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Instrumentation for in-field measurements of energy inputs to tractor-powered agricultural implements

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To the Graduate Council:

I am submitting herewith a dissertation written by Robert Sherron Freeland entitled "Instrumentation for in-field measurements of energy inputs to tractor-powered agricultural implements." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Mechanical Engineering.

Fred D. Tompkins, Major Professor

We have read this dissertation and recommend its acceptance:

Luther R. Wilhelm, Bobby L. Bledsoe, Don W. Bouldin

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

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and recommend its acceptance:

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Accepted for the Council:

CW Minkel
Vice Provost
and Dean of The Graduate School

INSTRUMENTATION FOR IN-FIELD MEASUREMENTS OF ENERGY INPUTS TO TRACTOR-POWERED AGRICULTURAL IMPLEMENTS

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Robert Sherron Freeland
August 1985

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ABSTRACT

A second generation data acquisition system, integrally mounted on a two-wheel drive 75-PTO kW agricultural tractor, was interfaced to various sensors which measured: (1) time, (2) implement draft, (3) left and right drive axle torque, (4) left and right drive wheel rotation, (5) ground surface displacement, (6) fuel flow, (7) PTO torque, and (8) engine flywheel rotation. This data gathering system was centered around a DEC PDP11/03-LK microcomputer using the RT-11 operating system and having a linkage of MACRO-11 and FORTRAN IV data acquisition routines. Magnetic memory, of the same capacity as two RX01 floppy disks, was subdivided into the system device and the data storage device. Real-time data were displayed in engineering units on the operator CRT console. Physical transfer of archived test data for mainframe statistical analysis was accomplished using a TU58 tape drive.

Sensors were simultaneously sampled once per second using a crystal controlled hardware interrupt. Before sampling by an A/D board, each analog signal was passed through an active low-pass filter having a one-half Hz cutoff frequency to satisfy the Nyquist Criterion of the Sampling Theorem. Digital signals were counted by an in-house designed counterboard. Digital count values were read and subsequently cleared through software.

Digital sensors were (1) two bi-directional optical shaft encoders measuring rear axle speeds, (2) a transducer sensing fuel consumption rates, (3) a single-beam radar unit measuring true ground speeds, and (4) a passive magnetic sensor monitoring engine speeds. Analog sensors included mounted strain gauges detecting drive wheel torques and implement drafts, and a commercial load cell sensing PTO torques.

The revised data acquisition system has been field tested for three growing seasons with repeatable results. Specific tests included gathering energy consumption data of tillage operations, and acquiring data showing the energy used throughout the formation of a round bale. In addition, the performance of three ground speed sensors was determined while traversing selected ground surfaces at various operating speeds.

Further work is needed on the sensor used for measuring the drafts produced by towed PTO-driven implements. Also, minor adjustments to the counterboard are required.

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INTRODUCTION

I. BACKGROUND AND STATEMENT OF THE PROBLEM

The agricultural tractor has been studied, evaluated, and continuously modified since its invention in the late 1880's. For more than half a century, research was primarily conducted on the tractor to increase its power and performance. Also, substantial public research was conducted to validate claims made by tractor manufacturers (Gray, 1954). Tractor research throughout this period was implemented using a combination of manual observations and bulky measuring and recording devices (examples illustrated in Figures 1 and 2).

Two events caused a significant evolution in tractor research during the 1970's. First, a major event was the introduction of micro-electronics and, subsequently, the microprocessor. Electronic sensors, recorders, and controllers replaced the bulky recording devices and manual observations used previously. Inexpensive, ultra-fast, low-power consuming, and small--such were the characteristics of the new micro-electronics. These new tools provided researchers assistance in monitoring and evaluating tractor performance.

Secondly, a powerful catalyst to tractor performance research was the Arab Oil Embargo of 1973-1974. Fuel prices escalated and shortages occurred periodically. Because approximately 15 billion

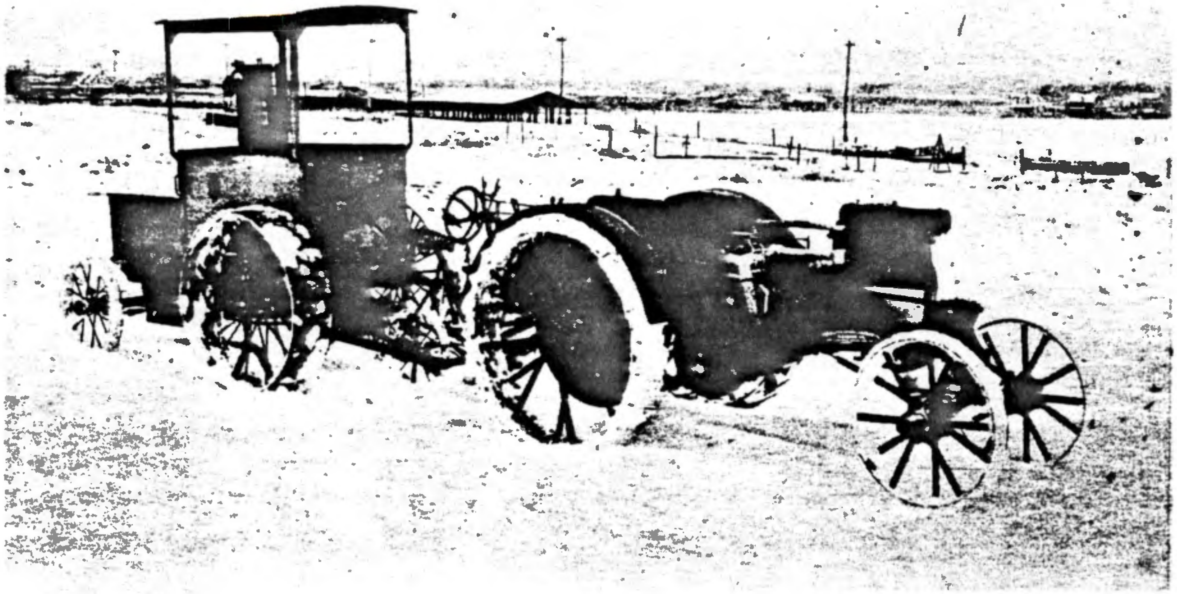

Figure 1. The State of Nebraska requires all tractors sold in the state to be tested. The results of the test are compared to published claims of the manufacturer covering that tractor. Shown is an early Nebraska test car and tractor (Twin City 12-20) being tested in the Fall of 1919 (Gray, 1954).

Figure 2. A Nebraska test car and tractor (Case VAC) being tested in 1949. The Nebraska tests have become a standard for the United States and for many foreign countries. The tests have been responsible for the removal from the market of many tractors of inferior design (Gray, 1954).

liters of fuel are used annually in the United States to power tractors (Chancellor and Thai, 1983), concern over these problems was expressed. Public awareness of energy use increased; thus, research was initiated in the areas of energy conservation and alternate energy sources.

Agricultural researchers rapidly started applying the new electronic technologies to investigating methods for conserving fuel. Numerous research institutions began instrumenting commercial tractors. Fuel consumption studies were conducted along with numerous other experiments.

The period from the Oil Embargo to the present has brought about significant changes in tractor instrumentation. New technological advances have reduced the size and cost of instrumentation and greatly increased instrumentation capability and performance. Sophisticated tools once used only by the researcher are now helping the farmer produce more economically. As hydraulics have expanded the muscle power of the tractor operator, electronics are expanding the capacity of the operator's mind (Jones et al., 1983).

Modern tractors can be equipped with a multitude of performance monitors and controllers. Instrumentation for monitoring engine and transmission performance is available as standard or optional equipment from tractor manufacturers. Various manufacturers supply hay bale formation monitors and implement depth/draft controllers. Seed placement and chemical application are being controlled with electronics. True ground speed is sensed through radar. Instrumentation systems for commercial tractors are routinely available in such quantities that industry interface and communication standards have been proposed (Jahns and Speckmann, 1984).

New technology always generates questions concerning how and where it should be applied. What type of sensors are required and in what manner should they be installed to get accurate, reliable, and precise results? The exponential pace of technology supplies superior, smaller, and less expensive instrumentation much faster than it can be applied and tested. Today's advanced technology will be considered obsolete within a decade.

Another evolution has recently started; it is the application of electronic monitoring to the area of feedback and control. Automation of tasks normally done by a tractor operator are being performed much more accurately, faster, and economically through use of microelectronics (Chancellor and Thai, 1984 and Murphy et al., 1984).

Advanced automation may continue to the point of entirely replacing the tractor operator. The high cost of labor, coupled with the hazardous environment associated with farm machinery, may justify complete automation (Shoup and Macchio, 1984).

The introduction of new technology continuously generates new questions to be addressed. Further study in the correct application and interaction of new sensors and electronic devices in agriculture is needed.

II. OBJECTIVES

The purpose of this research was to continue the design, installation, and testing of the instrumented research tractor reported by Hart (1982). Additional desired information and technological advances warranted further work on this system. Specific objectives of the research were as follows:

1. Design and evaluation of hardware and software for measuring the energy requirements of towed PTO-driven implements;
2. Correction of problems and errors occurring in the original system;
3. Application of new technologies to the system such that enhanced research may be conducted.

CHAPTER II

REVIEW OF LITERATURE

I. REPORTED INSTRUMENTED TRACTORS

Introduction

A review of the literature showed many similarities among a variety of recently implemented tractor-based data acquisition systems. Although each system was independently designed, the similarities between the systems were much greater than the differences. A given set of sensors, hardware, and software languages reoccurred among the various systems. Therefore, the similarities of the systems are presented, and then the variations among systems are explored.

Commonly Used Sensors

The strain gauge, a device used to measure force, was the most commonly occurring sensor among the reviewed systems. Researchers used discreet strain gauges, and they also used commercially available load cells which internally contain strain gauges. In addition, instrumentation for conditioning the output signal from a strain gauge was required.

Rotational displacement was measured using magnetic proximity sensors, tachogenerators, and/or rotational shaft encoders. Magnetic proximity sensors, mounted above a gear which was attached to a shaft, generated a digital pulse as each gear tooth passed near

near the sensor. Tachogenerators, attached to a shaft, produced a voltage linearly proportional to shaft speed. Rotational shaft encoders, also shaft attached, emitted a digital pulse for a given increment of shaft rotation.

Ground Speed, Fuel Consumption, and Draft Measurements

The majority of the reviewed systems obtained true ground speed using either a fifth wheel arrangement, a commercially obtained radar unit, or a fabricated front wheel speed sensor. When upgrading a system, researchers tended to progress from using front wheel speed sensors, to free-tracking fifth wheels, to commercially obtained radar units.

Almost all systems measured fuel consumption using commercially available flow meters. Meters employing volumetric positive displacement devices were the most numerous. Special plumbing was required to prevent remeasurement of the fuel returning from the tractor injector pump.

In most systems, implement draft measurements were made using quick-attach three-point hitch couplers. The couplers were either in-house constructed or commercially obtained. Draft was usually sensed using strain gauges attached to the couplers at strategic locations. Another common method for obtaining draft forces was through the application of discreet strain gauges to the drawbar or to the three-point hitch arms on the tractor.

Computer Systems

Among the reviewed systems, the greatest differences occurred with the type of computer components used. Systems tended to have different brands and series of central processing units; however, eight-bit processors were dominant among central processing units used. The ability to dump to a mainframe for data manipulation and statistical analysis was common to almost all systems.

Most systems used cassette tape for data recording. Researchers cited dust and vibration problems as the reason for using magnetic tape. However, floppy disk drives were reportedly successfully used by three investigators. Magnetic memory, nonvolatile and having mass storage device emulation capabilities, were becoming more popular in upgraded systems.

System software most often tended to be the linkage of two languages. Prevalent languages were assembly language for data acquisition and BASIC for on-site data manipulation. Assembly language was used for its fast execution times, compactness, and flexibility. Higher-level languages, such as FORTRAN and BASIC, were used for the ease of program development.

Instrumentation systems requiring AC power were always powered using either a DC-to-AC converter or an AC generator. In some systems, a DC-to-AC converter was desired because of the small space requirement. In other systems, an AC generator was used because it provided more current supplying capacity and more true "wall outlet" compatibility than a DC-to-AC converter.

Sensor-to-computer interfacing was most often accomplished using an analog-to-digital board (A/D). Sensors having digital pulse outputs were often converted to analog outputs using frequency-to-voltage converters. Otherwise, digital pulses were counted using either software polling routines or specially constructed counter-boards which used hardware counters.

Although many types of measurements were taken by the different systems, there were typically six basic measurements taken by the systems reviewed:

1. Time,
2. Surface distance,
3. Implement draft,
4. Fuel consumption,
5. Drive wheel rotation, and
6. Drive wheel axle torque.

Additional measurements less often reported were as follows:

1. Tractor magnetic heading,
2. PTO torque,
3. PTO speed,
4. Tractor pitch and roll angle,
5. Lift arm angle,
6. Gear selection,
7. Ambient air temperature,
8. Fuel temperature,
9. Return fuel flow,

10. Static axle loadings,
11. Engine temperature,
12. Engine speed,
13. Hydraulic system flow,
14. Hydraulic pressure, and
15. Vehicle acceleration.

Systems as Reported by Individual Researchers

Carnegie et al. (1983) reported the use of a personal computer in measuring the performance of a tractor. An Apple II was interfaced to sensors taking the basic measurements. Fuel consumption, a measurement automatically sensed by most instrumentation systems, was obtained manually using graduated cylinders. At timed intervals, the operator measured the amount of fuel consumed and recorded the consumption rate. Ground speed was measured using both a radar unit and a fifth wheel trailing behind a towed sled. Floppy disks, an integral component of the Apple II, provided satisfactory mass storage. However, dust settling inside the Apple II keyboard required this component to be cleaned periodically.

Palmer (1984) introduced a very sophisticated tractor data collection system. This system made the basic measurements described above and additionally measured (1) tractor heading, (2) pitch, and (3) slope. Operator gear selection and braking were also automatically recorded. Data were transmitted to a central station using FM telemetry. Accumulation of actual tractor operation measurements was a major objective of the research. Consequently, numerous tractors were instrumented and made available to farmers for use in day-to-day operations.

A second generation tractor performance monitor was presented by Summers et al. (1984). The monitor had several improvements and modifications over a previous design. Radar was included in the updated version for the measurement of true ground speed. Engine speeds and transmission ratios were used to calculate theoretical forward speeds, and fuel consumption was sensed through use of vortex flowmeters.

Green et al. (1983) and Morris et al. (1983) discussed an on-board tractor microcomputer system designed to sense the basic measurements and implement position. This monitoring system had several advanced features which included radar, bubble memory, and most uniquely, a speech card enabling the tractor to "talk" to the operator. Searcy and Ahrens (1983) provided detailed information on the speech card. The card was obtained commercially in kit form.

A portable instrumentation package was developed by Stange et al. (1984). This system was designed around a Hewlett-Packard 85 computer system. The package sensed all of the basic parameters except fuel consumption. A torque transducer detected PTO shaft torque and speed, a turbine flowmeter measured hydraulic system flow, and a pressure transducer sensed hydraulic system pressure. A tachogenerator measured ground speed through a fifth wheel arrangement. The package used a modified dynamometer based on the design reported by Johnson and Voorhees (1979). The modified dynamometer allowed the use of a PTO shaft which the original design prevented. Due to vibration problems, the instrumentation was carried in a truck traveling alongside the tractor during data acquisition. The truck-based instrumentation was connected to the tractor-mounted sensors using an umbilical cord.

Lin et al. (1980) and Clark and Adsit (1984) instrumented a low-power four-wheel drive tractor using a Heath H8 microcomputer. Magnetic tapes were initially used for mass storage. Magnetic tapes, however, were found to be undesirable because of frequent data loss and the time required to remove and analyze the data. Floppy disks were tried and performed with few data transfer errors, but the floppy disks were not accessed when the tractor was moving. Additional measurements made by this system were static axle loadings and engine speed.

Grevis-James et al. (1983) reported an instrumentation system which was inexpensive to implement. The system made the basic measurements using an AIM 65 microcomputer. The software for this system was written entirely in assembly language. Draft was sensed using strain gauges mounted in a hole drilled on the neutral axis of the drawbar. Rotational encoders were used to measure both front wheel speed and rear wheel speed. A Hall effect switch measured engine speed by detecting a magnet attached to a pulley mounted on the tractor crankshaft.

A system designed by Marshall et al. (1982) made the basic measurements and additionally measured fuel recirculation rate, fuel temperature, ambient temperature, lower lift arm angle, and engine temperature. Future plans for the system included incorporation of bubble memory for mass storage. This system used an AIM 65 microcomputer having battery backup memory.

Smith and Barker (1982) reported using a data logger for monitoring field energy requirements. A Category III quick-attach hitch was constructed employing six load cells for the measurement of implement draft. This system made the basic measurements plus engine speed and rear axle torques. Ground speed was measured using a front wheel speed sensor; however, ground speed was later monitored through use of a fifth wheel. To provide power to the data logger, an AC generator was mounted on the front of the tractor. This instrumentation system was later modified to facilitate automatic control of engine speed based on implement draft (Smith, 1985).

Reynolds et al. (1982), in the implementation of a tractor-based instrumentation system, stressed the sensitivity of electronic equipment to the harshness of the agricultural environment. Two almost identical computing systems were used to gather data. The first was housed in an air conditioned box constructed of plywood. The box was mounted on the tractor and carried; the instrumentation, an air conditioner, an AC generator, and an instrumentation operator. All data gathered by this unit were stored in RAM. This system was dependent on the second floppy-based system housed in an instrumentation van for program downloading and data uploading. Communication was accomplished using an umbilical cord. The instrumentation van maneuvered next to the tractor whenever program downloading or data uploading was desired.

An instrumentation system for a four-wheel drive tractor was reported by Musonda et al. (1983). The system used FM radio telemetry for transmission of data immediately upon sensing. An FM receiver was interfaced to a strip chart recorder for data storage. The strip charts were later digitized and analyzed by a mainframe computer. An accelerometer, mounted on the tractor frame, provided data relating to the changing conditions occurring under four-wheel drive traction conditions.

II. STUDIES CONDUCTED WITH THE INSTRUMENTATION SYSTEMS

Alternative methods for measuring true ground speed were investigated by Richardson et al. (1982). The system used for this study was reported by Carnegie et al. (1983). Researchers desired an accurate means for measuring and controlling wheel slip. By controlling wheel slip, an operator can increase fuel consumption efficiency and reduce tractor tire wear. For the measurement of ground speed, this study used both dual and single beam radar units. Outputs from these devices were compared to readings produced by a fifth wheel. The fifth wheel was mounted behind a towed loading sled. The leveling produced by the sled provided a smooth and firm surface for the fifth wheel.

Studies for determining the performance of radial and bias-ply R1 tractor drive tires were conducted by Tompkins and Wilhelm (1981b).

On tilled clay loam soil, radial tires were reported to exhibit less slip than bias-ply tires under the same drawbar load. Also, the tractor fuel consumption rate tended to be less for radial tires than for bias-ply tires under the same operating conditions.

The energy requirements of selected tillage and planting implements were studied by Hart and Tompkins (1984). In this study, the instrumented tractor reported by Tompkins and Wilhelm (1981a,c) was operated on three silt loam soils using three ground speeds. Tractor fuel consumption requirements of the various implements operated under the different conditions were reported.

Charles (1984) tested the effects of ballast and inflation pressure on the performance of tractor tires. An instrumented tractor was used to determine if the maximum tractive efficiency is a function of the adjustment of static vertical load and tire inflation pressure. The tests indicated overall tire performance could be altered through tire inflation pressure and ballasting, but tire wear and durability should also be considered.

A front wheel assist tractor was instrumented by Woerman and Bashford (1983) to determine the amount of drawbar pulling power provided by the front and rear drive wheels. Also studied were the effect of the different speed ratios between the front and rear drive wheels, the effect of ballasting, and the differences in performance of a tractor in four-wheel and two-wheel mode.

Musonda et al. (1983) used an instrumented four-wheel drive tractor equipped with a tractor frame accelerometer. This system was reportedly used in studying the energy losses due to tractor vibrations, the effects of inertia loading, and the effects of torque oscillations.

Adsit and Clark (1983) reported on a study of the wheel-to-wheel variability in slip on a small four-wheel drive tractor. The goal of this research was to gather field data for comparison to a computer model which predicted slip. An automated cone penetrometer was mounted on the three point hitch of the research tractor. This study used a modified version of the system presented by Lin et al. (1980).

Instrumentation for Feedback and Control

The automatic control of tractor engine speed and transmission ratio was presented by Chancellor and Thai (1983, 1984). This system performed satisfactorily using only a combination of hard-wired logic, analog transducers, and switches.

Hasson (1983) integrated a central tire inflation system to a ground speed and tire slip measurement sensor to automatically control tire inflation for maximum performance. True ground speed was sensed using radar. Wheel slip was determined using a magnetic sensor mounted above the right axle. She cited a true ground speed measurement within ± 2% of actual ground speed.

Performance of an automatic tractor steering controller was presented by McMahon et al. (1983). Using ultrasonic sensors for measurement of object distances, a microcomputer network steered an automated apple harvester. Several microcomputers were used, and each had a specific task to perform. Individual microcomputers reported to a main microcomputer using the network. The networking of the seven microcomputers interfaced to the sonar sensors was described by Murphy et al. (1984).

An automatic feedrate controller was designed by Famili (1983) for use on a combine. The system monitored and controlled groundspeed, engine speed, and thresher throughput. The operator had only to steer the combine and control the header height. Famili cited as justification for this research a shortage of skilled operators and the rapid change in operation parameters needed for efficient harvesting.

Smith (1985) introduced an automatic engine speed control device which maintained engine speed to within ± 10 rpm of the operator selected speed. Using thumb-wheel switches, the operator selected a reference speed. This produced a reference logic value to which the output from a digital tachometer could be compared. The results of the comparison indicated whether the engine speed should be increased, decreased, or maintained. Control was subsequently given to an actuated vacuum diaphragm which interfaced to the engine throttle control.

III. REVIEW OF THE HART SYSTEM

Instrumentation System

Hart (1982) described a microcomputer-based data acquisition system housed on an agricultural tractor (Figure 3). This system

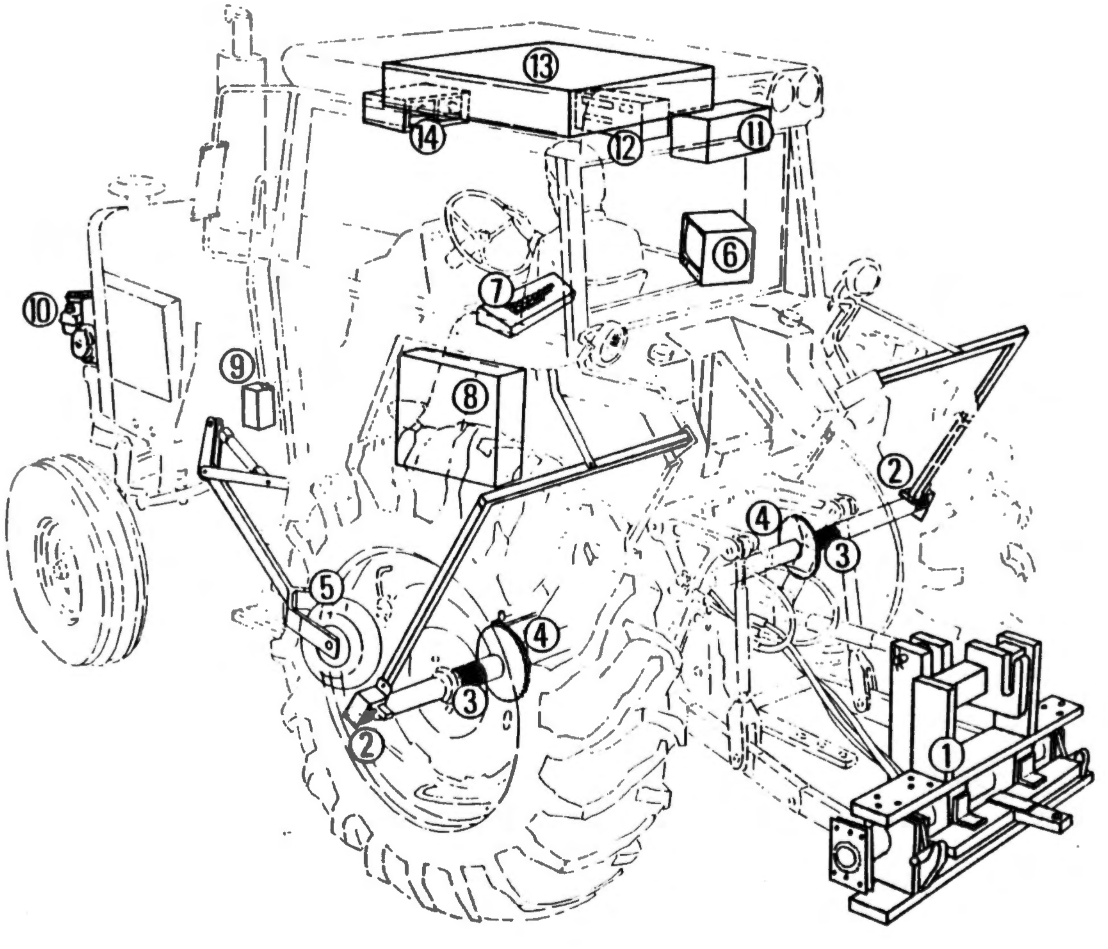

Figure 3. Schematic of the Hart (1982) microcomputer-based data acquisition system housed on a 75 pto kW agricultural tractor. System components included: (1) three-point hitch drawbar dynamometer, (2) slip rings, (3) strain gauges, (4) magnetic sensor and split gear, (5) fifth wheel assembly, (6) video monitor, (7) keyboard, (8) signal conditioner, (9) fuel transducer, (10) generator, (11) magnetic tape drives, (12) fuel meter display, (13) microcomputer, and (14) panel meter displays.

was centered around a Digital Equipment Corporation (DEC) PDP-11/03-LK microcomputer. The microcomputer was mounted in the cab of a Massey-Ferguson 2675 two-wheel drive agricultural tractor.

Using sensors installed on the tractor, the instrumentation package measured and recorded the following:

1. Time--A timer was initialized to interrupt, after a set time interval had elapsed, a program wait loop. Upon the interrupt, code was executed to (1) sample analog values, (2) read and clear digital pulse counters, (3) store raw data in one of two buffers, (4) calculate engineering values from the raw data, and (5) update the operator console with the new engineering values. After a data buffer was filled with raw data, the data were submitted to a queue for an interrupt-driven write to tape. The second data buffer was then made available for raw data storage which proceeded until it was filled and submitted to the queue. Data storage then alternated back to the other buffer. Thus, the sampling interval had to be long enough to accommodate all of the aforementioned tasks. The minimum interval was approximately one second, the interval used.
2. Right and left axle torque--Pairs of strain gauge rosettes, located opposite one another on the axle, were applied to each rear axle. The gauges were excited by a signal conditioning and amplification unit located inside the

tractor cab. After signal conditioning, the output signals from the gauges were sampled by an A/D board. A calibration routine, ran before data acquisition, generated an interpolation table based on the signals from the gauges as generated under a measured incrementing force. The calibration table was later accessed by the data sampling routine to convert raw strain gauge signals to calibrated torque values.

3. Implement draft--A custom constructed three-point hitch dynamometer, using a sensing tube, measured drawbar force. Strain gauges were mounted on the tube such that only the horizontal component of force was sensed. The conditioned output of the strain gauges was sampled by the A/D board and converted to a calibrated force using a previously generated interpolation table.
4. Right and left axle rotation--The rotational displacements of the right and left axles were obtained using active magnetic proximity sensors. A 120-tooth split gear was mounted on the right axle and on the left axle. Above each gear was positioned a magnetic proximity sensor. The number of teeth on the gear and the number of digital pulses detected per sampling interval enabled the calculation of axle speed.
5. Travel distance--True ground speed was obtained using the same sensor arrangement as used to measure shaft

speed on the axles. A similar sensor was mounted on a free-rolling fifth wheel having a 72-toothed split gear. Using an hydraulic cylinder, the wheel was lowered for data acquisition and raised during transport.

6. Fuel flow--Fuel consumption was determined by measuring the amount of fuel displaced per sampling interval. A Fluidyne Model 1240D flow sensor was installed between the fuel tank and the injector pump. Special plumbing was required to prevent the remeasurement of the fuel returned from the pump. This sensor emitted 100 pulses per 1 ml of fuel flow.
7. Fuel temperature--The Fluidyne flow sensor had an additional digital output signifying fuel temperature. Although measured by the data acquisition system, this measurement was determined to be nonsignificant for data analysis.

From the basic measurements and an operator-input implement width, the following calculations were made and the results were displayed on the operator console: (1) ground speed, (2) right and left wheel slip, (3) right and left axle horsepower, (4) drawbar horsepower, (5) fuel consumption, (6) acres per hour, and (7) gallons per acre.

Computer Hardware

Located inside of the DEC BA11-N microcomputer enclosure, a DEC H9273 Q-BUS backplane held the standard system component cards

(Figure 4). The microcomputer system contained standard components: (1) a dual-height DEC LSI 11/03 CPU card with a Floating Instruction Set (FIS) option, (2) a DEC MSV11 dual-height 64 kbyte memory card, (3) a DEC DLV11-J dual-height communication board, and (4) a quad-height DEC BDV11 bootstrap terminator board having on-board diagnostics and sockets for erasable programmable read only memory (EPROM). The backplane bus provided power to the cards and allowed communication between them. Extra slots in the backplane allowed for the addition of modules which measured analog signals and counted digital pulses.

slots	A	B	C	D
row 1:	LSI 11/03 CPU		**empty slot**	
row 2:	MSV11 memory		**empty slot**	
row 3:	DT1761 A/D			
row 4:	DRV11 counter board			
row 5:	DLV11-J communication		**empty slot**	
row 6:	VK-170 video board		**empty slot**	
row 7:	**empty slot**		**empty slot**	
row 8:	**empty slot**		**empty slot**	
row 9:	BDV11 terminator board			

Figure 4. Backplane locations of the system component modules in the Hart system.

Sensors having analog outputs were interfaced to a Data Translation DT1761-SE-PG A/D converter. This quad-height board has 16 single input analog-to-digital channels and two digital-to-analog (D/A) channels. The lower four A/D channels were tied to sensors measuring right axle torque, left axle torque, implement draft, and a calibration load cell, respectively. Analog voltage values were conditioned and amplified using a Vishay Model 2100 System strain gauge amplifier and conditioner. Two D/A channels were interfaced to a set of panel meters which provided operator feedback of selected operation parameters.

Digital pulses were counted by custom designed hardware up/down counter circuits. The counting circuits were mounted on a DEC DRV11-P interface foundation module. This quad-height board had five digital input channels which could be read and cleared under software control. A software programmable timer was also located on the board enabling hardware interrupt control at set time intervals. Channels 0 through 2 of this board were tied to active magnetic proximity sensors measuring right axle displacement, left axle displacement, and travel distance, respectively. Channels 3 and 4 were tied to the Fluidyne Model 1240D fuel consumptions meter measuring fuel displacement and fuel temperature, respectively.

A pulse interface box was located between the digital sensors and the counterboard. This interface box served two functions. First, the pulse interface box contained the Schmitt-trigger circuitry for buffering the counterboard from the sensors. Non-TTL voltage values, such as the 12-volt square wave signals emitted from the fuel meter, saturated the inputs of the Schmitt-triggers. The Schmitt-triggers provided to the counter circuitry TTL compatible outputs. These outputs had very fast rising and falling edges. Secondly, the interface box also acted as a repeater, restoring the TTL signal levels of the active magnetic proximity sensors after they had traveled several feet from the sensors to the counter circuitry. Because the Schmitt-triggers were subjected to voltage values exceeding their design specifications and acted as fuses, they were mounted in sockets for in-field replacement.

Communication input/output to the operator and to the mass storage system was accomplished using a DEC DLV11-J four port asynchronous communication card. This dual-height module provided EIA RS-232C compatible communication to a DEC TU58 tape drive, a DEC VK170 dual-height serial video board, and an optional line printer. The video board, in turn, supplied the circuits to drive an Electrohome V14 cathode ray tube and DEC compatible keyboard. The video board had no bus communication ability, and thus, it used the backplane for power and housing only. The baud rate for the video board, connected to Port 3, was 9600. The DEC TU58 tape drive was strapped at 19.2K baud on Port 2 and Port 0 for the optional printer was set at 300 baud. The serial communication interface for all ports were: (1) 8-bit bytes, (2) one start bit, (3) one stop bit, and (4) no parity enabled.

The mass storage system used with this system was a DEC TU58 dual-cassette tape drive. The capacity of each cartridge was 262,144 bytes, formatted in 512 blocks of 512 bytes each. Drive 0 of the TU58 was the system device for the DEC RT-11 Version 3B operating system. The data acquisition software was also stored on the cartridge operating in this drive. Drive 1 contained a nonRT-11 formatted TU58 tape used for data storage.

Computer Firmware

Upon power-up, code was automatically executed to load the operating system and the data acquisition program from the TU58 into memory. This code was burned into EPROMs and stored on the BDV11 bootstrap terminator board. After power was applied, system loading required approximately 9 minutes.

Computer Software

A nonRT-11 formatted tape located in Drive 1 required the operating system software to be modified. The device handler for the TU58 (DD.SYS) was modified such that data could be written and read from the tape located in Drive 1 in an adjacent block access manner rather than a numeric block access manner (Figure 5). Using this type of access, no rewinds of the tape were required in order to completely fill the tape. The source file for the TU58 handler was modified, recompiled, and added to a regenerated RT-11 operating system.

Another device handler (AD.SYS) was written to supply limited support to the A/D board. This non-DEC handler supplied support only for the lower four A/D channels, a specific operating system

```
------------------------------------        ------------------------
trk1 BOT: #128:#384:#129:#385:#130:. . .:#254:#510:#255:#511 :EOT
------------------------------------        ------------------------
trk2 BOT: #0  :#256:#1  :#257:#2  :. . .:#126:#382:#127:#383 :EOT
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Figure 5. A TU58 tape is formatted having two tracks of alternating block locations. Writing to each block in numeric order (numeric block access), as does the standard RT-11 handler, requires three rewinds of the tape. Each tape rewind requires 28 seconds, an unacceptable length of time for continuous data acquisition and storage.

version, and an operating system generation having non-standard options. Although this handler was inflexible, it worked adequately for the data acquisition system.

The data acquisition software was written almost entirely in assembly language. This was done for speed, flexibility, and most importantly, a reduced memory size requirement. Higher language subroutines written in FORTRAN IV were linked to the assembly language routines to provide support for floating point operations, numeric conversions, and video input/output.

The FORTRAN routines were compiled and linked to support the FIS option of the LSI 11/03. This option allowed the LSI 11/03 to perform in hardware at fast speeds both integer and floating point multiplication and division.

At the beginning of program execution, the operator was presented an option menu. Using a two letter selection code, the operator could select to do one of several tasks. After the completion of each task, control was returned to the option menu.

IV. PROBLEMS ENCOUNTERED

The data acquisition system was field tested for two seasons. Over this period of time, a need to expand on the system resources appeared. Minor errors originally occurring in the system became more and more apparent. Thus, solutions were needed to correct the following problems.

1. The software programmable timer was found to be programmed one-thirtieth of a second too slow. Over short test periods this timing error was inconspicuous, and the time period was insignificant when compared to the operator response time of starting and stopping the test. However, during long test periods lasting several minutes (e.g., roundbaler and mower operations), the error became apparent.
2. The counter circuits had bleedover of signals from adjacent channels. This became apparent only when signals having great frequency differences were input to the counterboard (e.g., 1 Hz and 1 kHz).
3. The first count period was always approximately 4 to 7 percentage points lower than the following counts.
4. The counter circuits only counted up. Although up/down lines were available, the lines were not connected because the sensors interfaced to the counters had no way of

controlling them. Therefore, any oscillation of the gear teeth adjacent to the magnetic proximity sensors, especially at low speeds or when the tractor was standing still but operating, triggered a burst of pulses to the counterboard. This produced an indication of traveling forward when only a rocking motion or vibration was occurring.

5. The data acquisition system was limited to sampling analog channels only once per second. This produced aliasing errors.
6. The fifth wheel provided accurate data when operating on a smooth firm surface. As the surface became softer and less uniform, the fifth wheel produced less reliable data. Hay windrows also provided a considerable obstacle in using the fifth wheel.
7. If a system crash occurred, the start-up time to reboot was approximately 9 minutes. This was acceptable unless the system was being demonstrated or when trying to debug the system.
8. The TU58 would randomly fail as the system was powered-up. Several attempts were sometimes required for the unit to respond and operate correctly.

CHAPTER III

REDESIGN OF THE EXISTING INSTRUMENTATION SYSTEM

I. MAJOR HARDWARE MODIFICATIONS

Several modifications and additions were made to solve the problems evident in the instrumentation system reported by Hart (1982). Minor adjustments were made to the counterboard, to the TU58 mass storage system, and to the data acquisition software. Major system hardware modifications included: (1) replacement of the magnetic proximity sensors used in the measurement of shaft speeds with optical incremental shaft encoders, (2) redesign of the digital pulse interface box, and (3) addition of pre-sampling analog filters.

Optical Shaft Encoders

The active magnetic proximity sensors located on the rear axles and fifth wheel were replaced with Disc Instruments EC80 Series optical incremental encoders with bi-directional sensing. A bi-directional optical encoder emits dual-line signals. Both signals are identical TTL waveforms which are 90 degrees out of phase. The frequency of the waveforms is directly proportional to the rotational speed of the optical encoder shaft, the same relationship that existed with the magnetic proximity sensors and gear teeth previously used.

A difference between the encoders and the replaced magnetic sensors was the ability to sense shaft rotational direction. If the rotational direction of an encoder shaft reverses, the encoder signals shift 180 degrees with respect to each other. After the shift, the signals still remain 90 degrees out of phase (see Figures 6 and 7). The 180-degree shift functions only to cause the TTL level of either signal to become inverted compared to the rising or falling edge of the accompanying signal.

The use of optical encoders for measuring slow to moderate shaft speeds was found to be superior to magnetic proximity sensors. Whereas, tractor vibration might cause an entire gear tooth, or a gear tooth edge, to vibrate back and forth across the field of a magnetic sensor producing pulses indicating an erroneous forward travel speed, bi-directional sensing of optical encoders offered a solution to eliminating this error.

<u>Rear axles</u>. The active magnetic proximity sensors and the 120-tooth split gear cogs were removed from each rear axle and replaced with Model EC82-512 optical shaft encoders (Figure 8). Dual TTL waveforms are generated by this encoder, each having 512 pulses per shaft revolution. The use of this sensor eliminated the vibration induced counts, and the resolution of the shaft rotation was increased by a factor greater than four.

<u>Fifth wheel</u>. The magnetic sensor and 72-tooth split gear on the fifth wheel axle were replaced with a Model EC82-512 encoder.

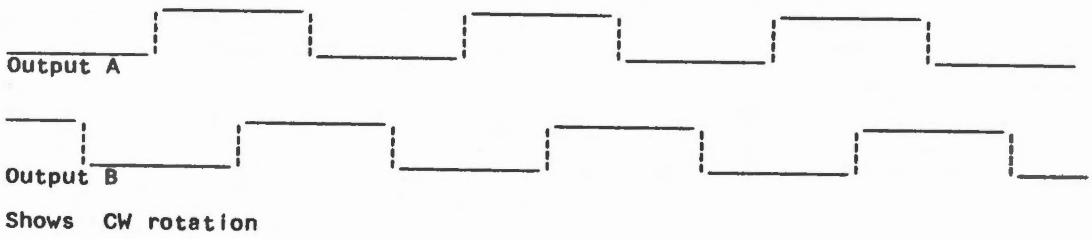

Figure 6. A bi-directional optical shaft encoder emits two separate TTL signals whenever the shaft is rotating. The frequency of the signals is identical, signifying shaft rotational speed. However, the signals are 90 degrees out of phase with respect to each other.

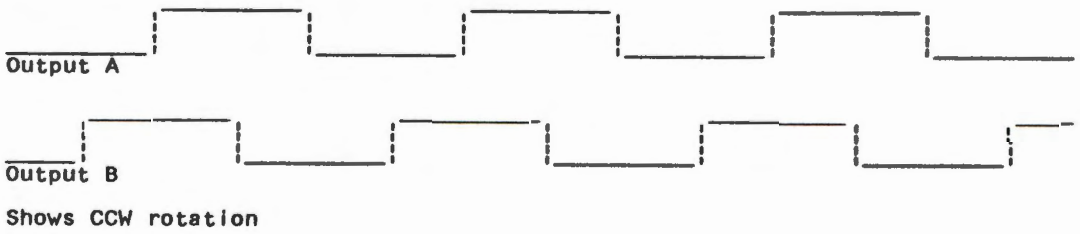

Figure 7. A 180-degree shift in phase between the two signals (compared to Figure 6) signifies a change in the direction of shaft rotation.

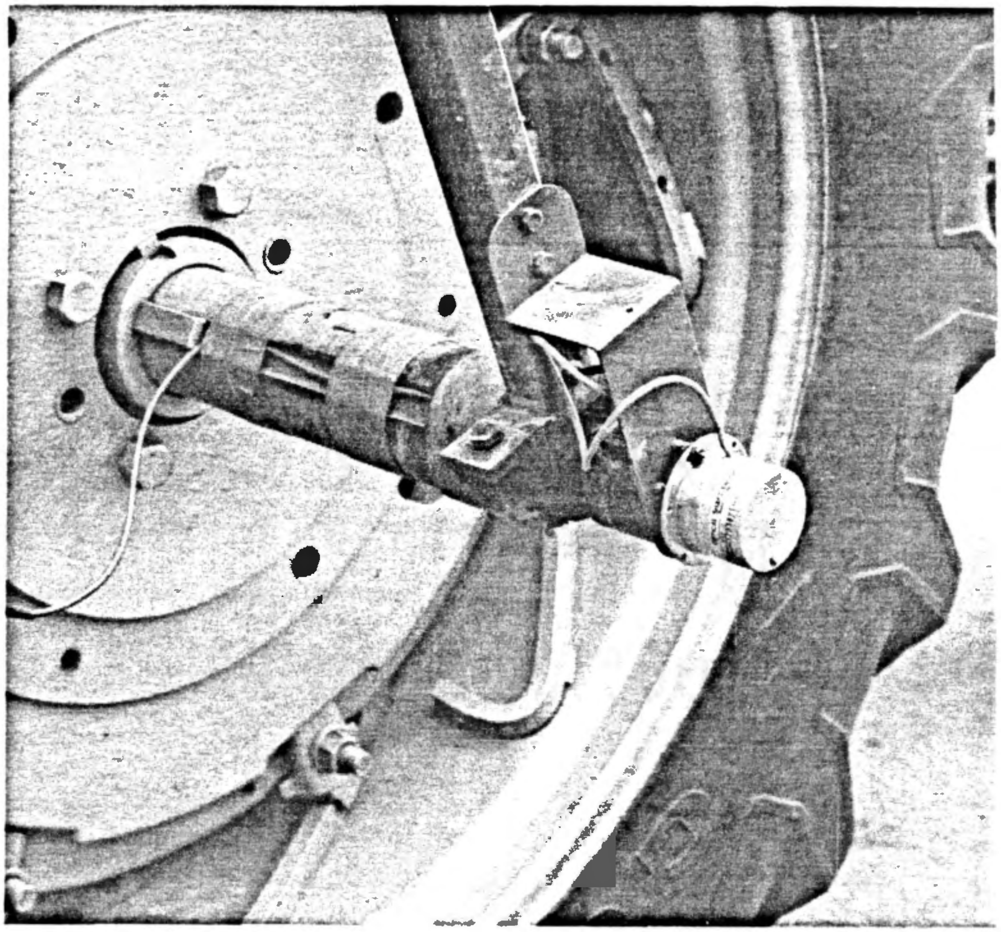

Figure 8. Magnetic proximity sensors used for the measurement of axle speed were replaced with optical incremental encoders. An encoder was installed on the end of the existing slip ring bearing located at the tip of each rear axle. An enclosure (not shown) protected the sensor, serving as a shield during field operation and vehicle transport.

Thus, the resolution of ground displacement sensing was increased by a factor of seven. The sensor was attached to the fifth wheel axle and enclosed by a shield (Figure 9).

Pulse Counter Interface Box

The newly installed optical encoders were capable of sensing clockwise and counter-clockwise rotation. This feature, in turn, required a new digital pulse counter interface box to be designed and built to accept the dual input signals from the new sensors (Figure 10).

The new interface box was located on the floor of the tractor cab in a position isolated from the operator. The 17 x 15 x 6 mm box displayed a power indicator LED (light emitting diode) to signal the operator that power was applied to the circuits (i.e., the power supply fuse had not blown). Due to its isolated mounting position, easy removal of the interface box from the floor of the tractor for maintenance purposes was a design requirement. Thus, all inputs and outputs to the box were made using cable connectors.

Five digital sensor inputs to the box were made with 5-pin DIN connectors. Each of the five connectors was labeled for correct insertion to channels having the appropriate circuitry and the correct channel interface. Signal outputs from the box to the pulse counter-board were accomplished using a single DB25 connector. Pin-outs of this connector and of each channel 5-pin DIN are given in Appendix A.

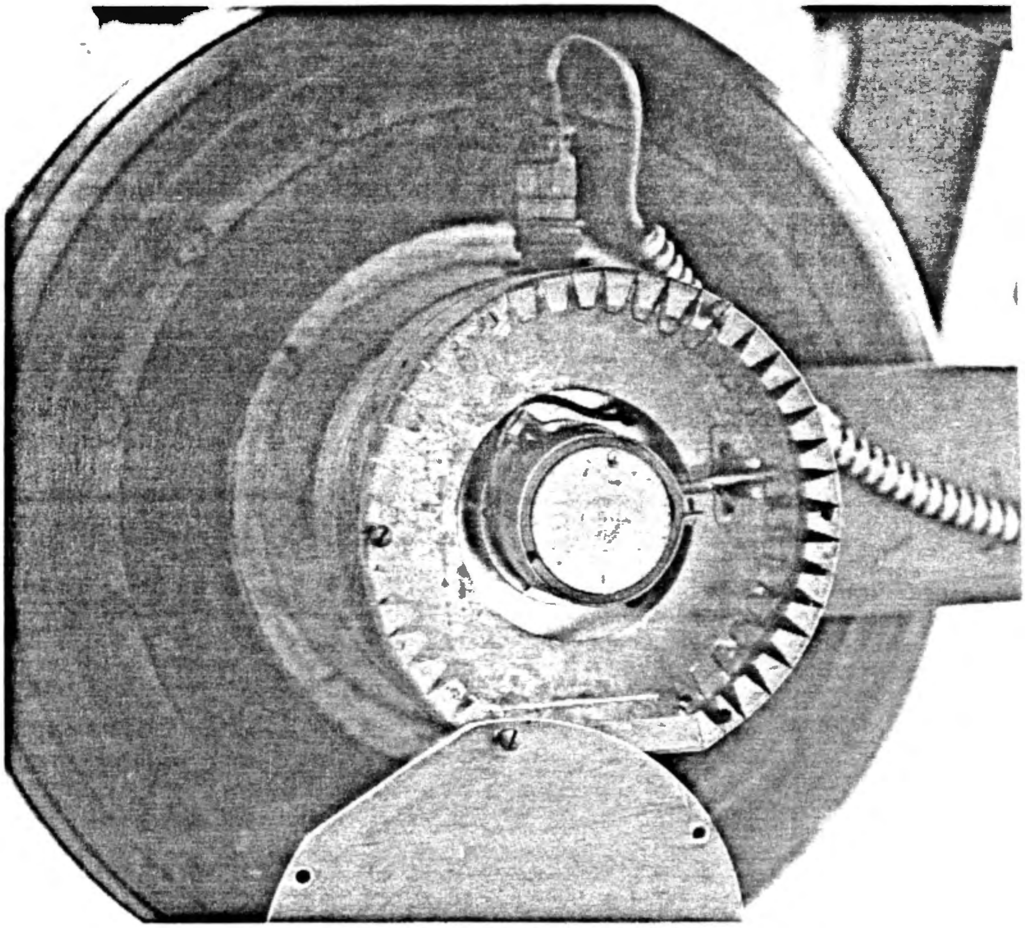

Figure 9. Optical shaft encoder mounted on the fifth wheel axle used for measuring ground speed (cover removed).

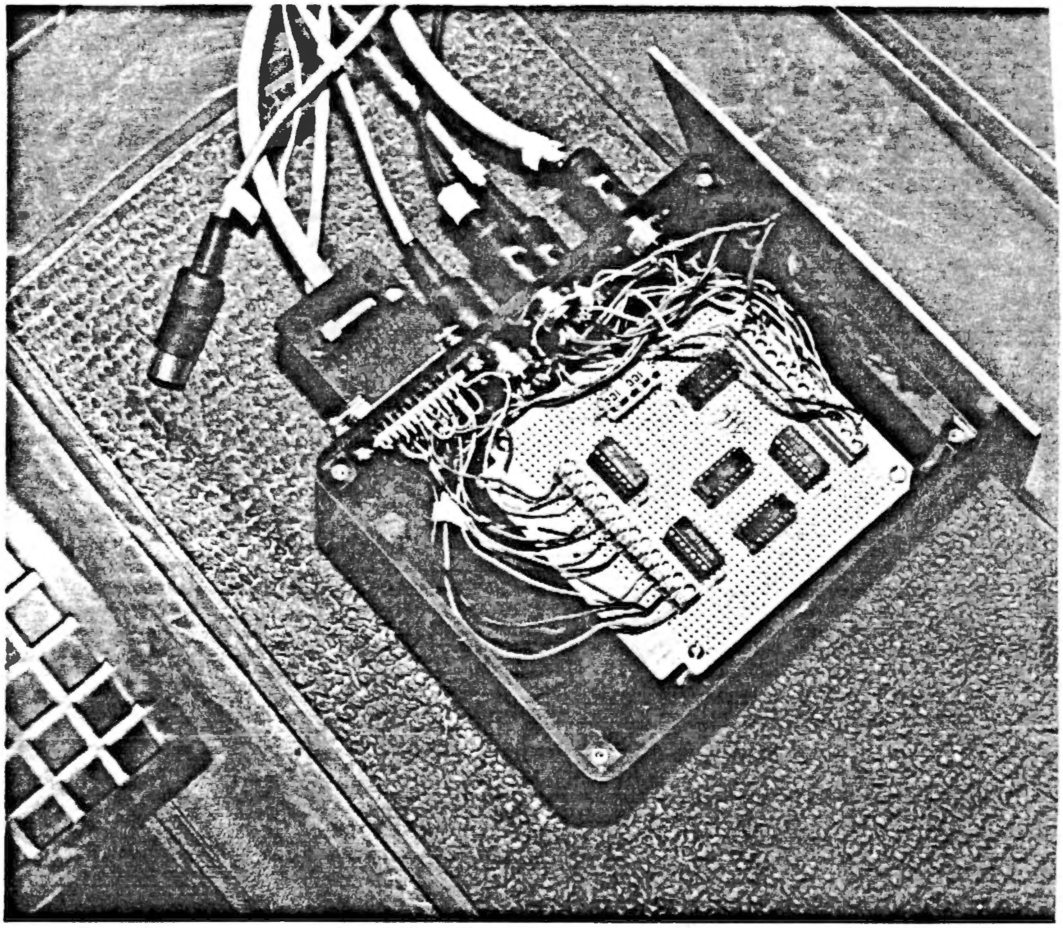

Figure 10. Pulse interface box located between the five remote digital sensors and counterboard (cover removed).

Of the five digital pulse channels located on the counterboard, three were obligated to the optical rotational encoders, one was designated for the fuel meter, and the fifth was reserved for the future interfacing of a new sensor for the measuring of engine speed. Therefore, three types of circuitry were needed for the five digital pulse channels used on the counterboard: (1) a bi-directional shaft speed circuit, (2) a bi-directional fuel consumption circuit, and (3) a uni-directional engine speed circuit.

Shaft speed circuit. The new pulse interface box was designed, not only to buffer the input signals and to restore signal length, but also to detect a 180-degree phase shift on the channels interfaced to the optical rotational encoders. The new circuitry was also required to manipulate the up/down count control lines of each channel interfaced to an encoder and to produce a TTL frequency directly proportional to shaft speed based on either of the two identical outputs of an optical encoder.

An advanced feature designed into the pulse counterboard but not previously used was up/down count lines for each channel. If a low level TTL signal was applied to a channel up/down line, subsequent pulses were added to the channel count value. Conversely, if a high level TTL signal was applied to a channel up/down line, subsequent pulses were subtracted from the channel count value. Previously, only uni-directional sensors were used. Consequently, each channel up/down line was grounded such that each pulse transmitted to a channel always incremented the channel count.

Dual edge-triggered flip-flops (74LS74) were used to detect the 180-degree phase shift caused by a reversal of the encoder shaft (Figure 11). Both the preset and clear of each flip-flop were tied high, and one of the dual encoder signals was tied to the clock and the accompanying signal was fed into the flip-flop input (D). The state of the input signal (D) was sensed on the rising edge of the encoder signal tied to the clock. Subsequently, this state was latched onto the output (Q) of the flip-flop providing TTL level control to the up/down line. Schmitt-triggers (74LS14) were used on both the inputs and the outputs of the flip-flops as buffers and drivers (Wilkerson, 1983).

Selection of which encoder signal was tied to the clock and which encoder signal was tied to (D) determined if the counter would increment or decrement during the clockwise rotation of a shaft. The two lines could be swapped if an error was made during installation and testing.

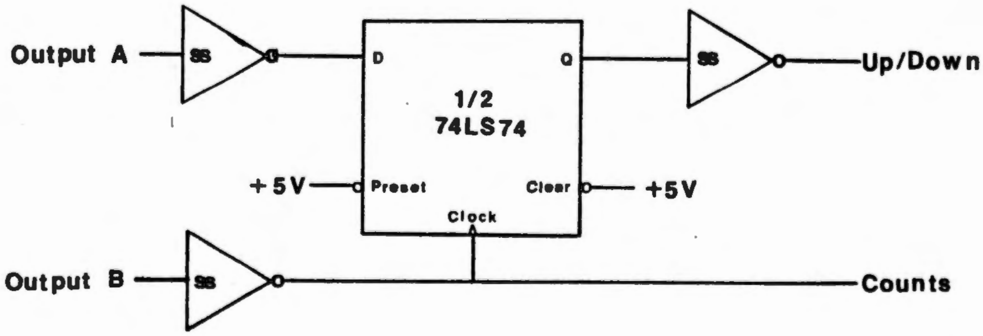

Figure 11. Circuit interfaced to optical encoders used for the bi-directional measurement of shaft speed.

Fuel consumption circuit. The circuit used in the measurement of fuel flow (shown in Figure 12) remained the same as in the design reported by Hart (1982). The 12-volt square wave produced by the fuel meter saturated the input of a Schmitt-trigger; however, the circuit provided a TTL level output of the same frequency as the input signal into the counterboard.

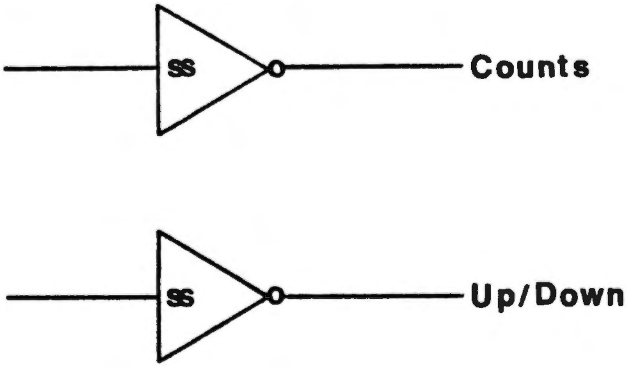

Figure 12. Circuit used in the measurement of fuel consumption. The fuel meter system compensates for return flow internally. Thus, the up/down count line for this channel was buffered.

Engine speed circuit. Redesign of the interface box provided an opportunity to expand the system to include measurement of engine speed. Although each of the five channels on the counterboard were being used, measurement of fuel temperature was deemed unnecessary. Therefore, this channel was reassigned to the measurement of engine speed.

Engine speed was measured using an Electro Corporation MAXI-MAG 3025A35 passive magnetic sensor mounted above the engine flywheel.

The signal produced by this sensor is a differential sine wave, the frequency of which is a direct function of engine speed. This differential signal was fed into the inputs of a National Semiconductor LM339 Quad Comparator generating a TTL frequency output equivalent to the sine wave input frequency (Figure 13).

During the initial testing, the output frequency produced by this circuit was high enough to cause significant bleedover to adjacent channels on the counterboard. Therefore, the output signal from the comparator was first passed through a 74LS90 decade counter which divided the signal by a factor of ten. Compensation for this signal division was made in software by multiplying the hardware count by a factor of ten.

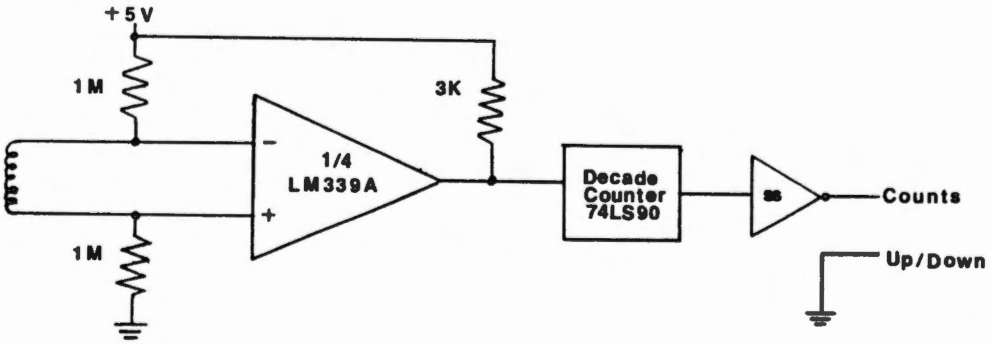

Figure 13. Circuit used in the measurement of engine speed. Since the sensor is uni-directional, the up/down line of this channel was grounded.

Analog Filters

Both digital and analog sensors were used in the previously reported data acquisition system. However, readings taken from the analog sensors were sometimes sporadic. Unexpected high or low values appeared randomly within uniform data values. Data averaging and/or removal of the spurious values were required in the later analysis. Research into this phenomenon revealed that improper data sampling techniques were being used.

The Nyquist Criterion of the Sampling Theorem states that an analog signal must be sampled at a frequency of at least twice that of the highest frequency component of the signal in order to prevent aliasing error. On signals having an unknown highest frequency, such as those occurring from field-operating farm machinery, the Nyquist Criterion is satisfied by passing the signal, before sampling, through a low-pass filter having a cutoff frequency of one-half or less of the sampling frequency (Data Translation, 1982).

To satisfy the Nyquist Criterion, three Frequency Devices Model 702L2L-A5 active low-pass filters were used for filtering the draft, the left axle torque, and the right axle torque signals. A fourth filter was included for future system expansion. Each two-pole filter had a Bessel response and a cutoff frequency of one-half Hz based on the system sampling interval of once per second. Sockets were used in mounting the filters for ease in exchanging filters having different cutoff frequencies. If the system sampling frequency was altered, filters having a different cutoff frequency would be required.

In the previous system, the case of the signal conditioning unit was not completely filled with signal conditioning instrumentation. Consequently, this left an extra slot covered by a metal plate. An enclosure containing the analog filters was designed to fit into the spare slot and power for the filters mounted inside the enclosure was drawn from the signal conditioning bus located at the base of the slot.

Signals previously traveling directly from the signal conditioning unit to the A/D board were instead passed first through the analog filtering enclosure. Toggle switches mounted on the face of the enclosure individually routed corresponding signals either through or around the analog filters. Thus, tests comparing filtered versus non-filtered data collection were easily accomplished.

Temperature induced voltage bias of the filters could have been adjusted using wire-round trim potentiometers connected to the voltage bias pins of the filters. However, each channel of the signal conditioning unit already had voltage bias potentiometers which served satisfactorily in eliminating both the conditioner and filter biases. But, this caused the plus and minus balance LED's on the signal conditioner to indicate a load under no load conditions. During system calibration, signal bias was easily removed by getting in a no load state, ignoring the balance LED's, observing the computer screen output, and adjusting the signal conditioner bias controls accordingly.

II. MINOR SYSTEM ADJUSTMENTS

A limited number of miscellaneous adjustments were made to the data acquisition system. Minor adjustments were made to the counterboard and to the system software.

Counterboard Modifications

A calibration test of the counterboard using a frequency generator indicated whether noise and/or signal bleedover were occurring on the board. In order to minimize this, the following modifications were made:

1. All integrated circuits (IC's) which were not in the LSTTL family were replaced. A mixture of TTL families was originally on the board due to lack of availability of LSTTL IC's when the board was first constructed.
2. All floating inputs of the IC's located on the counterboard were grounded.
3. The counterboard 40-pin BERG connector was reconfigured such that, on the ribbon cable joining the counterboard and the pulse interface box, a ground wire was located between each signal wire.

These adjustments eliminated the noise and signal bleedover occurring on the board except for signals having frequencies greater than 5k Hz. The only sensor in the system generating signals in this range was the engine speed sensor, and this signal was subsequently reduced by a factor of ten using a decade counter.

Software Modifications

Minor enhancements were made to the software:

1. The computer operating system was updated from DEC RT-11 Version 3B to RT-11 Version 5.0. This enabled the TU58 to operate at 38.4k baud instead of 19.2k baud, reducing the approximate startup time from 9 minutes to 5 minutes. The update also made the system completely compatible with an in-house minicomputer used for software development and data manipulation.
2. An unused RT-11 handler (JN.SYS), software used for communication to a device replaced by the counterboard, was removed from the system. Although having no effect on the data acquisition system, this removal helped in decreasing the system startup time.
3. The software programmable timed interrupt, used for reading of the sensor data values, was found to be one-thirtieth of a second too slow. The software was modified to correct this problem.
4. The panel meters used for operator feedback originally were pegged, one at maximum voltage and the other at minimum voltage. An operator selected routine was required to set the panel meters to zero volts. This was changed such that, upon program initialization, the panel meters were tested and set to zero volts automatically.

CHAPTER IV

ENHANCEMENTS TO THE INSTRUMENTATION SYSTEM

Major modifications and enhancements were made to the instrumented tractor reported by Hart (1982). Specifically, these included: (1) addition of instrumentation used for the in-field measurement of power inputs to towed PTO-driven implements, (2) an only partially successful redesign of the sensor used to measure implement draft, (3) the replacement of the TU58 drives with non-volatile solid-state memory which emulated a floppy disk, (4) implementation of a radar-based ground speed sensor, (5) design and mounting of a front wheel speed sensor, (6) appending of a routine to the original software for data averaging, and (7) introduction of a new software package for evaluation of selected ground speed sensors.

I. PTO ENERGY MEASUREMENT INSTRUMENTATION

Introduction

Power-take-off driven implements, such as silage choppers and haying equipment, are used extensively on the farm and consume considerable quantities of energy. Therefore, information gained through energy measurement research on PTO-driven equipment plays an important part in the energy conservation recommendations provided to farmers by agricultural extension agents.

The system reported by Hart (1982) was designed specifically for measuring the energy requirements of towed and mounted non-PTO-driven tillage implements. Therefore, additional instrumentation was designed to be used with the original instrumentation in the measurement of the energy consumed by towed PTO-driven implements (Figure 14).

PTO Drive Overview

The PTO shaft (Figure 15) provides a convenient way for transferring power from a tractor to an implement through a rotating shaft. A PTO shaft telescopes freely, thereby adjusting to relative distance changes between the tractor and the implement. Universal joints at each end of the PTO shaft compensate for angular and offset misalignments (Figure 16) between the tractor PTO stub and the implement PTO stub.

The universal joints on a standard PTO shaft possess a generally undesirable characteristic. When the driven and the driving ends of a universal joint operate at an angle to each other, the velocity of the driven end alternately lags and leads the velocity of the driving end twice for each revolution of the PTO shaft. Unfortunately, the leading and lagging of shaft velocity grows exponentially with increases in joint angle (Trotter, 1984).

The oscillation of shaft velocity transforms a constant driven torque load (supplied by a shop dynamometer, for example) into a pulsating torque load at the tractor. Rephrased, a constant torque

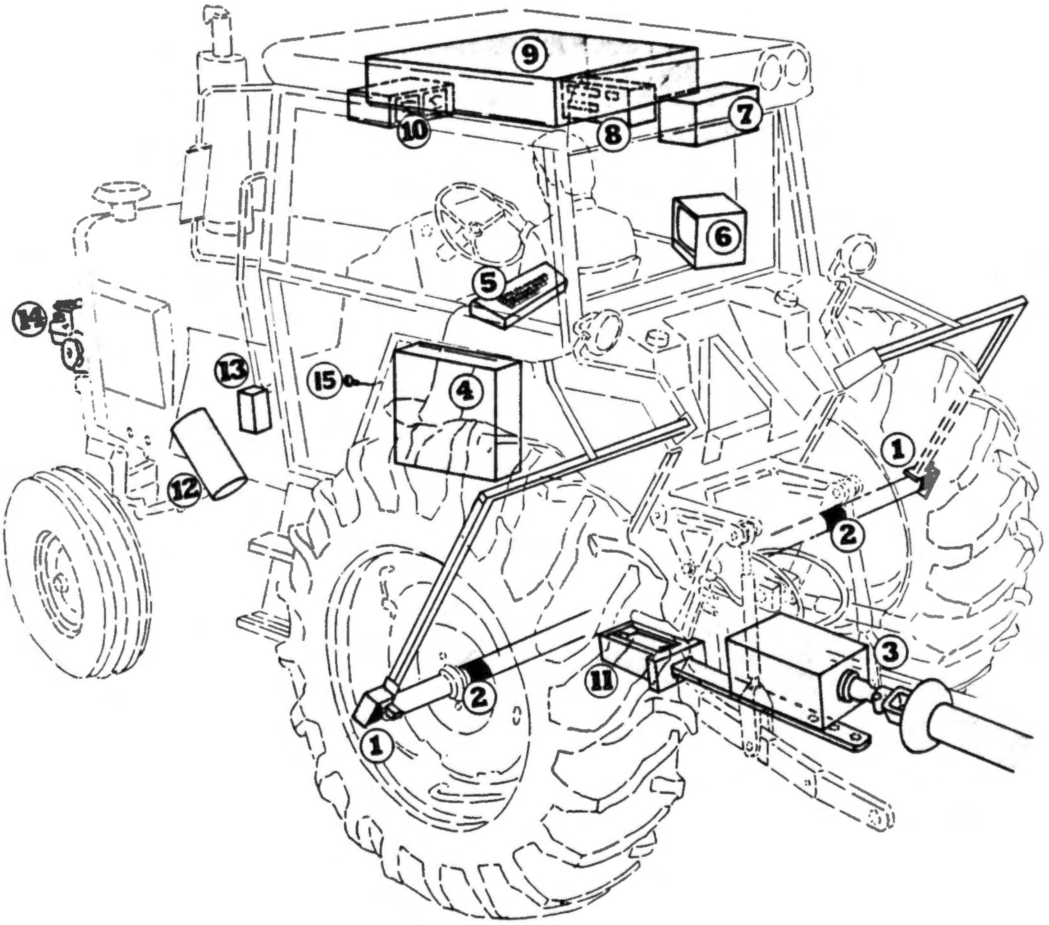

Figure 14. Schematic of the PTO modified data acquisition system for measuring energy requirements of towed, PTO-driven implements. System components are (1) optical encoders and slip rings, (2) strain gauges, (3) torque sensor, (4) signal conditioner/amplifier, (5) keyboard, (6) video monitor, (7) magnetic tape drives, (8) fuel meter display, (9) microcomputer, (10) panel meter displays, (11) draft sensor, (12) radar, (13) fuel transducer, (14) generator, and (15) engine speed sensor. Items 1, 3, 11, 12, and 15 represent modifications to the original system described by Hart (1982).

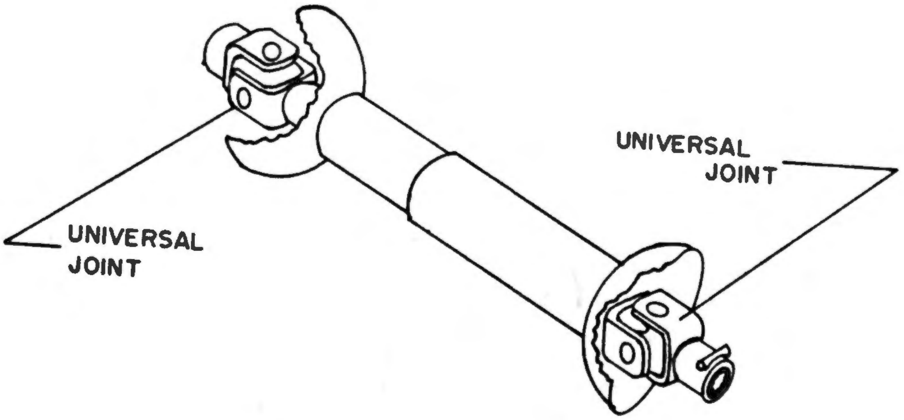

Figure 15. The standard PTO shaft has universal joints which may cause the shaft velocity at the implement to lag and lead the shaft velocity at the tractor PTO stub. Consequently, a non-uniform transfer of torque from the implement to the tractor could occur.

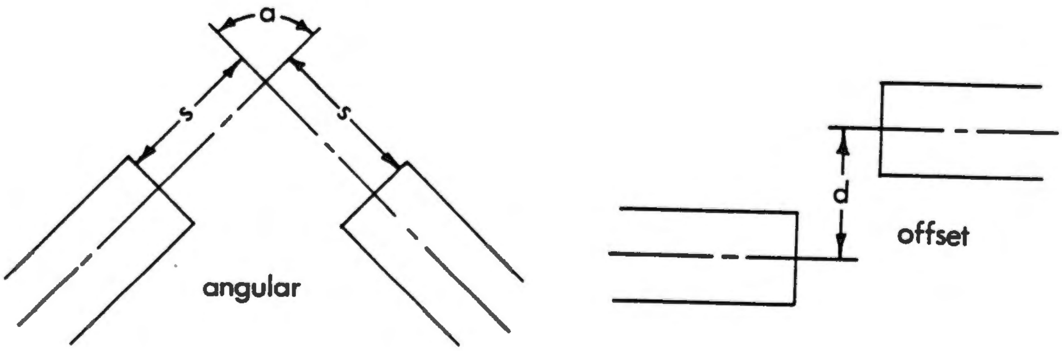

Figure 16. A combination of offset and angular misalignments occurs when shafts are coupled.

on a shaft turning with a pulsating velocity will switch through an angled universal joint to a pulsating torque on a shaft turning at a constant velocity. As with shaft velocity, the magnitudes of the torque pulsations increase exponentially with increases in the angle of the universal joint.

Theoretically, these pulsations should not occur in two instances. The first, an infrequent occurrence during field operations, happens if the PTO shaft operates precisely in line with the tractor PTO stub and the implement PTO stub. If the universal joints of a PTO shaft do not have to compensate for angular and/or offset misalignments, the driving and driven ends of each joint rotate at the same velocity.

Secondly, pulsations should not occur if all the following criteria are met:

1. the axes of all shafts lie in the same plane,
2. the angles of the two PTO-shaft joints are equal, and
3. each of the driving yokes is turned 90 degrees out of phase with respect to the other.

In this instance, which rarely occurs under field conditions, the velocity pulsations caused by one joint angle counteract the velocity pulsations caused by its matching joint (Trotter, 1984 and Richey et al., 1961).

Pulsations are readily apparent when operating tractor-mounted, PTO-driven implements such as rotary mowers and tillers. If an implement were to be lifted while operating at a high rate of PTO speed, vibrations may shake the tractor violently due to the drastic increase in the misalignment of the PTO shaft stubs.

Fortunately, constant velocity PTO shafts capable of reducing this undesirable pulsation characteristic have been developed. Nevertheless, the majority of PTO shafts in use on implements currently are standard shafts operated under non-uniform torque load conditions. The methods used to measure energy requirements of PTO-driven implements must accommodate the standard PTO drive components with their undesirable torque pulsation characteristic.

Energy Measurements

All energy measurement instrumentation components in the Hart (1982) system and the PTO-modified instrumentation packages reside permanently on the dedicated tractor. This arrangement provides compatibility with a wide variety of implements and eliminates the necessity of instrumenting each implement tested.

When determining the energy consumption of towed PTO-driven implements, four measurements are required. These measurements are (1) torque applied to the PTO shaft, (2) PTO shaft rotational speed, (3) implement draft, and (4) ground speed.

Torque measurement.

An instrument routinely employed to measure shaft torque is commercially available. This type of torque sensor attaches to the shaft, and actually becomes an extension of the shaft, so that the transducer is subjected to any torque applied to the shaft.

A torque transducer mounted on the output PTO stub of a tractor and in line with a rotating, angled PTO shaft subjected to a constant torque load generates an output sinusoidal waveform (Figure 17), a direct result of the previously noted torque pulsations which commonly occur when using PTO shafts. The principal frequency of the waveform is twice the frequency of the PTO shaft rotational speed, and the amplitude of the waveform changes as a function of the angle(s) of each universal joint. The offset from zero volts of the waveform represents the torque being applied to the shaft at an instant in time.

Output of the torque transducer actually consists of two principal waveforms. A fast, small waveform is superimposed on a large waveform caused by velocity pulsation of the PTO shaft. The smaller waveform appears to be due to the nonuniform torque developed by an internal combustion engine. This smaller waveform originates from consistent, high frequency power pulsations arising from the individual piston firings (S. Himmelstein and Co., 1981). Other pulsations arising from impulse loads and from possible background electrical noise may also randomly appear as tall spikes in the waveform.

The instantaneous torque being delivered through a tractor PTO shaft operating under a nonuniform torque load oscillates in magnitude. The magnitude depends primarily upon the shaft angle; secondly, upon the implement impulse loads; and, finally, upon the piston pulsations.

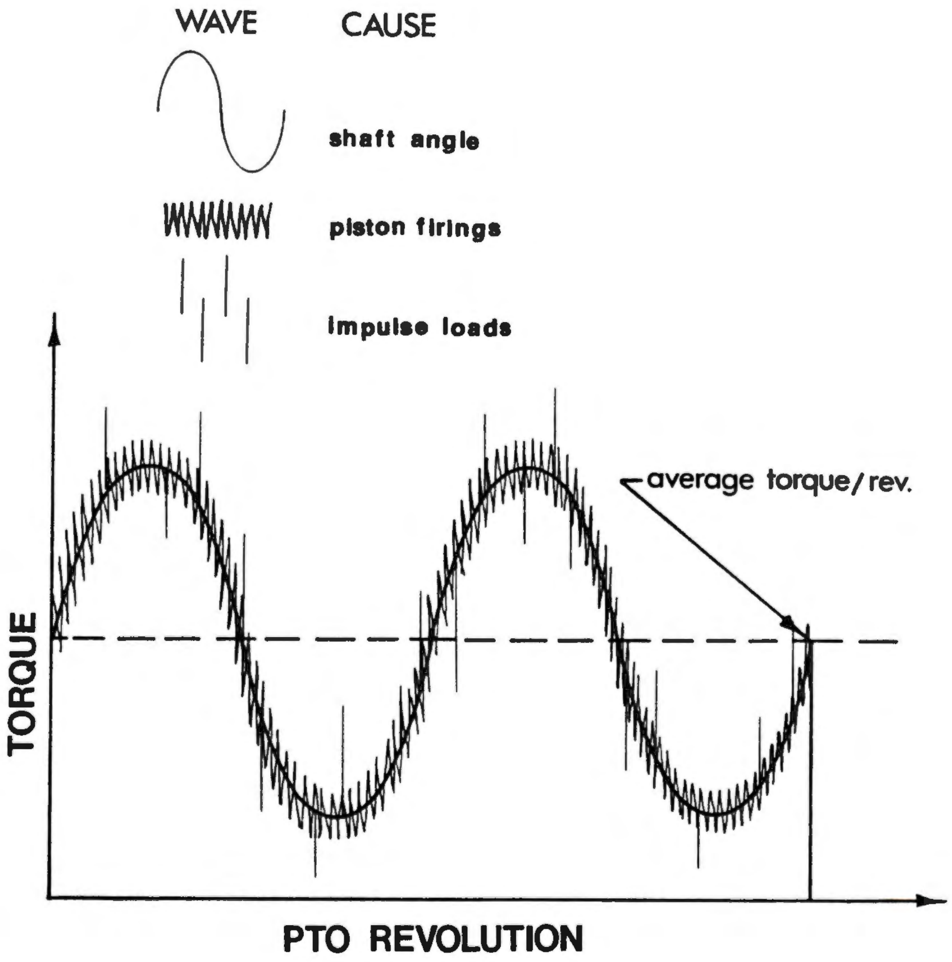

Figure 17. The torque delivered to a tractor by a standard PTO shaft driving a constant load has a frequency twice the shaft rotational speed and has an amplitude which is a function of the PTO shaft universal joints angle of operation. A superimposed higher frequency waveform is caused by the piston power pulsations generated by the tractor. Under non-constant loading conditions, varying frequency waveforms occur and may significantly distort the waveform.

Average torque value, instead of instantaneous torque value, represents the desired information to the researcher in most instances. Obtaining this average by storing many sampled instantaneous values for later mathematical averaging demands a tremendous amount of finite data storage space, thus reducing the potential duration of a given test. Therefore, some other form of signal averaging often becomes desirable or even necessary.

Signal averaging through software. Often analog signals are averaged through software. Yet, either random sampling of a signal or using an inadequate sampling rate can create grossly inaccurate average values for the signal. These inaccuracies are referred to as aliasing errors.

Slow sampling speeds tend to plague programs written in high level languages such as FORTRAN and BASIC. Assembly language routines are often needed to provide adequate sampling rates. Even so, continuous high-speed sampling unnecessarily loads a computer and complicates software development.

How frequently should an analog signal be sampled? To obtain its true average, based on the Nyquist Criterion of the Sampling Theorem, a signal must be sampled at a constant interval of at least twice the frequency of its highest frequency component (Datel Intersil, 1982).

Calculation of the required sampling interval for measuring PTO shaft torques, at first, seems easily accomplished. Principal frequencies of the waveform are predictable as they are controlled by engine speed and, consequently, PTO speed. However, the uncontrolled random impulse loads on the PTO shaft (illustrated in Figure 17 as spikes and routinely caused by drive chains, sears, cutterheads, etc.) coupled with a wide variety of implement types and loading conditions mandate a very high sampling frequency.

For example, the largest amplitude of the torque waveform shown in Figure 17 has a frequency twice the PTO shaft rotational speed. If the shaft is rotating at a frequency of 540 rpm, a minimum sampling speed for this waveform would be 36 samples per second. However, the second waveform caused by the power pulsations of the pistons has a frequency of approximately 100 Hz (this will vary among tractor models), requiring a minimum sampling rate of 200 samples per second. The third wave caused by impulse loads has an undetermined frequency. Thus, the software approach to signal averaging may not be satisfactory.

Signal averaging through hardware. A common way to avoid sampling an analog signal rapidly and at constant intervals involves simply passing the signal through a low-pass filter having a cutoff frequency of less than one-half the sampling frequency (Datel Intersil, 1982). Not only does this technique prevent any frequencies greater than one-half the sampling period from being sampled, but filtering also allows the average value of the signal to be sampled.

Thus, using hardware for signal averaging may be appealing. Signal averaging through hardware eliminates the necessity of sampling uncontrolled frequencies of the signal. The sampling interval no longer remains a function of the signal frequency. The interval depends solely upon the selection of a low-pass filter cutoff frequency.

S. Himmelstein and Co. (1981) states that the best way to eliminate aliasing errors due to inadequate sampling is to incorporate a low-pass filter into the signal conditioner and completely remove the periodic noise. However, when using multiplexed signal amplifiers, low-pass filters become impractical.

In the PTO modified version of the instrumentation system, four analog signals are sampled very slowly (once a second) after being passed through low-pass filters with cutoff frequencies of 0.5 Hz. Five pulse counters are also read and cleared simultaneously with the analog signals. This slow sampling rate frees the computer to do other tasks (e.g., store data, make calculations, check for errors, and update the video screen). Furthermore, a slow sampling and recording rate greatly lengthens the potential continuous test period for the system from a few seconds (a function of the computer dynamic memory) to approximately 14 hours (a function of the storage media capacity).

Low-pass filters fall into two categories, passive and active. With passive filters, the input signal powers the output signal. Thus, the passive filter loads the input signal and sometimes causes distortion if the input signal is weak.

In contrast, the output signal of an active filter draws power from a power supply instead of from the input signal. Moreover, a weak signal is converted to a strong signal when passed through an active filter. Because the active filter does not significantly load the input signal, active filters should be used for hardware signal averaging if possible.

Low-pass filters also come with several standard frequency response characteristics. According to one component manufacturer, a low-pass filter having a Bessel response is recommended for pre-filtering analog signals for averaging purposes. "A Bessel filter has a transfer function that approximates a constant time delay. Excellent low-overshoot, fast-settling pulse response and only moderate out-of-band frequency response rolloff rates characterize this design, making them desirable for A/D and D/A systems" (Frequency Devices, 1982).

PTO shaft speed measurement. Options to separately detect shaft speed are frequently available on commercial torque transducers. A common method involves using a toothed gear pressed onto the shaft of a torque transducer such that it becomes an integral part of the shaft. A magnetic proximity sensor near the gear emits an electrical pulse after each gear tooth passes. The number of pulses in a given period of time, combined with the number of teeth on the gear, determine the shaft rotational speed. Shaft power is a function of this rotational speed and shaft torque.

Engine speed on the instrumentation system similarly is measured by counting the teeth on the engine flywheel. A direct ratio between engine speed and PTO speed conveniently eliminates the need to measure both. Torque loads large enough to cause PTO clutch slippage exceed the design specifications of the torque measurement instrumentation.

PTO Instrumentation Hardware Description

The hardware used in the PTO modified system to obtain torque measurements from PTO-driven implements is illustrated in Figure 18. The hardware consists of:

1. an in-line torque transducer,
2. a double-flex coupling,
3. a smooth shaft to splined shaft adapter,
4. a mounting platform, and
5. an enclosure (not shown).

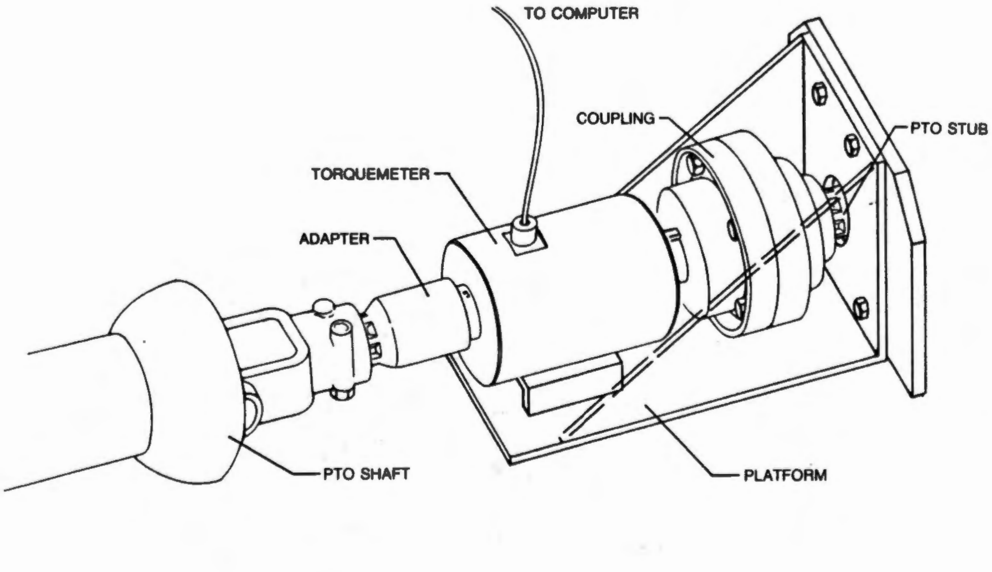

Figure 18. The PTO modified system hardware used for measuring power inputs to PTO-driven implements.

Torque Transducer

The transducer shown in Figure 18 is a Lebow 1100 in-line strain gauge rotary torque transducer. The device is rated by the manufacturer at 1,130 N-m (10,000 in.-lbf) with a maximum speed rating of 85,000 rpm.

The signal emitted by the sensor is amplified by a factor of 500 using a signal conditioning module. This provides a scaled output signal of ± 10 volts over the transducer range of ± 1,130 N-m (± 10,000 in.-lbf). A 1.0-mV change in the conditioned signal equals a 0.113 N-m (1.0 in.-lbf) change in torque on the shaft. A 12-bit A/D board, scaled over ± 10 volts full scale, samples the conditioned signal after the signal has been passed through a low-pass filter for averaging. The computer resolution of the sensor signal is 0.55 N-m (4.88 in.-lbf).

Double-flex Coupling

The coupling shown connects the shaft of the torque sensor to the tractor PTO stub. The manufacturer states that the FALK Model 1015G double engagement coupling accommodates offset misalignment, angular misalignment, and a combination of the two, as well as end float (Falk Corporation, 1982). The coupling is rated at 1,920 N-m (17,000 in.-lbf) and has a maximum speed rating of 6,500 rpm.

A special adapter for the coupling was designed and constructed in-house for use with a splined shaft. This coupling converts the smooth-keyed shaft of the coupling to a standard 540-rpm splined shaft.

PTO Adapter

A PTO adapter, rated at 790 N-m (7,000 in.-lbf), provides a safeguard from overloading the torque sensor. The adapted serves as a large shear pin and supplies a breaking point if overloading or damaging shock loads occur. This is the least expensive component of the system and can be replaced in the field.

Platform

A braced mounting platform constructed of 4.76-mm (3/16-in.) plate steel supports the torque sensor and prevents it from rotating. The torque sensor firmly bolts to the platform, which, in turn, bolts rigidly to the tractor frame. Bolt taps normally used for the PTO safety shield conveniently provide a means of attachment.

Enclosure

A sheet metal cover encloses the platform, coupling, and sensor. This cover protects the sensor from dust and moisture. The enclosure also serves as a safety shield.

II. PTO DRAFT MEASUREMENT ASSEMBLY

Introduction

A tractor-mounted dynamometer was described by Hart (1982) for the measurement of implement draft forces. However, this dynamometer physically prevented the connection of an implement PTO shaft to the tractor. Therefore, another method was investigated for measuring the draft forces of towed implements. This new method allowed for the connection of the PTO shaft to the tractor and the extension of the tractor drawbar. Drawbar extension was necessary to compensate for the relative increase in tractor PTO stub length caused by the torque box.

Normally, the drawbar of a Massey-Ferguson 2675 is attached to the undercarriage of the tractor frame by two suspension brackets, one located at the lower rear of the tractor frame and the other positioned approximately 1 meter forward from the rear. Several spaced holes located towards the forward end of the drawbar and a single corresponding hole in the forward bracket allow for the length adjustment of drawbar.

A large pin serves to fasten the drawbar to the forward bracket. This pin inserts into aligned holes of the two components and is secured by a cotter key. Thus, this pin is subjected to all forward and rearward horizontal forces. Without the pin, the drawbar slides freely on the brackets for extension adjustments or removal.

PTO Draft Measurement Instrumentation

The new method for measuring draft was centered around the replacement of the pin with a load cell. The physical size of any appropriate load cell prevented direct replacement. Therefore, a frame containing the load cell was located on the forward side of the forward bracket.

A fabricated drawbar extension was used to attach the load cell frame to the end of the original drawbar. The rear end of the extension slid over and pinned to the forward end of the original drawbar. The forward end of the extension connected through the forward suspension bracket to the load cell which in turn was attached to the frame.

A rearward pull on the drawbar would now be transmitted by the drawbar, supported vertically by the rear bracket, to the drawbar extension. The drawbar extension, supported by the forward bracket, would pull on the load cell which in turn resisted via its frame pushing against the forward side of the front bracket. Forward implement thrusts were restrained by reinserting the original pin in the forward bracket which was aligned with a slot in the drawbar extension. Adjustments were made using 0.254-mm (1-in.) threaded rod and lock nuts.

PTO Draft Instrumentation Performance

Shop tests indicated the assembly did transmit horizontal forces to the load cell subjecting the transducer to tension forces. However, the assembly failed to perform satisfactory under dynamic field conditions.

Field testing revealed the weight imposed by an implement hitch caused a bending moment to occur between the two brackets. This moment prevented the free sliding of the drawbar through the brackets. Furthermore, free-rolling towed implements have a tendency to both push and pull against the drawbar when operating on uneven surfaces and/or traveling up and down slopes. Because forward drawbar thrust was resisted by the pin located in the extension arm slot, test data appeared as sharp draft increases oscillating with neutral draft values. After visual interpretation, the draft data produced by the assembly provided an approximation of the force required to roll an implement over a given surface.

Currently, positive draft values (rearward forces from the tractor frame) appear as negative values both on the display and in the raw data. Use of the same load cell and wiring for both axle and draft calibration prevented rewiring to eliminate the discrepancy. Furthermore, a software negation of the value would affect the values obtained when using the same software with the standard dynamometer. Therefore, the PTO draft values were negated during data analysis.

PTO Draft Measurement Hardware Description

The transducer shown in Figure 19 is a Gentran, Inc. Model LG204A load cell. The device is rated by the manufacturer at 44,480 N (10,000 lbf) with a sensitivity of 8.85 N/mv (1.99 lbf/mv).

The signal emitted by the sensor is amplified by a factor of 500 using a signal conditioning module. This provides a scaled output signal of ± 10 volts over the transducer range of ± 44,480 N (± 10,000 lbf). A 1.0-mV change in the conditioned signal equals a 4.448 N (1.0 lbf) change in torque on the shaft. A 12-bit A/D board, scaled over ± 10 volts full scale, samples the conditioned signal after the signal has been passed through a low-pass filter

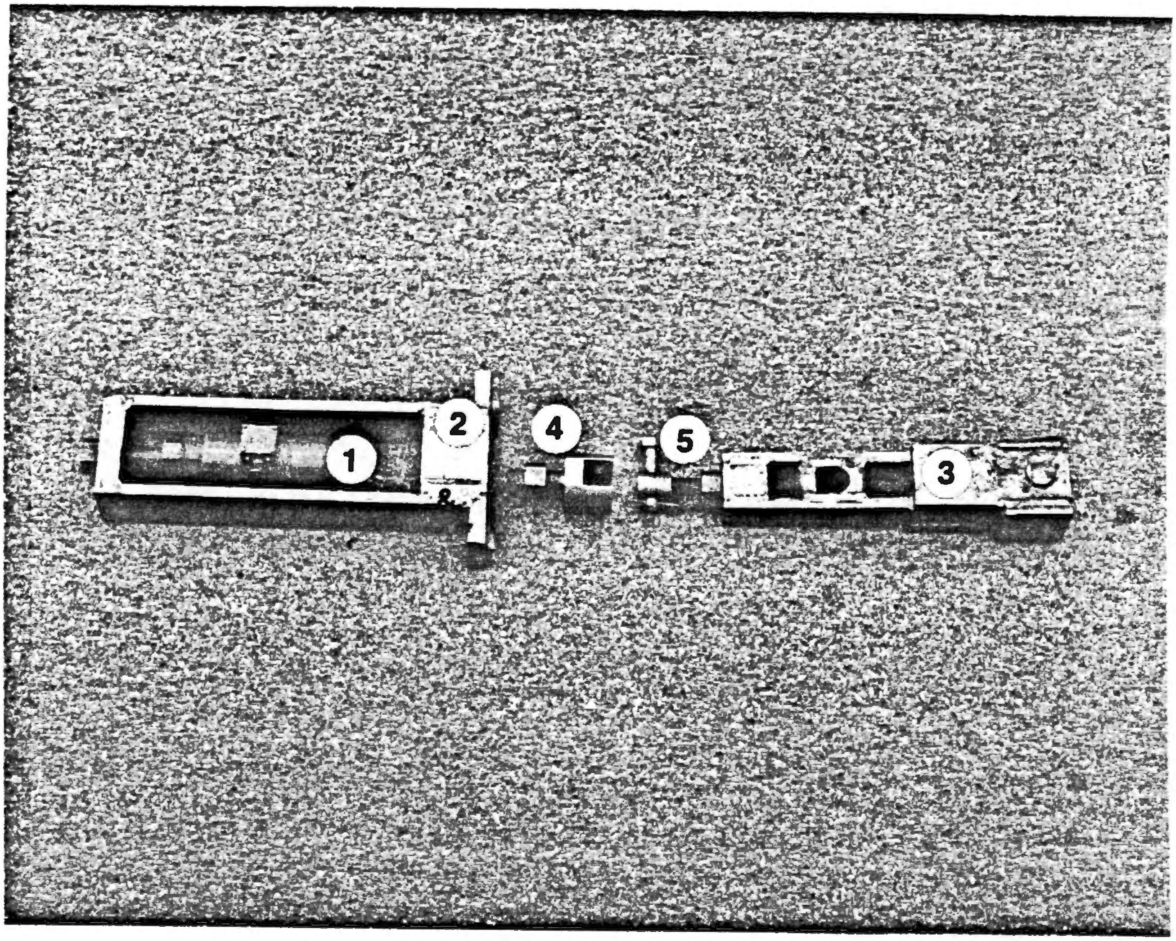

Figure 19. Assembly used for the measurement of draft produced by towed PTO-driven implements. Components are: (1) force transducer, (2) transducer frame, (3) drawbar extension, (4) threaded rod and lock nuts, and (5) extension pin.

for averaging. The computer resolution of the sensor signal is 0.55 N (4.88 lbf).

The transducer frame and drawbar extension were designed and constructed in-house. Flat-stock cold-roll steel, 0.127-mm (1/2-in.) thick, was used in the construction.

III. BUBBLE MEMORY MASS STORAGE SYSTEM

Introduction

A DEC TU58 dual tape drive was originally used as both the RT-11 operating system device and the data storage mass memory device. Drive 0 was an RT-11 file structured device having 256 Kb of storage. This drive contained both the operating system files and the data acquisition program file. Drive 1, also having a storage capacity of 256 Kb, was not RT-11 formatted. This drive was used as a sequential block access device for data storage.

The TU58 is a low-cost intelligent mass memory device used primarily for archiving and software transfer. Although RT-11 supports the TU58 as a system device, its 9.3-second average access time and 38,400 bits/second maximum transfer rate normally make it an undesirable system device. However, it is less susceptible to harsh environmental conditions than floppy or hard disk-based systems, making the TU58 a choice for a system and data storage device which operates under vibrating and/or dusty conditions.

TU58 Tape Drive Replacement

After four seasons of in-field use, two undesirable characteristics of the TU58 tape system became apparent. Foremost, the TU58 system did not perform reliably under all field conditions, device communication errors occurred frequently causing system crashing and preventing system initialization. Secondly, the tape system was slow. The average start-up time was approximately 9 minutes, a tedious and awkward length of time during program development and system demonstration.

A solid-state non-volatile mass storage system was introduced by Bubble-tec Corporation in 1982. This type of mass storage, commonly referred to as either magnetic or bubble memory, was designed specifically for operation in harsh environments. A Q-Bus controller card and a 512-Kb Q-Bus bubble memory board have the capability of totally emulating a RT-11 floppy disk based mass storage device (designated by "DY").

A 512-Kb Bubbl-Board has an average access time of 41 msec, an 82 msec maximum access time, and a transfer rate exceeding 270,000 bits/second. Thus, by substituting bubble memory for the TU58, the average increase in device speed of the system was a factor greater than 100. Although the TU58 (designated by "DD") was replaced as the system and data storage device through use of the bubble memory system, the TU58 drives were retained as a means to physically transfer software and data to and from the system. Figure 20 shows module placement in the backplane when using the bubble memory cards.

```
slots         A                 B                C                 D
row 1:-----------------------------------------------------------------
                 LSI 11/03 CPU        :        **empty slot**        :
       ----------------------------------------------------------------
row 2:           MSV11 memory         :        **empty slot**        :
       ----------------------------------------------------------------
row 3:                           DT1761 A/D                          :
       ----------------------------------------------------------------
row 4:                        DRV11 counterboard                     :
       ----------------------------------------------------------------
row 5:            QBC-11/02           :        **empty slot**        :
       ----------------------------------------------------------------
row 6:      DLV11-J communication     :        **empty slot**        :
       ----------------------------------------------------------------
row 7:        VK-170 video board      :        **empty slot**        :
       ----------------------------------------------------------------
row 8:           QBI-11/512           :        **empty slot**        :
       ----------------------------------------------------------------
row 9:                     BDV11 terminator board                    :
       ----------------------------------------------------------------
```

Figure 20. Backplane locations of the system component modules after the addition of the controller card (QBC-11/02) and bubble memory module (QBI-11/512).

The conversion to bubble memory required no software modification and only a limited amount of operating system reassignments. By subsetting the directory of the bubble memory into a logical disk (designated by "LD") having the same capacity as a TU58 tape, the following operating system commands, which were executed upon system initialization, made the conversion transparent to the data acquisition program:

```
.ASS DY0:  DD0:<RET>  !assign all references of Drive 0 to
                      !bubble memory

.ASS LD0:  DD1:<RET>  !assign all references of Drive 1 to
                      !the logical disk
```

After a logical disk is filled, data is physically transferred from the system by copying the logical disk onto a TU58 tape:

```
.COPY/DEV LD0: DD:<RET> !produce an exact image of the logical
                         disk
                        !on DD0:.
```

Although the command string interpreter of RT-11 decodes the designators "DD0:" and "DD:" as TU58 Drive 0, only "DD0:" has been assigned to DY0:. Thus, TU58 Drive 0 can be accessed without deassignment.

The use of bubble memory as a system device required the removal of the user supplied TU58 boot EPROMs from the BDV11 bootstrap terminator board. The EPROMs contained the firmware which was automatically executed upon power-up to bring up the system (Hart, 1982). However, the original ROMs supplied with the BDV11 contained the code to boot several mass storage devices, including a floppy disk. Therefore, after reconfiguration of the BDV11, a start prompt appeared on system power-up requiring the operator to type "DY" to boot the bubble memory as the system device. The following demonstrates how to start (boot) the system:

```
START?  dy <RET> !execute the code to boot a floppy disk.
```

Problems Encountered

The bubble memory controller board was found to operate improperly if it became overheated (i.e., exposed to temperatures greater than 70 degrees Celsius), a condition which might occur if the tractor is left out in the direct sun on a hot day with the air conditioning not operating and the cab door closed. Although the bubble card is not affected, trying to run the controller in this state will contaminate the system directory and any files which are accessed on the bubble board. If overheating should occur, it is recommended that the system be cooled down, using the tractor cab air conditioner, before power is applied to the computer.

A backup system tape containing all of the necessary files is maintained in the tractor cab. If the bubble card becomes contaminated, the system can be booted from the backup tape and the bubble card re-initialized. This procedure, along with how to create a logical disk which is a direct image of a TU58 tape, is described in Appendix B.

IV. GROUND SPEED RADAR

Introduction

Test data revealed that the fifth wheel slipped when operating on loose and/or rough surfaces. The counts produced by the fifth wheel could approach 20 percent less than the theoretical timed distance values. Thus, an alternate means of accurately measuring ground speed was investigated.

Typically, two methods in addition to the fifth wheel have been used for measuring ground speed. The most common way involves using engine speed and gear selection as an indication of groundspeed. However, this method neglects drive wheel slip. Another method involves counting the wheel lugs on a non-driven front wheel using a magnetic proximity sensor. However, a front wheel may slide on some surfaces and change in effective radius as the weight of the tractor transfers from the front wheels to the rear wheels during draft increases.

Radar Review

TRW, Inc. (1982) introduced a single beam radar unit designed for measuring the true ground speed of agricultural and off road equipment. The sensor mounted on the side of the vehicle at a location having an unobstructed view of the ground at a height of 610 to 990 mm (24 to 39 in.) above the ground surface with a depression angle of 37 ± 2 degrees.

Operating on the principal of the Doppler frequency shift, this sensor transmits and receives radio frequency at 24,125 GHz. The measured frequency difference between the signals sent to and those reflected from the ground surface is proportional to the ground speed of the vehicle. The sensor generates a TTL level output signal of approximately 35.9 Hz per km/h (57.5 Hz per mph), depending upon the depression angle of the sensor mount. Furthermore, the sensor is documented by TRW, Inc. (1982) to have an accuracy of 4.0% when data are averaged over 0.5 seconds intervals and the vehicle is traveling between 1.6 and 40.0 km/h (1.0 and 25.0 mph).

Three wires connect to the sensor: (1) 12-volt power, (2) ground, and (3) output signal. These wires would normally travel to a display unit housed near the operator. The display unit converts the sensor output signal frequency into a ground speed value for display and provides control for switching power on or off to the radar unit.

A radar sensing unit was purchased and mounted on the instrumented tractor (Figure 21). However, instead of using a display unit, the output signal from the sensor was input directly into the pulse counter interface box through a channel normally used for the fifth wheel. A software calibration test was used to automatically calculate and patch the new calibration factor required to convert the sensor output frequency into a displayed value of miles per hour.

The radar unit was wired such that whenever the ignition was turned on, power was supplied to a console-mounted toggle switch such that the operator could manually turn the radar unit on or off. Thus, the radar unit would not drain the battery if it were inadvertently left on after the tractor was shut down.

The 5-pin DIN connector of the radar unit was wired to be compatible with any of the three channels interfaced to an optical encoder. The up/down line was grounded (always counted up), and the sensor signal was tied to the count line. However, the sensor signal was offset from zero volts enough to prevent passage through the threshold of the Schmitt-trigger. Thus, a resistive voltage divider was constructed inside the connector to drop the input signal below the threshold level.

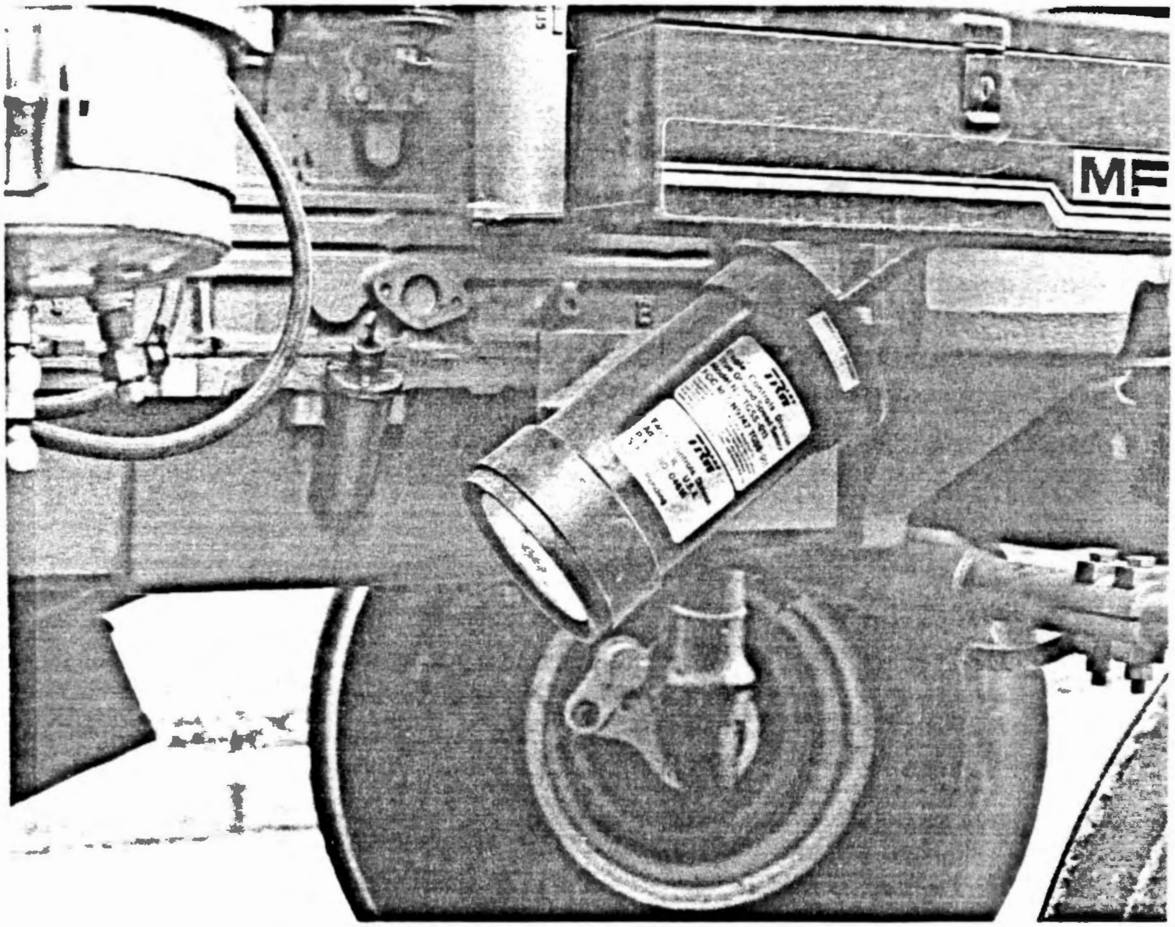

Figure 21. Radar-based ground speed sensor mounted on the instrumented tractor.

V. FRONT WHEEL SPEED SENSOR

A common method for measuring ground speed involves using a sensor mounted on the front wheel. Typically, a magnetic sensor is fastened in a stationary position inside the front wheel rim and used to detect hub nut passages. Another method uses an optical encoder mounted inside the front wheel rim.

To test the effectiveness and accuracy of the front wheel sensor, a decision was made to include this type of sensor on the instrumented tractor. Testing could then be conducted to compare radar, fifth wheel, and front wheel sensors for accuracy and precision when operating over various ground surface conditions.

An assembly was designed for mounting and driving a Disk Instruments EC80 series incremental optical encoder (Figure 22). This encoder emits 100 dual TTL waveforms per shaft revolution. The output from this sensor was fully compatible with the three existing optical encoder interfaces located on the instrumented tractor.

A spring-loaded arm, extended from the left front spindle shaft casting, supported the encoder. The arm supported a 96-tooth gear, attached at the end of the encoder shaft, such that this gear meshed with a 144-tooth gear mounted on the inside rim of the left front tractor wheel. Thus, a ratio of one tractor wheel revolution per 1.5 encoder revolutions was produced, or 150 pulses were generated for each revolution of the front wheel.

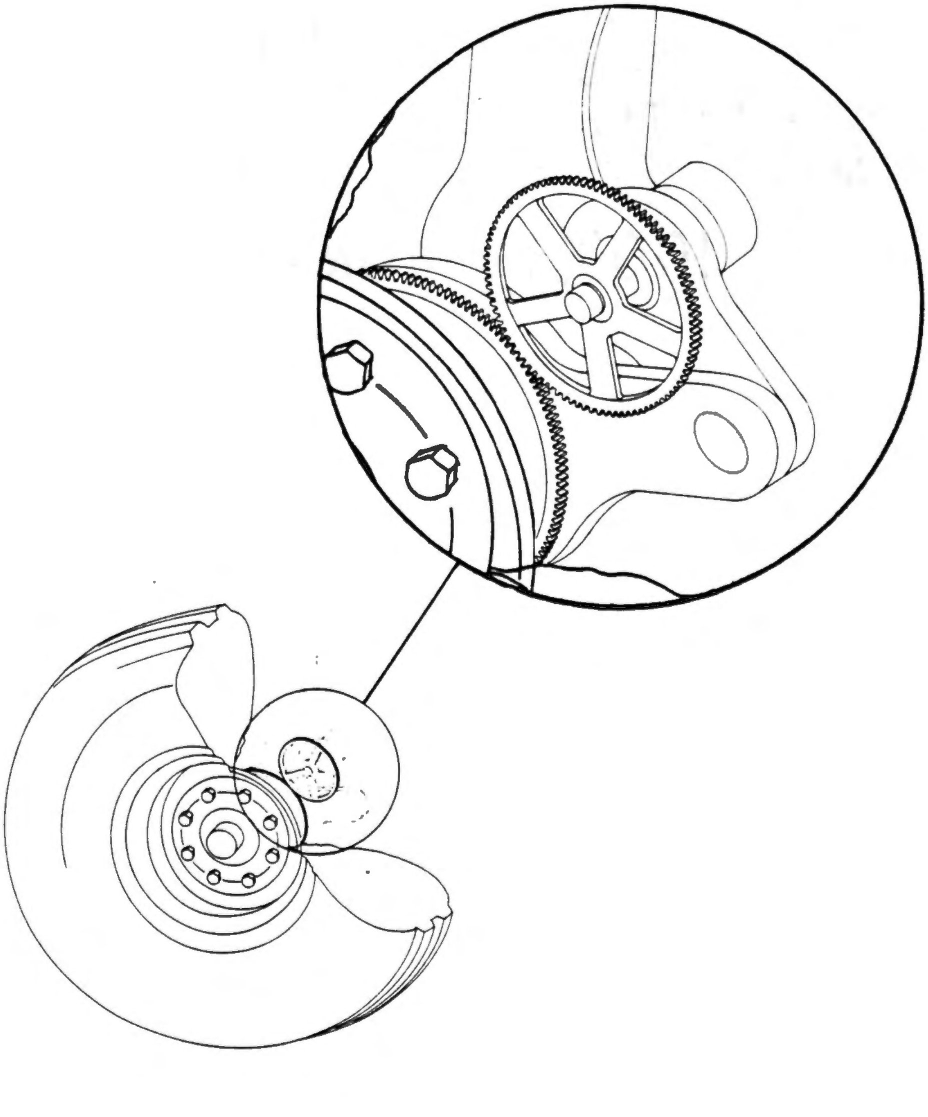

Figure 22. Assembly used for the measurement of front wheel rotation (Tompkins et al., 1985). Components are: (1) optical encoder, (2) mount arm, (3) encoder gear, (4) tire rim gear.

The mounting arm could be locked back, preventing the encoder gear from meshing with the rim gear. When disengaged, the encoder shaft did not rotate, thus, limiting sensor wear or possible damage. This feature was useful when transporting the tractor.

VI. INSTRUMENTATION SOFTWARE ENHANCEMENTS

Introduction

A new routine was written to provide an immediate summary of a given test at the conclusion of each test run. This information was especially useful during system demonstrations and evaluation. Furthermore, the addition of new instrumentation for sensing engine speed and PTO power required that the existing data acquisition software to be modified.

Data Averaging Routine

A new subroutine was appended to the original data acquisition software to automatically summarize and display test data results at the immediate conclusion of each test. Thus, the operator was instantly provided an overall analysis of the preceding test. This routine tabulated 10 arithmetic means derived from the test data which included: (1) implement draft, (2) ground speed, (3) engine speed, (4) drive wheel slip, (5) drawbar power, (6) axle power, (7) tractive efficiency, (8) theoretical field capacity, (9) fuel consumption per unit area, and (10) fuel consumption per unit time.

New code was inserted into the original routine which, throughout the test period, was responsible for converting raw data into engineering units and updating the display values on the operator console once per second. After each value was displayed, the inserted code added that value to a corresponding accumulator. Also, an observation count was incremented after all of the accumulators had been serviced in this manner. At the conclusion of the test, the data averaging routine was called to divide each accumulated value by a modified observation count.

All values were summed except the first and last scan values. The first value was omitted due to it being approximately 4 percent less than the true value. The last value was excluded because it represented a fraction of a second scan count. Therefore, the true observation count was decremented by two before data averaging.

Additional calculations were performed, such as averaging both drive wheel slip values into a single slip value, deriving theoretical field capacity, and computing tractive efficiency. Furthermore, the display was cleared, a template was displayed, and the corresponding values were inserted. Finally, the accumulators and observation count were cleared for the next test.

The averaged values were not saved on tape for later analysis. However, printed forms were provided with an identical template. Before starting the next test, the operator had the option of manually saving the displayed information for later reference. An example of this template is provided in Appendix C.

Engine Speed Sensor Code

Software was added to the original code for calculating and displaying engine speed. This parameter replaced the fuel temperature value originally located in the template on the operator console during testing (Hart, 1982). The original code used to calculate and display fuel temperature was maintained in the source code but this code was commented out.

Engine speed was calculated by multiplying the counts received over one second from the engine speed sensor, mounted above the 132-tooth flywheel, by a constant factor. This factor was 4.5454..., determined as follows:

$$Y \text{ rpm} = X(\text{counts/sec})*(60\text{secs/min})*(\text{rev}/132\text{counts})*10$$

or

$$Y \text{ rpm} = X(\text{counts/sec}) * 4.5454 \ (\text{rpm-sec/counts}).$$

The engine speed factor was multiplied by ten since the pulses were earlier divided by ten when passed through the pulse counter interface box. This division was used to alleviate channel bleedover on the counterboard.

PTO Interface Code

Additional code inserted in the same routine as the engine speed code calculated and displayed PTO power. The computation was based upon a 12-bit, two's complement (2048) PTO shaft torque value, a previously calculated engine speed, and a conversion factor. Due to the limitations of operator screen space, the original display of acres per hour was eliminated from the template.

The conversion factor was determined as follows:

Y PTO hp = S engine-rpm * X bits
* 10,000 in.-lbf/10 volts * 1 ft/12 in.
* 10 volts/2048 bits
* 540 PTO rpm/1990 engine rpm * 1 PTO hp/5252 PTO rpm-ft-lbf

or

Y PTO hp = S eng. rpm * X bits * .000021 PTO hp/engine rpm-bits.

VII. GROUND SPEED SOFTWARE

A new data acquisition software package (RGS.SAV) was written to evaluate three sensors commonly used in measuring true ground speed of off-road vehicles: (1) a front wheel sensor, (2) a fifth wheel sensor, and (3) radar. The new software program (RGS.FOR) was written primarily in FORTRAN IV, using a limited number of assembly language routines (RGSM.MAC) for direct counterboard control. The counterboard was the only interface required since all of the sensors involved emitted digital pulses.

A main design goal of this package was to store all test data and limited statistical analysis in ASCII format inside an RT-11 structured file. Thus, the data and file could be manipulated with standard RT-11 operating system commands such as COPY, PRINT, DIR, and TYPE. A one character line prefix was used to identify each line of data within the data file (Table 1). Test information, raw data, data statistics, and operator comments about the test were adjacently stored in table format within the file (Table 2).

Table 1. A one character line prefix was used to identify each line of information contained within the data file.

Prefix	Description
< H >	= operator supplied description of ground surface
< G >	= operator supplied tractor gear selection used during the test, followed by a computer incremented test number
< L >	= operator supplied location of the test
< T >	= computer supplied time and date of the test
< D >	= raw data of timer, front wheel, fifth wheel, radar, and engine speed
< m >	= minimum count observed
< M >	= maximum count observed
< A >	= mean of the counts
< S >	= standard deviation of the counts
< V >	= coefficient of variation of the counts
< C >	= operator supplied comments about test (e.g., independent time, bad test, vibrations, etc.)

Table 2. Sample listing of test data obtained using the ground speed software.*

Prefix	Time	Front Wheel	Fifth Wheel	Radar	Engine
D	1.00	135	918	346	399
D	2.00	140	972	363	411
D	3.00	141	969	398	409
D	4.00	141	959	372	410
D	5.00	139	955	376	408
D	6.00	139	971	363	408
D	7.00	139	954	358	409
D	8.00	139	962	380	408
D	9.00	140	973	364	409
D	10.00	140	961	372	409
D	11.00	141	967	385	409
D	12.00	139	994	375	411
D	13.00	138	960	366	408
D	14.00	140	971	361	408
D	15.00	140	966	370	409
D	16.00	139	952	359	409
D	17.00	141	998	376	410
D	18.00	141	966	377	411
D	19.00	139	963	363	408
D	20.00	140	959	348	408
D	21.00	141	955	370	410
D	21.87	120	826	323	348
m		135	918	346	399
M		141	998	398	411
A		139.62	964.05	368.67	408.62
S		1.36	15.34	11.61	2.38
V		0.98	1.59	3.15	0.58

*Additional one character prefixes and example data contained in each data set are as follows:

"C 21.53 SEC #2 DWN MINOR CLEAT VIBRATIONS,"
"H TALL GRASS,"
"G 7L 106,"
"L RIVER BANK," and
"T 15:39:15 13-MAY-85."

However, there is a serious drawback to storing data in an RT-11 structured file. If the computer system has a non-recoverable crash, the information gathered since the last test exit will be lost. To help alleviate this problem, the size of the file was limited in size to hold approximately 10 tests. This required the operator to exit the program periodically and close (save) the file.

Program Initialization

Although required only once at computer booting and before starting the program, the output normally written to tape should be routed to the logical disk:

```
.ASSIGN LDO:  DD1:  !assign all references of DD1:  to the logical disk
```

If the bubble memory has been contaminated, the logical disk will have been destroyed. This will be indicated by an illegal device error. Although seldom used, the following commands will recreate the logical disk.

```
.CREATE RDIR.DSK/ALL:512.<RET>  !create a file named RDIR.DSK
                                !having 512 blocks

.MOUNT LDO:  RDIR.DSK<RET>      !create a logical disk inside the file

.INIT/NOQ LDO:<RET>             !initialize the directory.
```

The following operating system command will initiate the ground speed program:

```
.RGS<RET>     !run program RGS.SAV.
```

Upon program initialization, the operator was given the choice of either (1) changing the data header information set-ups, (2) observing the output of the sensors continuously without data storage,

(3) initiating a test with data storage, or (4) stopping the program and closing the data file. Normally, after first entering the program, the operator would choose to change the data header information:

```
1=change set-ups, 2=continuous scan, 3=data, 4=stop > .
```

Data Header Information

After selecting to change the data header information set-up, the current set-ups were displayed and the operator was given the choice of changing (1) surface condition, (2) gear selection, (3) test location, (4) test number, or (5) return to main selection (Figure 23). Each change request was followed by an appropriate prompt for input. After each change, the display was cleared and the current set-ups were displayed, followed by a selection request.

The selection to change header information was required only if conditions of the test changed such as location, gear selection, and/or surface condition. The test number was incremented automatically by the computer after the initial starting test number was input.

```
Ground surface > **************************************
Gear > **
Location > **********
Test no. > 0
Type 1=change surface, 2=change gear, 3=change location,
     4=change test number, 5=return
>
```

Figure 23. Selection template and code to change current test information. The "*" symbol designates initial number of character spaces available.

Continuous Scan Without Storage

An option of the main selection routine is continuous scanning of the sensors counts without storing the data in a file. This selection is useful for testing the sensors and counterboard before a test run. After selecting this routine, a line feed character is required to both start and stop the test.

Data Gathering

The principal routine used in the program is the one which actually gathers data during a test run. Upon selection of this routine, a line feed character is required to both start and stop the test. Once the test has been initiated, counts from each sensor are scrolled upon the display. At the conclusion of the test, data are re-scrolled on the display, data statistics are calculated, and the results are displayed.

Since data are stored in RAM, the maximum length of a test is 5 minutes. This was based upon a 60-m course traveling at a minimum speed of 0.72 km/h (or 200 ft at 0.5 mph). Exceeding 300 scans will cause "buffer overflow" to appear on the display which is a non-fatal error.

A single line feed character was required to start and stop the test for two reasons. First, the return key (a carriage return, line feed) distorted the count table. Secondly, several returns could possibly be inadvertently pressed after selecting data gathering, causing an erroneous test to be started. The start-of-test prompt is:

<Line Feed> starts-stops test ....

Program Exit

The program should be exited whenever testing is complete or the data file is approaching capacity. After exiting the program, the data file must be renamed or the data file will be written over (lost) whenever the program is restarted. This is required because RT-11 FORTRAN IV does not support appending a data file. Once exit has been selected, the following prompt should be displayed:

```
STOP -- Successful close.
```

The following operating system command renames the default filename of the data file to an operator-selected new file name. Usually, a filename descriptive of the test surface condition and location is given.

```
.RENAME/PROJECT LD:DATA.GSD LD:newfile.ext.<RET> ! rename file.
```

The next command copies the data file onto a TU58 tape for archiving:

```
.COPY LD:newfile.ext DD:<RET>  !copy file.
```

Trouble Shooting

The following is a list of problems and their solutions which may occur during the execution of the ground speed software:

1. The current time and date should be current before program execution. However, this is not mandatory.
2. A count value on the timer channel of any magnitude except 0 indicates a bad IC is on the counterboard. Counterboard maintenance is required.

3. The program should be exited after approximately ten tests to prevent data file overflow. If overflow should occur, type CLOSE immediately upon receiving the command prompt "." or the current data file will be lost.
4. Failure of the TU58 to communicate may be corrected by several re-powerings of the unit and/or directory requests.
5. A total system crash is indicated by a "@" symbol on the operator screen. Immediately type "P" to determine if a recovery is possible. If successful, exit the program and rename the data file. Re-booting the system is advised. If not successful, the current data file is lost and the system must be re-booted. Note: A possible system crash (causing data loss) is the reason for limiting the size of the data file.
6. A flood of "Err. 62" errors indicates the current program was compiled and linked for the wrong target CPU. The source should be re-compiled and linked using FIS support.
7. All "STOP ? xxx ?" errors can be diagnosed by referencing the source code, listed in Appendix D.

CHAPTER V

RESEARCH CONDUCTED WITH THE ENHANCED INSTRUMENTATION SYSTEM

The instrumentation system, since reported by Hart (1982), has been used to successfully gather field data in three growing seasons. Energy requirements of various tillage and planting implements were measured the first season on West Tennessee soils (Hart and Tompkins, 1983). The following season, energy requirements of tillage machines operated on Mississippi soils were researched, and the system was field-demonstrated to area farmers (Tompkins et al., 1984). Later in the season, the energy required in the formation of a round bale was investigated (Bledsoe, 1984). Finally, at the beginning of the third season, a study was conducted to evaluate three sensors commonly used for measuring true ground speeds of agricultural vehicles (Tompkins et al., 1985).

I. WEST TENNESSEE FIELD TESTS OF 1983

Introduction

The instrumented tractor was used in 1983 cropping season at the Milan Experiment Station in West Tennessee (Hart and Tompkins, 1983). Seven tillage and planting implements were operated at different speeds over three 61-m (200-ft) courses, each course being on a different soil type. Due to weather conditions, all of the selected implements were not operated over each course. However, implements were used in their normal sequence (i.e., plow, disk, and plant).

Test Procedure

Each implement was drawn across a 61-m (200-ft) course at predetermined no-load speeds maintained by using a selected gear and engine speed. A range of 11 to 20 replications per course were run for each implement-speed combination. For each replication, depth of implement operation, effective implement width, and soil moisture content were manually measured and recorded.

As the implement was drawn through the course, the instrumentation system automatically measured and recorded (1) time, (2) draft, (3) fuel flow, (5) fifth wheel rotation, (6) right axle rotation, (7) left axle rotation, (8) right axle torque, and (9) left axle torque. From these raw values, the following were calculated: (1) ground speed, (2) drive wheel slip, (3) drawbar power, (4) axle power, (5) tractive efficiency, and (6) fuel consumption.

Test Results

Hart and Tompkins (1983) reported the 100-ptohp tractor consumed from 0.33 gal/acre, for row-crop planter producing 400 lbs of draft, to 1.82 gal/ac, for a chisel plow having 5520 lbs of draft. Results of the research are given in Tables 3 and 4.

Table 3. Description of Tillage and Planting Implements Evaluated and Soil Conditions Characterizing the Test Plots--1983 West Tennessee Field Tests.

Implement	Effective Width (ft.)	Description	Surface Condition and Soil Type	Depth of Operation (in.)	Gear Setting with No. Reps.
Chisel plow	9	9 shanks equipped with 2-inch chisel points 3-point hitch mounted	Firm surface with soybean stubble plus heavy screen vegetative cover {Memphis}	10-12	3L-20 4L-20 5L-19
Heavy tandem disk harrow	14	22-inch notched disk blades in front 22-inch smooth disk blades in rear 9-inch disk spacing	(A) Moderately firm surface chisel plowed approx. 2 months earlier. Light vegetative cover {Loring}	7-8	3I-15 4I-11 5I-13
			(B) Loosely tilled, moderately cloddy with heavy plant residue, chisel plowed immediately before disking {Memphis}	7-8	3I-16 4I-16
Light tandem disk harrow	12	20-inch notched disk blades in front 20-inch smooth disk blades in rear 7-inch disk spacing	(A) Loosely tilled with few clods and some green plant residue {Loring}	5-6	3I-18 4I-20 5I-20
			(B) Thoroughly tilled, cloddy with considerable plant residue mixed in tillage zone {Memphis}	5-6	4I-14 5I-12 6I-12
Soil pulverizer	13	19 field cultivator tines plus clod pulverizer plus spike-tooth harrow	Thoroughly tilled soil surface with some plant residue {Lexington}	6-7	3I-12 4I-12 5I-12
Cultimulcher	13.6	25 field cultivator tines plus 2 rows of rollers	Thoroughly tilled soil surface with virtually no plant residue {Lexington}	4-5	4I-21 5I-18 6I-14
Row-crop planter	13.3	4 rows with 16-inch diameter ripple coulter plus double disk furrow openers plus 12-inch double press wheels 3-point hitch mounted	Thoroughly tilled soil surface {Lexington}	--	3H-18 4H-15
Drill seeder	13.3	24 seed tubes equipped with double disk furrow openers and single press wheels plus 1 pair tire track scratchers (5-cultivator times) plus 2 ground driven wheels 3-point hitch mounted	Thoroughly tilled soil surface {Lexington}	--	3H-12 4H-11

[*] Data originally presented by Hart and Tompkins (1983).

Table 4. Energy requirements of selected tillage and planting implements operated at various ground speeds with a 100-ptohp tractor--1983 West Tennessee Field Tests.

Implement	Gear	Ground Speed (mph)	Drive Wheel Slip %	Drawbar Pull (lbs)	Drawbar Power (hb)	Energy (dbhp-hr/ac)	Axle Power (hp)	Tractive Eff. (hp)	Fuel Consumption		Moisture Content (%db)
									Gal/hr	Gal/ac	
Heavy tandem disk harrow	3I	2.68	11.6	3929	28.1	6.18	47.6	59.0	3.97	0.88	19.5
	4I	3.78	12.1	4216	42.5	6.62	68.9	61.8	5.03	0.79	
	5I	4.31	13.4	4312	49.5	6.77	82.9	59.8	5.96	0.82	
Light tandem disk harrow	3I	2.82	6.9	2421	18.2	4.44	35.7	51.3	3.42	0.83	17.2
	4I	3.95	8.0	2519	26.5	4.62	53.5	49.7	4.25	0.74	
	5I	4.52	9.0	2553	30.8	4.67	62.5	49.3	4.66	0.71	
Chisel plow	3L	1.85	14.9	5518	27.2	13.40	41.6	65.7	3.68	1.82	20.8
	4L	2.59	16.4	5815	40.2	14.19	62.0	64.8	4.67	1.65	
	5L	2.89	19.1	6201	47.7	15.15	75.0	63.7	5.49	1.75	
Heavy tandem disk harrow	3I	2.75	9.2	3680	27.0	5.78	44.9	60.8	3.92	0.84	17.0
	4I	3.88	9.9	4035	41.7	6.34	65.5	64.0	4.94	0.75	
	5I	4.45	10.6	4049	48.0	6.35	77.3	62.3	5.66	0.75	
Light tandem disk harrow	4I	4.02	6.5	2386	25.6	4.37	48.9	52.6	3.92	0.67	14.0
	5I	4.66	6.3	2497	31.0	4.58	58.3	53.5	4.43	0.66	
	6I	6.26	8.5	2755	46.0	5.05	84.7	54.7	5.95	0.65	
Soil pulverizer	3I	2.89	4.6	2853	22.0	4.82	33.7	65.3	3.44	0.75	11.4
	4I	3.97	7.7	3707	39.2	6.26	59.6	66.0	4.58	0.73	
	5I	4.46	10.4	4324	51.3	7.30	77.2	66.6	5.58	0.80	
Cultimulcher	4I	4.09	4.8	1867	20.4	3.02	36.3	56.4	3.51	0.52	9.7
	5I	4.73	4.8	1892	23.9	3.06	46.6	51.2	3.89	0.50	
	6I	6.54	4.5	2596	45.2	4.19	71.9	62.8	5.54	0.51	
Cultimulcher	4I	4.12	4.3	1910	20.9	3.08	34.2	61.3	3.45	0.51	7.6
	5I	4.72	5.1	2018	25.3	3.24	40.6	62.2	3.66	0.47	
	6I	6.46	5.8	2014	34.6	3.25	57.2	60.3	4.58	0.43	
Row-crop planter	3H	3.77	2.7	395	4.0	0.65	17.1	23.3	2.52	0.41	7.6
	4H	5.33	3.0	396	5.6	0.65	24.7	22.9	2.85	0.33	
Drill seeder	3H	3.78	2.4	1019	10.3	1.68	21.1	49.0	2.75	0.45	7.6
	4H	5.34	2.7	1052	15.0	1.74	30.3	49.5	3.18	0.37	

Refer to Table 3 for a description of implements, surface conditions, and operating conditions.

Refer to Table 3 for a description of heavy tandem disk harrow-surface condition A.

Refer to Table 3 for a description of light tandem disk harrow-surface condition A.

Refer to Table 3 for a description of heavy tandem disk harrow-surface condition B.

Refer to Table 3 for a description of light tandem disk harrow-surface condition B.

*Data originally presented by Hart and Tompkins (1983).

II. 1984 MISSISSIPPI FIELD TEST AND DEMONSTRATION

Introduction

The Mississippi Cooperative Extension Service provided funds to transport the instrumented tractor throughout the State of Mississippi for 2 weeks in August of 1984. The funds were provided for three purposes: (1) gathering of tillage energy data on Mississippi soils, (2) demonstration of the system, and (3) presentation of the tillage energy data at meetings of area farmers.

Test Procedure

Test sites were selected typifying the northern, southern, and delta soils of the state. Weather permitting, testing was conducted during the morning and afternoon with presentation of the results to local farmers in the evening. The instrumented tractor was also demonstrated at the gatherings using voice-actuated FM headsets for the immediate transmission of the test results by the operator to the speaker.

Selected tillage and planter implements were operated in a manner consistent with previous tests on 61-m (200-ft) courses over a wide range of soils and surface conditions. Soil moisture samples were gathered and implement operation depths were recorded. In addition, computer displayed individual test summaries were manually recorded by the operator for later use at the meetings.

A 9-shank chisel plow, used with the instrumentation system in previous research on West Tennessee soils, was transported along with the instrumented tractor. Thus, comparisons of West Tennessee and Mississippi energy data could be made.

Test Results

The data gathered throughout Mississippi compared favorably with test data of previous research (Tompkins et al., 1984). Operating conditions and test results are presented in Tables 5 and 6.

III. ROUND BALER RESEARCH OF 1984

Introduction

Energy requirement of round bale formation was investigated using instrumentation designed to measure PTO hp (Freeland et al., 1984). A New Holland Model 845 round baler was used to package hay composed of fescue, orchard grass, and clover at 12 percent (w.b.) moisture content.

Test Procedure

Data acquisition was started at the beginning of bale formation and was concluded after the bale was formed. Hay input to the baler was not controlled during the first field tests; but, the input was approximately the same as under normal operating procedures. The hay field used had asymmetric boundaries. Consequently, the windrows were uneven and of varying length. Thus, some tests required implement turn-around (i.e., dead heading) to finish bale formation.

Specific measurements obtained by the instrumentation were ground speed, implement draft, drive wheel axle torques, drive axle

Table 5. Description of tillage and planting implements evaluated and soil conditions characterizing the test plots--1984 Mississippi Field Tests.

Implement	Effective Width (ft.)	Description	Surface Condition	Depth of Operation (in.)
IH-55 Chisel	9.0	9 shanks equipped with 2-in. chisel points 3-opint hitch mounted	(A) Tilled surface, top surface crusted after previous disking	9-12
			(B) Tilled surface, disked prior to chisel	8-12
			(C) Firm surface, freshly mowed soybeans and wheat stubble	8-11
			(D) Firm surface, corn stover	10-12
JD-210 Heavy tandem disk harrow	13.0	22-in. notched disk blades in front, 22-in. smooth disk blades in rear, 9 blades per gang at 9-in. spacing	Loosely tilled surface, chisel plowed immediately before disking	6-8
IH-480 Heavy tandem disk harrow	14.0	22-in. notched disk blades in front, 22-in. smooth disk blades in rear, 9-in. disk spacing	Loosely tilled, slightly cloddy corn stover, chisel plowed immediately before disking operation	7-8
Tufline TW-52 Light tandem disk harrow	10.0	21-in. notched disk blades in front, 21-in. notched disk blades in rear, 7 blades per gang at 9-in. spacing	Loosely tilled surface, disked and chiseled prior to disking operation	5-7
JD No. 1 Soil pulverizer	12.5	Rotary clod pulverizer plus 2-section spike tooth harrow plus board drag	Thoroughly tilled soil surface, chisel plowed plus disk harrow immediately prior to operation	4-6
JD No. 2 Soil pulverizer	13.0	18 field cultivator tines plus 2-section spike tooth harrow plus board drag	Thoroughly tilled soil surface, chisel plowed plus disk harrow plus soil pulverizer immediately prior to operation	5-7
Bush Hog-8000 To-till	6.0	2 rows equipped with 18-in. straight notched coulter followed with subsoil shank plus 18-in. diameter 2-in. diameter 1-1/2 in. fluted coulter plus 17-in. diameter 2-in. fluted coulter plus 14-in. diameter 1-in. fluted coulter plus basket roller clod pulverizer per row, 3-point hitch mounted	Firm surface, freshly mowed soybeans and wheat stubble	7-8
JD-984 Disk bedder	12.6	4 rows equipped with a pair of 16-in. and 18-in. diameter disk blades per row, 3-point hitch mounted	(A) Thoroughly tilled soil surface chisel plowed plus disk harrow plus two soil pulverizing implements prior to operation	--
			(B) Firm surface, corn stover	--
JD-7000 Row crop planter	13.3	4 rows equipped with 3/4 in. wide ripple coulters 16 in. in diameter plus double disk furrow openers and gauge wheels plus 12-in. diameter angled double rubber press wheels	(A) Firm surface, freshly mowed soybeans and wheat stubble	--
			(B) Thoroughly tilled soil surface	

*Data originally presented by Tompkins et al. (1984).

Table 6. Energy requirements of selected tillage and planting implements operated at various ground speeds with a 100-ptohp tractor--1984 Mississippi Field Tests.

Implement[a]	Gear	Engine Speed (rpm)	Ground Speed (mph)	Drive Wheel Slip (%)	Drawbar Pull (lbs)	Drawbar Power (hp)	Axle Power (hp)	Tractive Eff. (%)	Fuel Consumption	
									Gal/hr	Gal/ac
Firm tractive surface, sandy loam soil underlain with clay, Poplarville, Ms.										
IH-55 Chisel plow	4L	2203	2.68	15.89	5760	41.2	56.6	72.8	4.56	1.56
Firm tractive surface, sandy loam soil, Poplarville, Ms.										
JD-7000 Row crop planter	3H	2015	3.54	2.12	760	7.2	18.8	38.2	2.60	0.45
	4I	2029	3.96	2.98	760	8.0	21.4	37.3	2.56	0.40
	4H	2042	5.11	3.02	700	9.6	25.9	36.8	2.96	0.36
Bush Hog-8000 Ro-till	4L	2228	3.03	5.93	2330	18.8	27.1	69.8	3.21	1.46
	5L	2204	3.48	5.42	2070	19.2	29.5	65.0	3.22	1.27
	6L	2209	4.82	5.89	2230	28.6	44.2	65.0	3.92	1.12
	4H	2232	5.43	5.72	2300	33.3	50.4	66.2	4.32	1.09
	5H	2218	6.18	6.47	2560	42.1	61.6	68.4	4.86	1.08
	6I	2232	6.72	6.52	2470	44.2	66.4	66.8	5.07	1.04
Firm tractive surface, silt loam soil, Raymond, Ms.										
IH-55 Chisel plow	3I	2146	2.54	16.32	5710	38.7	53.9	71.8	4.44	1.60
	4I	2141	3.62	15.95	6020	58.1	78.7	73.8	5.92	1.50
	5I	2051	4.09	14.32	5550	60.5	82.6	73.2	6.08	1.37
JD-984 Disk bedder	6L	2138	4.52	8.65	2640	31.8	53.5	59.6	4.49	0.65
	6I	2184	6.34	9.92	2990	50.5	75.8	66.8	5.82	0.59
Tilled tractive surface, sandy loam soil underlain with clay, Poplarville, Ms.										
IH-55 Chisel plow	4L	2210	2.74	14.33	4700	34.3	54.7	62.8	4.53	1.52
	5L	2186	3.09	15.48	4760	39.2	64.2	61.0	5.15	1.53
	4I	2088	3.56	15.22	4700	44.6	68.8	64.8	5.62	1.45
Tilled tractive surface, fine sandy loam soil mixed with clayey soil depressions, Stoneville, Ms.										
IH-55 Chisel plow	4L	2138	2.71	12.38	4600	32.9	50.0	65.3	4.22	1.44
	5L	2161	3.13	13.37	4860	40.2	62.0	64.8	4.87	1.44
	4I	2078	3.65	12.88	4480	43.4	68.1	63.7	5.25	1.33
	5I	1955	3.93	13.61	4720	49.2	77.0	64.0	5.70	1.34
JD-210 Heavy tandem disk harrow	4I	2184	4.00	8.95	2850	30.3	54.8	55.5	4.49	0.71
	5I	2159	4.43	11.72	2970	35.1	69.8	50.7	5.21	0.75
	6I	1982	5.86	8.31	2560	40.2	83.5	48.0	6.09	0.66
Tilled tractive surface, sandy loam soil, Poplarville, Ms.										
Tufline TW-52 Light tandem disk harrow	4I	2155	4.04	6.85	2010	21.6	47.6	45.4	4.09	0.84
	5I	2149	4.64	7.13	2220	27.5	59.4	46.4	4.62	0.82
	6I	1746	5.26	6.54	2300	32.3	61.9	52.2	4.28	0.67
	6I	2062	6.08	8.59	2640	42.7	85.4	50.0	6.29	0.86
JD-7000 Row crop planter	3H	2093	3.54	3.90	970	8.9	26.8	33.1	2.97	0.52
	4H	1912	4.53	3.49[*]	770	9.3	32.5	28.6	2.97	0.41
Tilled tractive surface, silt loam soil, Raymond, Ms.										
IH-480 Heavy tandem disk harrow	3I	2152	2.65	13.10	4610	32.6	50.1	65.2	4.22	0.94
	4I	2150	3.68	14.94	4860	47.8	74.9	63.9	5.63	0.90
	5I	2065	4.07	15.34	5020	54.5	83.6	65.1	6.30	0.92
JD No. 1 Soil pulverizer	4I	1835	3.47	6.08	2450	22.7	36.2	62.8	3.18	0.61
	5I	1855	4.03	6.46	2490	26.7	44.2	60.5	3.56	0.58
	6I	1831	5.45	7.56	2470	35.8	64.0	56.2	4.59	0.56
	7L	1828	5.73	7.47	2630	40.3	65.8	61.2	4.77	0.55
	6H	1748	6.73	6.74	2530	45.4	73.8	61.6	5.35	0.53
JD No. 2 Soil pulverizer	4I	1888	3.59	5.63	2020	19.3	31.0	62.5	3.05	0.54
	5I	1859	4.07	5.89	2090	22.7	36.7	61.8	3.25	0.51
	6I	1819	5.48	6.45	2160	31.6	52.3	60.9	4.04	0.47
JD-984 Disk bedder	6L	2102	4.40	9.59	3060	35.9	54.1	66.6	4.45	0.66
	6I	2093	6.05	10.28	3130	50.6	76.0	66.6	5.69	0.62
	7L	2083	6.32	10.53	2980	50.3	79.9	62.9	6.12	0.63

[a] Refer to Table 5 for a description of implements, surface conditions, and operating conditions.

[*] Data originally reported by Tompkins et al. (1984).

speeds, PTO torque, engine speed, and fuel consumption. These values were read once per second and stored periodically on magnetic tape. At the conclusion of the test, the bales were individually weighed and bale moisture samples were taken.

Test Results

The instrumentation package developed to measure the in-field energy consumption of PTO-driven implements performed satisfactorily under field conditions. The package produced repeatable results with an accuracy based on calibration with a shop dynamometer. However, the modified draft sensor, as discussed in Chapter IV, failed to perform satisfactorily under dynamic field conditions. Results of the test are presented in Table 7.

Typical curves of time versus PTO horsepower during the bale formation process (Figure 24 and Appendix E) show a sharp increase in PTO power consumption during the initial stages of bale formation. Power requirement leveled off and remained almost constant throughout most of the bale formation cycle. Toward the end of the cycle, power requirement increased dramatically. This curve was described by a factory representative as characteristic for this model of baler.

IV. 1985 EVALUATION OF GROUND SPEED SENSORS

Introduction

Three commonly used methods for measuring true ground speed of agricultural vehicles were evaluated: (1) a front wheel sensor,

Table 7. Energy requirement of round bale formation using a New Holland Model 845 Round Baler operated in ochard grass, fescue, and clover mixture, 12% wet bulb.

Test	Bale Weight (lbs)	Bale Weight (kg.)	Dry Matter (lbs)	Dry Matter (kg.)	Energy hp-hr	Energy hp-hr/ton	Energy mJ	Energy mJ/kg	Energy Peak hp
1	760	344.67	668.8	303.31	1.36	3.58	3.65	0.0120	32.5
2	840	380.95	739.2	335.24	1.45	3.45	3.89	0.0116	35.0
4	800	362.81	704.0	319.27	1.87	4.68	5.01	0.0157	30.4
5	800	362.81	704.0	319.27	3.46	8.65	9.28	0.0291	37.0
6	760	344.67	668.8	303.31	1.55	4.08	4.16	0.0137	29.8
8	760	344.67	668.8	303.31	1.46	3.84	3.91	0.0129	32.9
10	780	353.74	686.4	311.29	1.12	2.87	3.00	0.0096	30.0
11	780	353.74	686.4	311.29	1.48	3.79	3.97	0.0127	35.2
13	780	353.74	686.4	311.29	1.72	4.41	4.61	0.0148	35.0
14	440	199.55	387.2	175.60	0.74	3.36	1.98	0.0113	16.5
*mean	787	356.76	692.3	313.95	1.50	3.41	3.58	0.0115	32.6
*P.S.D.	27	12.09	23.5	10.64	0.21	1.31	1.37	0.0044	2.1
*S.S.D.	28	12.83	24.9	11.29	0.23	1.38	1.46	0.0046	2.2

*Test numbers 5 and 14 are omitted from the average, population standard deviation, sample standard deviation, and variance due to the dead heading in test number 5 and an incomplete bale in test number 14.

**Test numbers 3, 7, 9 and 12 are omitted due to communication problems with the TU58.

***Data originally reported by Bledsoe (1984).

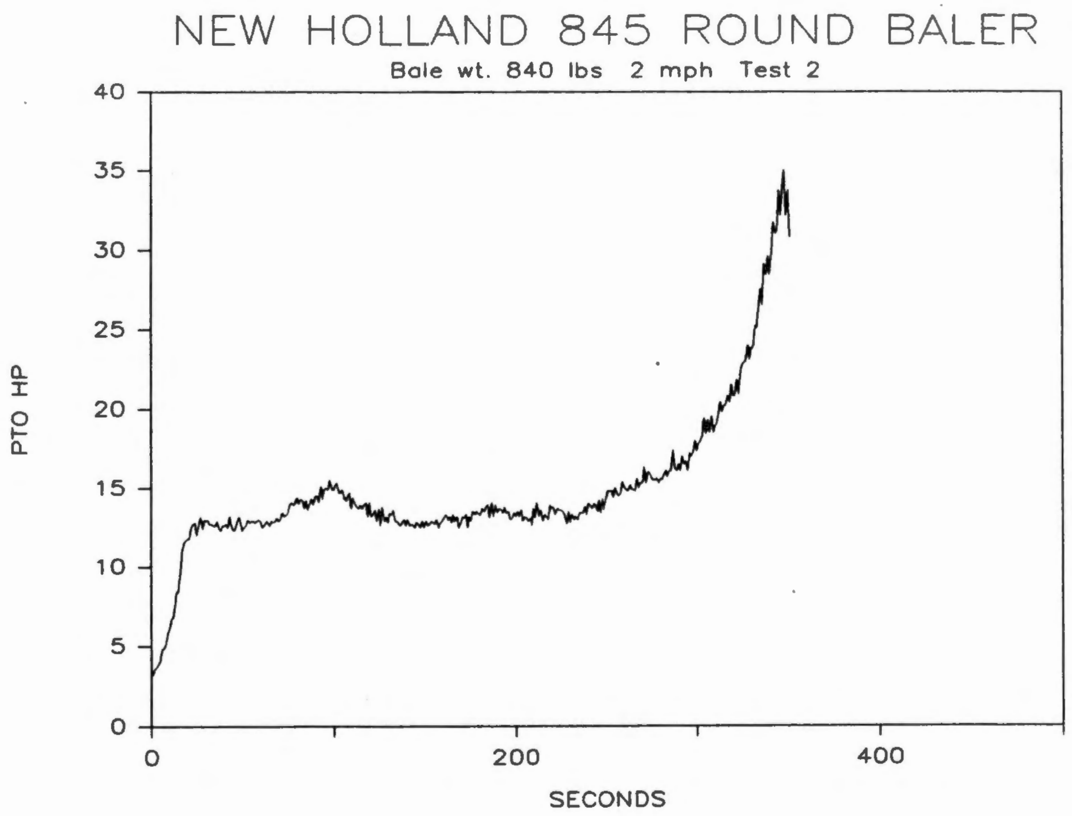

Figure 24. Example of curve generated using field test data collected with the PTO instrumentation system.

(2) a fifth wheel arrangement, and (3) a radar sensor. Each of the sensors emitted digital pulses which were supposedly directly proportional to surface distance traversed. These pulses were counted and stored on a one second interval by the instrumentation system. During later analysis this data provided a means of comparison.

Test Procedure

The three sensors were operated simultaneously across 60-meter courses, each course having a characteristic surface condition. Three no-load speeds (4, 7, and 10 km/h) were used for each surface condition. In addition, each speed was replicated four times per surface condition.

The gear selection and engine speed required to maintain a given no-load speed were determined by operating the tractor on asphalt. These values were found to be (1) 1800 engine rpm in gear 3I for 4 km/h, (2) 1725 engine rpm in gear 4H for 7 km/h, and (3) 1900 engine rpm in gear 7L for 10 km/h. Thus, traveling a 60-meter course would require approximately 54.0 sec in 3L, 30.9 sec in 4H, and 21.6 sec in 7L.

For each speed, an average one-second count for each sensor was calculated from the four replications. By assuming the average count obtained when operating on asphalt to be the theoretical one-second count, a sensor error for each surface condition-gear selection calibration was calculated. For example, if the fifth wheel at 6 km/h produced an average of 100 pulses per second on asphalt and an average of 90 pulses per second in tall grass, then a -10 percent error would result. A negative value signifies the fifth wheel was sliding, in this case, 10 percent when operating in tall grass. A positive percent error would indicate slippage.

Calibration constants were obtained for each sensor by operating the tractor on asphalt at the selected gears and engine speeds. Averages of the counts generated by each sensor per ground speed selection were calculated and were found to be linear when plotted against ground speed. Therefore, a one-second conversion factor was calculated for each sensor: (1) for the front wheel sensor, .070163 km/h-count; (2) for the fifth wheel, .0100925 km/h-count; and (3) for the radar sensor, .0283794 km/h-count.

Test Results

Of the three sensors, radar exhibited the least error over all the tested surface conditions and speed ranges. However, radar produced the most error when operating in tall weeds. The percent error of each sensor for a given surface condition are tabulated in Tables 8, 9, and 10.

Table 8. Performance of three speed sensors on various surfaces relative to operation on asphalt--4 km/h. Tractor was operated at 4 km/h through 60-m measured courses. Engine speed was 1800 rpm.

Surface Condition	Percent Error				Percent Difference From Theoretical Time	
	Front	5th	Radar	Engine	Computer	Spotter
Asphalt	0.00	0.00	0.00	0.00	1.35	0.96
Disked, rough, some furrows and clods	-7.19	-11.49	-0.93	-0.05	0.94	0.57
Disked, rough, some furrows	-10.35	-13.82	-2.26	-0.39	2.63	1.67
Disked, rough, 5th wheel in tire track	-8.57	-5.94	-2.62	-0.82	2.56	2.13
Disked with drag, smooth surface	-8.14	-11.41	-1.86	-0.46	1.74	1.19
Cultimulch, smooth seed bed	-6.36	-10.34	-2.25	-0.82	----	1.52
Tilled, ridged by deep chisels	-11.96	-20.96	-1.59	-0.11	1.65	1.41
1-m mixed weeds	-4.35	-4.12	8.55	-0.15	2.00	1.81
0.1-m wheat stubble	-2.11	-4.63	-1.58	-0.45	3.13	2.11
0.1-m mowed grass	-2.04	-2.88	-1.07	-0.55	0.22	-0.09
Disked, pulverized surface	-7.86	-17.72	-2.04	-0.78	1.65	1.06
Disked, pulv., 5th wheel in tire track	-6.02	-6.38	-1.72	-0.55	1.50	0.98
0.8-m fescue	-2.65	-3.14	1.42	-0.46	1.30	0.61
Mean Error	-5.97	-8.68	-0.61			
Error standard deviation	3.55	6.24	2.96			

Table 9. Performance of three speed sensors on various surfaces relative to operation on asphalt--7 km/h. Tractor was operated at 7 km/h through 60-m measured courses. Engine speed was 1725 rpm.

	Percent Error				Percent Difference From Theoretical Time	
Surface Condition	Front	5th	Radar	Engine	Computer	Spotter
Asphalt	0.00	0.00	0.00	0.00	1.33	0.97
Disked, rough some furrows and clods	-7.86	-14.21	-0.61	0.05	0.49	0.13
Disked, rough, some furrows	-9.44	-14.55	-2.32	-0.43	2.27	1.59
Disked, rough, 5th wheel in tire track	-8.06	-7.14	-1.76	-0.35	1.52	1.07
Disked with drag, smooth surface	-7.84	-13.30	-2.10	-1.00	1.88	1.39
Cultimulch, smooth seed bed	-5.90	-10.47	-1.65	-0.57	----	0.71
Tilled, ridged by deep chisels	-10.68	-19.37	-1.47	-0.64	2.01	1.39
1-m mixed weeds	-3.73	-4.09	1.63	-0.56	1.75	1.33
0.1-m wheat stubble	-2.46	-10.22	-1.61	-0.77	2.78	2.17
0.1-m mowed grass	-2.10	-4.46	-1.20	-0.72	0.58	-0.16
Disked, pulverized surface	-7.90	-18.70	-1.94	-0.84	1.48	0.97
Disked, pulv., 5th wheel in tire track	-7.65	-9.27	-2.06	-0.85	1.72	0.91
0.8-m fescue	-2.53	-4.55	-0.16	-0.67	1.17	0.00
Mean error	-5.86	-10.03	-1.17			
Error standard deviation	3.31	5.90	1.12			

Table 10. Performance of three speed sensors on various surfaces relative to operation on asphalt--10 km/h. Tractor was operated at 10 km/h through 60-m measured courses. Engine speed was 1900 rpm.

	Percent Error				Percent Difference From Theoretical Time	
Surface Condition	Front	5th	Radar	Engine	Computer	Spotter
Asphalt	0.00	0.00	0.00	0.00	2.73	2.08
Disked, rough, some furrows and clods	-5.77	-9.78	1.23	1.87	0.51	0.32
Disked, rough, some furrows	-7.11	-14.38	-0.14	1.72	1.53	1.16
Disked, rough, 5th wheel in tire track	-6.88	-6.90	-0.68	1.21	3.43	1.62
Disked with drag, smooth surface	-6.30	-12.78	-0.29	1.26	0.74	0.83
Cultimulch, smooth seed bed	-5.17	-10.26	-0.01	1.24	----	0.14
Tilled, ridged by deep chisels	-7.76	-20.86	-0.44	1.27	3.06	1.48
1-m mixed weeds	-1.96	-2.81	4.09	1.49	1.53	0.56
0.1-m wheat stubble	-0.30	-8.90	0.48	1.72	3.24	1.25
0.1-m mowed grass	-0.26	-5.11	1.08	1.43	-0.19	-1.06
Disked, pulverized surface	-5.56	-17.24	-0.21	1.19	1.20	0.42
Disked, pulv., 5th wheel in tire track	-5.56	-6.09	-0.28	1.38	2.59	0.37
0.8-m fescue	-0.82	-3.52	1.59	1.36	0.51	-0.09
Mean error	-4.11	-9.13	0.49			
Error standard deviation	2.95	5.99	1.29			

CHAPTER VI

DISCUSSION OF THE RESULTS

I. INSTRUMENTATION PERFORMANCE

Counterboard

The counterboard has operated dependably under field environmental conditions for the last four test seasons. However, the unit has three inherent problematic traits, two of which introduced error into the data gathered by the instrumentation system.

A major problem area involves the first count values of each test measured by the counterboard. The counterboard continues to randomly exhibit 4 to 7 percent less counts on the first scan of the counter channels than on the following scans. In the past, this symptom was compensated for by either subjectively editing the raw data such that the first scans represented the succeeding scans, omitting the first scans from the data analysis calculations, or assuming the first scan values as correct.

Initially, this error was attributed to software. The execution time required for the software code to initialize the channels for counting consumed several milliseconds. If a given test was initiated while the counters were not yet set-up to begin counting, then several counts would be lost at the beginning of the first scan.

This assumption was later disproved by temporarily replacing the standard data acquisition CPU module (PDP 11/03) with an upgraded version CPU module (PDP 11/73). The upgraded CPU module was capable of executing the same channel initialization software code at a rate nine times faster than that of the original CPU. After numerous tests of several frequency inputs, no improvement in the first scan values were noted. Therefore, the problem was assumed to be caused by the counterboard hardware.

The problem may be due to a larger-than-necessary capacitor on the circuit used to initialize the channels for counting. This capacitor greatly lengthened the pulse produced by a one-shot, such that the pulse could be seen when using a logic probe for debugging purposes. Thus, the problem may be corrected by reducing the size of the capacitor which, in turn, would shorten the time required for the hardware to initialize the counters (Wilkerson, 1985).

An additional error associated with the counterboard is the inability to program the interrupts, which read and clear each channel, to occur very accurately at one-second intervals. For example, a value of 32 loaded through software into the counter-timer register produces an interrupt on a continual basis of within approximately one-hundredth of a full second. A value of 16 loaded into the counter-timer register causes an interrupt to occur at approximately every half second. Thus, a unit change in the counter-timer value has a precision of only a thirty-secondth of a second, whereas, adjustment needs to be made in the hundredth of a second range.

This problem can be solved by increasing the counterboard clock by a factor of 10 and loading a timing value in the 320 range

(Wilkerson, 1985). By using this alteration, the interrupts can then be made to occur more accurately at one-second intervals. A test for accuracy would be to input a true 1-kHz signal to each counter channel and to observe the one-second scan values scrolled onto the display screen.

Finally, the remaining problem is that the IC's located on the counterboard have been found to be permanently affected by the extreme heat occurring on a hot day when the tractor cab is left in the direct sunlight without air conditioning and/or ventilation. Two symptoms of the damage caused by the overheating are scan values which consistently have the same bit set or cleared (i.e., frozen) on a given channel, and overflow values (denoted by "****" data values) in the final fraction of a second time value. Replacement of the affected IC's corrects the problem.

Not allowing the tractor cab to overheat or the removing of the sensitive instrumentation when the system is to be idle for extended periods in the direct sunlight are the only preventions of this problem. Obvious protection methods are using the cab air conditioning unit and, if the engine must be shut down, by parking the trator out of the direct sunlight with the cab windows open. An additional measure might be draping a thermal blanket over the cab if the system must be left parked idle in the direct sunlight.

Pulse Counter Interface Box

The redesigned pulse counter interface box has performed for two seasons with no apparent difficulties. The 5-pin DIN connectors, used to plug the signal wires running from each sensor to the interface box, were very convenient during system debugging and testing. This was especially true for the changing from the standard configuration of having the axle optical encoders interfaced to the counterboard to the temporary configuration of having the three ground speed sensors interfaced.

The circuitry of the pulse counter interface box has not, to date, been affected by the extreme temperatures which have occasionally occurred in the tractor cab. However, if the circuitry should fail, the components can be easily replaced in the field.

The box is located in the floor of the cab at the forward right of the operator. This location is susceptible to standing water due to leaks in the cab. Therefore, some effort should be taken to keep this area dry.

Rear Axle Optical Encoders

The EC80 series bi-directional incremental optical encoders used to measure axle speeds were tied to the circuits in the pulse counter interface box that, in turn, manipulated the counterboard up/down lines. As discussed previously, this eliminated the problem of spurious counts introduced by the magnetic sensors. For slow to moderate shaft speeds (such as those speeds occurring on axles), the encoders were found to be more accurate and reliable than the previously used magnetic sensors in an environment with substantial vibration.

The only apparent problem associated with the encoders is that they physically extend the length of the drive axles. The additional length makes transportation on public roads hazardous and maneuvering in confinements difficult. Further, this additional length was found to prohibit testing silage choppers since the encoder extended into the row of corn to be chopped.

Engine Speed Sensor

Two seasons of use have produced no difficulties with the engine speed sensor and interface circuitry. However, the rpm values calculated by the computer, and subsequently displayed on the operator screen, show approximately 40 rpm less than the engine tachometer. This converts to about 9 counts per second less than the theoretical value when the engine is turning at 1800 rpm and the counterboard is receiving 396 pulses per second.

Some of the error may be accounted for due to the inaccuracy of the counterboard in measuring one second scans (e.g., one hundredth of a second error equates to 4 counts at 1800 engine rpm). Or, the stock engine tachometer may be out of calibration, an assumption which may be tested through the use of a strobe light.

Radar

The single beam radar works well for most agricultural surface conditions except for those that contain tall crops. Research has shown that this sensor is greatly affected by rapidly changing surface conditions, such as those encountered when operating in standing hay and mature row crops (Tompkins et al., 1985). For proper operation, the unit requires a consistent target for the reflection of its beam.

A major plus for this sensor is operator convenience. The unit needs only to have power applied, whereas, the fifth wheel was required to be raised and lowered if reversing or turning sharply. In addition, the fifth wheel had to be chained into position for transport and later unchained for data gathering.

Front Wheel Sensor

The sensor was found to work adequately if the operating ground surface was firm. However, the sensor is inherently sensitive to operator steering. The sensor exhibits some sliding on loose surfaces, but will produce consistent values if calibrated for the specific operating surface (Tompkins et al., 1985).

Meshed gears were used to drive the encoder shaft, instead of driving the encoder shaft directly by the wheel axle. This design concept was found to perform satisfactorily.

Pre-Sampling Filters

The active low-pass filters greatly reduced the fluctuation of analog signals sampled by the instrumentation system. The slow sampling rate of the system, coupled with the high frequencies of the analog signals required the use of pre-sampling filters in order to satisfy the Nyquist Criterion of the Sampling Theorem.

After two seasons of use, no difficulties related to the analog filters or to the enclosure and associated wiring have become evident. However, the additional cabling and connectors require substantially more effort and concentration during the installation of the signal conditioning unit. Reinstallation is required only if the unit was removed for transport or service.

PTO Instrumentation

The modified PTO data acquisition system used an additional sensor, a tractor-mounted PTO dynamometer, and replaced the standard draft dynamometer with a load cell assembly which attached to the front of the tractor drawbar. The tractor-mounted PTO dynamometer performed satisfactorily for the in-field measurement of PTO torque. However, the load cell assembly used in the measurement of implement draft failed to produce satisfactory results when used in the field.

Bubble Memory

The substitution of bubble memory for the TU58 drives as the primary system and data devices has decreased system start-up time significantly (by a factor of 100). In addition, the bubble memory is much more reliable than the TU58. Whereas, the TU58 commonly failed during field work, the bubble memory has never failed.

The bubble memory was field tested during the 1985 ground speed sensor tests and the device performed excellently. However, the device was found to be susceptible to heat extremes which may occur during idle periods on hot, sunny days. The device is not permanently affected, but the device must be cooled to normal operating temperature before power is applied to the device, or data contamination will occur.

Software Enhancements

The data averaging routine, executed at the conclusion of each test, provides the operator an opportunity to quickly review the last test run. Because the operator is not always able to give full attention to the immediate displayed values during the test, this routine provides a valuable service.

II. RECOMMENDATIONS FOR FURTHER ENHANCEMENTS

Counterboard

The counterboard is the Achilles' heel of the data acquisition system. Although this module performed as required without major problems in the past, this component of the data acquisition system would be the most difficult to replace or trouble-shoot. The hundreds of wire wraps on the board make it very susceptible to failure. As a backup component, an identical counterboard needs to be constructed or an equivalent commercial counterboard should be acquired.

PTO Draft Measurement

The draft measurement assembly used in the modified PTO data acquisition system needs to be totally redesigned, possibly using a drawbar extension instrumented with strain gauges. This drawbar extension of length equal to the displacement of the PTO stub by the PTO torque box would slide over the existing drawbar and be pinned. The strain gauges could be aligned to compensate for bending and non-draft forces.

Optical Encoders and Slip Rings

A desirable feature for future research might be the relocation of the optical encoders and slip rings from the outboard ends of each drive wheel axle to a location between each rear wheel hub and tractor frame. This would make much easier both the transportation of the system and the maneuvering of the system in confinements. In addition, this redesign would allow for the removal of the slip ring cable arms. Narrowing of the tractor profile would simplify implement field testing for equipment such as silage choppers in corn.

Removal of the Second Operator

To relieve some of the work load from the tractor operator, a second operator may also ride in the cab to perform three tasks: (1) to operate the data acquisition system, (2) to closely monitor the data values obtained as the test is being conducted, and (3) to make manual recordings of information related specifically to the test run. The space available for the second operator is limited. A potential safety hazard exists due to the second operator using the glass of the cab as a back rest.

Some method of removing the second operator from the cab is needed. Telemetry could be used as a means of allowing the second operator to be located outside of the tractor cab.

Method of Accurately Starting and Stopping a Test

Research has shown (Tompkins et al., 1985) that as much as 3 percent error (based upon the theoretical time to traverse the course) can occur in total test duration measurement. This error is caused by the present inadequate method of manually pressing a keyboard key after a field marker has been passed for starting and stopping of a given test run. In order to decrease data error caused by human error, a precise mechanical method of starting and stopping each test run is needed.

CHAPTER VII

SUMMARY AND CONCLUSIONS

I. SUMMARY

Introduction

An existing microcomputer-based data acquisition system, originally reported by Hart (1982), was revised and enhanced. This data acquisition system was centered around a DEC PDP 11/03 microcomputer. The computer had component modules interfaced to various digital pulse and analog emitting sensors measuring: (1) time, (2) ground distance, (3) fuel displacement, (4) right and left rear axle rotation, (5) right and left rear axle torque, (5) fuel temperature, and (6) implement draft. Software sampled each of the sensors at set intervals. The software code both stored the raw data on tape for later analysis and calculated engineering values to be displayed on the operator console.

Research using the system was conducted for two seasons with successful results. However, subsequent work with the data acquisition system indicated that further modifications to the system were required and additional enhancements were desired.

System Revisions

Major revisions made to the system were as follows:

1. Bi-directional optical encoders were installed to replace the active magnetic sensors originally used in the system. The sensors were used for measuring shaft rotation of the tractor drive wheel axles and the fifth wheel.
2. Modifications were made to the counterboard to prevent channel bleedover. Specifically, original IC's not belonging to the LSTTL family were replaced with the equivalent LSTTL components. All signal lines coming to the counterboard via ribbon cable were separated by ground lines, and all input frequencies were limited to less than 1 kHz.
3. The combination of a long sampling interval between samples and a signal having an unknown frequency mandated the use of pre-sampling filters. Low-pass filters with cut-off frequencies of less than one-half of the sampling interval were used to satisfy the Nyquist Criterion of the Sampling Theorem. Active low-pass filters were placed on each analog signal line between the signal output of the signal conditioner and the signal input of the A/D board.
4. The operating system used by the data acquisition system was upgraded from RT-11 Version 3b to RT-11 Version 5.0. This software upgrade was required to maintain compatibility with the operating system used on a separate minicomputer used for data analysis and software development.

5. Pulse counter interface circuits were designed to interface the various digital pulse emitting sensors to the counterboard. Circuits were designed to interface the fuel meter, the optical encoders, and a sensor proposed to be used in the measurement of engine speed.

System Enhancements

Technological advancements and additional research requirements initiated enhancements to be made to the instrumentation system. Major enhancements were as follows:

1. The fifth wheel used for the measurement of ground displacement was replaced by a single-beam radar ground speed sensing unit.
2. A passive magnetic sensor was mounted above the engine flywheel. The signal produced by this sensor was passed through an interface circuit which produced a single TTL pulse for 10 gear teeth passages by the sensor. The reduction in signal frequency by a factor of 10 was required to prevent signal bleedover to adjacent channels on the counterboard.
3. A tractor-mounted PTO dynamometer was designed and tested to work with the instrumentation system for the in-field measurement of power inputs to PTO-driven implements. The instrumentation used for measuring torque on the PTO shaft worked satisfactorily with an accuracy compared

to that of a standard shop dynamometer. However, the assembly for measuring implement draft, designed to be used in conjunction with the PTO instrumentation, failed to perform adequately in field use.

4. The TU58 tape drives were replaced with bubble memory as the primary system and data storage devices. This replacement decreased the start-up time of the system by a factor of 100. More importantly, mass storage dependability and reliability were increased by using bubble memory.
5. A front wheel speed sensor was designed and mounted inside the left front wheel hub. Meshed gears turned an optical encoder which emitted pulses to the counterboard. This sensor was designed for performance comparisons with the fifth wheel and radar units.

Research Conducted

Field tests were conducted using the revised and enhanced data acquisition system. The research was conducted over a period of three cropping seasons at four locations.

1. Energy requirements of various tillage machines and planting implements were measured the first season on three West Tennessee soils (Hart and Tompkins, 1983).
2. Energy requirements of tillage machines operated on Mississippi soils were measured, and the instrumentation

system was field-demonstrated to area farmers (Tompkins et al., 1984).

3. The energy required for the formation of a round bale was investigated on the Plateau of Middle Tennessee (Bledsoe, 1984).
4. A study was conducted in East Tennessee to evaluate the effectiveness of the fifth wheel, the front wheel sensor, and the radar unit in measuring true ground speed on various surface conditions over a range of operating speeds (Tompkins et al., 1985).

II. CONCLUSIONS

Principal conclusions drawn from field studies conducted using the instrumented tractor are as follows:

1. Based on a single surface condition calibration and a one-second integration period, radar generally produces a more accurate indication of ground speed than ground-contacting speed sensors. The radar failed to produce an accurate indication of ground speed where the reflective surface was row crops and tall vegetation.
2. A ground-contacting speed sensor, such as the fifth wheel and front wheel, tends to slip more as the operating surface becomes less firm. However, the one-second standard deviation of this type of sensor for all surfaces is small and the slip is uniform for a given surface. Thus,

these sensors give an acceptable indication of ground speed if they are calibrated for the ground surface condition.

3. Optical encoders were found to eliminate the spurious count characteristic of the magnetic sensors, especially when the instrumented axle was revolving at slow speeds and the tractor frame was vibrating.
4. The energy consumed in the few seconds of deadheading, if required toward the end of the bale formation cycle, may be equal to or greater than the energy required to form a complete bale without deadheading.
5. The magnitude of the error introduced into the data by manually starting and stopping a 60-m test run approaches 3 percent when traveling at speeds ranging from 4 to 10 km/h.
6. Bubble memory performs excellently as a mass storage device in a harsh environment. However, data contamination can occur if the device is operated at elevated temperatures.

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APPENDIXES

APPENDIX A

CONNECTOR PIN-OUTS

Pulse Box RS232-C Pin-Outs

PIN	SIGNAL	WIRE COLOR
1 -	Shield	
2 -	Ch. 5 count	orange
3 -	ground	red
4 -	Ch. 5 u/d	blue
5 -	ground	black/white
6 -	Ch. 4 count	black
7 -	ground	black/red
8 -	Ch. 3 count	black/green
9 -	ground	white
10 -	Ch. 3 u/d	black/orange
11 -	NC	
12 -	NC	
13 -	NC	
14 -	Ch. 2 count	white/red
15 -	ground	white/green
16 -	Ch. 2 u/d	white/black
17 -	ground	green
18 -	Ch. 1 count	black/blue
19 -	Ch. 1 u/d	white/blue
20 -	NC	
21 -	NC	
22 -	NC	
* 23 -	+5 volts	clear
* 24 -	ground	black
* 25 -	shield	

* = power cable input   NC = not connected   stripe color/base color

Pulse Box 5-Pin Din Conectors

```
          NC
signal    -     signal
       /     \
gnd    \     /  +5 V out
```

Counter Board 40 Pin BERG Connector Pin-Outs

```
                       counts    up/down

                      --------- ---------
                     |5 4 3 2 1|5 4 3 2 1|
 -----------------------------------------
| o o o o o o o o o o o o o o o o o o o o |
| o o o o o o o o o o o o o o o o o o o o |
 -----------------------------------------
                      |-----------------|^
                          grounded        \
                                           \__ pin 1
```

APPENDIX B

BUBBLE CARD RE-INITIALIZATION

REINSTALLING BUBBLE MEMORY AS A DEVICE

Place Bubble Bac Tape in Drive 0.
Use ODT as follows. See RT-11 Users's Guides for more information.
xxxx = some random number

```
START? dk

@1000/xxxx 106427 <LF>
1002/xxxx 340 <LF>
1004/xxxx 12701 <LF>
1006/xxxx 176520 <LF>
1010/xxxx 12702 <LF>
1012/xxxx 176524 <LF>
1014/xxxx 10100 <LF>
1016/xxxx 5212 <LF>
1020/xxxx 105712 <LF>
1022/xxxx 100376 <LF>
1024/xxxx 6300 <LF>
1026/xxxx 1005 <LF>
1030/xxxx 5012 <LF>
1032/xxxx 12700 <LF>
1034/xxxx 4 <LF>
1036/xxxx 5761 <LF>
1040/xxxx 2 <LF>
1042/xxxx 42700 <LF>
1044/xxxx 20 <LF>
1046/xxxx 10062 <LF>
1050/xxxx 2 <LF>
1052/xxxx 1362 <LF>
1054/xxxx 5003 <LF>
1056/xxxx 105711 <LF>
1060/xxxx 100376 <LF>
1062/xxxx 116123 <LF>
1064/xxxx 2 <LF>
1066/xxxx 22703 <LF>
1070/xxxx 1000 <LF>
1072/xxxx 101371 <LF>
1074/xxxx 5007 <CR>
@1000G
        Once booted:
.COPY/VER/SLOW/SYS DD0:*.* DY0:
.COPY/BOOT DY:RT11SJ.SYS DY:
.BOOT DY:
```

APPENDIX C

DATA RECORDING FORM

1984 Implement Energy Requirement Tests

Test Location ______________________________ Date __________

Soil: Type ________________________ Surface Condition __________

Moisture Content ______________

Implement: Type ____

Width ____________________ Depth ________________

Parameters: Gear Setting ______________ Replication ____________

Test Number ______________ Data Tape No. ____________

Block Numbers ____________

Results:

Implement Draft	________________	lbs
Ground Speed	________________	mph
Engine Speed	________________	rpm
Drive Wheel Slip	________________	%
Drawbar Power	________________	hp
Axle Power	________________	hp
Tractive Efficiency	________________	%
Field Capacity	________________	ac/hr
Fuel Consumption	________________	gal/hr
Fuel Consumption	________________	gal/ac

Comments:

____

____

____

____

APPENDIX D

GROUND SPEED SOFTWARE

```
C Program RGS.FOR
C
C Written by: Robert Freeland  2/12/85
C
C This program and RGSM.MAC were used to evaluate three ground speed sensors
C mounted on an agricultural tractor.
C Must be compiled with FIS option to work with 11/03.
C-----------------------------------------------------------------------------
        CALL OPF                    !open data file
        CALL VTCLR                  !clear screen
10      WRITE(5,20)                 !display and accept prompt
20      FORMAT(' 1=change set-ups,
     > 2=continuous scan, 3=data, 4=stop > ',$)
        READ(5,30)I
30      FORMAT(I)
        IF (I.EQ.1) CALL CS         !change set-ups
        IF (I.EQ.2) CALL CNTST      !do continuous scan of data without storage
        IF (I.EQ.3) CALL DT         !take data
        IF (I.EQ.4) CALL CLSF       !close file
        GOTO    10
        END
C-----------------------------------------------------------------------------
        SUBROUTINE CMNT
C+
C
C This routine ask the operator for comments about the test
C
        LOGICAL*1       COMM(80)
        WRITE(5,10)
10      FORMAT(' Test comments > ',$)
        READ(5,20)COMM
20      FORMAT(80A1)
        WRITE(21,30)COMM
30      FORMAT(/,' C ',70A1)
        RETURN
        END
```

```
C-----------------------------------------------------------------------
C+
      SUBROUTINE DT
C
C This routine is called whenever data is scanned with storage.
C
      CALL WHB                  !write header block information
      CALL DATA                 !gather data
      CALL CMNT                 !accept operator comment
      RETURN
      END
C-----------------------------------------------------------------------
C+
      SUBROUTINE WHB
C
C  WHB: Write file header block
C
C  This routine writes the information header block in the
C  data file.
C
      COMMON /BLK1/SRFCE,GEAR,LCTION,ITEST,K
      DIMENSION K(3)
      LOGICAL*1 SRFCE(60),GEAR(2),LCTION(10)
      LOGICAL*1 TSTRG(8),DSTRG(9)
C
      CALL TIME(TSTRG)                !get time
      CALL DATE(DSTRG)                !get date
      WRITE(21,10,ERR=99)SRFCE        !write surface condition in header
      WRITE(21,20,ERR=99)GEAR,ITEST   !write gear and test no. in header
      WRITE(21,30,ERR=99)LCTION       !write test location in header
      WRITE(21,40,ERR=99)TSTRG,DSTRG  !write time and date in header
      ITEST = ITEST + 1               ! increment test number
      RETURN
10    FORMAT(' H ',60A1)
20    FORMAT(' G ',2AI,1X,I4)
30    FORMAT(' L ',10A1)
40    FORMAT(' T ',8A1,X,9A1)
50    FORMAT(' K ',3(1X,I4),/)
99    CLOSE(UNIT=21)
      STOP '?Header block error?'     !an error occurred when writing data
      END
```

```
C----------------------------------------------------------------------
        SUBROUTINE CS
C+
C
C  CS: Change set-ups
C
C  This routine is called whenever the operator wishes to change
C  operator supplied information written to the header block of
C  the data file.
C
        COMMON /BLK1/SRFCE,GEAR,LCTION,ITEST,K
        DIMENSION K(3)
        LOGICAL*1 SRFCE(60),GEAR(2),LCTION(10)
        DATA GEAR/2*'*'/, LCTION/10*'*'/, SRFCE/60*'*'/, ITEST/0/
        DATA K/2030,20,100/
1       CALL VTCLR
        WRITE(5,10) SRFCE,GEAR,LCTION,ITEST
10      FORMAT(' ',//
     1  ' Ground surface > ',60a1,/,
     2  ' Gear > ',2a1,/,
     3  ' Location > ',10a1,/,
     4  ' Test no. > ',I4,///,
     5  ' Type 1=change surface, 2=change gear, 3=change location,'/
     6  '      4=change test number, 5=return',
     7  /,' > ',$)
        READ(5,*)I
        IF(I.EQ.1) GOTO 30
        IF(I.EQ.2) GOTO 40
        IF(I.EQ.3) GOTO 50
        IF(I.EQ.4) GOTO 60
        IF(I.EQ.5) RETURN
        GOTO 1
```

```
C--change surface condition
C
30      WRITE(5,31)
31      FORMAT(' Surface condition > ',$)
        READ(5,32)SRFCE
32      FORMAT(60A1)
        GOTO 1
C--change gear
C
40      WRITE(5,41)
41      FORMAT(' Gear > ',$)
        READ(5,42)GEAR
42      FORMAT(2A1)
        GOTO 1
C--change test location
C
50      WRITE(5,51)
51      FORMAT(' Test location > ',$)
        READ(5,52)LCTION
52      FORMAT(10A1)
        GOTO 1
C--test number
C
60      WRITE(5,61)
61      FORMAT(' Test number > ',$)
        READ(5,62)ITEST
62      FORMAT(I)
        GOTO 1
        END
```

```
C-----------------------------------------------------------------------
        SUBROUTINE DATA
C+
C
C -- DATA: gather data
C
C This routine gathers data for a given test.
C
C Storage for 300 scans per second per 200 ft gives
C a minimum speed of .5 mph
C
C ICNT passed is column size of data buffer
C ICNT returned is length of data taken
C
        DIMENSION IBUF(6,300),IMAX(5),IMIN(5),SDV(5),AVG(5),COV(5)
        COMMON /BLK2/IBUF,ICNT
        COMMON /BLK3/IMAX,IMIN,SDV,AVG
        INTEGER*2 IDT,ISTAT
        ICNT = 300
        ISTAT = IDT(IBUF,ICNT)
        WRITE(5,5)
5       FORMAT(' ',/)
        DO 20 I=1,ICNT
        TIME = I
        IF(IBUF(6,I).NE.31) TIME = I - IBUF(6,I)/31.
        WRITE(5,10) TIME, (IBUF(ID,I),ID=1,5)
        WRITE(21,10) TIME, (IBUF(ID,I),ID=1,5)
10      FORMAT(' D ',1X,F6.2,5(1X,I6))
20      CONTINUE
C
        IF (ISTAT) WRITE(5,30)ISTAT
30      FORMAT(' BUFFER OVERFLOW ',I)
```

```
C
C The following calculates mean, standard deviation, coefficient of variation,
C maximum and minimum values of the data set contained in IBUF.
C
C
C ICNT contains the length of data
C
        INUM=ICNT-1              !disregard fractional seconds
C
C-- set initial values
        DO 90 I=1,5
         IMIN(I)=32767
         IMAX(I)=0
         AVG(I)=0.
         SDV(I)=0.
90      CONTINUE
C
C-- determine max and min values
        DO 100 I=1,INUM
         DO 100 J=1,5
         IF(IBUF(J,I).LT.IMIN(J)) IMIN(J) = IBUF(J,I)
         IF(IBUF(J,I).GT.IMAX(J)) IMAX(J) = IBUF(J,I)
         AVG(J)= AVG(J) + IBUF(J,I)
100     CONTINUE
C
C-- calculate average values
        DO 200 I=1,5
         AVG(I)= AVG(I)*1./INUM
200     CONTINUE
```

```
C
C-- calculate standard deviation and coef. of variation
        DO 400 J=1,5
         DO 300 I=1,INUM
           X = (IBUF(J,I) - AVG(J))**2/(INUM-1)
           SDV(J) = SDV(J) + X
300     CONTINUE
        SDV(J) = (SDV(J))**.5
        COV(J) = (SDV(J)*100)/AVG(J)
400     CONTINUE
C
        WRITE(21,29,ERR=99)(IMIN(I),I=1,5)
        WRITE(21,31,ERR=99)(IMAX(I),I=1,5)
        WRITE(21,32,ERR=99)(AVG(I),I=1,5)
        WRITE(21,33,ERR=99)(SDV(I),I=1,5)
        WRITE(21,34,ERR=99)(COV(I),I=1,5)
        WRITE(5,29)(IMIN(I),I=1,5)
        WRITE(5,31)(IMAX(I),I=1,5)
        WRITE(5,32)(AVG(I),I=1,5)
        WRITE(5,33)(SDV(I),I=1,5)
        WRITE(5,34)(COV(I),I=1,5)
29      FORMAT(/,' M ',6X,5(1X,I6))
31      FORMAT(' M ',6X,5(1X,I6))
32      FORMAT(' A ',6X,5(1X,F6.2))
33      FORMAT(' S ',6X,5(1X,F6.2))
34      FORMAT(' V ',6X,5(1X,F6.2))
        RETURN
99      CLOSE(UNIT=21)
        STOP '?DATA FILE WRITE ERROR?'
        END
```

```
C-----------------------------------------------------------------------
        SUBROUTINE OPF
C+
C
C  OPF: Open data file
C
C  This routine opens a pre-named data file.
C
C
        OPEN(UNIT=21,TYPE='NEW',NAME='DD1:DATA.GSD',
     >  INITIALSIZE=50,ERR=99)
        RETURN
99      STOP 'Data file open error'
        END
C-----------------------------------------------------------------------
        SUBROUTINE CLSF
C+
C
C CLSF: Close data file
C
C  This routine closes the data file.
C
        CLOSE(UNIT=21,DISPOSE='KEEP',ERR=99)
        STOP 'Successful close'
99      STOP 'Data file close error'
        END
C-----------------------------------------------------------------------
        SUBROUTINE OSI1(I,STRING)
C+
C
C OSI1: Output a string of integers, FORTRAN support routine for assembly
C       language routines.
c
        BYTE STRING(8)
        ENCODE(8,500,STRING)I
500     FORMAT(I8)
        RETURN
        END
```

```
        .MCALL .PRINT,.TTINR,.TTYOUT,.TTYIN
        .GLOBL  OSI1
        .NLIST  BEX
        .SBTTL Macro Support Subroutines For Ground Speed Testing
;++
;
;  RGSM --- Macro support subroutines for Ground Speed Testing
;
;    Author:    Rob Freeland
;               Department of Agricultural Engineering
;               University of Tennessee
;
;   Created:    12-Jan-85
;
;   Based upon code written by Mark Cantrell of Unique Software Development.
;--
        .SBTTL  Local Macros
;
; Local macros
;
        .MACRO  COUNT   ARG
        MOV     ARG,@#176530
        MOV     @#176532,R0
        .ENDM

        .MACRO  CNT     ARG
        MOV     ARG,@#176530
        MOV     @#176532,(R1)
        MOV     (R1)+,TSTMP
        OSI     TSTMP
        .ENDM
```

```
.MACRO  RET     ARG
CALL    TIMCLR
CALL    CLRBUF
MOV     ARG,R0
RETURN
.ENDM

.MACRO  SAVREG
MOV     R1,-(SP)
MOV     R2,-(SP)
MOV     R3,-(SP)
MOV     R4,-(SP)
MOV     R5,-(SP)
.ENDM

.MACRO  RESTOR
MOV     (SP)+,R5
MOV     (SP)+,R4
MOV     (SP)+,R3
MOV     (SP)+,R2
MOV     (SP)+,R1
.ENDM

.MACRO  OSI     I
SAVREG
MOV     #'I,ARG1
MOV     #NARG,R5
CALL    OSI1
.PRINT  #STRING
RESTOR
.ENDM
```

```
;
; Local data
;
TICKS:  .WORD   0
TSTMP:  .WORD   0
PROMT:  .ASCII  /<Line Feed> starts-stops test ... /<200>
JTNUL:  .BYTE   0
        .even
NARG:   .WORD   2                ; arglist for I/O routines
ARG1:   .WORD   0                ; moved by I/O macros
ARG2:   .WORD   STRING           ; points to 8 char string
STRING: .BLKB   8.               ; string used with I/O macros
        .BYTE   <200>            ; no more new lines
        .EVEN
        .WORD   0                ; make sure it stays here


        .page
        .SBTTL Misc Routines For Timer Control
;
;  Routines for timer
;

TIMINT: CLR     TICKS            ; Routine to initialize timer
        MOV     #TIMISR,@#334
        MOV     #341,@#336
TIMCLR:                          ; Routine to clear timer
        MOV     #077777,@#176534
        RETURN
```

```
TIMWT:  TST     TICKS           ; Routine to wait on timer
        BEQ     TIMWT
        DEC     TICKS
        RETURN

TIMISR: INC     TICKS           ; Timer interrupt service routine
        RTI


        .SBTTL Display With Storage

IDT::   CALL    VTCLR           ;clear display
        TST     (R5)+           ;skip argument count
        MOV     (R5)+,R1        ;put address of IBUF into R1
        MOV     (R5)+,R2        ;put address of ICNT into R2
        MOV     (R2),R3         ;R3 contains maximum buffer size
        CLR     (R2)            ;clear ICNT
        MOV     #37,R4          ;set timer for 1 sec interrupts
        BIS     #100000,R4      ;R4 has time in seconds * 1000.
;
        CALL    CLRBUF          ;clear keyboard buffer
        .PRINT  #PROMT
10$:    .TTINR
        NOP
        BCS     10$
        CALL    TIMINT          ;install isr
        MOV     R4,@#176534     ; ... Go
        COUNT   #7              ;       '
        COUNT   #0              ;Clear counts
        COUNT   #1              ;       '
        COUNT   #2              ;       '
        COUNT   #3              ;       '
```

```
;

1$:     .TTINR                          ; look for keyboard input
        BCS     2$                      ; none, then keep counting
        JMP     4$                      ; yes, then operator says finished
2$:     TST     TICKS                   ; wait on timer ...
        BEQ     1$
        DEC     TICKS
        .PRINT  #JTNUL
        CNT     #0                      ;RA
        CNT     #1                      ;FW
        CNT     #2                      ;SW
        CNT     #3                      ;ENG speed
        MOV     #3,(R1)+                ;Draft?
        CNT     #7                      ;time
        INC     (R2)
;
;-- check for buffer full
;
        DEC     R3
        BNE     3$
        RET     #1                      ;return buffer full
3$:     JMP     1$

4$:     .PRINT  #JTNUL
        CNT     #0
        CNT     #1
        CNT     #2
        CNT     #3
        MOV     #3,(R1)+
        CNT     #7
        INC     (R2)
        RET     #0                      ;return success
```

```
        .SBTTL Display Without Storage

CNTST:: CALL    VTCLR           ;clear display
        MOV     #37,R4          ;set timer for 1 sec interrupts
        BIS     #100000,R4      ;R4 has time in seconds * 1000.
;
        CALL    CLRBUF          ;clear keyboard buffer
        .PRINT  #PROMT
10$:    .TTINR
        NOP
        BCS     10$
;
        CALL    TIMINT          ;install isr
        MOV     R4,@#176534     ; ... Go
        COUNT   #0              ;Clear counts
        COUNT   #1              ;       "
        COUNT   #2              ;       "
        COUNT   #3              ;       "
        COUNT   #7              ;       "
```

```
;
1$:     .TTINR                  ; look for keyboard input
        BCS     2$              ; none, then keep counting
        JMP     3$              ; yes, then operator says finished
2$:     TST     TICKS           ; wait on timer ...
        BEQ     1$
        DEC     TICKS
        .PRINT  #JTNUL
        COUNT   #0              ;RA
        MOV     R0,TSTMP
        OSI     TSTMP
        COUNT   #1              ;FW
        MOV     R0,TSTMP
        OSI     TSTMP
        COUNT   #2              ;SW
        MOV     R0,TSTMP
        OSI     TSTMP
        COUNT   #3              ;ENG speed
        MOV     R0,TSTMP
        OSI     TSTMP
        MOV     #3,TSTMP        ;Draft?
        OSI     TSTMP
        COUNT   #7              ;time
        MOV     R0,TSTMP
        OSI     TSTMP
        JMP     1$

3$:     .TTYOUT #15
        .TTYOUT #12
        RETURN
```

```
        .SBTTL Misc Routines For Keyboard/Video I/O
;
;  Routine to clear keyboard buffer
;
CLRBUF: .TTINR
        BCC     CLRBUF
        RETURN
;
;  Routine to clear display
;

VTCLR:: .TTYOUT #14
        CLR     R2
1$:     NOP
        SOB     R2,1$
        RETURN
        .END IDT
```

APPENDIX E

ROUND BALER POWER CURVES

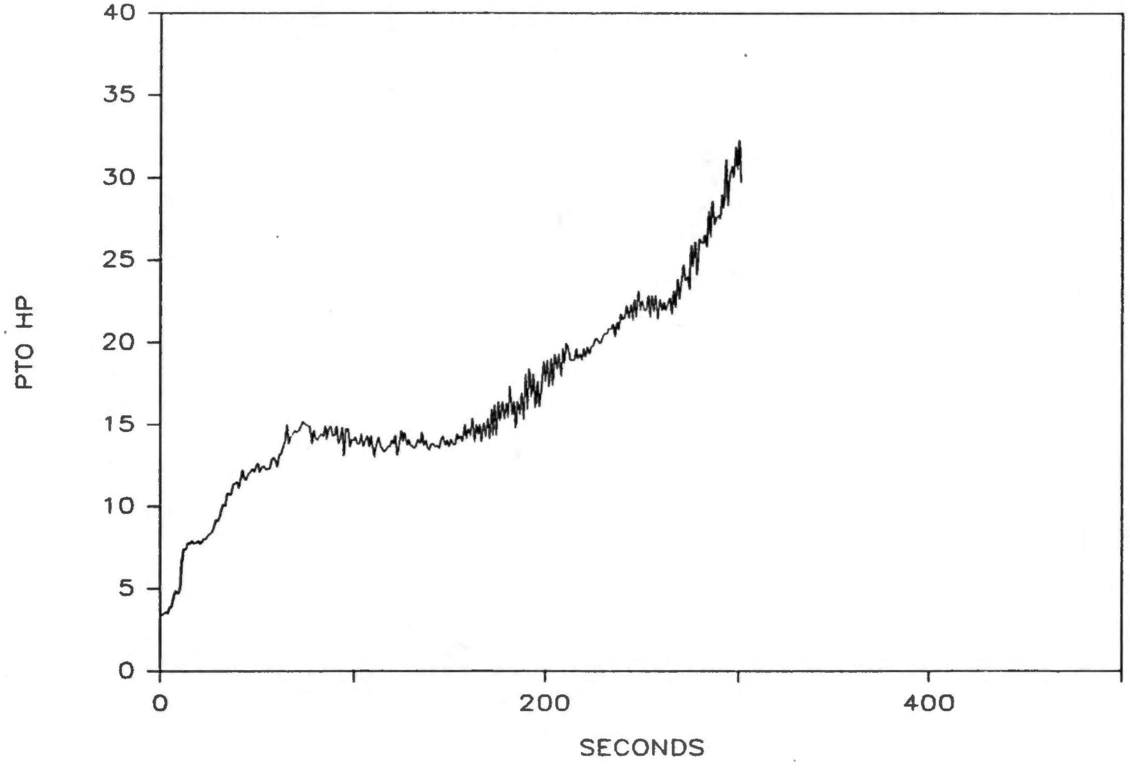

Figure 25. New Holland 845 Round Baler: Bale wt. 760 lbs., 2 mph, Test 1.

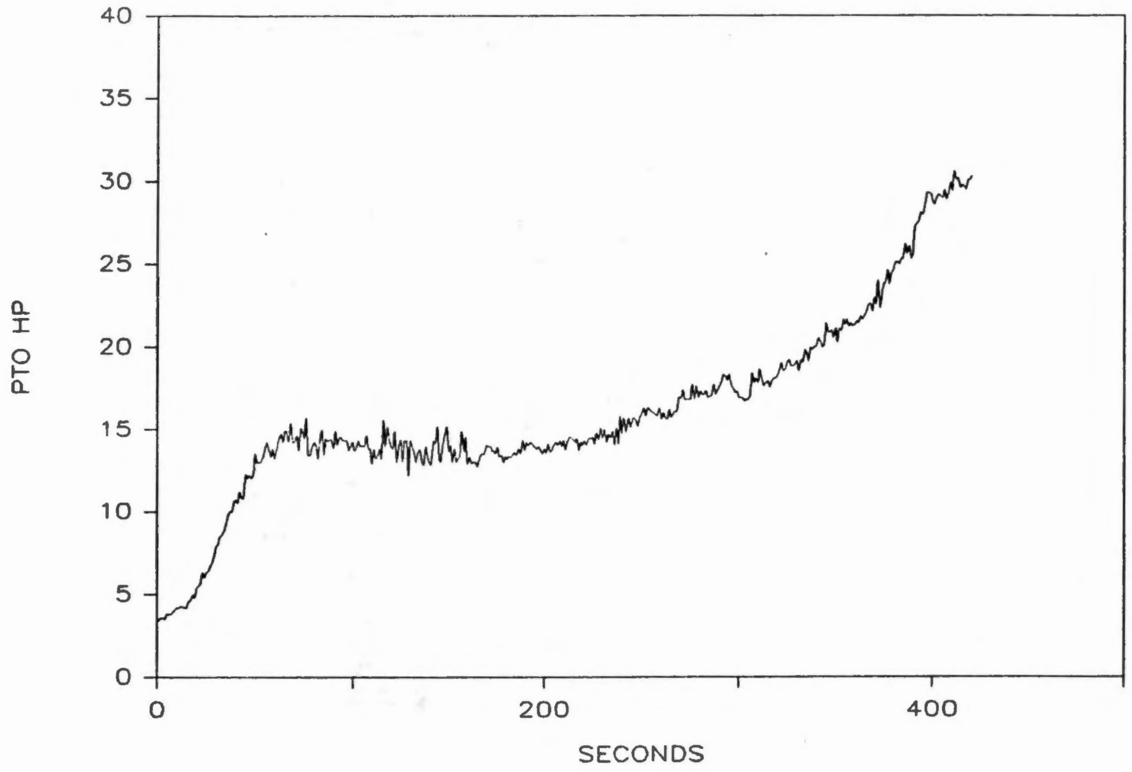

Figure 26. New Holland 845 Round Baler: Bale wt. 800 lbs., 2 mph, Test 4.

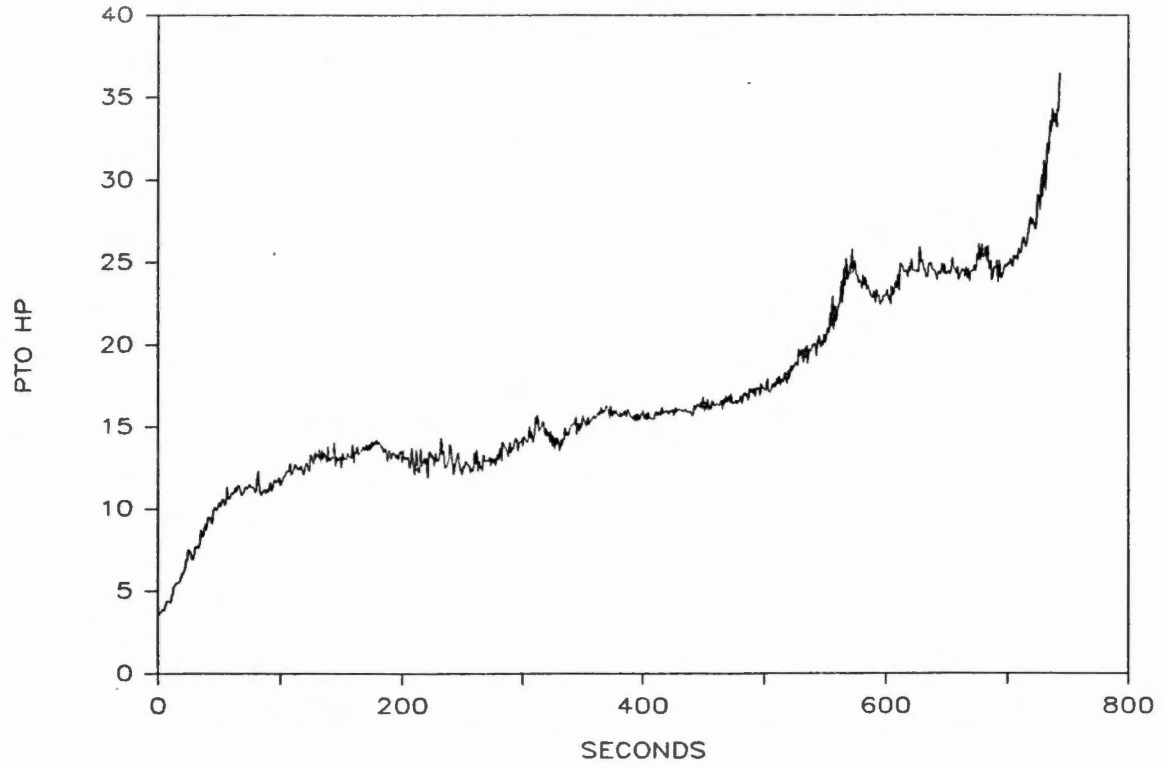

Figure 27. New Holland 845 Round Baler: Bale wt. 800 lbs., 2 mph, Test 5.

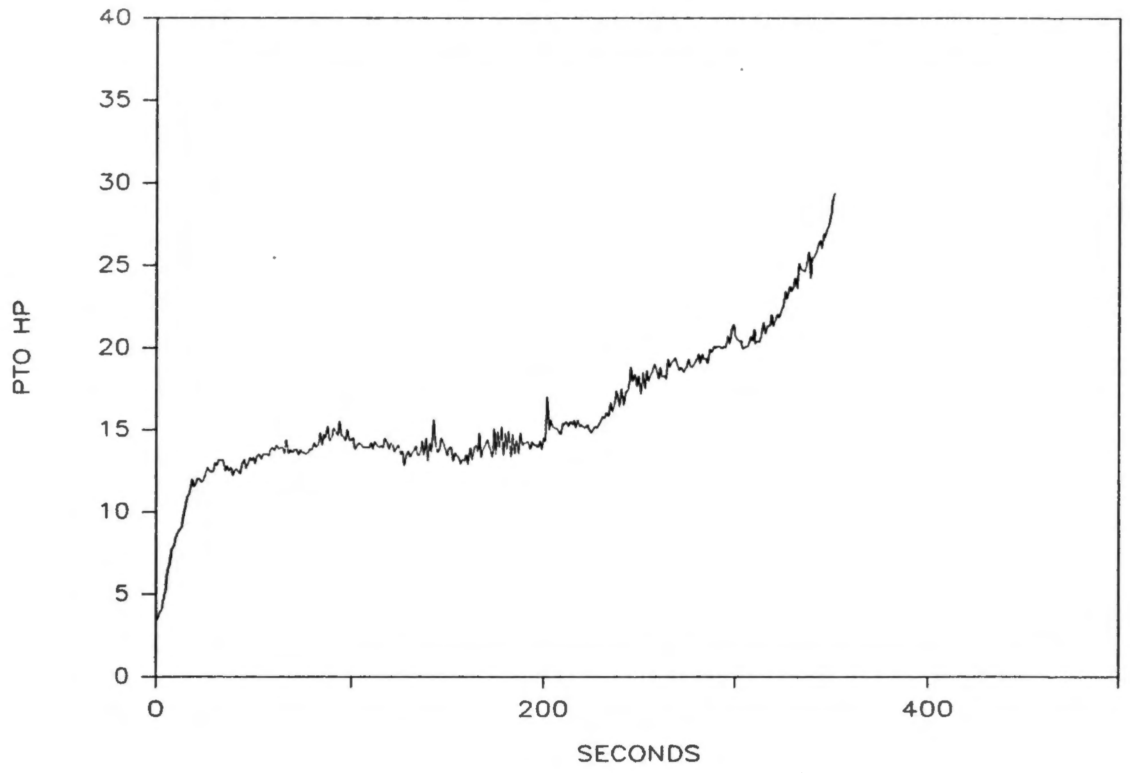

Figure 28. New Holland 845 Round Baler: Bale wt. 760 lbs., 3 mph, Test 6.

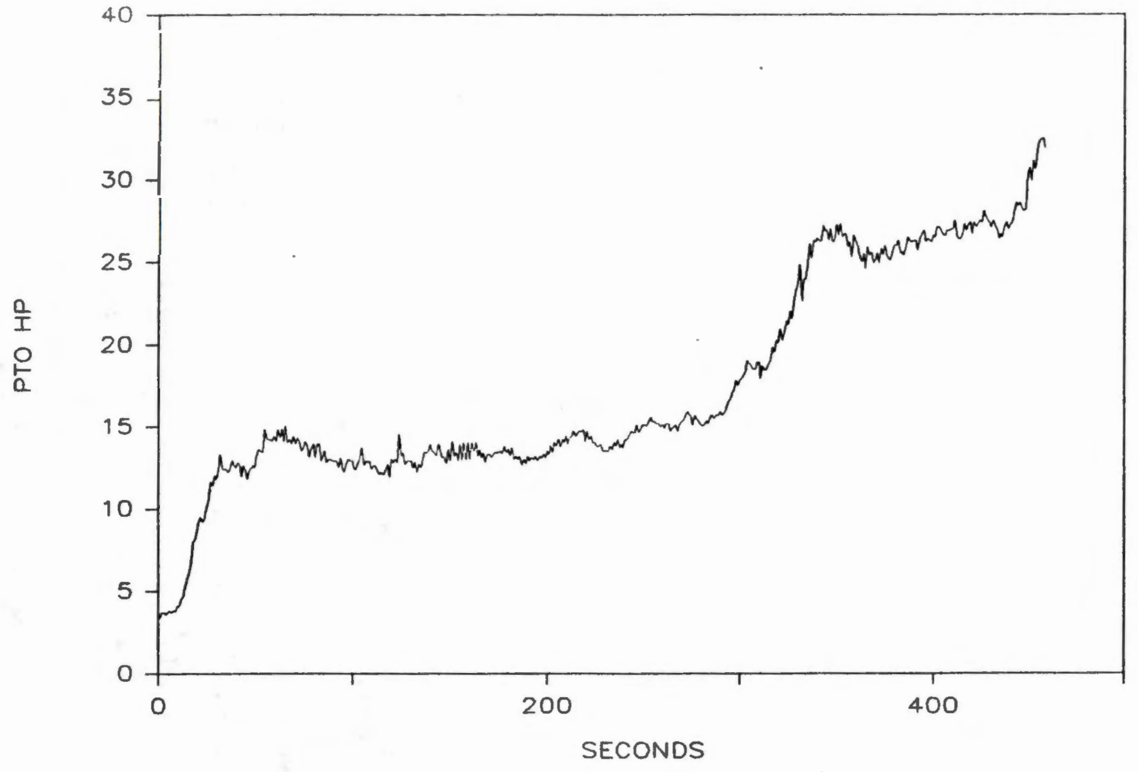

Figure 29. New Holland 845 Round Baler: Bale wt. 820 lbs., 3 mph, Test 7.

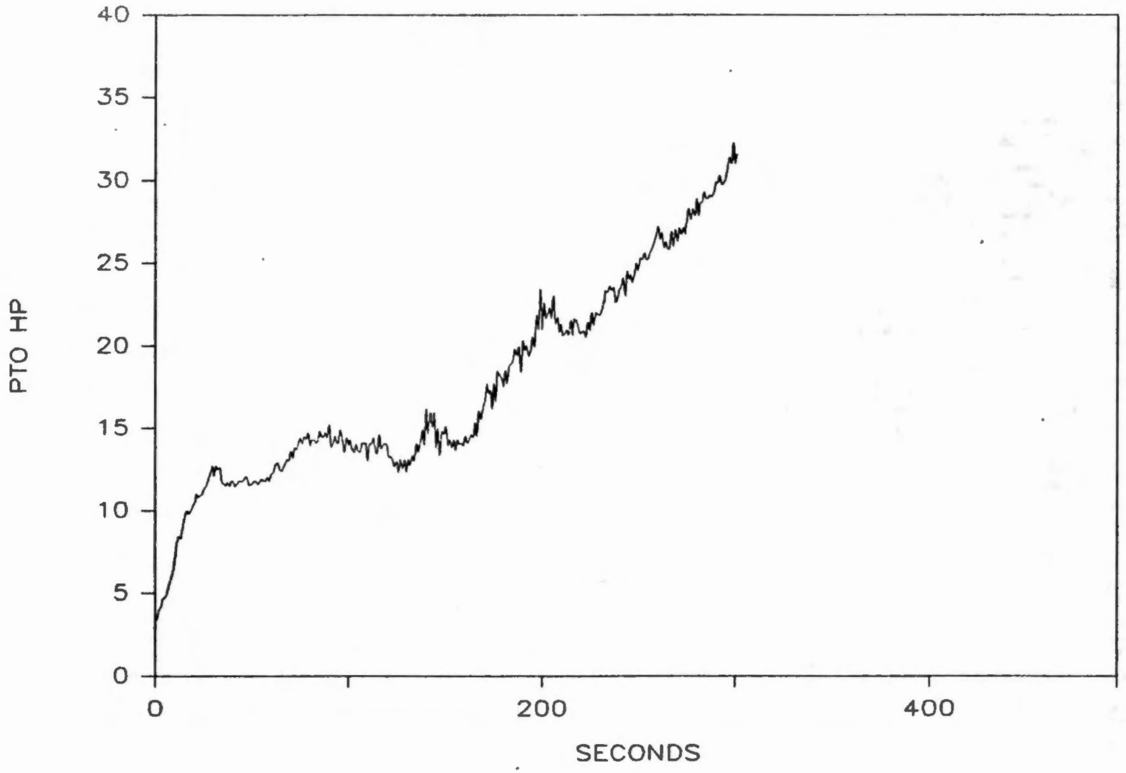

Figure 30. New Holland 845 Round Baler: Bale wt. 760 lbs., 3 mph, Test 8.

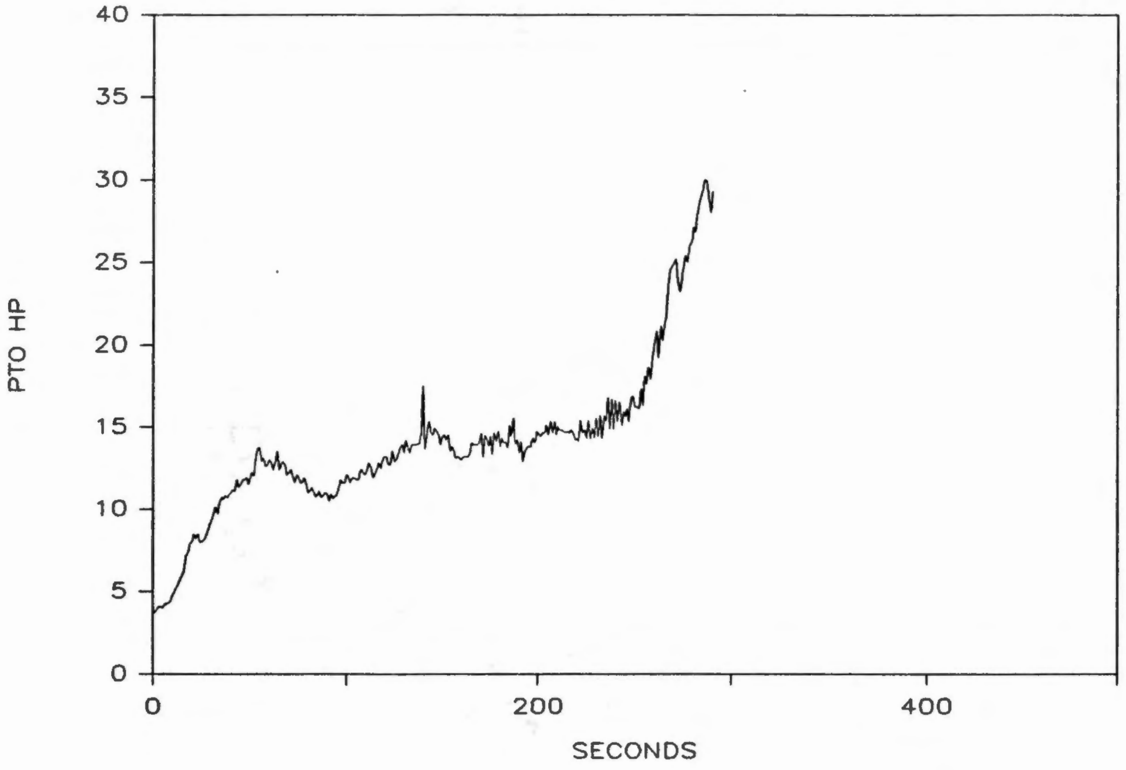

Figure 31. New Holland 845 Round Baler: Bale wt. 780 lbs., 3 mph, Test 10.

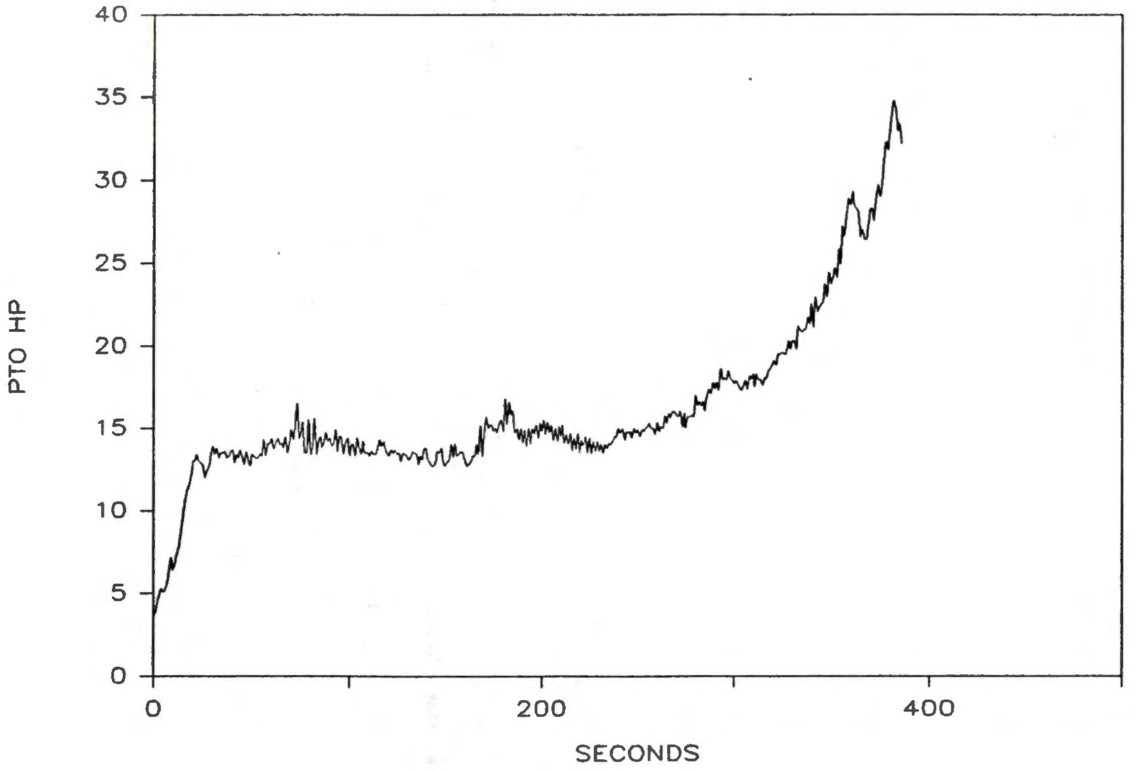

Figure 32. New Holland 845 Round Baler: Bale wt. 780 lbs., 3 mph, Test 13.

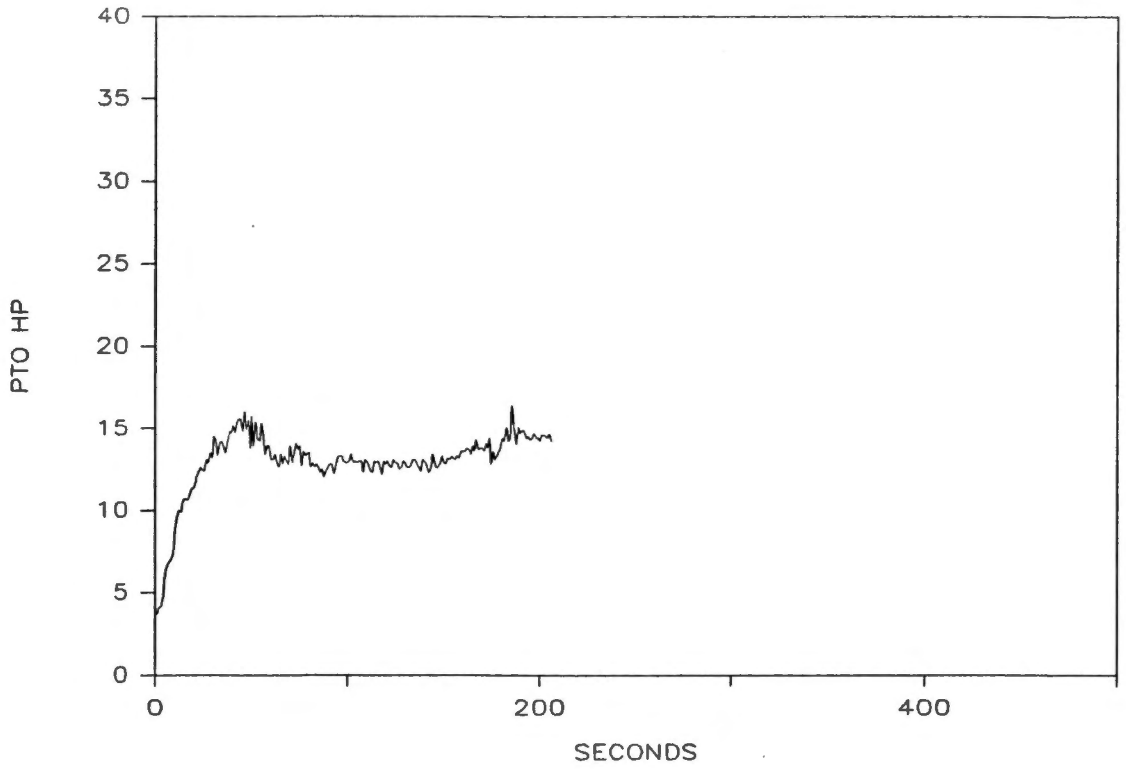

Figure 33. New Holland 845 Round Baler: Bale wt. 440 lbs., 3 mph, Test 14.

VITA

Robert Sherron Freeland was born in Knoxville, Tennessee, on September 4, 1957. He attended elementary schools in that city. In 1972 he entered Cumberland County High School, Crossville, Tennessee and graduated in 1975. In the fall of 1975 he entered The University of Tennessee, Knoxville, and received a Bachelor of Science degree in Agricultural Engineering in December of 1980.

In the winter of 1981 he accepted a graduate research assistantship at The University of Tennessee, Knoxville, and began study toward a Doctor of Philosophy degree in Agricultural Engineering. This degree was awarded in August of 1985.

The author is a member of Gamma Sigma Delta and the student branch of the American Society of Agricultural Engineers. He is the recipient of the 1985 Chancellor's Citation for Professional Promise and is registered as an Engineer-In-Training with the State of Tennessee.