a network of independent controllers defined by ISO standard ISO11783 and the SAE standard J1939. (Ping, 2008).

Calibration: the process of determining and adjusting a piece of equipment or an instrument's accuracy to make sure that it is within the manufacturer's specifications. This is accomplished through the use of software.

Configuration: refers to the different options that are provided in combination with the hitch assembly during the programming process of the control unit.

Control Unit: a programmable unit that has the memory for storing information, control algorithm, and responsible for controlling the hitch functionality in accordance to the stored algorithm, and for detecting, categorizing, and recording failures that occur in the various stages of hitch assembly calibration process.

Diagnostic Mode: a configuration mode that can be accessed by an operator from the operator interface to make any configuration changes. It consists of engineering addresses that contains programmed parameters and variables.

Draft Sensitivity: is a control means responsive to changes in the draft command signal for low pass filtering and draft feedback signal.

Draft Sensor: is a sensor responsible for sensing the draft on the hitch, produced by ground/implement interaction, and providing a draft feedback signal. It measures the compressive and pulling force of the agricultural equipment and converts the forces from mechanical force to electrical signal. (Kollath, Kreis, Schutte & Thompson, 2006).

Draft Control System: is an automatic system that varies the position of the hitch lower links within the system's lift range. (Squires, 1983).

Hitch Position Sensor: is a sensor that senses the position of the hitch and produces a positional signal that represents the position of the hitch, and a command generating means for the hitch movement.

Hitch Solenoid: the Hitch Solenoid is a coil of wire connected to a Direct Current (DC) or an Alternating Current (AC) voltage source. This spring-biased operated solenoid is used for controlling the fluid flow to and from the rockshaft cylinder.

Hitch Control Valve: is a valve that directs the flow of hydraulic oil to the actuator, and to and from the hitch lift cylinders to raise or lower the hitch in response to commands or signals. (Bellanger & Graaskamp, 1990).

OBD: On-Board Diagnostics is a computer-based system built into all 1996 and later light-duty vehicles and trucks to monitor the performance of engine's major components and emissions control as a requirement by the Clean Air Act Amendments of 1990, (U.S. Environmental Protection Agency [EPA], n.d.).

PGN: Parameter Group Number is a group of numbers that uniquely identifies a grouping of specific parameters in the J1939 network standard.

SPN: Suspect Parameter Number is a number that has been assigned by the Society of Automotive Engineers committee to a specific parameter.

CHAPTER II

REVIEW OF RELATED LITERATURE

Introduction

In the review of literature, there is a wide variety of research sources that have been carefully examined. The review of literature has been divided into seven major headings: (a) Theory of Hitch Control System and Functionality, (b) Theory of Hitch, (c) CAN Communication, (d) SAE J1939 Network Standard, (e) On-Board Diagnostics (OBD), (f) Power Flow Architecture of the Implement Hitch System, and (g) Application of Hitch in Agriculture Equipments. This section analyzes the various factors and procedures that are synthesized to produce a complete hitch and functionality in agricultural equipments.

Theory of Hitch Control System and Functionality

A hitch control system includes a draft position sensor, a hitch position sensor, an operator-commanded lever (usually located in the cab), and a control unit for generating the control signals, (Alderson, 1984; Allen, Easton & Newendorp, 2005). The Hitch Control System in this study is based on a hitch implement system having a rockshaft hydraulic cylinder as shown in Figures 1a and 1b.

Figure 1a. Implement Hitch

Figure 1b. Implement Hitch

The rockshaft hydraulic cylinder moves the position of the hitch under the control of a valve (in this case Husco Control Valve; Bellanger & Graaskamp, 1998), a control unit, a hitch position parameter and a draft force parameter. The control unit is responsible for controlling the control valve's operation in response to the movement of a hitch operator-movable switch or lever. (Jeyong, Nakashima, Oida, Shimizu & Yamazaki, 1998). The hitch position parameter is sensed by a hitch position sensor and the draft force parameter sensed by a draft position sensor. A display panel or information center monitor attached to the control unit displays the stored valve parameters during the calibration process and also for storing index values associated with a particular volume of rockshaft cylinder type.

The flow of the hydraulic oil to the control valve from the rockshaft cylinder is controlled by a spring-loaded solenoid. During hitch functionality, the spring loaded valve solenoid is energized from the control unit command. This energizing of the valve solenoid determines the amount of preload solenoid current required to overcome the spring bias of the valve. Energizing of the valve solenoid causes the rockshaft cylinder to move the hitch by gradually reducing the preload solenoid current at a rate of change relative to the hitch position drop, below a certain level (Holloway, Lark, McLaughin & Mortonson, 1979). The hitch control system consists of a first control mode and a second control mode. In the first control mode, the hitch is controlled primarily as a linear function of the sensed draft force while in the second control mode, the hitch is purely controlled as a non-linear function of the sensed hitch position.

Theory of Hitch System Calibration

There are many variables contributing to a successful hitch system calibration. The hitch system calibration for agricultural equipment, tractor, which is built with hitch lift cylinders and well configured for coupling to an agricultural implement, will depend on:

1. Coupled actuator circuits, responsible for moving the hitch lift cylinders between a lower position and a raised position in response to command signals.
2. A hitch position sensor, which is configured to produce a position signal that determines the position of the hitch lift cylinders.
3. A control circuit that is configured to receive the position signal and based on the position signal, reproduce command signals capable of being stored in a memory location.

Based on the three factors above, a command signal is applied to the actuator circuit to determine the first threshold value, which is directly proportional to the minimum current required to move the hitch arm either from a lower position to a raised position or vice versa. After applying the command signal, the magnitude of the command signal is incrementally increased while monitoring the position signal from the sensing device. Right after the sensing device detects a change in position of the hitch lift cylinders, the first threshold value obtained is stored in the memory location or memory circuit. All the steps are repeated twice to determine the second and the third thresholds. The average value is determined and stored as the final threshold value.

A diagnostic address is provided to allow a technician to interactively control the calibration process of the rear hitch electro-hydraulic system components. During the calibration process, the rear hitch algorithm verifies the functionality of the following components:

1. Rear hitch control lever function.
2. Rear hitch position sensor function.
3. Draft sensor function.
4. Rear hitch EH valve Raise (Pressure) and Lower (Return) solenoid circuitry.

In the determination of the threshold value, the rear hitch algorithm determines and records the following component characteristics:

1. Opening threshold (deadband) of the Raise (Pressure) valve and repeatability.
2. Opening threshold (deadband) of the Lower (Return) valve and repeatability.
3. Minimum rear hitch position sensor voltage when hitch is fully raised.
4. Maximum rear hitch position sensor voltage when hitch is fully lowered.
5. Valve deadband hysteresis.

6. Zero-Load draft sensor voltage.
7. Raise rate to adjust valve flow for cylinder size/option.

In preparing the hitch system for calibration, a 70 – 90 kg (150 – 200 lb) was installed in addition to quick-coupler if equipped (or a total of 300 – 500 lbs) to enable easy and quickly lowering of the hitch during the calibration processes. When the tractor was started, the diagnostic mode was accessed for proper configurations. The address containing the draft sensor zero-load voltage was accessed to verify that the voltage is within the required specification range 2.15 V +/- 0.25 V. In cases where the value is out of range, the draft sensor is adjusted to fall within the specified range. Based on the tractor model, specific draft sensitivity will be set in the specified address if not configured during the controller programming process. Once the operator initiates the calibration process, the calibration algorithm will go to valve control mode (Open-Loop) to allow the operator to purge air from the system. During this stage of the calibration process, the "HCAL" will be displayed on the display panel to show that the hitch calibration process has began, after which, the hydraulic oil temperature will be shown in Degree Celsius (^{o}C). Any of the exceptions in Table 1 can be displayed based on the status of the calibration process.

Table 1.

Calibration Status Description 1

Display	Indicates	Description
"VALV"	Status	Valve "Check" mode is enabled.
"????"	Status	"Save" icon selection is invalid. Wait for "????" to clear and go to next step or select "Abort" to cancel Calibration.
"- - -"	Prompt	Hydraulic Temperature is unknown. Check oil temperature circuit and start at Step 1.
"Err"	Prompt	Component failure has occurred. Go to step 16 to initiate controller "Save" of Rear Hitch Calibration Data or Recall Service Code.

In cases where the Error “Err” message was displayed, it was probably due to one of the following reasons and need to be resolve for proper calibration:

- Lever failure was received from Armrest Control Unit (ACU).
- Hitch 12V Valve Supply is low.
- Rear hitch “Disable.”
- 5V Sensor Supply is too low or high.
- Hitch position sensor output voltage is too low or high.

In cases where there is no “Err” message, the algorithm prompts the operator to set the engine speed to 1900 rpm to ensure adequate hydraulic oil flow during the calibration process. If engine speed goes below 1800 rpm, Engine Speed “ESpd” was displayed to prompt the operator that the engine speed is not sufficient enough for a successful calibration. The hydraulic oil temperature was allowed to warm up to at least 50°C before engaging the hitch control lever. Once the hydraulic oil temperature reaches the minimum required temperature, the algorithm prompts the operator to move the hitch control lever full forward and full rearward to cycle the hitch full down and full up respectively to ensure that hot oil is in the hitch hydraulic circuits and will purge any entrapped air. For consistent performance of the calibration process, the hitch was fully lowered down before proceeding to the next phase. The algorithm displays are shown in Table 2.

Table 2.

Calibration Status Description 2

Display	Indicates	Description
"UP"	Status	Hitch lever is moved rearward. Current applied to the hitch pressure valve solenoid should be proportional to the amount of rearward movement
"DOWN"	Status	Hitch lever is moved forward. Current applied to the hitch return valve solenoid should be proportional to the amount of forward movement
Numeric	Status	Hydraulic oil temperature (°C)

During Rear Hitch Raise calibration, the Hitch Raise characteristics which include:

1. Pressure valve deadband
2. Pressure valve deadband repeatability
3. Deadband hysteresis
4. Raise rate (cylinder volume and flow limit)
5. Upper hitch position sensor voltage (minimum sensor voltage output)

were all determined from a full down to full up position while making sure that all hydraulic flow were shut off and one SCV dead-headed to keep hydraulic oil at high standby pressure. Again during the rear hitch lower calibration, the hitch-lower characteristics which include:

1. Return valve deadband
2. Return valve deadband repeatability
3. Valve hysteresis
4. Lower hitch position voltage (Maximum sensor voltage output)

were all determined from a full up to a full down position. During the deadband current ramp up, the algorithm monitors the hitch position sensor. The solenoid current at the time the voltage changes more than 0.1 V (approximately 1 inch of downward movement) will be considered the valve deadband. The algorithm will display Center "cntr" prompting the operator to release the lever to center. The display then will go to "DONE" indicating successful raise and lower calibrations were performed. Once the calibration values are saved and the algorithm prepares to display the calibration data, it will display “EOC” to indicate “End Of Calibration” for 2 seconds and the display will sequence through the calibration data in the order listed below. In instances where calibration data was not valid or not determined during the calibration process, the default value will be set in the specified address. The calibration status description is shown in Table 3.

Table 3.

Calibration Status Description 3

Display	Description	Calibrated Value	Default Value
"P-db"	Pressure Valve Deadband is next to be displayed		
Numeric	Pressure Deadband......................................	.... (mA)	500 mA
"R-db"	Return Valve Deadband is next to be displayed		
Numeric	Return Deadband...	.... (mA)	500 mA
"LIMT"	Raise Current Limit is next to be displayed		
Numeric	Current Limit..	.... (mA)	950 mA
"D-Zr"	Zero-Draft voltage is next to be displayed		
Numeric	Draft Zero...	..............(volts)	2.15 volts
"P-Mn"	Hitch fully Raised is next to be displayed		
Numeric	Hitch Raised (min)......................................	..............(volts)	0.00 volts
"P-Mx"	Hitch fully Lowered is next to be displayed		
Numeric	Hitch Lowered (max)....................................	..............(volts)	0.00 volts

CAN Communication

The CAN is a serial communication protocol that efficiently supports distributed real-time control systems with extremely high security level. Originally, the CAN bus standard was developed by Bosch and Intel. The current CAN standard has been in use since 1990. According to the International Organization for Standardization that developed the Open System Interconnect model in 1984 as a computer communication architecture model, the CAN was divided into two different layers for achieving transparency and implementation flexibility in the design process.

Within the CAN bus modules are two wires, dedicated for communication. These two wires are called CAN high and CAN low respectively. In the situation where the CAN bus is in idle mode, the two lines carry 2.5V. However, during the transmission of data bits, the CAN high line can potentially reach a maximum of 3.75V and the CAN low line can potentially drop to 1.25V, thereby setting an equidistance of 2.5V between the two lines as shown in appendix A. The CAN bus is considered to be a reliable choice for network communications on mobile equipment simply because it relies on the voltage differential between the two bus lines. As a result, the CAN bus is not sensitive to electrical fields, inductive spikes or other noise.

The practical limit of data throughput on the CAN bus can vary. The CAN bus can use multiple baud rates up to 1 Mega bit/s. Within this particular application, the computer interface that was used for the calibration process was using 250 Kilo bit/s compatible with the J1939 standard other than the 125 Kilo bit/s that is compatible with CANopen.

SAE J1939 Network Standard

The J1939 standard was developed by the Society of Automotive Engineers (SAE) to be the preferred CAN for all equipments used in industries ranging from agriculture, construction, and fire/rescue to forestry, as well as materials handling and off-highway vehicles. Since the J1939 is a specific network standard, it is only supporting specific sets of applications in specific industries. An example of communication is the transmission of message on the network with the Electronic Control Unit (ECU) when the bus is idle.

Each message sent includes a 29-bit identifier, that defines the message priority, what data is contained within the 8-byte data array following the identifier, and finally the ECU that sent the message. The 29-bit consists of a Parameter Group Number (PGN) which is a combination of the Reserved bit (always 0), the data page bit (either 0 or 1), a Protocol Data Unit format (PF) and a Protocol Data Unit Specific (PS), both of which are a byte (8-bits) long. The unique purpose of the PGN is to identify the Parameter Group (PG) that is being transmitted in the message. Each Parameter Group has a definition that includes the assignment of each parameter within the 8-byte data field, the transmission rate and priority of the message. Each parameter used in the J1939 network is described by the standard. Each Suspect Parameter Number (SPN) has data length in bytes; data type; resolution; offset; range; and a reference tag or label. The Suspect Parameter Numbers that share common characteristics are grouped into a Group Parameter (PG) and are transmitted to the network by using the same PGN.

During the calibration process, each type of potential fault in the module had associated with it, a Diagnostic Trouble Code (DTC) sent to the ECU which in this case, was the Hydraulic Controller Unit (HCU). Every DTC generated during the calibration process consisted of a combination of four independent fields: the Suspect Parameter Number (SPN) of the channel or the feature that has faults; a Failure Mode Identifier (FMI) of the specific fault; the Occurrence Count (OC) of the SPN/FMI combination; and finally the SPN Conversion Method (CM) which tells the receiving mode how to interpret the SPN. The DTC formed by combining the SPN, the FMI, the OC (if present), and the CM (if present), was used by a diagnostic tool to understand the failure mode that was being reported. (Refer to Table 4).

Table 4.

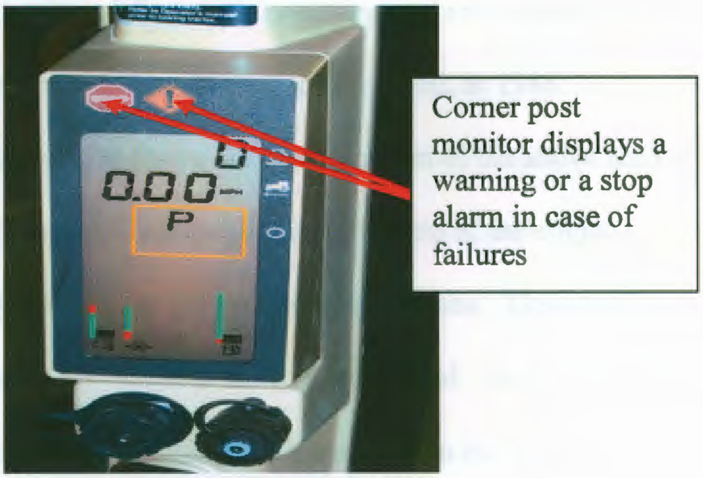
Diagnostic Trouble Codes (DTCs)

ECU	SPN Number	FMI Number	Engineering Description	Tech Manual Description
HCU	521001	13	Rear Hitch Raise Valve Threshold requires calibration. A failure to calibrate or an unsuccessful calibration may cause this code to be stored.	Rear Hitch Raise Valve Not Calibrated Rear Hitch Raise Valve Not Calibrated
CU	521002	5	Rear Hitch Lower Valve solenoid current OOR Low.	Rear Hitch Return Solenoid Current Low
HCU	521002	6	Rear Hitch Lower Valve solenoid current OOR High.	Rear Hitch Return Solenoid Current High

In situation where the HCU detects a fault, it will send an Active Diagnostic Trouble Code message that will be present and displayed on the display unit in Figure 2 and Figure 3 for the operator until the fault is cleared.

In presence of a DTC, the DTC will be displayed on the Information Center Monitor

Figure 2. Information Center



Corner post monitor displays a warning or a stop alarm in case of failures

Figure 3. Corner Post Monitor

On-Board Diagnostics (OBD)

The emission of air pollutants such as benzene, sulfur dioxide, ammonia, and particulate can be related to regulatory violations. The ambient concentrations of pollutants have raised public health concerns. The State of California in 1966 started requiring emission control systems on the same year model cars. The federal government extended this control nationwide in 1968, and subsequently, the Congress passed the Clean Air Act in 1970 that called for the establishment of the Environmental Protection Agency, (US EPA, n.d.).

The EPA started a series of graduated emission standards and requirements for maintenance of vehicles over an extended period of time. In order to meet the proposed EPA standards, manufacturers turned to electronically controlled fuel feed and ignition systems, allowing the use of sensors to measure engine performance and adjusted the systems to provide minimum pollution during the early 70s and early 1980s. These sensors were also assessed to provide early diagnostic assistance. The EPA adapted most of their standards from the SAE on-board diagnostic programs and recommendations after the SAE set a standard connector plug, a diagnostic test signal, in 1988.

The tractors manufactured at John Deere are no exemption of the above named EPA regulations. Since the hitch system functionality is a function of the engine operating system, it is comparative to review the emission regulations. Through the years, on-board diagnostic systems have become more sophisticated. Over a decade ago, OBD-II, a new and expanded set of standard has been introduced in the mid 90s by the SAE. This new standard provides almost complete engine control and monitors part of the chassis, body and accessory devices, as well as the diagnostic control network of all automotive equipment.

Some of the advantages of using OBD are but not limited to serving as a valuable tool that assists the technicians in the service and repair of vehicles by providing a simple, quick, and effective way to pinpoint problems by retrieving DTCs from the OBD systems. To the State Agencies, OBD plays an important role where vehicle inspection and maintenance programs are required. As a vehicle owner, the OBD provides an early warning system by allowing the owner the potential need to repair vehicle through the "Check Engine" light on the dashboard. Finally, the OBD systems allow vehicle and engine manufacturers to abide to the EPA regulations and contribute to the Clean Air ACT Amendments.

The electronic draft control system is configured to send operational or diagnostic information through a serial link to the designated display unit through the use of OBD. The main control unit of an electronic hitch control system can either be analog or digital electronics. In this study, the focus is on digital electronics that requires the use of a microprocessor based system. The general operation of an electronic draft control system unit can be classified into three different categories as shown in Figure 4. The first category involves a subsystem taking the information from the sensors and operator controls and converts it into a form acceptable by the control system. In this first subsystem is the main circuitry that regulates the incoming supply voltage to the sensors. The second subsystem functions to evaluate the information in accordance to the algorithm and provide signals to the third subsystem. In this study, the entire second subsystem is accomplished within the microprocessor. The third subsystem then modifies the provided signals into a form required by the hitch control valve as well as any other auxiliary outputs.

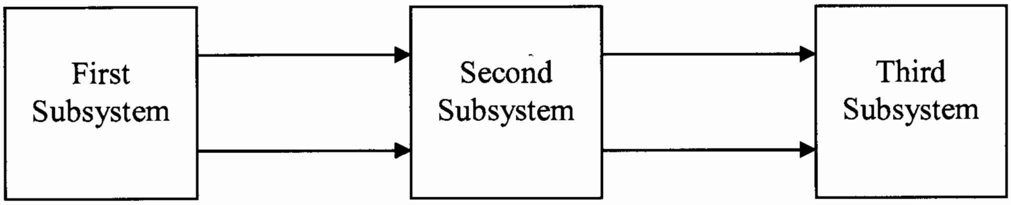


Figure 4: Block Diagram of Subsystems.

Power Flow Architecture of the Implement Hitch System

The power flow architecture reflecting electrical and communication flow for the calibration processes is shown in Appendix C for 7030 and 8030 tractor models. The architecture for the two different tractor models are very similar except that the deluxe hydraulic controller for the 7030 tractor model consists of Hydraulic Controller Unit (HCU) while the 8030 tractor model has the hydraulic CAN controller (HCC). This difference in the hydraulic controller determines which type of valve is used. On the 7030 tractor model, electro-hydraulic valves are used for the hitch functionality while on the 8030 tractor model, CAN valves are used.

Looking at the power flow architecture, the battery supplies power to all controllers involved for the functionality of the implement hitch system. However, none of the controllers is turned on at this point. When the key switch is turned to the ON position, an ignition read message is sent from the key switch to the Cab Load Center (CLC) and the Engine Control Unit (ECU). Besides the ignition read massage, the key switch also sends an ELX 1 input to the Cab Load Center, the Vehicle Load Center (VLC) which contains the Chassis Control Unit (CCU), and to the Engine Control Unit. Once the CLC receives the two messages from the key switch, it powers itself up and sends an ELX 1 Output to the Armrest Control Unit (ACU), a VLC Wakeup Output to the VLC/CCU controllers, and finally a CAN Wakeup Output to the active terminator. The active terminator then communicates with the passive terminator and sends CAN communication network throughout the tractor system.

In order for the Hydraulic Control Unit to power up and respond to the hitch calibration, the Vehicle Load Center sends an ELX 2 Output. The Hydraulic Control Unit then provides power to the respective sensors which in turn provide feedback to the controller during calibration and implement hitch usage. During the initialization of the hitch calibration process, the RTT computer interacts with the tractor system through a service advisor connection, connected to the CAN network. The CCU also provides power to the hydraulic oil temperature sensor that determines the hydraulic oil temperature, during and after the calibration process and provides feedback to the CCU controller. The ACU on the other hand, provides power to the hitch lever located in the cab for operator control.

During the calibration process, once the lever is actuated, a feedback message is sent to the ACU which then communicates with all the other controllers of the position of the hitch lever. At this point, all the controllers function interactively to proceed with the calibration process to finish. The hydraulic controller becomes the main contributor in the calibration process by commanding the opening of the hitch valves to allow the flow of hydraulic oil to the cylinders.

The main key communication comparison between the hydraulic controller for the 7030 tractor model and the 8030 tractor model is shown Figure 5a and Figure 5b respectively. The communication system on the 7030 tractor model is based on a Pulse Width modulation (PWM) while that of the 8030 tractor model is based on CAN network system. The blue lines are the PWM communication signals and the green lines are the CAN bus communication signals.

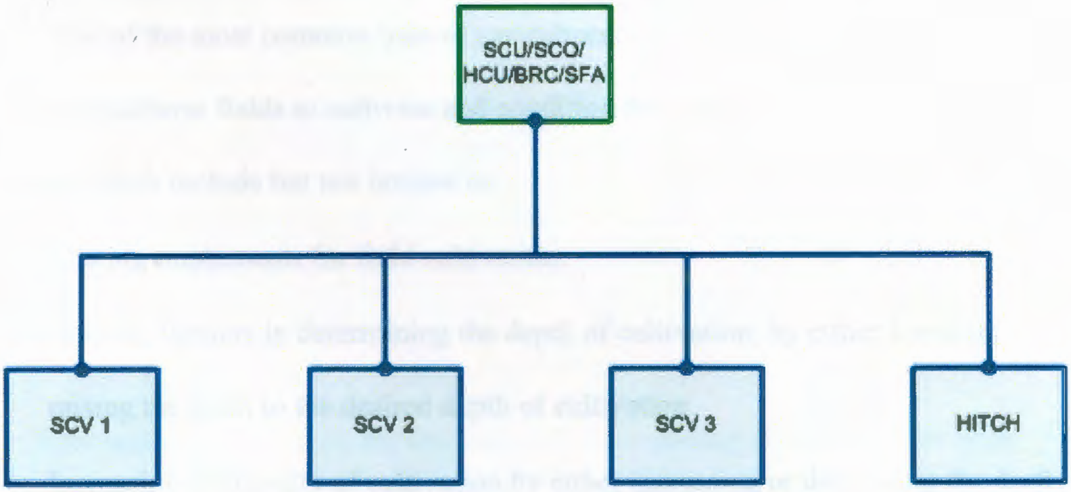


Figure 5a. 7030 HCU / Valves Communication

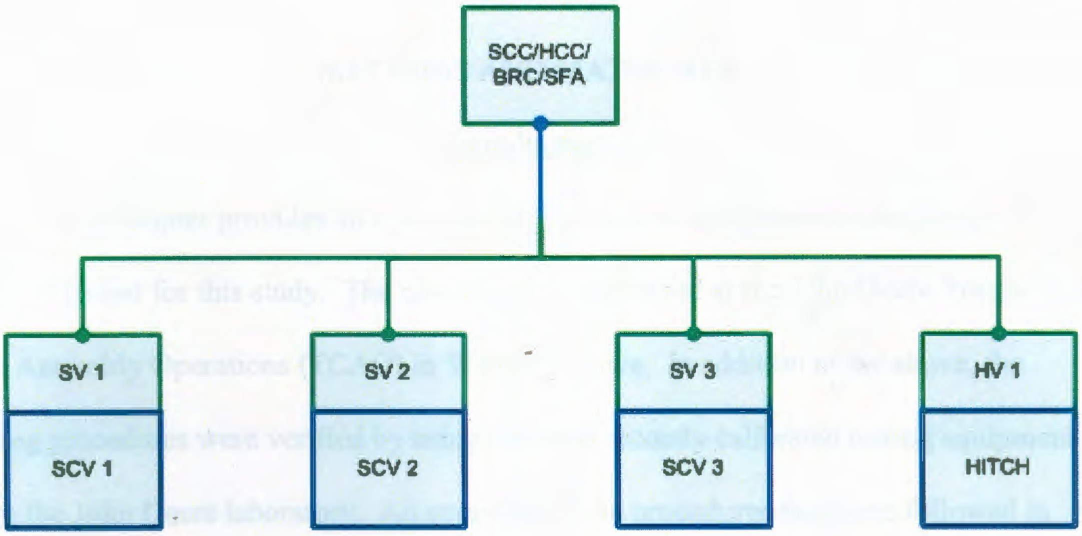


Figure 5b. 8030 HCC / Valves Communication

Application of Hitch in Agriculture Equipments

One of the most common uses of agricultural tractors is to move implements through agricultural fields to cultivate and condition the soil. Some of the uses of the implement hitch include but not limited to:

- Towing implements for field cultivation.
- Helping farmers in determining the depth of cultivation, by either lowering or raising the hitch to the desired depth of cultivation.
- Increasing the quality of cultivation by either increasing or decreasing the draft load. This adjustment of the draft load allows for deep or shallow ground-engineering.

CHAPTER III

METHODS AND MATERIALS

Introduction

This chapter provides an overview of the experimental research and design that was conducted for this study. The research was performed at the John Deere Tractor and Cab Assembly Operations (TCAO) in Waterloo, Iowa. In addition to the above, the testing procedures were verified by using the most recently calibrated testing equipment from the John Deere laboratory. An overview of the procedures that were followed in this study is shown below.

Procedure of Study

In conducting this study, the following five main steps were undertaken: (a) research design, (b) sensors selection, (c) hitch valve selection and functionality, (d) material preparation, and (e) the experiment. Included with the methods and materials is a description of statistical procedures that will be utilized for data collection in this study.

Research Design

This study was based on the analysis of factors causing failure mode in hitch system calibration in agricultural equipments. The study used the calibration method in gathering the necessary data needed for analysis at the various stages of the calibration process. The automated calibration process was accomplished with the use a computer system that had the algorithm installed for the calibration process. The algorithm used in the calibration process is well defined in Lab View programming (Wong, 2006). The factors and components that contribute to the functionality of the hitch system were calibrated and measured accordingly, to record data for both successful and failed calibration processes.

Sensors Selection

In selecting the various sensors responsible in data collection and responding properly to the commands needed for successful calibration and functionality of the hitch system, it was necessary that the sensors meet certain criteria or specifications.
The two sensors, hitch position sensor and draft position sensor, shown in Figures 6a and 6b, provide feedback voltages that are proportional to their supply voltage, as such; the hitch control hardware will provide the supply voltage to the sensors. According to the sensors specification, the reference or the supply voltage will always be approximately 5 volts, in other words the reference voltage will be within the range of 5 volts +/- 2.5 volts. Table 5 displays the manufacturing specifications of the hitch position sensor and Table 6 displays the manufacturing specifications of the draft position sensor respectively.

Table 5.

Hitch position sensor specification

Supply Voltage	- 5V
Output Voltage	- 2.5 V
Operating Temperature	- 40 °C to + 85 °C
Linearity	+/- 3.5 % of Supply Voltage
Hysteresis	+/- 0.25 % of Supply Voltage
Repeatability	+/- 0.25 % of Supply Voltage

Table 6.

Draft position sensor specification

Supply Voltage	5 V +/- 0.25 V
Supply Current	10 mA Max Per Sensor
Sensor 1 Output	10 % to 90 % of 5 V; 0.5 V to 4.5 V
Sensor 2 Output	5 % to 45 % of 5 V; 0.25 V to 2.25 V
Electrical Travel Distance	- 60° to + 60° from Index Point
Mechanical Travel Distance	- 90° to + 90° from Index Point

Figure 6a. *Figure 6b.*

Dual Output Hall Effect rotary sensor. Courtesy of BEI Technologies Inc.

During the calibration process, the draft sensor was calibrated by storing the draft sensor zero value and the draft sensor gain value obtained and stored in a memory. The draft sensor functions to measure the amount of force required to move the implement through the soil. The hitch position sensor on the other end was also calibrated by allowing the hitch to go through a full range of travel distance for minimum and maximum calibrated voltages. The hitch position sensor functions as a feedback device for the draft control system. In essence, the hitch position sensor informs the hydraulic controller of the actual position of the hitch. One significant advantage that the draft sensor offers is the large output voltage range, usually a dynamic range of 0.6 to 0.9 volts. The draft sensor also provides negligible effect on sensor output when properly installed.

Hitch Valve Selection and Functionality

The hitch implement is movable by a hydraulic positioning assembly including an actuator and a hitch valve assembly required for system operation. The valve assembly controls the flow of hydraulic oil to and from the rockshaft cylinders or actuator in response to control signals. The valve is required to interface the electronics into the tractor's hydraulic system and must be capable of monitoring the amount of hydraulic oil required to position the hitch links within the desired accuracy. The valve assembly as shown in Figure 7a and 7b comprises of a raise valve and a lower valve, which are typically solenoid-operated valves and include electrical coils. These valves require a control signal which must be equal or proportional to a threshold value in order for the valve to open and allow the flow of hydraulic oil to begin. The threshold value must overcome the inherent deadband in the valve and the fluid flow forces within the valve. The control signals are generated by a control system, and may include pulse-width-modulated (PWM) signals. These signals allow the rate of change in the actuator movement to be proportional to the duty cycle of the control signals. In response to a change in a position command, the control circuit applies a control signal to the appropriate raise or lower valve in accordance to the determined threshold value. The hitch position sensor then determines the control command and positions the rockshaft to the required position. During the calibration process, the hitch valve output needs to be normalized in order to match the different flow requirements, as such; the calibration data is used to normalize the input data of all sensors. The normalization equation is in the form: $Y = M \times (X - B)$ where;

Y = the normalized output,

M = the slope determined by the calibration process,

X = the sensor input read by the analog input device, and

B = the X-intercept (sensor zero reading) stored during the calibration process.

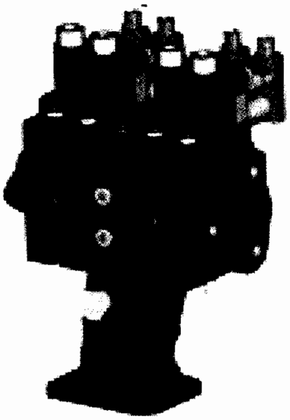


Figure 7a. Full hitch control valve set. Courtesy of Husco International Inc.

The force feedback is an electrohydraulic actuation for the hydraulic valves shown in Figure 8 (Husco Inc.). The valves are proven for durability that involves Proven™ Technology with a mechanical spool position feedback for high performance, high servo force to position spool, less sensitive to contamination and less spool leakage. The outlet section of the hitch control valve is shown in Figure 9. The advantages on selecting this type of valves include but not limited to reduced hysterisis, improved valve resolution, dynamic valve response, and precision fine metering.

Figure 7b. Hitch control valve (Electrohydraulic actuator).

Courtesy of Husco International Inc.

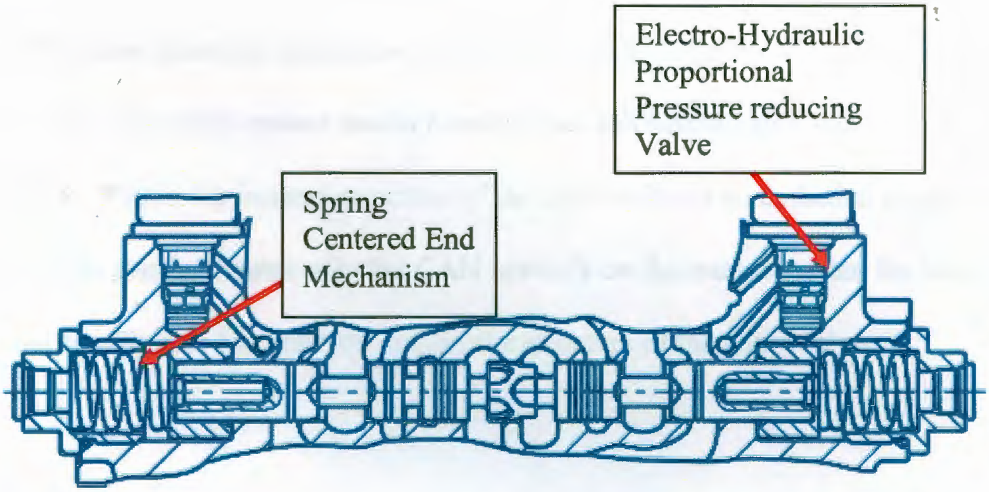


Figure 8. Internal Structure of the Hitch Control Valve displaying the coil.

Courtesy of Husco International Inc.

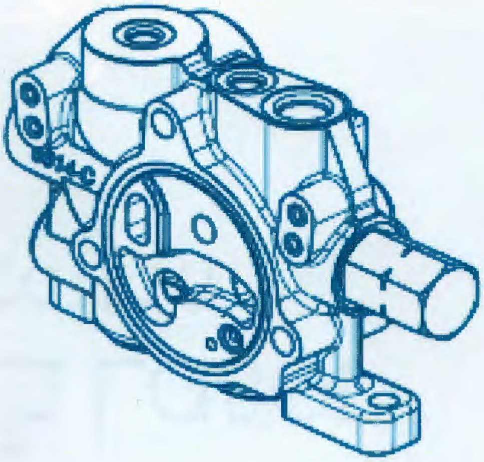


Figure 9. Outlet Section of the Hitch Control Valve.

Courtesy of Husco International Inc.

The valve selection and characteristics described is mainly related to the 7030 tractor model. The 8030 tractor model however has a different valve selection called CAN valve. Within the internal structure of the CAN valve is an embeded programmed controller that communicates with the CAN network on the tractor system for hitch functionality. Figures 10a and 10b display the structure of the CAN valve.

Figure 10a. CAN Valve Set

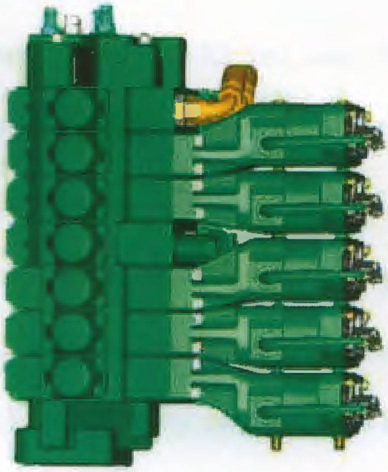


Figure 10b. Side View of CAN Valve Set

The Can valve set is a combination of the Selective Control Valve (SCV) and hitch valve. Some of the characteristics of the CAN valve include but not limited to the existance of controller in each section compartment unlike the electro-hydraulic valves used on the 7030 tractor model. The CAN valve also provide better flow resolution with more valve spool steps. Within the main spool position sensor, the controller verifies operator requested valve position and enhances precision for close loop.

Some of the characteristics of a good valve include proportional flow to the electrical signal, rapid valve response to an electronic signal, negligible temperature drift, and a minimum life cycle of 6000 hours (Squires, 1983).

Engine Specifications

PowerTech™ Plus 6.8L Engine

The 7030 large frame series tractors range from 7630, 7730, 7830, and 7930 series. These models respectively have 140, 152, 165, and 180 Power Take-Off (PTO) horsepower (hp). However, the engines installed in this series of tractors are 6.8L. The engines deliver outstanding fuel economy with 175, 190, 205, and 220 engine horsepower respectively and come with a wide operating range of 1000 – 2100 revolution per minute (rpm). The engine horsepower rating used by John Deere is the standard 97/68 EC. The standard 97/68 EC is a widely used standard in Europe in compliance to various regulations (John Deere Corporation, n.d.b).

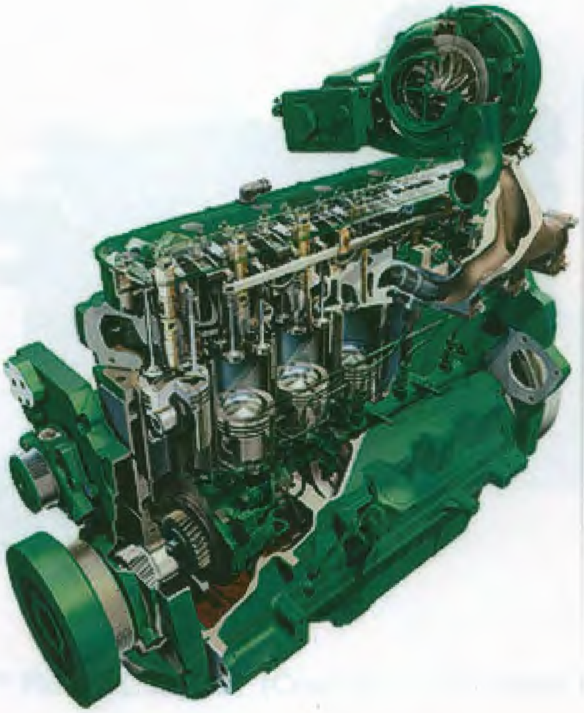


Figure11 . PowerTech™ Plus 6.8L engine. (Courtesy of John Deere Corporation, n.d.b)

PowerTech™ Plus 9.0L Engine

The 8030 series tractors range from 8130, 8230, 8330, 8430, and 8530 series. These models respectively have 180, 200, 225, 250, and 275 Power Take-Off (PTO) horsepower (hp). However, the engines installed in this series of tractors are 9L. These engines also deliver outstanding fuel economy with 225, 245, 275,305 and 330 engine horsepower (hp) respectively and come with a wide operating range of 1000 – 2100 revolution per minute (rpm). The engine horsepower rating used by John Deere is the standard 97/68 EC. The standard 97/68 EC is a widely used standard in Europe in compliance to various regulations (John Deere Corporation, n.d.a).

Figure 12. PowerTech™ Plus 9.0L Engine. (Courtesy of John Deere Corporation, n.d.a)

Material Preparation

In preparing the materials for the calibration process, it was assumed that all components including the draft sensor, the hitch position sensor were tested from the suppliers prior to delivery. It will also be assumed that the harness connections were tested from the suppliers before delivery. The installation of the harness on the final line was critical in making sure that all sensors were well connected and the hitch controller had a good connection to the CAN system so as to allow for the transmission of information from the operator-commanded lever as shown in Figures 13a and 13b to the controller for the execution of the hitch controlling algorithm. One method of converting the position of the lever into an electronic signal is through the use of a potentiometer. This was achieved by placing the potentiometer at the rotational point of the lever.

Figure 13a. Power Quad Transmission (PTQ) Control center

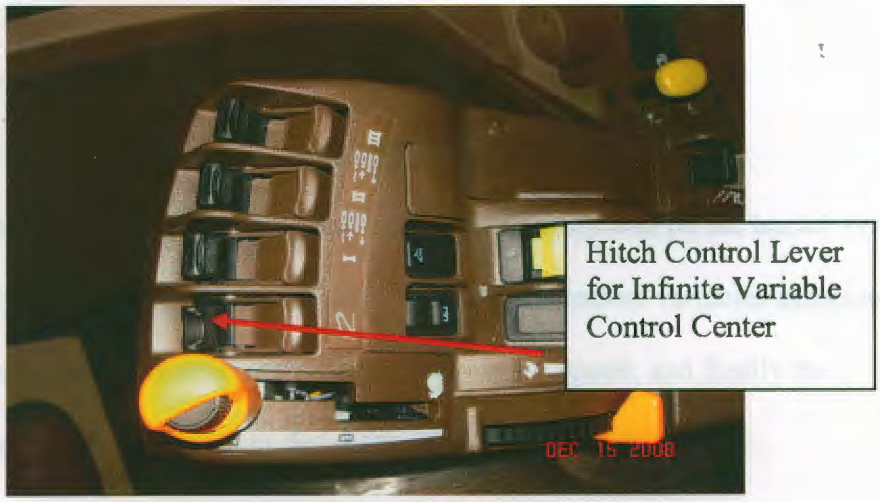


Figure 13b. Infinite Variable Transmission (IVT) Control Center

The Experiment

In order to perform the calibration process accordingly, a number of twenty (20) tractors were randomly selected from the 7030 tractor model production line and another twenty (20) tractors from the 8030 tractor model production line, and the hitch system will be calibrated using an automated roll testing computer that has the calibration algorithm installed in a Lab View programming. Data will be recorded at the various stages of the calibration process for analysis. During the calibration process, engine speed, engine oil temperature, hydraulic oil temperature, draft sensor voltage, hitch position sensor voltage, the pressure and reverse deadbands as well as deadband-zero will be recorded for analysis. This experiment sampled and analyzed a total of forty (40) tractors.

Variables of the Study

The dependent variable for the hitch calibration system will be the tractor system voltage which ranges between 12.5 V to 14.5 V. The independent variables associated with the hitch calibration process will be the tractor engine speed, and finally the hydraulic oil temperature throughout the entire calibration process.

Statistical Analysis

All data analyses were completed using the Statistical Package of STATISTICA software version. STATISTICA was developed by StatSoft, Inc. and provides a selection of data analysis, data management, data mining, and data visualization procedures. Some of the features of the STATISTICA software include basic and multivariate statistical analysis, quality control modules, neural networks, and a collection of data mining techniques provided in an open architecture. Released in 1993, STATISTICA has received the highest rating in every published comparative review, (StatSoft, Inc). Using the named software above will help in selecting a variety of combinations of variables that can be statically examined and graphed to help in data presentation. The descriptive statistics feature will be used to determine the mean response value, standard deviation, range, and variance. In addition, the explore feature will be used to analyze the data and histograms and frequency distributions will be produced to examine the existence of outliers.

A primary analysis data tool that was used in this research study was the Pearson Product-moment Coefficient of Correlation (r). According to Borg and Gall (1983), the product-moment coefficient is the most stable bivariate correlational statistic. “For any two variables no matter how they have been measured, a product-moment correlation coefficient (r) can be calculated.” (Borg & Gall, 1983, p.586).

CHAPTER IV

ANALYSIS OF THE RESULTS

Experimental Data

During the calibration processes, the variables that were controllable are the engine speed and the calibration weight on the 7030 tractor model. In view of that, the data collected during the hitch calibration experiments is classified in two main categories. The first category involves hitch calibration experiments performed at different engine speed varying between 1900 rpm and 2000 rpm with a hitch calibration weight of 70 – 90 kg (150 – 200 lb) was installed in addition to quick-coupler if equipped (or a total of 300 – 500 lbs). The second category involves hitch calibration experiments performed at different engine speed varying between 2200 rpm and 2300 rpm with the same hitch calibration weight of 70 – 90 kg (150 – 200 lb) was installed in addition to quick-coupler if equipped (or a total of 300 – 500 lbs). The data collected during the experiment is shown in the Table 7 of Appendix E.

The data set in Table 7 was divided into two categories showing the engine speed range at which the test was run. For the test run at engine speeds ranging from 1900 rpm to 2000 rpm on the 7030 tractor model, the results obtained are shown in Table 8 of Appendix E. Subsequently for the test run at engine speed ranging from 2200 rpm to 2300 rpm on the 7030 tractor model, the results are displayed in Table 9 of Appendix E.

On the 8030 tractor model, the only controllable variable is the engine speed. The calibration weight is neglected so as to perform the calibration without imposing weight for the calibration. It is important to note here that the valve used for the hitch system functionality on the 8030 is different from the valve used on the 7030 tractor model. The differences between the two valves were shown in Chapter III under Hitch Valve Selection and Functionality. In view of that, the data collected during the hitch calibration experiments is classified in two main categories.

. The first category involves hitch calibration experiments performed at different engine speed varying between 1900 rpm and 2000 rpm without imposing hitch calibration weight. The second category involves hitch calibration experiments performed at different engine speed varying between 2200 rpm and 2300 rpm without hitch calibration weight. The data collected during the experiment is shown in the Table 10 of Appendix E.

Table 10 was divided into two categories showing the engine speed range that the test was run. For the test run at engine speeds ranging from 1900 rpm to 2000 rpm on the 8030 tractor model, the results obtained are displayed on the table is shown in Table 11 of Appendix E. Again, for the test run at engine speed ranging from 2200 rpm to 2300 rpm on the 8030 tractor model, the results are displayed on the Table 12 of Appendix E.

Data Analysis

This chapter is to provide a meaningful presentation and interpretation of the data set collected during the calibration experiments performed in this study. Two set of data, twenty (20) each, were collected for two different tractor models for a total of 40 samples involved in this study, 7030 tractor model and 8030 tractor model. The collected data from sample (N = 20) test tractors from each tractor model are presented and analyze.

The relevant data analyses are presented both in table and figure form with brief descriptions in this chapter and in Appendix E. All data analyses were completed using the Statistical software package, STATISTICA, from StatSoft, Inc. A descriptive statistics was performed to determine and present a summary of the basic features of the data set collected. Table 13 and Table 14 show the descriptive statistic results for 7030 tractor model and 8030 tractor model respectively.

Descriptive Statistics

Based on the descriptive statistics results obtained from both tractor models, a scatter plots of the engine speed vs. pre-calibration and post-calibration hydraulic oil temperatures were obtained to see how much of effect engine speed has on the hydraulic oil temperature and to determine if the change in anyway affected the calibration process. The models shown in Figure 14 and Figure 15 show the plots for both 7030 and 8030 tractor models.

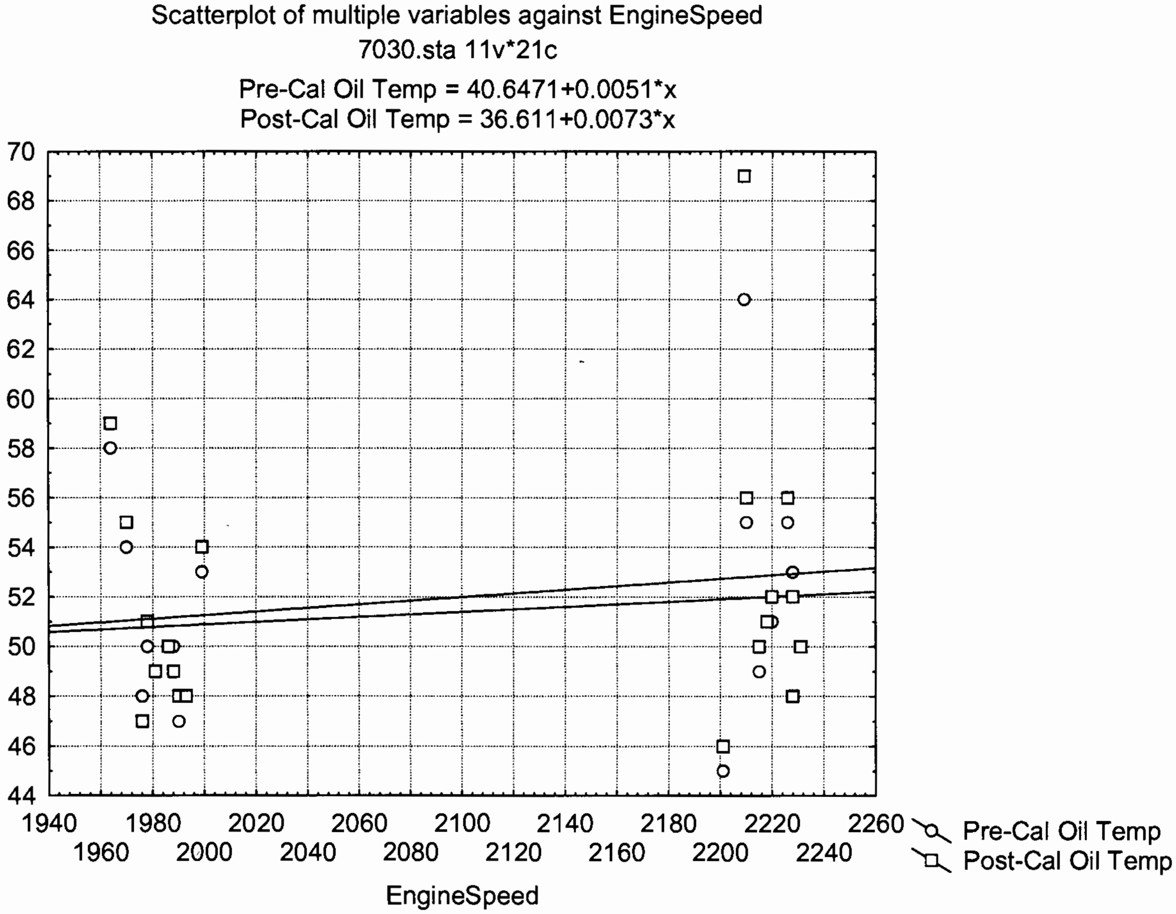


Figure 14. Scatter plot of Hydraulic Oil Temperature (7030)

The original assumption was that increasing the engine speed will drastically change the hydraulic oil temperature simply because the higher the torque, the higher and faster the transmission runs, thereby increasing the hydraulic oil temperature while at the same time eliminating the viscosity of the oil for easy and faster flow into the cylinders as well as valves during the calibration process. Figure 14 and Figure 15 show the change in the hydraulic oil temperature before and after the calibration process. On the 7030, a minimal change was observed between the two oil temperatures. On the 8030 however, the scatter plot shows a bigger change compared to the 7030. Many factors could have possibly contributed to the differences in the change of the hydraulic oil temperatures between the two tractor models. One of the major contributors could possibly be the differences in the valves used for the implement hitch system. Beside the differences in the valve, the experiment performed on the 8030 was done without calibration weight while the experiment performed on the 7030 was done with calibration weight.

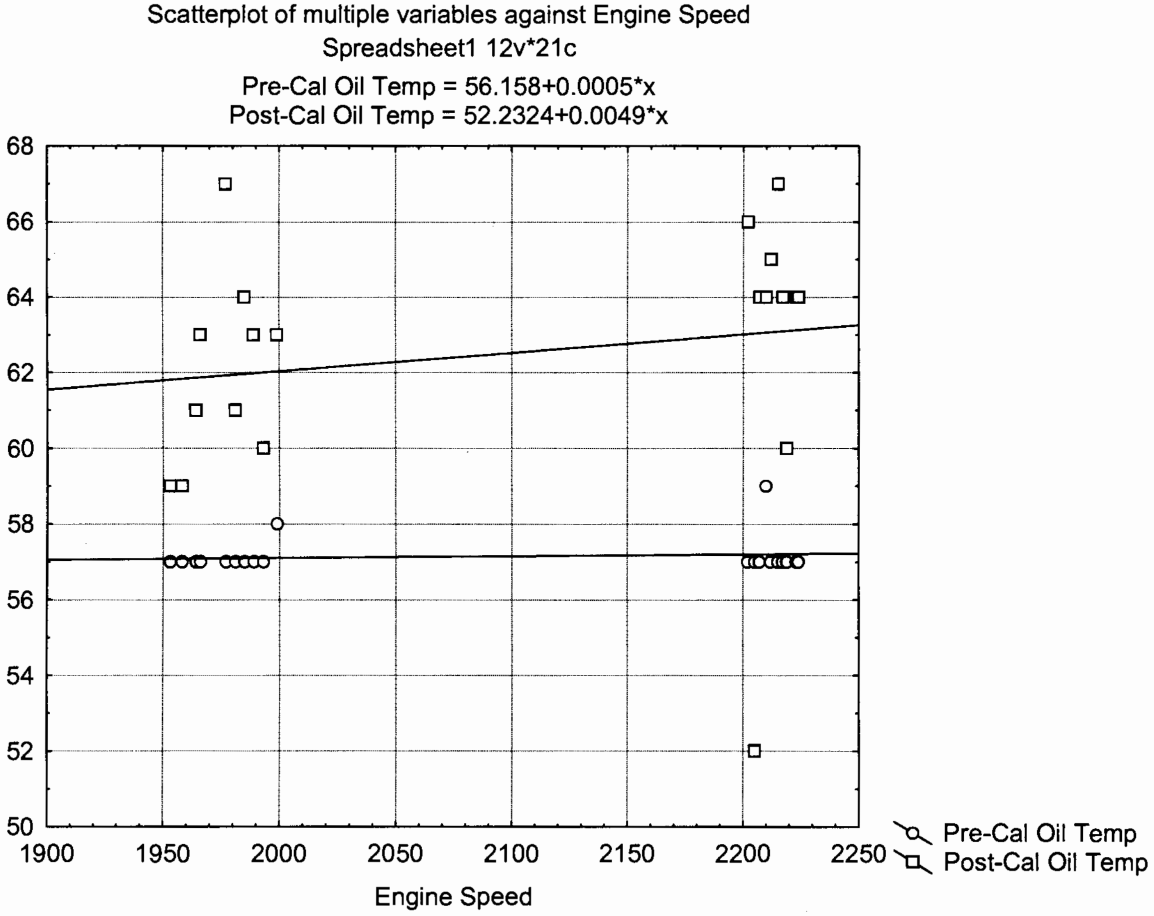


Figure 15. Scatter plot of Hydraulic Oil Temperature (8030)

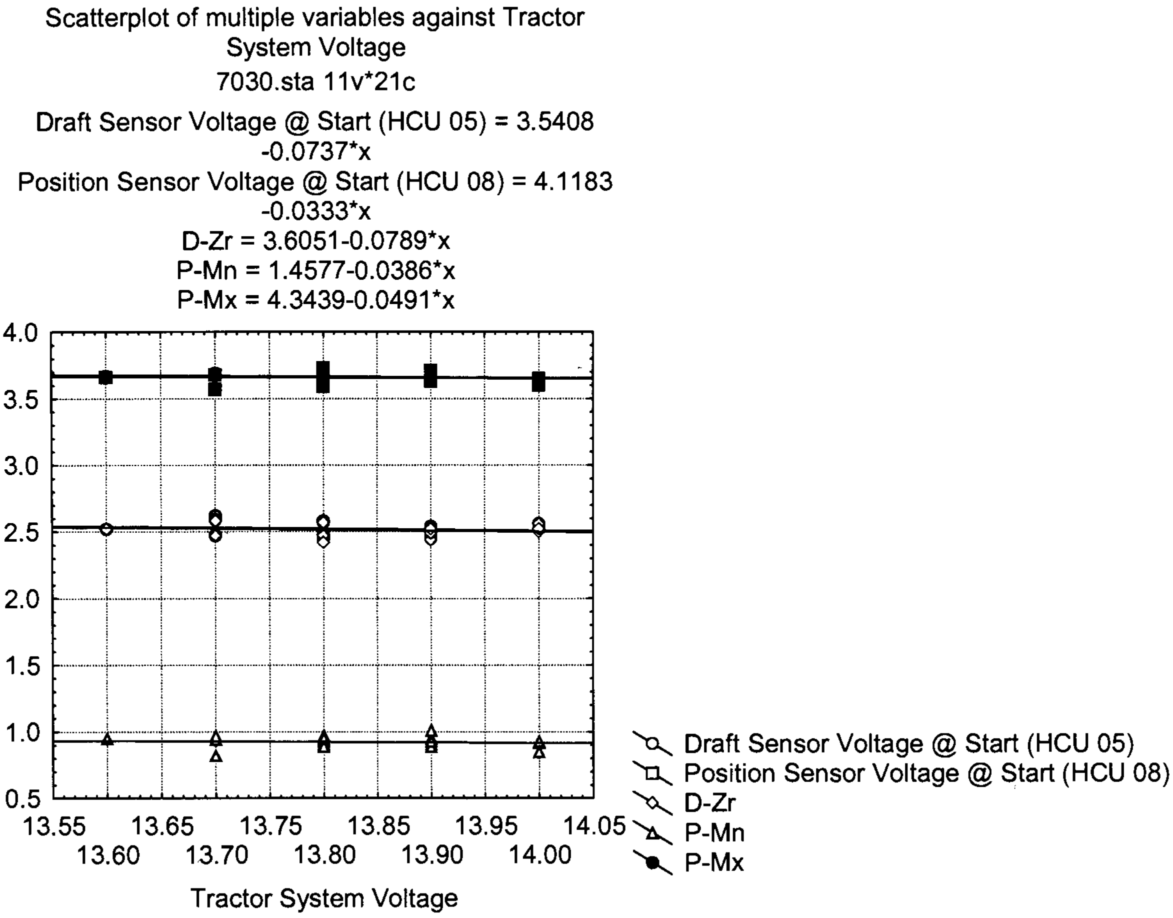


Figure 16. 7030 Scatter plot of System Voltage vs. Sensors Voltage

It was also important to take a look at the distribution of the various sensor voltages as well as the zero draft voltage (D-Zr), the hitch fully raised voltage (P-Mn), and finally the hitch fully lowered voltage (P-Mx). It was seen from both Figure 16 and Figure 17 for 7030 and 8030 tractor models respectively that, with higher tractor system voltage, there was no change in the sensor voltages as well as the zero draft voltage (D-Zr), the hitch fully raised voltage (P-Mn), and finally the hitch fully lowered voltage

(P-Mx). The two graphs are very similar to each other and there is no significant difference between the supplied voltages in relation to the tractor system voltage.

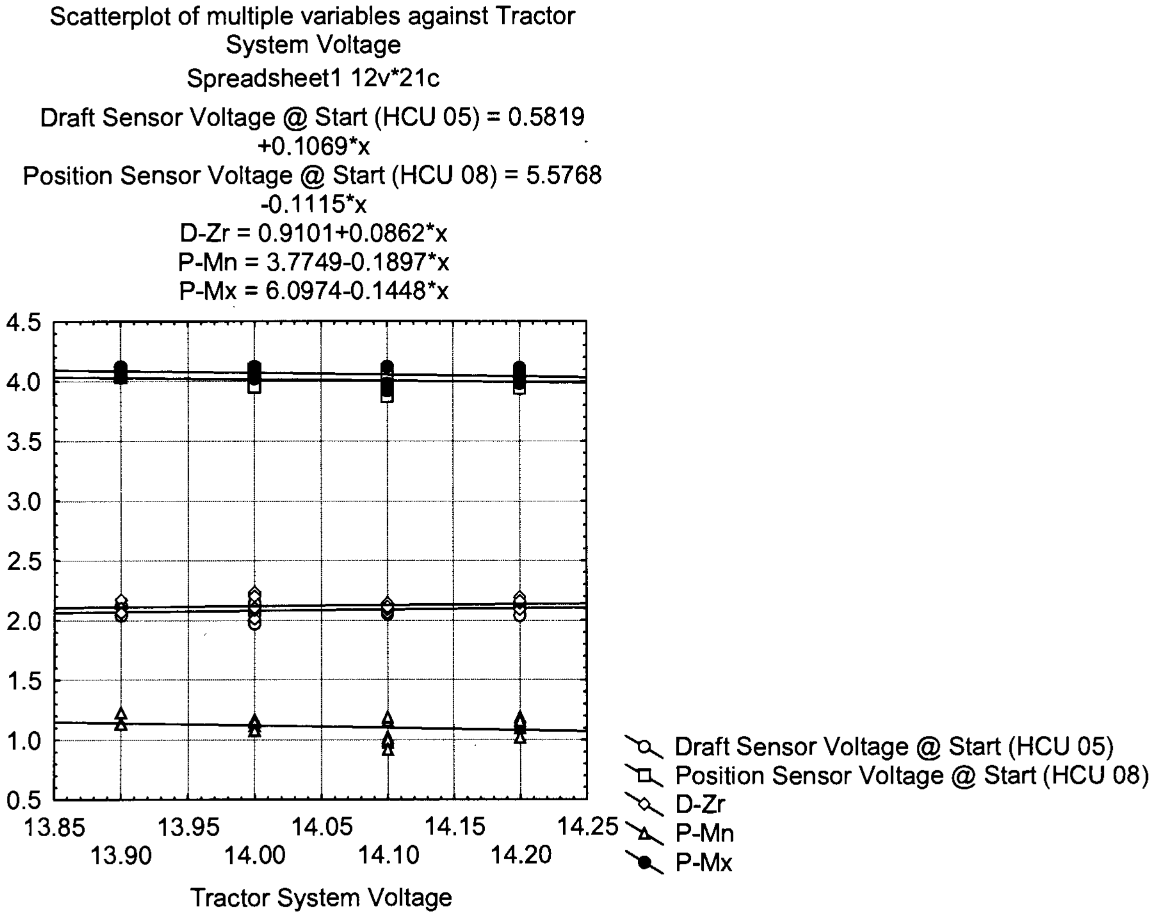


Figure 17. 8030 Scatter plot of System Voltage vs. Sensors Voltage

The histogram in Figure 18 shows the distribution of the data collected for hydraulic oil temperature before the calibration process begun on the 7030 tractor model. The data set follows a proper bell curve for a normal distribution plot, indicating the normality of the data set with a range of 25 °C from the lowest temperature to the highest temperature.

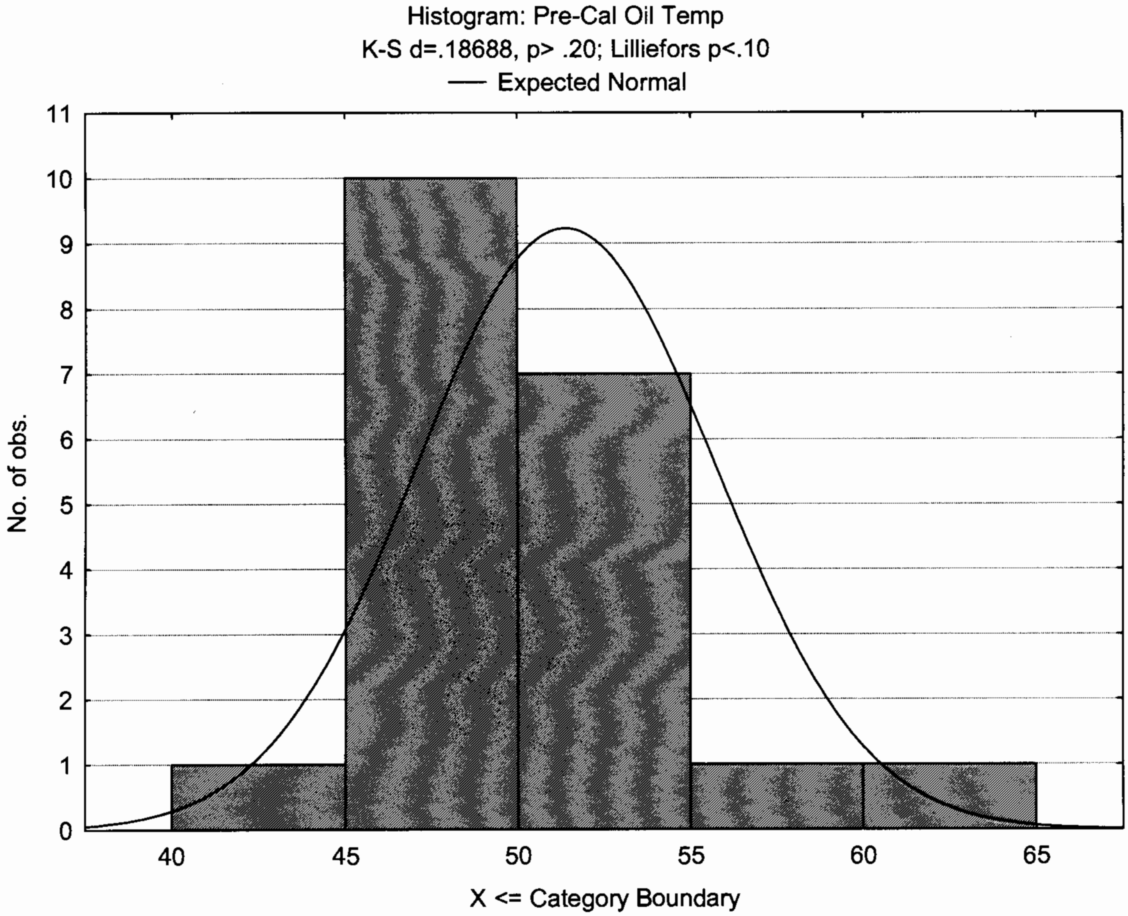


Figure 18. Histogram on Pre-Cal Oil Temperature (7030)

The pre-calibration oil temperature histogram distribution is shown in Figure 19 for the 8030. It can be observed from the graph that the data set does not follow a bell curve for a normal distribution plot. The data set however, is skewed to the right with a range of 2.5 °C from the lowest temperature to the highest temperature, a much less variation in the 8030 data set for pre-calibration oil temperature compared to how much variation exists in the 7030 pre-calibration oil temperature.

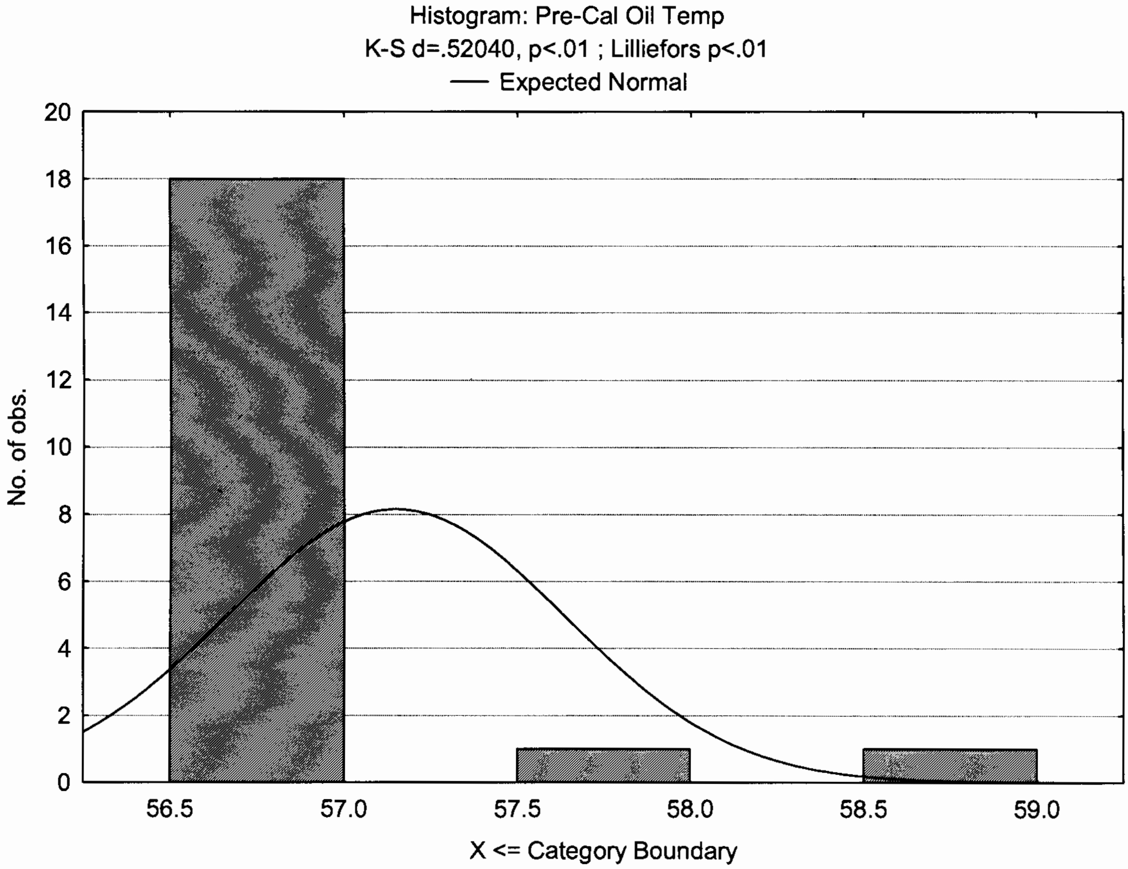


Figure 19. Histogram on Pre-Cal Oil Temperature (8030)

After calibration on the 7030, the hydraulic oil data set collected is plotted in Figure 20. Again, the histogram of the data set collected still follows a normal distribution curve; however, the data set is skewed to the right with a range of 25 °C from the lowest temperature to the highest temperature.

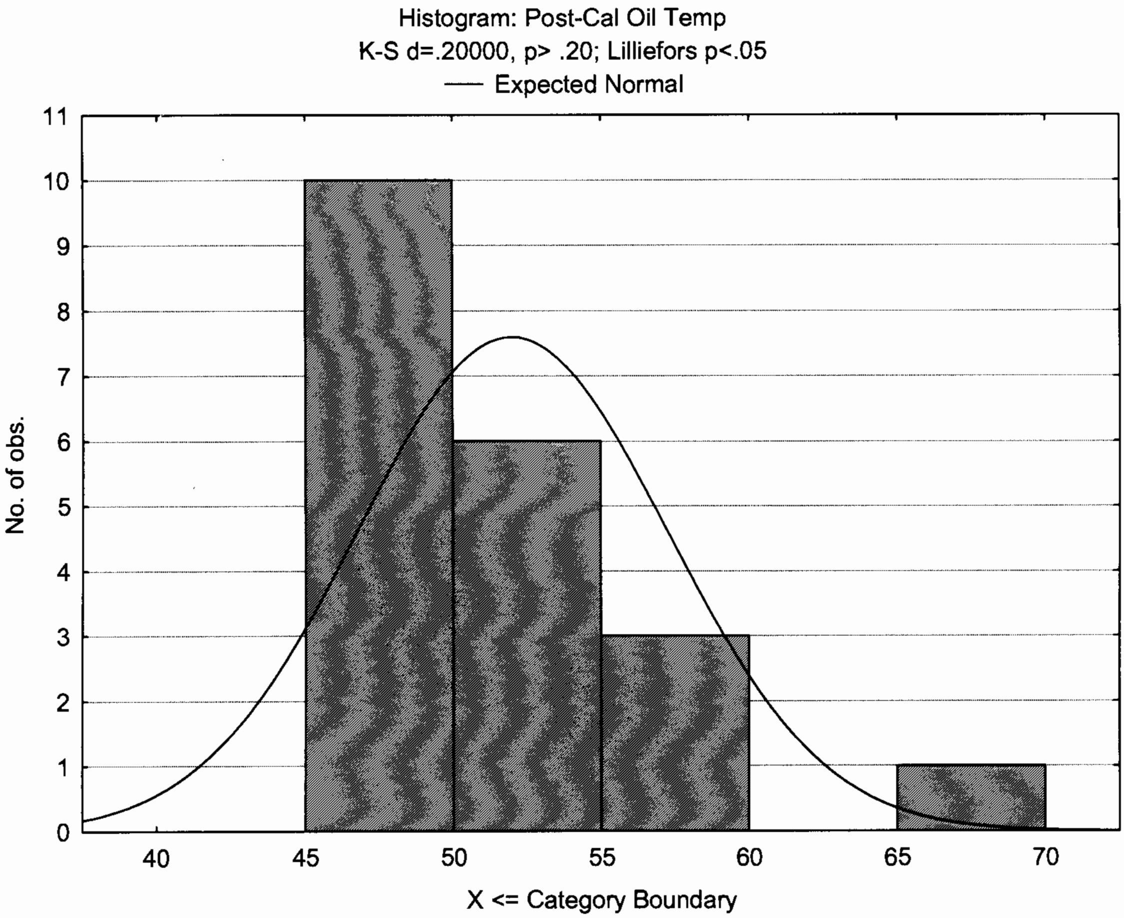


Figure 20. Histogram on Post-Cal Oil Temperature (7030)

The 8030 post-calibration hydraulic oil temperature on the other hand has an outlier which skewed the data set to the left from the histogram graph in Figure 21. Neglecting the outlier will cause the data set to be more normal with a range of 10 °C from the lowest temperature to the highest temperature.

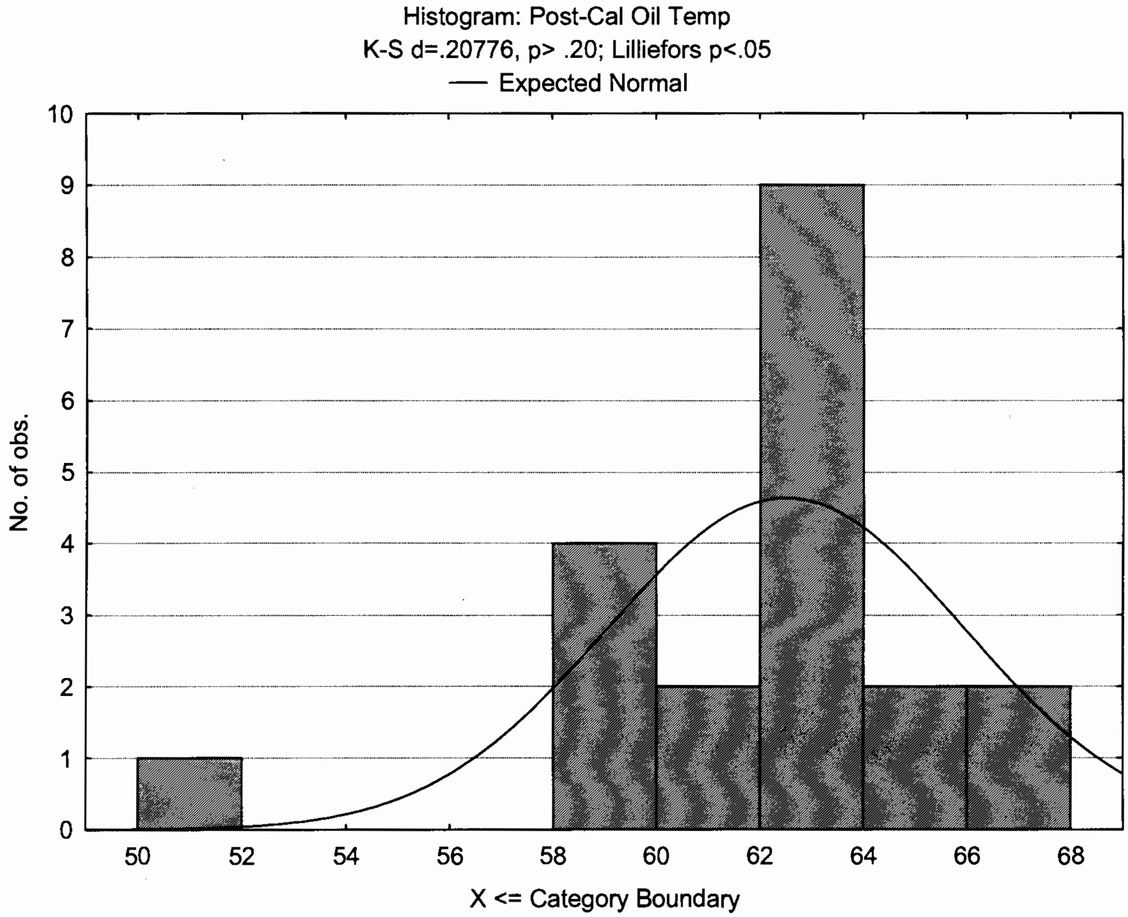


Figure 21. Histogram on Post-Cal Oil Temperature (8030)

Multiple Regression

A regression analysis was conducted using data generated from the calibration experiment. A regression analysis is an extension of correlation that defines the relationship between two or more variables and allows the researcher to predict the Y value in response to any known X value of which, the regression prediction equation is $\hat{Y} = a + bX_1 + cX_2 + dX_3 + eX_4 + fX_5 + gX_6 + hX_7 + iX_8 + jX_9$, where (b); (c); (d); (e); (f); (g); (h); (i); and (j) are the estimated slopes of the regression model, and (a) is the Y-intercept.

7030 Regression

From the first regression analysis, there was practically no significant variable from the result obtained in Table 15 of Appendix E. Table 15 displays the regression model for all variables for 7030 tractor model, but that does not mean that all the independent variables do not have any relationship with the dependent variable. In view of that, a second regression analysis was run with backward elimination of the most non-significant variable and the result obtained is shown in Table 16 of Appendix E. Again none of the independent variables were showing any significant relationship to the dependent variable. A third regression analysis was run with backward elimination and the result shown in Table 17 of Appendix E. It was deduced from Table 17 that, even with backward elimination, none of the variables were significant to each other. In the last regression analysis with backward elimination, though the p-values of some variables were 0.1157 and above, the analysis of the data set was ended here simply to allow for flexibility in the data set with higher alpha level of $\alpha = 0.05$. The same assumption was also made on the analysis made on the 8030 tractor model.

From the multiple regression analysis for 7030, it was seen that the p-value of P-Mn was 0.99, very meaningless. So another regression analysis was run with backward elimination of P-Mn. The result is shown as Table 16 of Appendix E.

Again a third regression analysis was run with backward elimination of draft sensor voltage, pre and post cal oil temperature, and D-Zr. The result obtained is shown in Table 17 of Appendix E.

Even with backward elimination of engine speed in the regression model shown in Table 18 of Appendix E, none of the variables was shown to be statistically significant in the 7030 tractor model data collected. However, with the entire remaining variables combined, the value of R was 0.4738 with R-square value of 0.2245 and an adjusted R-square value of 0.07916.

8030 Regression

The same regression analysis that was run on the 7030 was run on the 8030 and likewise, the first analysis did not indicate any of the independent variables to be significant as shown in Table 19 of Appendix E. A second regression analysis was run with backward elimination of the most non-significant variable and the result is displayed in Table 20 of Appendix E. It was observed that engine speed was fairly close to be statistically significant in relation to the tractor system voltage. A third regression analysis with backward elimination was run with the results displayed in Table 21 of

Appendix E. Unlike the 7030, the third regression analysis proved engine speed to be really significant with p-value of 0.0434 which is less than 0.05. The draft sensor voltage was also proven to be close to being significant. In respect to that, a final regression model with backward elimination of the most non-significant variable was run and the result obtained is shown in Table 22 of Appendix E.

A multiple regression analysis was also run for the 8030 with backward elimination of position sensor voltage, and the result obtained is shown in Table 20 of Appendix E. A third regression analysis was run with backward elimination of D-Zr and the result is shown in Table 21 of Appendix E. With the entire remaining variables combined, the value of R was 0.5778 with R-square value of 0.3339 and an adjusted R-square value of 0.1563.

7030 Regression Analysis on Oil Temp Change

A regression analysis was performed on the differences on the hydraulic oil temperature change in relation to the tractor system voltage. The regression analysis result for the 7030 is shown in Table 23 of Appendix E. The criterion variable (Y') tractor system voltage and the predictor variable (X) hydraulic oil temperature change are identified, as is the estimated Y-intercept (a) and the estimated regression slope (b). In addition, the sample size (N) used for generating the regression analysis result was N = 20.

Using the regression prediction equation relative to the criterion and predictor variables of this study, we have the following:

$\hat{Y} = bX + a$

Now, substituting the calculated values from Table 23 of appendix E, the derived equation for predicting changes in hydraulic oil temperature in relation to the tractor system voltage was found to be:

$\hat{Y} = -0.0091(X) + 13.845$

The strength of correlation was reported at -0.1056, which shows that the correlation was not statistically significant since the slope was not significant at the alpha level of $\alpha = 0.05$..

8030 Regression Analysis on Oil Temp Change

Again, a regression analysis was performed on the differences on the hydraulic oil temperature change in relation to the tractor system voltage. The regression analysis result for the 8030 is shown in Table 24 of Appendix E. The criterion variable (Y') tractor system voltage and the predictor variable (X) hydraulic oil temperature change are identified, as is the estimated Y-intercept (a) and the estimated regression slope (b). In addition, the sample size (N) used for generating the regression analysis result was N = 20.

Using the regression prediction equation relative to the criterion and predictor variables of this study, we have the following:

$\hat{Y} = bX + a$

Now, substituting the calculated values from the table above, the derived equation for predicting changes in hydraulic oil temperature in relation to the tractor system voltage was found to be:

$\hat{Y} = 0.00573(X) + 14.0444$

From the regression model above, the strength of correlation was reported at 0.1833, which shows that the correlation was not statistically significant since the slope is also not significant at the alpha level of $\alpha = 0.05$.

t-test Analysis

t-test for 7030

Based on the results from the regression model on hydraulic oil temperature change, a one sample t-test analysis was run on the differences in hydraulic oil temperature at a 95% Confidence Interval (CI) with $\alpha = 0.05$ for two-tail. By setting our hypothesis,

H_o: $\mu_d = 0$ meaning that there is no significance difference between the means of the pre-calibrated hydraulic oil temperature and the post-calibrated hydraulic oil temperature.

The results obtained from the t-test are shown in Table 25 of Appendix E. The t value (t stat) would have to fall in the +/- range of the critical value for a two-tail test in order to accept the hypothesis that, the difference between the means of pre-calibrated oil temperature and post-calibrated oil temperature is not significant. From Table 25 of Appendix E, the calculated t value (t stat) was found to be 2.107. However, the t critical value for two tail at a 95% Confidence Interval (CI) with degrees of freedom, df = 19 obtained from the Table of Critical T-Values of Appendix F was found to be 2.093. Comparing the calculated t-value to the critical value, it was seen that the calculated t-value = 2.107 was outside the range of +/- 2.093. The researcher therefore rejects the hypothesis and concludes that there is a significant difference between the means of the pre-calibration and post-calibration hydraulic oil temperatures.

<u>t-test for 8030</u>

Based on the results from the regression model on hydraulic oil temperature change, a one sample t-test analysis was run on the differences in hydraulic oil temperature at a 95% Confidence Interval (CI) with $\alpha = 0.05$ for two-tail. By setting our hypothesis,

H_o: $\mu_d = 0$ meaning that there is no significance difference between the means of the pre-calibration hydraulic oil temperature and the post-calibration hydraulic oil temperature. The results obtained from the t-test are shown in Table 26 of Appendix E. The t-test value (t stat) would have to fall in the +/- range of the critical value for a two-tail test in order to accept the hypothesis that the difference between the means of pre-calibration oil temperature and post-calibration oil temperature is not significant. From the table above, the calculated t value (t stat) is 6.991. From the t-table in Appendix F, the t critical value for two tail at a 95% Confidence Interval (CI) with degrees of freedom, df = 19 was found to be 2.093. Comparing the calculated t-value to the critical value, it was seen that the calculated t-value = 6.991 was outside the range of +/- 2.093. The researcher therefore rejects the hypothesis and concludes that there is a significant difference between the means of the pre-calibration and post-calibration hydraulic oil temperatures.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Discussion

The problem of this experimental research study was to determine the strength of the correlational relationship between factors; hydraulic oil temperature, engine speed, and calibration weight, to the tractor system voltage affecting failure mode of hitch system calibration in agricultural equipment. This was performed using the Pearson Product-Moment Coefficient of correlation (r). A descriptive statistics was performed to help represent the data set. A regression model was performed to see if there is any statistically significance different between the factors needed for successful calibration. A multiple regression prediction equation was derived from the multiple regression analysis to finalize the data analysis.

The research was performed to answer primarily the following hypothesis questions, and finally investigate if tractor system voltage influenced the calibration process in any means in terms of supplied voltage to the draft sensor and hitch position sensor.

Hypothesis 1:

The null hypothesis 1, H_{01} is that there are no significance differences in the hydraulic oil temperature that affects hitch system calibration.

The alternative hypothesis 1, H_{A1} is that there are significance differences in the hydraulic oil temperature that affects hitch system calibration.

Hypothesis 2:

The null hypothesis 2, H_{02} is that there are no significance differences in engine speed during the calibration process thereby providing successful hitch system calibration.

The alternative hypothesis 2, H_{A2} is that there are significance differences in engine speed during the calibration process thereby providing successful hitch system calibration.

First of all, the study showed that with increase in engine speed, there is a slight change in hydraulic oil temperature. Secondly, the study determined the strength of the correlational relationship between the variables under study and the dependent variable, tractor system voltage. Finally, the study showed the distribution of the hydraulic oil temperatures before and after calibration to determine if the change on the 7030 tractor model is different from the change on the 8030 tractor model and how this change contribute to the calibration process.

The Pearson Product-Moment, Coefficient of Correlation was used to assess the strength of the relationship between the variables. The data were examined at a 95% confidence interval or a .05 significance level using a two-tail test. At the .05 confidence level, a value of $p < .05$ level indicated statistical significance while a value of $p > 0.05$ level indicated not statistical significance.

Conclusions

The results of this study show that there are not enough evidence in the study to reject the null hypothesis one *H_{01}*, which says: there are no significance differences in the hydraulic oil temperature that affects hitch system calibration. The results consequently suggested that the hydraulic oil temperature however, differs from tractor model to model. This change might have been contributed by some other factors that may be included in further studies relating to this study. Some of these factors may include contamination in the valves. It would be therefore important to look at some analysis assuming all the tractor models have the same hitch valve, the same hydraulic oil brand, viscosity, and contamination.

In the second hypothesis, the null hypothesis two, *H_{02}* is that there are no significance differences in engine speed during the calibration process thereby providing successful hitch system calibration. The analysis of the results show that the calibration processes are not affected in any significant way by increasing the engine speed beyond 1900 rpm. However, it was noticed that, increasing engine speed has a higher impact on hydraulic oil temperature on the 8030 tractor model than it did to the 7030 tractor model. In the 7030 tractor model, the scatter plot in Figure 14 of Appendix E shows a very sharp change in the hydraulic oil temperature compared to the scatter plot in Figure 15 of Appendix E which displays a wider range of change for the 8030 tractor model.

Recommendations

Upon the review of the related literature, data analyses, and conclusion of the study, the following recommendations were made. Given the results obtained from this study, it was reported that there was not enough evidence to statistically accept the hypotheses of the study. It is therefore important to give recommendations for further studies. These further studies may be conducted to determine the differences between the two different hitch valves used in the experiment.

The recommendations for further studies are as follows:

1. It is recommended that future experiments replicate this study using a larger sample size with the same tractor models in order to obtain more accurate results.
2. It is also recommended that the experimental test procedures be conducted on other tractor models or other non John Deere tractors.
3. It is recommended that further studies be performed to identify other important factors such as sensors and hydraulic oil flow rate to mention a few that may cause failure mode in the hitch system calibrations in agricultural equipment, specifically tractors.
4. It is recommended that this study be replicated using other experimental techniques in determining the relationship between the dependent and independent variables.
5. It is recommended that future replication of this study analyzes the brand and grade of the hydraulic oil used and their possible contamination due to storage method if different type of oil are used.

6. It is recommended that further studies be performed to include hydraulic oil flow pressure and hoses involved in the study, and also separate the sources of the hydraulic oil.

In closing, extending the current study would provide additional information to the already documented knowledge. In view of the limited research and relationship between the variables studied in this experiment, further studies are strongly recommended.

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APPENDIX A

HALL EFFECT ROTARY SENSOR

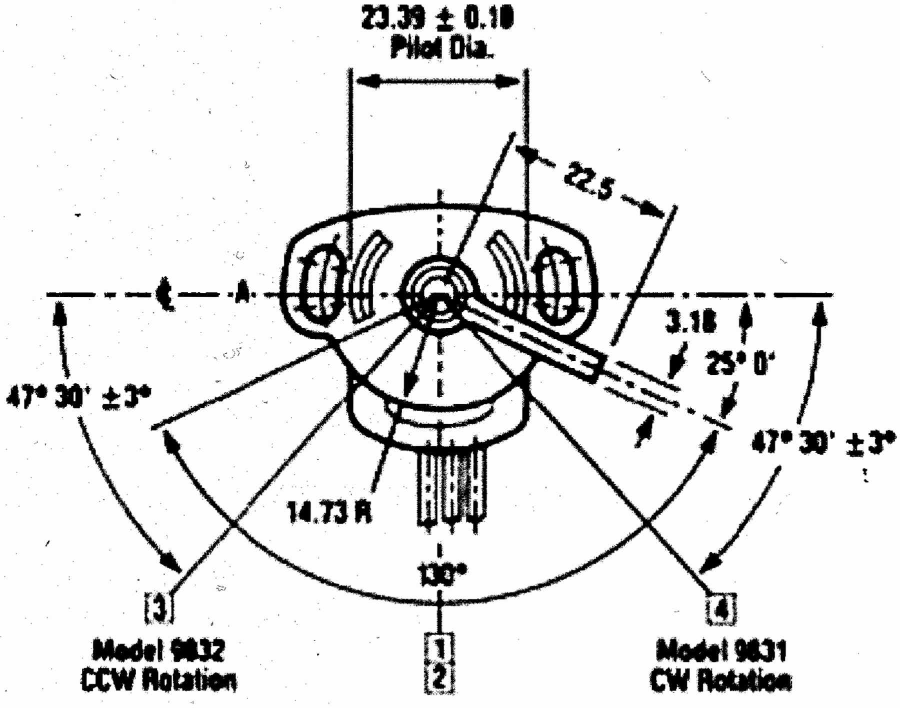

Figure 22. Internal diagram of the Hall Effect rotary sensor.

Courtesy of BEI Technologies Inc.

APPENDIX B

CAN VOLTAGE LIMITS

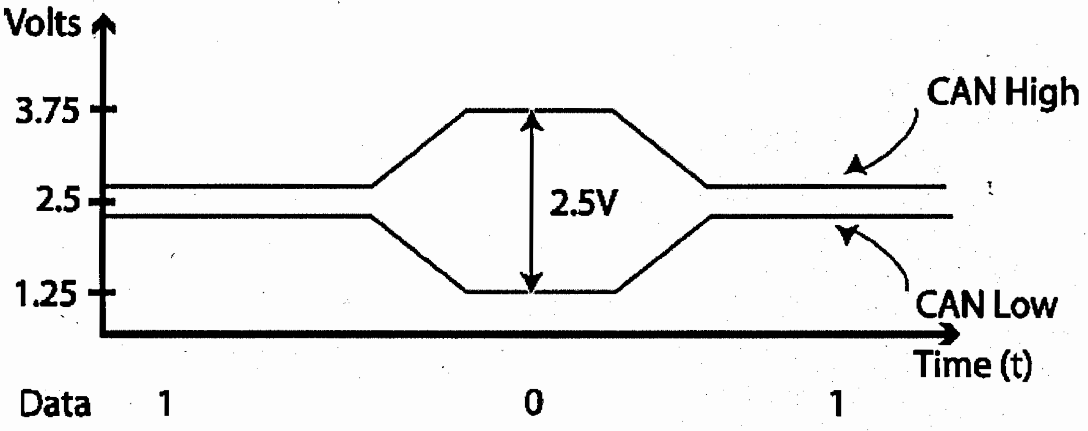

Figure 23. CAN Voltage Limits

APPENDIX C

ELECTRICAL NETWORK SYSTEMS

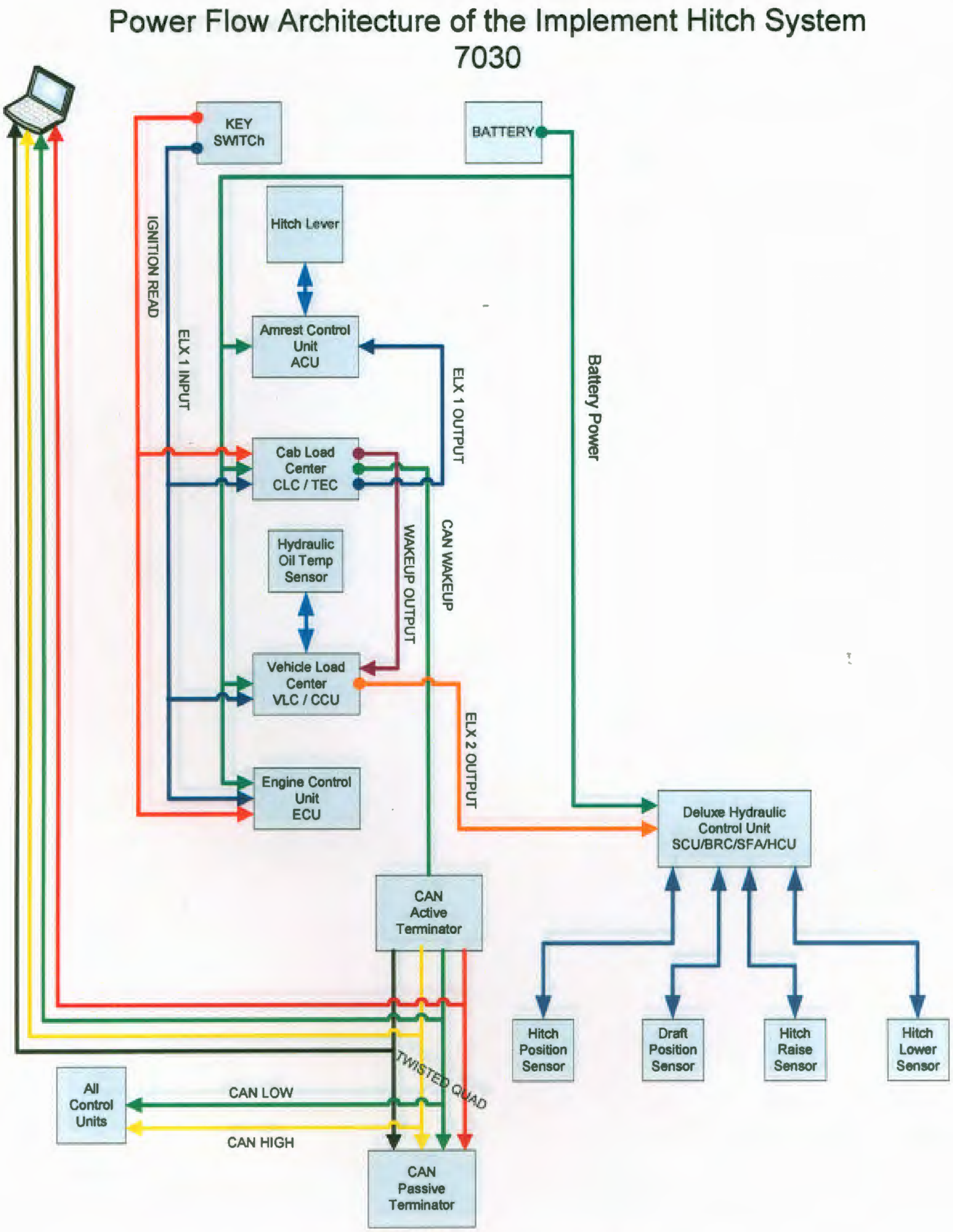

Figure 24. Power Flow Architecture of the Implement Hitch System 7030

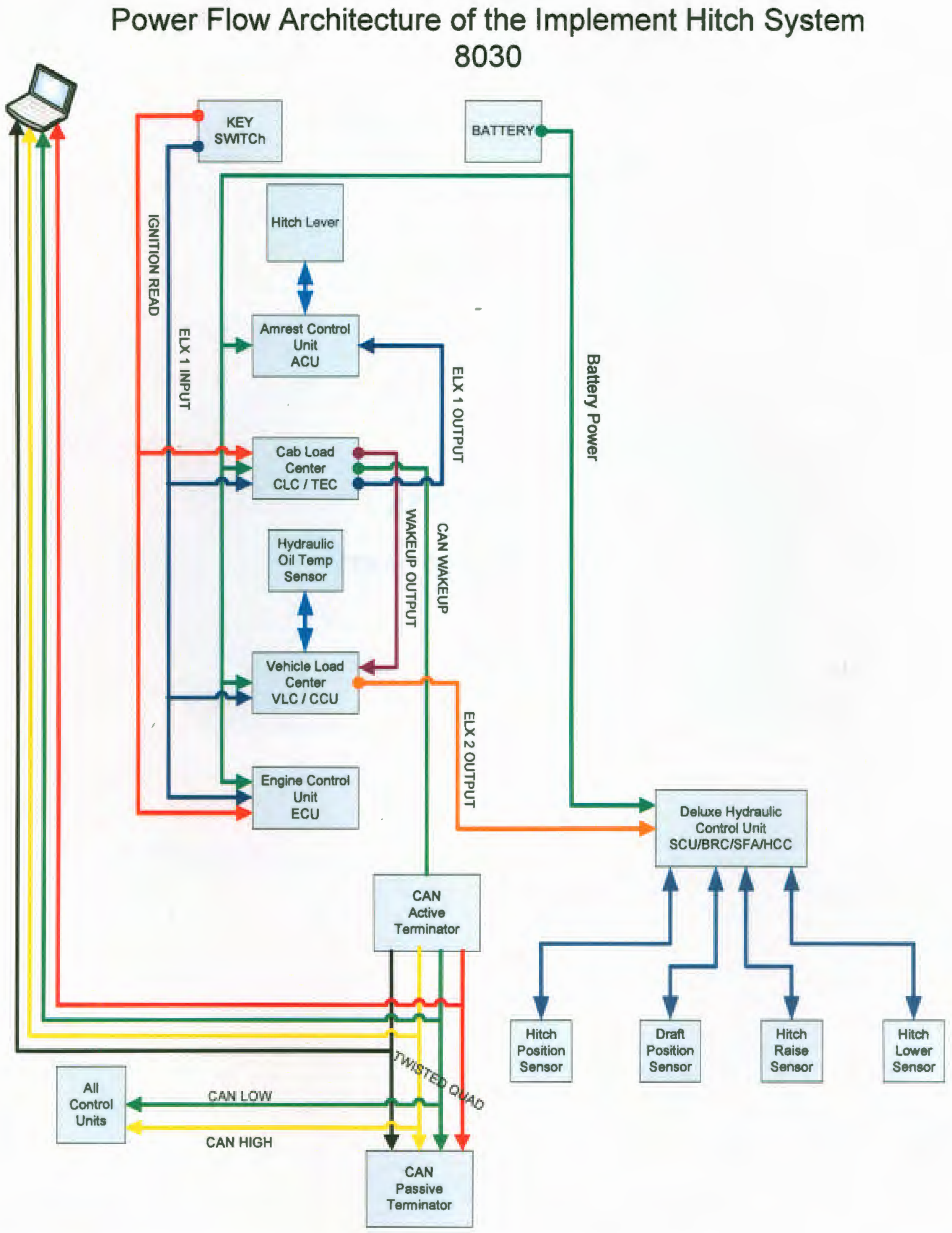

Figure 25. Power Flow Architecture of the Implement Hitch System 8030

APPENDIX D

TRACTOR MODELS

7030 Tractor Model

Figure 26. 7030 Tractor Model

8030 Tractor Model

Figure 27. 8030 Tractor Model

APPENDIX E

LIST OF TABLES

Table 7.

7030 Calibration Data Set

Experiment	Tractor System Voltage	Draft Sensor Voltage @ Start (HCU 05)	Position Sensor Voltage @ Start (HCU 08)	Pre-Cal Oil Temp	Post-Cal Oil Temp	EngineSpeed	LIMT	D-Zr	P-Mn	P-Mx
1	14.00	2.56	3.60	58	59	1964	467	2.56	0.92	3.61
2	13.90	2.48	3.66	54	55	1970	392	2.46	0.91	3.66
3	13.80	2.57	3.66	48	47	1976	471	2.57	0.91	3.68
4	13.80	2.58	3.60	50	51	1978	498	2.56	0.91	3.61
5	13.90	2.50	3.70	49	49	1981	485	2.50	0.95	3.70
6	13.80	2.46	3.68	50	50	1986	364	2.46	0.93	3.69
7	13.80	2.48	3.73	50	49	1988	504	2.47	0.97	3.73
8	13.90	2.54	3.68	47	48	1990	379	2.53	0.91	3.70
9	13.80	2.57	3.59	48	48	1993	410	2.57	0.89	3.60
10	13.90	2.51	3.63	53	54	1999	384	2.51	0.89	3.64
11	13.70	2.62	3.68	45	46	2201	486	2.60	0.94	3.69
12	13.70	2.47	3.57	64	69	2209	459	2.47	0.82	3.58
13	13.60	2.52	3.66	55	56	2210	449	2.52	0.95	3.67
14	13.90	2.45	3.67	49	50	2215	472	2.44	0.93	3.68
15	14.00	2.52	3.65	51	51	2218	381	2.50	0.93	3.65
16	14.00	2.52	3.60	51	52	2220	444	2.52	0.85	3.60
17	13.90	2.50	3.68	55	56	2226	448	2.49	1.01	3.68
18	13.80	2.44	3.71	48	48	2228	467	2.42	0.95	3.72
19	13.70	2.59	3.68	53	52	2228	496	2.58	0.97	3.68
20	13.9	2.54	3.71	50	50	2231	425	2.52	0.93	3.71

Table 8.

7030 Calibration Data Set with Engine Speed (1900 – 2000) rpm

Experiment	Tractor System Voltage	Draft Sensor Voltage @ Start (HCU 05)	Position Sensor Voltage @ Start (HCU 08)	Pre-Cal Oil Temp	Post-Cal Oil Temp	EngineSpeed	LIMT	D-Zr	P-Mn	P-Mx
1	14.00	2.56	3.60	58	59	1964	467	2.56	0.92	3.61
2	13.90	2.48	3.66	54	55	1970	392	2.46	0.91	3.66
3	13.80	2.57	3.66	48	47	1976	471	2.57	0.91	3.68
4	13.80	2.58	3.60	50	51	1978	498	2.56	0.91	3.61
5	13.90	2.50	3.70	49	49	1981	485	2.50	0.95	3.70
6	13.80	2.46	3.68	50	50	1986	364	2.46	0.93	3.69
7	13.80	2.48	3.73	50	49	1988	504	2.47	0.97	3.73
8	13.90	2.54	3.68	47	48	1990	379	2.53	0.91	3.70
9	13.80	2.57	3.59	48	48	1993	410	2.57	0.89	3.60
10	13.90	2.51	3.63	53	54	1999	384	2.51	0.89	3.64

Table 9.

7030 Calibration Data Set with Engine Speed (2200 – 2300) rpm

Experiment	Tractor System Voltage	Draft Sensor Voltage @ Start (HCU 05)	Position Sensor Voltage @ Start (HCU 08)	Pre-Cal Oil Temp	Post-Cal Oil Temp	EngineSpeed	LIMT	D-Zr	P-Mn	P-Mx
11	13.70	2.62	3.68	45	46	2201	486	2.60	0.94	3.69
12	13.70	2.47	3.57	64	69	2209	459	2.47	0.82	3.58
13	13.60	2.52	3.66	55	56	2210	449	2.52	0.95	3.67
14	13.90	2.45	3.67	49	50	2215	472	2.44	0.93	3.68
15	14.00	2.52	3.65	51	51	2218	381	2.50	0.93	3.65
16	14.00	2.52	3.60	51	52	2220	444	2.52	0.85	3.60
17	13.90	2.50	3.68	55	56	2226	448	2.49	1.01	3.68
18	13.80	2.44	3.71	48	48	2228	467	2.42	0.95	3.72
19	13.70	2.59	3.68	53	52	2228	496	2.58	0.97	3.68
20	13.9	2.54	3.71	50	50	2231	425	2.52	0.93	3.71

Table 10.

8030 Calibration Data Set

Experiments	Tractor System Voltage	Draft Sensor Voltage @ Start (HCU 05)	Position Sensor Voltage @ Start (HCU 08)	Pre-Cal Oil Temp	Post-Cal Oil Temp	Engine Speed	LIMT	D-Zr	P-Mn	P-Mx
1	14.20	2.10	4.01	57	59	1953	141	2.14	1.10	4.05
2	14.10	2.05	4.09	57	59	1958	99	2.06	1.16	4.12
3	14.10	2.09	3.91	57	61	1964	88	2.13	1.02	3.97
4	14.10	2.12	3.93	57	63	1966	128	2.14	0.98	3.98
5	14.00	1.97	4.05	57	67	1977	121	2.01	1.12	4.10
6	14.10	2.05	3.91	57	61	1981	125	2.09	1.00	3.97
7	14.20	2.14	4.01	57	64	1985	102	2.19	1.10	4.07
8	14.20	2.11	4.05	57	63	1989	112	2.13	1.13	4.09
9	14.10	2.08	3.87	57	60	1993	170	2.14	0.92	3.92
10	14.00	2.07	4.10	58	63	1999	127	2.08	1.17	4.12
11	14.00	2.05	3.96	57	66	2202	126	2.10	1.12	4.03
12	13.90	2.12	4.03	57	52	2205	125	2.17	1.14	4.09
13	14.00	2.21	4.08	57	64	2207	125	2.23	1.15	4.12
14	14.00	2.14	3.95	59	64	2210	147	2.20	1.08	4.02
15	14.20	2.04	4.03	57	65	2212	148	2.09	1.19	4.10
16	14.20	2.13	4.08	57	67	2215	124	2.14	1.16	4.11
17	14.20	2.12	3.94	57	64	2217	146	2.16	1.02	3.98
18	14.10	2.06	4.05	57	60	2219	144	2.11	1.19	4.12
19	13.90	2.04	4.05	57	64	2223	138	2.10	1.23	4.12
20	13.90	2.04	4.05	57	64	2224	121	2.06	1.13	4.10

Table 11.

8030 Calibration Data Set with Engine Speed (1900 – 2000) rpm

Experiments	Tractor System Voltage	Draft Sensor Voltage @ Start (HCU 05)	Position Sensor Voltage @ Start (HCU 08)	Pre-Cal Oil Temp	Post-Cal Oil Temp	Engine Speed	LIMT	D-Zr	P-Mn	P-Mx
1	14.20	2.10	4.01	57	59	1953	141	2.14	1.10	4.05
2	14.10	2.05	4.09	57	59	1958	99	2.06	1.16	4.12
3	14.10	2.09	3.91	57	61	1964	88	2.13	1.02	3.97
4	14.10	2.12	3.93	57	63	1966	128	2.14	0.98	3.98
5	14.00	1.97	4.05	57	67	1977	121	2.01	1.12	4.10
6	14.10	2.05	3.91	57	61	1981	125	2.09	1.00	3.97
7	14.20	2.14	4.01	57	64	1985	102	2.19	1.10	4.07
8	14.20	2.11	4.05	57	63	1989	112	2.13	1.13	4.09
9	14.10	2.08	3.87	57	60	1993	170	2.14	0.92	3.92
10	14.00	2.07	4.10	58	63	1999	127	2.08	1.17	4.12

Table 12.

8030 Calibration Data Set with Engine Speed (2200 – 2300) rpm

Experiments	Tractor System Voltage	Draft Sensor Voltage @ Start (HCU 05)	Position Sensor Voltage @ Start (HCU 08)	Pre-Cal Oil Temp	Post-Cal Oil Temp	Engine Speed	LIMT	D-Zr	P-Mn	P-Mx
11	14.00	2.05	3.96	57	66	2202	126	2.10	1.12	4.03
12	13.90	2.12	4.03	57	52	2205	125	2.17	1.14	4.09
13	14.00	2.21	4.08	57	64	2207	125	2.23	1.15	4.12
14	14.00	2.14	3.95	59	64	2210	147	2.20	1.08	4.02
15	14.20	2.04	4.03	57	65	2212	148	2.09	1.19	4.10
16	14.20	2.13	4.08	57	67	2215	124	2.14	1.16	4.11
17	14.20	2.12	3.94	57	64	2217	146	2.16	1.02	3.98
18	14.10	2.06	4.05	57	60	2219	144	2.11	1.19	4.12
19	13.90	2.04	4.05	57	64	2223	138	2.10	1.23	4.12
20	13.90	2.04	4.05	57	64	2224	121	2.06	1.13	4.10

Table 13.

7030 Descriptive Statistics Results

Descriptive Statistics (7030)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
Tractor System Voltage	20	13.840	13.600	14.000	0.1095
Draft Sensor Voltage @ Start (HCU 05)	20	2.521	2.440	2.620	0.0499
Position Sensor Voltage @ Start (HCU 08)	20	3.657	3.570	3.730	0.0449
Pre-Cal Oil Temp	20	51.400	45.000	64.000	4.3213
Post-Cal Oil Temp	20	52.000	46.000	69.000	5.2516
EngineSpeed	20	2100.550	1964.000	2231.000	121.5334
LIMT	20	444.050	364.000	504.000	44.6725
D-Zr	20	2.512	2.420	2.600	0.0500
P-Mn	20	0.924	0.820	1.010	0.0420
P-Mx	20	3.664	3.580	3.730	0.0438

Table 14.

8030 Descriptive Statistics Results

Descriptive Statistics (8030)

	Valid N	Mean	Minimum	Maximum	Std.Dev.
Tractor System Voltage	20	14.075	13.900	14.200	0.1070
Draft Sensor Voltage @ Start (HCU 05)	20	2.087	1.970	2.210	0.0523
Position Sensor Voltage @ Start (HCU 08)	20	4.008	3.870	4.100	0.0688
Pre-Cal Oil Temp	20	57.150	57.000	59.000	0.4894
Post-Cal Oil Temp	20	62.500	52.000	67.000	3.4412
Engine Speed	20	2094.950	1953.000	2224.000	122.1093
LIMT	20	127.850	88.000	170.000	19.0464
D-Zr	20	2.124	2.010	2.230	0.0526
P-Mn	20	1.106	0.920	1.230	0.0799
P-Mx	20	4.059	3.920	4.120	0.0642

Table 15.

7030 Regression Model Results

Regression Summary for Dependent Variable: Tractor System Voltage (7030.sta) R= .59378750 R^2= .35258360 Adjusted R^2= ----- F(9,10)=.60511 p

	Beta	Std.Err. - of Beta	B	Std.Err. - of B	t(10)	p-level
Intercept			20.20952	5.491190	3.68035	0.004244
Draft Sensor Voltage @ Start (HCU 05)	0.43507	1.829921	0.95440	4.014231	0.23776	0.816871
Position Sensor Voltage @ Start (HCU 08)	2.31236	2.319508	5.64778	5.665236	0.99692	0.342315
Pre-Cal Oil Temp	0.26770	2.006839	0.00679	0.050873	0.13339	0.896528
Post-Cal Oil Temp	-0.62776	2.073550	-0.01309	0.043253	-0.30275	0.768286
EngineSpeed	-0.20237	0.302397	-0.00018	0.000273	-0.66920	0.518516
LIMT	-0.26644	0.279186	-0.00065	0.000685	-0.95436	0.362401
D-Zr	-0.69187	1.873113	-1.51462	4.100550	-0.36937	0.719553
P-Mn	-0.00286	0.467424	-0.00747	1.220248	-0.00612	0.995236
P-Mx	-2.68687	2.195069	-6.71718	5.487673	-1.22405	0.248990

Table 16.

7030 Backward Elimination 1.

Regression Summary for Dependent Variable: Tractor System Voltage (Spreadsheet1.sta) R= .59378546 R²= .35258117 Adjusted R²= ----- F(8,11)=.74882 p

	Beta	Std.Err. - of Beta	B	Std.Err. - of B	t(11)	p-level
Intercept			20.22379	4.74027	4.2663	0.00132
Draft Sensor Voltage @ Start (HCU 05)	0.43307	1.71665	0.95001	3.76577	0.2522	0.80548
Position Sensor Voltage @ Start (HCU 08)	2.31064	2.19529	5.64358	5.36184	1.0525	0.31512
Pre-Cal Oil Temp	0.26275	1.75141	0.00666	0.04439	0.1500	0.88346
Post-Cal Oil Temp	-0.6230	1.83280	-0.01300	0.03823	-0.3399	0.74032
EngineSpeed	-0.20251	0.28750	-0.00018	0.00025	-0.7043	0.49584
LIMT	-0.26675	0.26204	-0.00065	0.00064	-1.0179	0.33057
D-Zr	-0.69026	1.76810	-1.51108	3.87067	-0.3903	0.70370
P-Mx	-2.68706	2.09270	-6.71766	5.23177	-1.28401	0.22552

Table 17.

7030 Backward Elimination 2.

Regression Summary for Dependent Variable: Tractor System Voltage (Spreadsheet1.sta) R= .52264805 R^2= .27316098 Adjusted R^2= .07933724 F(4,15)=1.4093 p

	Beta	Std.Err. - of Beta	B	Std.Err. - of B	t(15)	p-level
Intercept			15.67006	2.057618	7.61563	0.000002
Position Sensor Voltage @ Start (HCU 08)	2.63201	1.594449	6.42849	3.894329	1.65073	0.119570
EngineSpeed	-0.23577	0.235419	-0.00021	0.000212	-1.00151	0.332464
LIMT	-0.33751	0.224652	-0.00083	0.000551	-1.50236	0.153762
P-Mx	-2.67742	1.586724	-6.69355	3.966809	-1.68739	0.112207

Table 18.

7030 Backward Elimination 3.

Regression Summary for Dependent Variable: Tractor System Voltage (Spreadsheet1.sta) R= .47387623 R²= .22455868 Adjusted R²= .07916343 F(3,16)=1.5445 p						
	Beta	Std.Err. - of Beta	B	Std.Err. - of B	t(16)	p-level
Intercept			15.31597	2.027206	7.55521	0.000001
Position Sensor Voltage @ Start (HCU 08)	2.13733	1.516156	5.22027	3.703106	1.40970	0.177769
LIMT	-0.36982	0.222345	-0.00091	0.000545	-1.66328	0.115717
P-Mx	-2.20129	1.513971	-5.50323	3.784929	-1.45398	0.165285

Table 19.

8030 Regression Model Results

Regression Summary for Dependent Variable: Tractor System Voltage (Spreadsheet1) R= .68713587 R²= .47215570 Adjusted R²= ----- F(9,10)=.99389 p

	Beta	Std.Err. - of Beta	B	Std.Err. - of B	t(10)	p-level
Intercept			-23.13876	6.401882	3.61437	0.004734
Draft Sensor Voltage @ Start (HCU 05)	0.81132	1.739067	1.65840	3.554795	0.46652	0.650838
Position Sensor Voltage @ Start (HCU 08)	0.29979	2.350963	0.46611	3.655229	0.12752	0.901058
Pre-Cal Oil Temp	-0.38077	0.246909	-0.08325	0.053983	-1.54215	0.154064
Post-Cal Oil Temp	0.32170	0.249160	0.01000	0.007747	1.29113	0.225707
Engine Speed	-0.69415	0.392197	-0.00061	0.000344	-1.76990	0.107170
LIMT	0.33167	0.355233	0.00186	0.001996	0.93366	0.372473
D-Zr	-0.32217	1.695778	-0.65479	3.446504	-0.18999	0.853121
P-Mn	1.23144	1.014861	1.64900	1.358986	1.21340	0.252858
P-Mx	-1.42805	2.467841	-2.37887	4.110970	-0.57866	0.575616

Table 20.

8030 Backward Elimination 1.

Regression Summary for Dependent Variable: Tractor System Voltage (Spreadsheet4.sta) R= .68651102 R^2= .47129738 Adjusted R^2= .08678639 F(8,11)=1.2257 p

	Beta	Std.Err. - of Beta	B	Std.Err. - of B	t(11)	p-level
Intercept			23.0552	6.076844	3.79395	0.002974
Draft Sensor Voltage @ Start (HCU 05)	0.99206	0.961507	2.02786	1.965399	1.03178	0.324328
Pre-Cal Oil Temp	-0.38021	0.235572	-0.08313	0.051505	-1.61399	0.134825
Post-Cal Oil Temp	0.31895	0.236870	0.00992	0.007365	1.34654	0.205219
Engine Speed	-0.71659	0.334439	-0.00063	0.000293	-2.14267	0.055347
LIMT	0.35577	0.286995	0.00200	0.001612	1.23965	0.240900
D-Zr	-0.49478	0.974730	-1.00560	1.981043	-0.50761	0.621749
P-Mn	1.22969	0.968331	1.64666	1.296677	1.26991	0.230324
P-Mx	-1.13960	0.941506	-1.89837	1.568376	-1.21040	0.251491

Table 21.

8030 Backward Elimination 2.

Regression Summary for Dependent Variable: Tractor System Voltage (Spreadsheet4.sta) R= .67743103 R²= .45891280 Adjusted R²= .14327860 F(7,12)=1.4539 p

	Beta	Std.Err. - of Beta	B	Std.Err. - of B	t(12)	p-level
Intercept			21.52135	5.106618	4.21440	0.001201
Draft Sensor Voltage @ Start (HCU 05)	0.521746	0.248909	1.06649	0.508790	2.09614	0.057941
Pre-Cal Oil Temp	-0.384153	0.228046	-0.08399	0.049859	-1.68454	0.117885
Post-Cal Oil Temp	0.349354	0.221973	0.01086	0.006901	1.57385	0.141504
Engine Speed	-0.729173	0.323039	-0.00064	0.000283	-2.25723	0.043427
LIMT	0.310805	0.264402	0.00175	0.001485	1.17550	0.262590
P-Mn	1.003755	0.832951	1.34411	1.115392	1.20506	0.251408
P-Mx	-0.875699	0.760283	-1.45875	1.266491	-1.15181	0.271832

Table 22.

8030 Backward Elimination 3.

Regression Summary for Dependent Variable: Tractor System Voltage (Spreadsheet4.sta) R= .57784338 R²= .33390297 Adjusted R²= .15627710 F(4,15)=1.8798 p

	Beta	Std.Err. - of Beta	B	Std.Err. - of B	t(15)	p-level
Intercept			16.15533	2.672488	6.04505	0.000022
Draft Sensor Voltage @ Start (HCU 05)	0.372465	0.219862	0.76135	0.449416	1.69409	0.110905
Pre-Cal Oil Temp	-0.278755	0.216991	-0.06095	0.047442	-1.28464	0.218404
Post-Cal Oil Temp	0.300939	0.218311	0.00936	0.006788	1.37849	0.188267
Engine Speed	-0.419802	0.217976	-0.00037	0.000191	-1.92591	0.073285

Table 23.

7030 Regression on Oil Temp Change

Regression Summary for Dependent Variable: Tractor System Voltage (Spreadsheet1) R= .10566113 R²= .01116427 Adjusted R²= ----- F(1,18)=.20323 p

	Beta	Std.Err. - of Beta	B	Std.Err. - of B	t(18)	p-level
Intercept			13.84545	0.027797	498.0954	0.000000
Oil Temp Change	-0.105661	0.234383	-0.00909	0.020166	-0.4508	0.657513

Table 24.

8030 Regression on Oil Temp Change

Regression Summary for Dependent Variable: Tractor System Voltage (Spreadsheet4) R= .18325961 R^2= .03358408 Adjusted R^2= ----- F(1,18)=.62552 p

	Beta	Std.Err. - of Beta	B	Std.Err. - of B	t(18)	p-level
Intercept			14.04435	0.045670	307.5186	0.000000
Oil Temp Change	0.183260	0.231711	0.00573	0.007244	0.7909	0.439300

Table 25.

7030 t-test Analysis Result on Oil Temp Change

Test of means against reference constant (value) (Spreadsheet1)

	Mean	Std.Dv.	N	Std.Err.	Reference - Constant	t-value	df	p
Oil Temp Change	0.6000	1.273206	20	0.284697	0.00	2.107501	19	0.0485

Table 26.

8030 t-test Analysis Result on Oil Temp Change

Test of means against reference constant (value) (Spreadsheet4)

	Mean	Std.Dv.	N	Std.Err.	Reference - Constant	t-value	df	p
Oil Temp Change	5.3500	3.42244	20	0.765283	0.00	6.990879	19	0.000001

APPENDIX F

T - VALUES

Table 27.

Table of Critical T-Values

	alpha = (1-tailed)	0.25	0.1	0.05	0.025	0.01	0.005	0.001
	alpha ( ) = (2-tailed)	0.5	0.2	0.1	0.05	0.02	0.01	0.002
degrees of freedom (df)								
1		1.000	3.078	6.314	12.706	31.821	63.657	318.309
2		0.816	1.886	2.920	4.303	6.965	9.925	22.327
3		0.765	1.638	2.353	3.182	4.541	5.841	10.215
4		0.741	1.533	2.132	2.776	3.747	4.604	7.173
5		0.727	1.476	2.015	2.571	3.365	4.032	5.893
6		0.718	1.440	1.943	2.447	3.143	3.707	5.208
7		0.711	1.415	1.895	2.365	2.998	3.499	4.785
8		0.706	1.397	1.860	2.306	2.896	3.355	4.501
9		0.703	1.383	1.833	2.262	2.821	3.250	4.297
10		0.700	1.372	1.812	2.228	2.764	3.169	4.144
11		0.697	1.363	1.796	2.201	2.718	3.106	4.025
12		0.695	1.356	1.782	2.179	2.681	3.055	3.930
13		0.694	1.350	1.771	2.160	2.650	3.012	3.852
14		0.692	1.345	1.761	2.145	2.624	2.977	3.787
15		0.691	1.341	1.753	2.131	2.602	2.947	3.733
16		0.690	1.337	1.746	2.120	2.583	2.921	3.686
17		0.689	1.333	1.740	2.110	2.567	2.898	3.646
18		0.688	1.330	1.734	2.101	2.552	2.878	3.610
19		0.688	1.328	1.729	2.093	2.539	2.861	3.579
20		0.687	1.325	1.725	2.086	2.528	2.845	3.552
21		0.686	1.323	1.721	2.080	2.518	2.831	3.527
22		0.686	1.321	1.717	2.074	2.508	2.819	3.505
23		0.685	1.319	1.714	2.069	2.500	2.807	3.485
24		0.685	1.318	1.711	2.064	2.492	2.797	3.467
25		0.684	1.316	1.708	2.060	2.485	2.787	3.450

	alpha = (1-tailed)	0.25	0.1	0.05	0.025	0.01	0.005	0.001
	alpha ( ) = (2-tailed)	0.5	0.2	0.1	0.05	0.02	0.01	0.002
degrees of freedom (df)								
26		0.684	1.315	1.706	2.056	2.479	2.779	3.435
27		0.684	1.314	1.703	2.052	2.473	2.771	3.421
28		0.683	1.313	1.701	2.048	2.467	2.763	3.408
29		0.683	1.311	1.699	2.045	2.462	2.756	3.396
30		0.683	1.310	1.697	2.042	2.457	2.750	3.385
31		0.682	1.309	1.696	2.040	2.453	2.744	3.375
32		0.682	1.309	1.694	2.037	2.449	2.738	3.365
33		0.682	1.308	1.692	2.035	2.445	2.733	3.356
34		0.682	1.307	1.691	2.032	2.441	2.728	3.348
35		0.682	1.306	1.690	2.030	2.438	2.724	3.340
36		0.681	1.306	1.688	2.028	2.434	2.719	3.333
37		0.681	1.305	1.687	2.026	2.431	2.715	3.326
38		0.681	1.304	1.686	2.024	2.429	2.712	3.319
39		0.681	1.304	1.685	2.023	2.426	2.708	3.313
40		0.681	1.303	1.684	2.021	2.423	2.704	3.307
41		0.681	1.303	1.683	2.020	2.421	2.701	3.301
42		0.680	1.302	1.682	2.018	2.418	2.698	3.296
43		0.680	1.302	1.681	2.017	2.416	2.695	3.291
44		0.680	1.301	1.680	2.015	2.414	2.692	3.286
45		0.680	1.301	1.679	2.014	2.412	2.690	3.281
46		0.680	1.300	1.679	2.013	2.410	2.687	3.277
47		0.680	1.300	1.678	2.012	2.408	2.685	3.273
48		0.680	1.299	1.677	2.011	2.407	2.682	3.269
49		0.680	1.299	1.677	2.010	2.405	2.680	3.265
50		0.679	1.299	1.676	2.009	2.403	2.678	3.261