To the Graduate Council:

I am submitting herewith a thesis written by William Earl Hart entitled "Tractor Instrumentation for Monitoring Energy Inputs to Implements." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Mechanization.

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TRACTOR INSTRUMENTATION FOR MONITORING ENERGY INPUTS TO IMPLEMENTS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

William Earl Hart

August 1982

3063078

TO:

My wife Cindy for her patience, understanding, and support throughout my graduate program.

My parents, Mr. and Mrs. William Hart, Jr. for their encouragement and support over the past 25 years.

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ABSTRACT

A 100-pto-horsepower agricultural tractor was instrumented with a microcomputer-based data acquisition system for monitoring energy inputs to implements powered by the tractor. The data acquisition system included instrumentation for measuring and recording fuel consumption, implement draft, travel speed, angular velocity of each drive wheel axle, and torque on each drive axle. Drive wheel slip, fuel consumption per unit time and area, drawbar horsepower, axle horsepower, tractive efficiency, and implement energy requirement per unit area could be subsequently computed from these measurements.

The data acquisition system was installed on a 2675 Massey-Ferguson (two-wheel drive) tractor. The system was centered around a DEC PDP11/03-LK microcomputer that was installed in a rack above the head of the operator. A DEC TU58 cassette tape system, which incorporated dual tape drives, was used for system program and data storage. Communication between the operator and data acquisition system was through a 64-key keyboard and a compact CRT unit for external monitoring of program execution and data display. Other components of the data-handling system included a microprocessor counter box for summing digital signals and a strain gauge signal conditioner/amplifier. All electronic data handling components were mounted within the confines of the tractor cab. The sensing hardware on the instrumented tractor consisted of a fuel transducer and display, a three-point hitch drawbar dynamometer, a free-rolling fifth wheel to indicate travel speed, axle speed indicators, and axle torque sensors. Power for the data handling

equipment and sensing transducers was supplied by a portable gasoline generator mounted on the front of the tractor.

The instrumented tractor was used during two cropping seasons to measure energy inputs to selected tillage and planting implements. Implements included a subsoiler, chisel plow, heavy tandem disk harrow, light tandem disk harrow, soil pulverizer, cultimulcher, row-crop planter, and no-till row-crop planter. Implements were operated to simulate the cultural practices associated with conventional seedbed preparation and planting.

The procedure for data collection consisted of operating a given implement with the instrumented tractor over measured 200-ft plots. The data acquisition system sampled and recorded the monitored parameters at one-second intervals during the test run. Each of the implements, except the subsoiler and row-crop planter, were operated at three travel speeds to obtain a range of energy requirements associated with implement operation. Field data were reduced by averaging numerous test replications of each operating speed-implement combination to obtain mean values for the desired energy-related parameters.

The data acquisition system performed satisfactorily with some modifications. Results of the field measurements indicated that the drawbar pull, drawbar power, drive wheel slip, fuel consumption per unit time, and the energy input per unit area processed all tended to increase for each implement as the travel speed was increased. However, the quantity of fuel required to process a unit area tended to decrease slightly for a given implement as the travel speed was increased.

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CHAPTER I

INTRODUCTION

I. BACKGROUND AND STATEMENT OF THE PROBLEM

A major problem faced by many Tennessee agricultural producers has been the proper selection and operation of farm implements for maximizing energy outputs. Since the advent of the first tractors powered by internal combustion engines in the early 1890's, agricultural producers have become highly dependent on the use of fossil fuels for operation. According to a USDA task force report cited by Reid (1978), the agricultural industry consumes approximately 3 percent of the nation's energy budget as on-farm usage, with more than one-half of this amount used for tillage. However, during the Arab Oil Embargo of 1973-1974, the nation was faced with high fuel prices and limited supplies of petroleum products. Economically priced fuels for the production of agricultural products were no longer available. For example, prior to the energy crisis in 1971, Tennessee agricultural producers paid an average of 31.0 cents/gal for regular gasoline (bulk delivery) and 18.5 cents/gal for diesel fuel (USDA, 1972). As of March 15, 1982 Tennessee farmers paid an average of $1.13/gal for regular gasoline (bulk delivery) and $1.06/gal for diesel fuel (USDA, 1982). Within an 11-year period, Tennessee farmers had absorbed 264 and 473 percent increases in the prices of gasoline and diesel fuel, respectively.

Along with the dramatic escalation of petroleum prices, Tennessee agricultural producers have also been confronted with rapid

increases in machinery costs. For example, in September 1973 Tennessee farmers paid an average of $6,400 for 50-59 pto-hp tractors, $650 for 3-bottom moldboard plows, and $16,000 for medium capacity self-propelled combines with 13.5-ft headers (USDA, 1974). Within six years the price of these machines had approximately doubled. In September 1979, Tennessee farmers paid $11,700, $1,260, and $44,600 for comparably sized tractors, plows, and combines, respectively (USDA, 1980).

Due to the rapid escalation of these fixed and variable costs of operation, many agricultural producers are searching for methods to insure the efficient operation of their existing implements and develop better criteria for future machinery selections. Presently only limited information is available on the energy requirements of machine operations employed in crop production (Tompkins and Wilhelm, 1981a). One example of such information is reported by Hunt (1977) for implements applicable to the Midwest. Such energy-related data are needed for the complete operating range of applicable implements for various soil types, moisture levels, and tractive surface conditions (Tompkins and Wilhelm, 1981a).

Many agricultural researchers and machinery manufacturers have developed instrumentation packages to monitor various tractor-implement operating parameters to determine energy inputs. These systems have ranged from manual recording of transducer readings (Williford, 1981) to highly advanced microcomputer-based instrumentation systems (Hendrick et al., 1981; Grevis-James et al., 1981; and Smith et al., 1981). A study was initiated to install a microcomputer-based data acquisition system on an agricultural tractor to monitor energy-inputs.

II. OBJECTIVES

The purpose of this study was to install an instrumentation system on an agricultural tractor to determine energy inputs to various tractor-implement combinations used in a range of operating conditions encountered in Tennessee crop production. Specific objectives of the study included:

1. Fabrication and installation of the data acquisition system on a 2675 Massey Ferguson agricultural tractor.
2. Field testing and evaluation of the performance of the instrumented tractor in monitoring energy inputs to selected tillage and planting implements.

CHAPTER II

REVIEW OF LITERATURE

I. FUEL CONSUMPTION MEASUREMENT

Volumetric Methods Using Graduated Cylinders

The volumetric measurement of fuel flow has been used by many researchers to determine the fuel consumption of mobile power units. The use of calibrated measuring vessels proved to be an accurate and inexpensive method for the determination of fuel flow. Fornstrom and Becker (1976) reported the measurement of fuel consumption with a volumetric cylinder described by Dowding et al. (1967). Solenoid valves controlled the path of fuel flow and allowed installation of the system on a gasoline tractor. Dowding et al. (1967) reported the accuracy of fuel measurement within 0.05 pint during a 300 ft run.

Tompkins and Carpenter (1977) measured fuel consumption on gasoline and diesel tractors with graduated cylinders. System components were mounted on a plywood board to allow installation on various tractors. A 2000 ml graduated cylinder was used on gasoline tractors and could be read to the nearest 20 ml. Solenoid valves were used to connect the metering system in the fuel line between the supply tank and carburetor. A transfer pump supplied fuel to fill the cylinder from the fuel tank on the tractor. Fuel measurement on diesel tractors was accomplished in the same manner using a 1000 ml graduated cylinder which could be read to the nearest 10 ml. Additional valves were required to handle the return fuel from the injector pump

and injectors. Return fuel was routed back to the cylinder so that liquid level indicated only fuel consumption by the engine. The cylinder was refilled between tests using return fuel or from the supply tank.

Reid (1978) used two plot tanks constructed from plexiglass to measure fuel consumption. The tanks were 23.62 inches in length. One tank had a 1-inch inside diameter and the other a 2-inch inside diameter with volumes of 0.08 and 0.32 gallon, respectively. Only one tank was used per test, depending on the required precision. The tanks were mounted on double swivels to maintain a vertical position. Three-way solenoid valves were used to install the measuring system on a diesel tractor. While the valves were in the deenergized position, fuel followed the normal path. In the energized position fuel from the selected tank was routed to power the tractor, and the return fuel from the injectors flowed back to the appropriate tank. To correct fuel volume due to changes in temperature a dial thermometer was placed in the line that connected the plot tanks with the engine. Time of fuel use was recorded on a strip chart.

Beppler and Shaw (1980) measured fuel consumption on gasoline and diesel tractors and self-propelled harvesting units with vertically mounted calibrated cylinders constructed from cast acrylic tubing. A 12v dc fuel pump with appropriate check valves was used to fill the cylinder from the fuel reservoir. Installation of the system required a 2-position, 3-port direction control solenoid valve. When the system was used on diesel engines, a tee was required between the flow control valve and the filters to reroute the return fuel. Activation of the

system was controlled from a central panel located near the operator.

Researchers that used visual metering devices such as graduated cylinders and plexiglass tanks physically observed fuel levels and manually recorded their fuel consumption data.

Flow Meters

LePori and Stapleton (1965) measured fuel flow on a diesel tractor with a positive-displacement piston meter. The meter contained a snap-action switch activated by a cam which produced an electric pulse for each 0.001 gallon of fuel flow. The meter was installed between the fuel tank and fuel pump. An auxiliary fuel tank was installed downstream from the meter to route return fuel back to the fuel pump. Signals from the meter were plotted against time with a modified two-channel recorder.

Shelton and Bashford (1977) used a fuel metering system to measure fuel consumption of a diesel tractor for demonstrations and energy measurements. The metering system consisted of a four-piston positive displacement flowmeter equipped with a pulse output tachometer. A Fluidyne model 1226 pulse counter display unit monitored the flowmeter output. The system used a heat exchanger to cool return fuel. Fuel consumption data were manually recorded from the display unit.

Collins et al. (1978) reported the measurement of fuel consumption of a diesel tractor using a Fluidyne model 1214 fuel meter. The flow rate transducer was installed inline before the injector pump. Output from the transducer was recorded on an oscillograph. The authors made an analytical correction for fuel returned to the supply tank. The system was used as a part of an instrument

package developed to follow up energy measurements initiated in 1973.

Smith and Fornstrom (1978) determined the fuel consumption of a gasoline tractor by combining output from a volumetric meter and the elapsed time of fuel usage. Specific details of the metering system were not discussed. Fuel was routed through the volume meter with a solenoid actuated valve during data collection.

Frisby and Summers (1978) reported measuring fuel consumption with a vortex flowmeter used with an instrument package developed by S. A. Langewisck, a graduate student at the University of Missouri. Specific details of the meter were not discussed. Fuel data were recorded with a light-beam oscillographic recorder in the previous instrument package. The authors monitored the output of the flowmeter with a digital display discussed by Summers and Frisby (1978). Data were temporarily stored with the monitor and manually recorded by the operator.

Grevis-James et al. (1981) used a Fluidyne model 1240T flowmeter to measure fuel flow. The transducer was comprised of four radially opposed pistons that rotated an encoder shaft as fuel flowed. The transducer was installed in the fuel line between the filters and the injector pump. Return fuel was routed downstream from the metering transducer. Output from the transducer was interfaced with a microcomputer and stored on magnetic tape.

Bedri et al. (1981) measured fuel flow with a FloScan, model 201A turbine flow transducer. The transducer consisted of a notched rotor that rotated proportionally to fuel flow. Rotational velocity of the rotor was sensed with a light emitting diode and a

photo-transistor. Square wave output from the transducer was interfaced with a single-chip microcomputer to calculate rate of fuel consumption and total fuel consumed. Data were displayed at the end of a test run for manual recording. Installation of the system was accomplished with two solenoid valves.

Clark and Gillespie (1980) and Morton et al. (1981) reported measuring fuel flow with a flowmeter that used two rotating geared bodies. One of the gears contained a magnet which activated a reed switch as the gear rotated. Clark and Gillespie (1980) used the output from the reed switch and incorporated it and other monitored parameters with a performance meter that calculated and displayed an operating efficiency number. Morton et al. (1981) used two flowmeters to monitor fuel consumption on a diesel tractor. One meter was installed in the fuel supply line and the other in the fuel return line. Net fuel consumption was obtained with circuitry that compared counts from each fuel meter and displayed the fuel information to the operator for manual recording.

Smith et al. (1981) and Williford (1981) measured the fuel consumption of diesel tractors with Fluidyne model 1250 fuel transducers. The metering systems consisted of a 4-piston positive displacement flow transducer, a fuel vapor eliminator, a check valve, and fuel filter. The transducer could measure fuel flow to the nearest cm^3. The metering system also included a temperature sensor, pressure differential sensor, a clock, and its own electronics with a seven segment LED (light emitting diode) display. The metering systems were powered from the 12v electrical system on the tractors. The researchers installed the

transducers to measure only fuel consumed by the engine. Williford (1981) manually recorded data at the end of a test run. Smith et al. (1981) used a 16-channel datalogger to monitor and record fuel consumption data on magnetic tape.

Adsit and Clark (1981) and Lin et al. (1980) reported fuel measurement on a small four wheel drive instrumented tractor using an Omniflo paddle wheel flow transducer and temperature sensor. The transducers were installed in the fuel line between the fuel filter and injector pump. A three-way valve was inserted in the return line to route fuel back to the injector pump. The sensing transducer consisted of a bladed rotor which turned with fuel flow. Rotational speed of the rotor was measured by a magnetic pickup coil. Output from the coil was a current frequency proportional to rotor speed. The signal was amplified and converted to a voltage read by an analog to digital convertor (ADC). Data collection was microprocessor controlled, and data were stored on cassette tapes.

Indirect Methods

Collins et al. (1978) reported measuring fuel consumption of a gasoline tractor with a calibrated vacuum gauge installed on the intake manifold. Calibration curves were developed using a dynamometer and flowmeter at several governor settings to relate manifold pressure to power and fuel consumption. Based on the average manifold pressure and governor setting for a given operation the fuel consumption was determined by referring to the calibration curves. The system was used in a preliminary energy study for corn production in 1973.

Koertner et al. (1977) determined fuel consumption on a diesel tractor by monitoring the metering valve position of the fuel pump. Metering valve position was determined with a variable impedance transducer and a wedge-shaped metallic target attached to the valve. The transducer contained a pair of coils arranged in opposite arms of a bridge. One coil was used as a temperature compensator and the other produced a magnetic field that caused an eddy current in the target surface mounted on the metering valve. Coil losses were related to the distance between the transducer and the target by a millivolt output. Transducer output was recorded on a light-beam oscillograph. Fuel consumption was calculated with a prediction equation that utilized calibrated power and fuel consumption curves and transducer data from the tractor.

II. GROUND SPEED, DRIVE WHEEL SPEED, AND WHEEL SLIP

Researchers have generally measured ground speed by using variations of two basic methods. One method involved the measurement of the angular velocity of a wheel with a known effective circumference. The second method required the measurement of time to traverse a known distance. Garner et al. (1980) illustrated the first method. The author monitored ground speed with a dc generator attached to a free rolling fifth wheel. The generator produced an analog signal proportional to the rotational speed. Based on the effective circumference and the angular velocity of the wheel, ground speed was calculated. Smith and Fornstrom (1978) illustrated the second method by measuring the time required to traverse a known distance to determine ground

speed. Reid (1978) also derived ground speed by measuring the time required to travel a known distance. To determine travel distance Reid (1978) mounted a commercial land measuring wheel on a tractor. The wheel had a circumference of 10 feet with four evenly spaced spokes that activated a microswitch. An event marker recorded microswitch activation on a strip chart. Each mark on the chart represented a travel distance of 2.5 feet.

Many researchers have measured drive wheel speed in addition to ground speed. Drive wheel speed can be determined by measuring the angular velocity and effective circumference of the drive wheel. The angular velocity of the drive wheels has been measured using several methods. Some researchers have manually counted drive wheel revolutions per unit of time to determine drive wheel speed. Other researchers such as Williford (1981) and Smith et al. (1981) determined drive wheel speed with mechanical or electronic sensing devices.

Once ground speed and drive wheel speed have been measured, wheel slip or travel reduction can be determined. Researchers have used the terms wheel slip and travel reduction synonymously in the past. Although both terms have been used to represent the loss of travel speed, each is calculated using a different no-load base condition for comparison. Collins et al. (1980) suggested that the term travel reduction be used when comparing drive wheel measurements obtained during loaded field conditions to those while operating in a no-load situation over a similar surface. The term wheel slip should be used when comparing drive wheel measurements collected under loaded field conditions to measurements obtained while operating the

implement package under a no-load condition over a hard, nondeformable surface for the base condition. Throughout the literature many researchers described various methods used to measure ground speed and drive wheel speed to determine wheel slip and travel reduction. Most researchers did not specify which no-load base condition was used to compare with the loaded conditions; therefore, the meanings of slip and travel reduction overlap.

Many researchers found it necessary to measure only the rotational speed of the drive wheels to determine drive wheel slip or travel reduction. To use this method, the test vehicles were operated across test surfaces twice. One time was required to record data at no-load condition and a second time to obtain information under loaded conditions. Ground speed was determined by measuring the amount of time required to traverse a known distance.

Fornstrom and Becker (1976) determined drive wheel rotation with an instrument package developed by Dowding et al. (1967). Drive wheel revolutions were counted using a pair of self-synchronous motors and a revolution counter. One motor was connected through a one-to-one ratio belt drive to the drive axle and the other motor was connected directly to the revolution counter. Counts from the revolution counters were apparently manually recorded at the end of a test run.

Williford (1981) measured drive wheel rotation with hubs mounted on the rear axles of a tractor. Each hub contained six evenly-spaced indentions which activated microswitches. Signals from the microswitches were counted and displayed with counters. Each count

represented one-sixth of a wheel revolution. Physical recording of the data was required at the end of a test run.

Many systems that use only rear wheel revolutions to calculate wheel slip or travel reduction have been used. However, specific details were not available. For example, Smith and Fornstrom (1978) measured drive wheel speed with photo-electric devices that recorded drive wheel rotation in increments of one-tenth of a revolution, and Collins et al. (1978) monitored drive wheel revolutions with magnetic sensors and recorded information on an oscillograph.

Other researchers found the need to monitor both rear wheel rotations and the rotational speed of an independent wheel such as a front wheel or a fifth wheel. These researchers calculated wheel slip or travel reduction by analytically comparing the two measured travel speeds or distances.

LePori and Stapleton (1965) measured distance and drive wheel rotation with event markers. Distance was measured by a wheel with a 10-ft circumference. A cam on the wheel operated an event marker that closed a circuit every one-half revolution. Drive wheel rotation was monitored with event markers on each wheel, and could be measured to the nearest whole revolution. The events were plotted against time as on-off events on a chart recorder.

Lyne and Meiring (1976) used photoelectric speed transducers to measure the rotational speed of the wheels on a tractor. Each transducer consisted of a light dependent resistor, light source, and perforated disc. All components were housed inside aluminum enclosures that attached to the tractor chassis and hub of each wheel. As the

wheels turned the perforated discs rotated allowing light to reach the light dependent resistors. Pulse signals from the transducers were converted to analog voltages proportional to the rotational speed of the wheels. Ground speed was measured by one of two methods to calculate wheel slip. The first method used circuitry to compare pulses from the front wheel transducers and used the faster of the two indicated ground speeds. The second method used the speed indicated by a fifth wheel equipped with a speed transducer. Signals from the transducers were conditioned, digitized, and recorded on punched paper. Instantaneous slip was also displayed on a panel meter to the operator.

Shelton and Bashford (1977) monitored the revolutions of one front and one rear wheel on a tractor and employed electronic calculators to determine ground speed, distance traveled, and wheel slip. Two modified electronic calculators were used as wheel counters. Microswitches were installed on the wheels with tripping mechanisms to supply signals to the calculators. Each time a switch was activated the appropriate calculator displaying the total number of counts increased by one. Eight counts represented one revolution of the rear wheel and four counts represented one revolution of the front wheel. Data collection required manual recording from the calculator displays.

Frisby and Summers (1978) reported using notched rings mounted on the rear axle and front wheel to monitor wheel rotation and ground speed. The rotation of the wheels was measured with microswitches actuated by the notches in the mounted rings. Information from the microswitches was displayed on a digital monitor with numeric display.

Clark and Gillespie (1979) determined travel speed and drive wheel speed by monitoring the rotational speed of the drive wheels and one front wheel. Perforated discs and light sensitive transducers were attached to both rear wheels and one front wheel. The light sensitive transducers sensed the passage of holes in the disc. Each hole represented a travel distance of six inches. Counts from the transducers were displayed to the operator and every 100th count was recorded with an oscillograph.

Grevis-James and Bloome (1980) used slotted discs and magnetic pickups to measure ground speed and drive wheel speed. Two transducer assemblies were used to monitor rotation. One unit was mounted on the front wheel and the other on one drive wheel axle. The slotted discs contained 5-mm slot and interslot widths around its outer perimeter. Each slot represented a travel distance of 32 mm. Frequency signals from the magnetic sensors were converted to voltages proportional to travel speed. Wheelslip, travel speed, and other parameters were displayed on a monitor to the operator.

Beppler and Shaw (1980) monitored wheel rotation by attaching aluminum discs with embedded horseshoe magnets to both rear axles and one front wheel. Each disc contained 10 magnets. Miniature reed switches were used to indicate the passage of a magnet by interrupting a signal from a control box. A LED display incorporated into the control box was used to display counts for manual recording.

Smith et al. (1981) measured the angular velocity of both rear wheels and the right front wheel of an instrumented tractor with magnetic sensors and actuator sprockets. A 45-tooth actuator sprocket was

attached to the front wheel and two 60-tooth sprockets were mounted on the rear axles. Passage of a tooth in front of the magnetic sensors produced a square wave signal. Output from the sensors was used as an input to a frequency to voltage converter to produce an analog signal. A 16-channel datalogger was used to record the analog signal on magnetic tape.

Bedri et al. (1981) also measured the angular velocity of the front and rear wheels of an agricultural tractor with magnetic sensors and ferrous gears. As described earlier the magnetic pickups produced a pulse for each gear tooth that passed in front of them. Pulses were related to the effective circumferential distance traveled per unit time to calculate angular velocity. The front wheel was used to measure ground speed by accumulating pulses for a one-second time period. Rear wheels were used in a similar manner to measure theoretical travel speed. Variables were displayed to the operator during data collection routines. At the end of a data collection sequence output could be displayed as requested by the operator for recording.

Grevis-James et al. (1981) measured ground and wheel speeds with rotary shaft optic encoders. Each encoder contained a small disc divided into equal transparent and opaque sections. Disc rotation was monitored with light sensitive circuitry that produced a square wave signal proportional to shaft speed. The encoders produced 360, 5-volt pulses per revolution. Ground speed was measured by driving an encoder from the front wheel of the tractor. Rear wheel speed was measured by driving another encoder from a ring attached to the rear axle. Data could be printed out on hard copy and recorded on magnetic tape.

All researchers discussed previously directly measured drive wheel speed to compute wheel slip or travel reduction. Some researchers such as Adsit and Clark (1981) and Lin et al. (1980) used an indirect method to determine drive wheel speed or theoretical travel speed. These authors measured ground speed by monitoring the angular velocity of a fifth wheel. Drive wheel speed was derived by monitoring the engine speed with a dc tachometer. The theoretical ground speed was computed by relating engine speed to the transmission gear ratio and drive wheel radius of the tractor. Data from the dc tachometers installed on the fifth wheel and engine were recorded on cassette tape and transferred to floppy discs for analyses.

III. MEASUREMENT OF FORCES BETWEEN TRACTOR AND IMPLEMENT

To determine the energy requirements of implements, researchers have developed a variety of methods and devices to measure the forces associated with implement operation. Some researchers have concentrated their efforts on the measurement of forces associated with towed implements that required power transmission through the tractor drawbar. Other researchers have dealt with the measurement of power transmission through the links of the three point hitch.

Force Measurement Using Drawbar Sensing Devices

Zoerb (1963) developed a strain gauge drawbar dynamometer that measured the draft component of a horizontal straight pull or a horizontal angled pull of towed implements. The system also indicated horsepower on a dc meter from the combination of draft and travel speed. The dynamometer consisted of a vertical shaft supported by two pillow

block bearings mounted on a vertical plate. The assembly mounted directly to the drawbar of a tractor. Strain gauges were mounted on the vertical shaft in the form of a wheatstone bridge to sense loading. Gauges were powered by a tachometer generator attached to a bicycle wheel, which also served as a speed indicator. Output parameters consisted of horsepower or draft and speed in miles per hour. Draft was displayed on a microammeter to the operator.

Grevis-James and Bloome (1980) and Grevis-James et al. (1981) reported the measurement of drawbar pull of trailed implements with a strain gauge equipped drawbar. Strain gauges were mounted on the inside surface of a hole drilled through the drawbar. Two gauges were used to form arms of a bridge circuit to monitor loading. Grevis-James and Bloome (1980) interfaced information from the drawbar transducer to a tractor power monitor which displayed drawbar power and drawbar pull to the operator. Grevis-James et al. (1981) monitored drawbar transducer output with a microcomputer and recorded data on hard copy or stored information on magnetic tapes.

Wendte and Rozeboom (1981) measured the draft component of trailed implements with a double bending moment drawbar dynamometer. The drawbar had a capacity of 36,000 lbf and a sensitivity of 4.2 lbf/ με. The gauge elements measured only the draft forces and cancelled vertical and lateral components. Those forces were measured with separate bridge circuits. The design featured overload protection for the gauge element. Output from the drawbar transducer was stored with a computerized data acquisition center.

Force Measurement Using Two-point Hitch Links

Fornstrom and Becker (1976) reported using a strain gauge dynamometer developed by Dowding et al. (1967) to measure implement draft. The dynamometer was incorporated into the two-point hitch mechanism of a tractor. Four strain gauges were mounted on the pitman link of the hitch to form a wheatstone bridge to sense implement loading. Two gauges were active and two were used for temperature compensation. The design measured the tension on the pitman produced by implement loading. The tension measured by the strain gauges was reportedly proportional to implement draft. The load range of the dynamometer was between 100 and 5,000 lbf. Output from the sensing mechanism was recorded with an oscillograph.

Smith and Fronstrom (1978) also measured implement draft by incorporating a strain gauge dynamometer into the two-point hitch linkage of a tractor. However, information from the dynamometer was recorded on an ink writing chart. Deflections on the data chart reflected actual drawbar loading.

Force Measurement Using Three-point Hitch Sensing Mechanisms

Lal (1959) constructed a dynamometer assembly to measure the forces of integrally-mounted implements. The device was incorporated into the design of a moldboard plow. The unit replaced the normal cross shaft of the plow with a straight shaft equipped with strain gauges. The gauges were arranged at each end of the shaft to measure horizontal and vertical forces separately. A top link assembly used a short strain gauge dynamometer to measure the horizontal force and transmit the vertical force through the framework to be measured by the

cross shaft sensing assembly. Gauges were connected so that vertical and horizontal forces could be recorded separately or vectorially summed.

Scholtz (1964) measured the forces of integrally-mounted implements with three strain gauge traverse beams mounted on a tractor. Each beam contained four strain gauges to detect desired forces. The three point links of the tractor attached between the beams and the implement. However, the beam system only worked correctly when used on three-point hitch systems without hydraulic depth control. Due to the inadequacy of the beam system, Scholtz (1966) designed and constructed a three-point hitch dynamometer that could be used with draft control systems. The dynamometer was reported to resemble an inverted U. The configuration allowed the dynamometer to be used with implements that required power transmission through the PTO shaft. The main frame was constructed from hollow rectangular tubing that hinged together. Two struts were required to restrict movement of the vertical arms and allow implement hook up. The dynamometer contained two L-shaped transducers for lower link force measurement and a U-shaped transducer for the center link. One end of the L-shaped transducers bolted rigidly inside the two vertical shafts of the main frame with the other ends containing ball joints to connect to the lower links of the implement. The U-shaped transducer acted as the center link for the main frame. The transducers contained strain gauges in the form of wheatstone bridges to measure the draft and vertical forces of mounted implements. The force measurement system could be monitored with three meters or three channels of a recording device.

Reid (1978) reported measurement of draft using a three-point hitch dynamometer. The dynamometer consisted of three aluminum cantilever beams. Two strain gauges were mounted on each beam with two additional gauges for temperature compensation. Gauges were connected in a bridge circuit to produce a net draft reading. Transducer output was recorded on a strip chart.

Johnson and Voorhees (1979) described a three-point hitch dynamometer that measured draft, vertical force, and torque of an implement. The dynamometer was designed for two load ranges on tractors between 100 to 134 hp. Maximum draft in the high range was 14,990 lbf and 8,090 lbf in the low range. The dynamometer could be used with category II and III tractor hitches and couple with mounted or semimounted implements with category II or III hitches. The dynamometer was described as having three subassemblies. The first assembly attached to the three-point hitch of the tractor. The second assembly was the sensing unit which contained strain gauges mounted on an aluminum tube. The third assembly was a quick hitch unit to attach implements. Strain gauges could be attached to the aluminum tube in locations and configurations to measure draft, vertical force, and torque of an implement independently of other forces. The dynamometer could not be used with implements that required power transmission through the PTO shaft or with implements with control levers that protruded beyond the plane of the three-point hitch.

Lin et al. (1980) and Adsit and Clark (1981) reported the measurement of implement draft with a three-point linkage dynamometer developed by D. B. Chandler, a graduate student at the University of

Georgia. The design reportedly used bending movements instead of pure tension. Strain gauges were used as the sensing devices. The gauges were arranged to measure draft with the cancellation of all vertical forces. Signals from the dynamometer were conditioned and stored on cassette tapes.

Garner et al. (1980) measured the forces on the three-point hitch links of a tractor with transducers constructed into a three-point hitch dynamometer. The transducers measured loads due to simple bending. Load sensing members were constructed from 3/4 inch x 4-inch steel bar stock. Sensing was accomplished with four strain gauges mounted to each load cell. Data were printed on hard copy or recorded on cassette tapes.

Barker et al. (1981) designed and constructed a three-point hitch dynamometer that could be used on tractors up to 80 horsepower. The authors reported that the dynamometer was designed for easy interchangeability between tractors and implements. The dynamometer was constructed from 6-inch steel channel to form a triangular frame. Six load cell transducers were incorporated into the design to measure draft, side, and vertical components of implement loading. A 16-channel datalogger, with strain gauge bridges and amplifiers was used to record data on magnetic tape.

LePori and Stapleton (1965) and Frisby and Summers (1978) also reported the measurement of implement loading with three-point hitch dynamometers. However, specific details of the sensing mechanisms were not discussed. Luth et al. (1978) and Collins et al. (1978) incorporated sensing transducers into the three-point hitch links of tractors

to measure the forces of implement loading. Luth et al. (1978) monitored transducer signals with a telemetry data acquisition system. Collins et al. (1978) recorded transducer signals with an oscillograph.

Some researchers found it necessary to instrument the implement instead of the tractor. Clark and Gillespie (1979) and Abernathy (1976) measured the draft and vertical forces of implements by mounting strain gauges directly to implements.

IV. COMPLETE DATA ACQUISITION SYSTEMS

By combining the various energy measurement devices discussed previously, some researchers and manufacturers have developed complete data acquisition systems. These systems have ranged from manual data collection to highly advanced computer-based collection systems. Some systems displayed information to the operator for manual recording. Other systems were equipped with internal storage systems which required minimum operator input. With the advent of solid state electronics and microcomputers, data collection systems have changed dramatically. Systems described by LePori and Stapleton (1965), Dowding et al. (1967), and Fornstrom and Becker (1976) which used mechanical sensors, chart recorders, and oscillographs for instrumentation have become obsolete.

Luth et al. (1978) described a mobile telemetry-computer system used to collect and evaluate data on machines operating in the field. The system was comprised of an instrumented tractor and a signal receiving station. The instrumented tractor was equipped with transducers to measure energy inputs and implement loading. The receiving

station was contained in a fifth wheel trailer. The system could collect either 15- or 16-channels of data with one telemetry frequency or 31-channels with two frequencies. The transducer signals were conditioned on the instrumented tractor and could be transmitted up to five miles to the receiving station. The trailer contained its own power generating system which operated the telemetry receiving equipment and minicomputer. The minicomputer system could sample data at rates up to 50,000 samples per second. Data were stored on magnetic disks and digital tape. The system also contained two cathode ray tubes (CRT). One was used during data acquisition to display summaries after each test. The second CRT was used for data analysis and system programming. The minicomputer system also had graphics and statistical analysis capabilities.

Wendte and Rozeboom (1981) used an on board computerized data center on a tractor to monitor transducer signals that measured implement depth, engine speed, and travel speed. The data center included an Intel 8080 processor with parallel input-output boards, 4K bytes of random access memory (RAM), 3K bytes of programmable read only memory (PROM), and various counters for input pulses. Sampling and calculated values were produced two times per second. Inputs consisted of magnetic pickups located on the engine and a fifth wheel along with digital signals from three possible implement depth sensors. The data center calculated and displayed ground speed, time, distance traveled, and percent slip and travel reduction. Additional features of the system included the display of average speed, slip, and travel reduction for an entire run. Calibration factors for wheel slip and travel

reduction were stored in the data center. The data center had enough memory for 20 minutes of data collection or could be used with a telemetry transmitter.

Hendrick et al. (1981) designed and constructed a computer-based field measurement system for recording field performance of tillage and traction machinery. The system was designed around an Intel 80/30 board level microcomputer. An additional math board was included for executing calculations on the data. System dimensions were 52 cm wide, 32 cm high, and 51 cm deep; the system weighed 15 Kg. Transducer interface was accomplished with an 8-channel analog-to-digital conversion (ADC) board. The system was powered from the 24v dc electrical system on the tractor. Operator communication with the system for calibration and data acquisition was accomplished with an alphanumeric keyboard and liquid-crystal display (LCD). Push button switches were used to start and stop data acquisition. The minimum scan rate was 140 scans per second for eight channels. That included data acquisition, computation of a running mean and standard deviation for each channel. Channel scanning could be in any selected order, including the repetition of channels, so that a channel could be scanned more frequently than the others (up to a total of 15 channels). The only data storage consisted of the running mean and standard deviation for each channel. At the conclusion of a test the calculated means and standard deviations for each channel were printed on paper with a thermal printer. The use of specific transducers was not discussed.

Grevis-James et al. (1981) developed a microcomputer based data acquisition system on an instrumented tractor. The system was based

around two Rockwell AIM 65 microcomputers. One microcomputer was installed on the tractor to control data measurement, display, and recording. The system consisted of a single board microcomputer which used a 6502 microprocessor and other 65XX series components. Other features included were a 20 character alphanumeric display, 20 column printer, 64 key keyboard, 20 lines of application I/O, two 16-bit timers, tape recorder control, and a serial interface. System components were powered by the tractor electrical system. The system had the capability to print data while simultaneously recording it on magnetic tape. The second AIM 65 microcomputer was located separately from the tractor to read data from the tapes and transmit it in serial form to a Tektronix 4052 computer equipped with printer and plotter for data analysis. The instrument package measured drawbar pull and power, ground speed, wheel slip, fuel flow, and engine speed.

Smith et al. (1981) developed an on-board instrumentation package that monitored and recorded transducer outputs from an instrumented tractor. The system monitored fuel consumption, engine speed, forward travel speed, rear axle torque, rear axle angular velocity, and implement load. Transducer signals were monitored with a Dynatech 6200 series 16-channel datalogger. Input signals to the datalogger were all analog. Digital transducer signals from magnetic sensors were made compatible with a frequency to voltage converter. The datalogger used a high speed 12-bit A/D converter that was capable of scanning 25 channels per second. Channels were sampled 64 times per scan. Average values for each channel were computed and recorded on magnetic tape.

Garner et al. (1980) developed an instrumentation package that monitored and recorded ground speed and the three-point hitch forces of a tractor due to implement loading. A microprocessor was used to control data acquisition and storage. The microprocessor was a single board Intel iSBC TM 80/20-4 computer with additional memory capabilities. A Burr-Brown MP8408/8416 analog to digital converter allowed communication between transducers and the computer. External communication with the computer was through a Texas Instrument 745 terminal or a Techtran 815 program cassette recorder. Data were recorded with a Texas Instruments terminal or a Techtran 8400 cassette recorder. Data collection for the four channels monitored was at intervals of 1/30 of a second. Histograms for draft and velocity could be computed and plotted at the end of a collection sequence. Statistical functions and printouts were also possible. All electronic equipment was housed inside a dust-proof enclosure that mounted on the front of the tractor.

CHAPTER III

DESIGN OF INSTRUMENTATION PACKAGE

I. DESIGN CRITERIA

The decision was made at the outset to instrument one tractor with a data acquisition system. The instrumented tractor would then be used to operate various tillage and planting implements over a range of soil types, field conditions, and tractor and implement operating parameters. However, this approach virtually eliminated the possibility of evaluating the effect due to the tractor. Hence, energy-related parameters to be evaluated would be restricted to a quantitative comparison of the various implements and operating condition parameters. Energy-related parameters for which measurements were deemed essential included travel speed, drive wheel slip, fuel consumption, implement draft, and axle power.

The data acquisition system was to be installed on a 2675 Massey-Ferguson agricultural tractor (two-wheel drive, maximum 100-pto-HP) equipped with an enclosed cab with standard air conditioning and filtration systems. A principal guideline for instrument selection and installation was related to the space restrictions imposed by the cab. All electronic instruments had to fit within the confines of the controlled environment of the cab to protect against the harsh field conditions anticipated. Data handling equipment was to be installed so as not to interfere with the normal duties of the tractor operator.

The tractor operator would be required to perform all manual functions associated with data acquisition. Thus, all functions associated with the operation of the instrumentation package were to be actuated from the tractor cab with a minimum of additional workload for the unassisted operator.

The data collection system had to be versatile for a spectrum of test applications. For example, the system had to be capable of collecting data for extended periods of time while operating in large field situations. Also, the system would be required to collect data over short periods while operating on small plots. Therefore, priority was given to control of the monitoring and data sampling frequencies.

The final area given consideration in designing the system was the actual handling of data. A system that eliminated manual manipulation and translation of collected data was desired. Therefore, a decision was made to construct the data acquisition system around a microcomputer. A computer-based system would allow use of a higher level programming language instead of machine language. Also, easier interfacing between system components and greater expansion capabilities of the system were anticipated. Moreover, by having a computerized data acquisition center on the tractor, the operator would be able to continuously monitor collected data to insure that the system and transducers were producing expected values. Finally, a computer-based system would facilitate development of diagnostic programs for system calibration and trouble shooting.

II. SYSTEM SENSING DEVICES

Fuel Meter

A Fluidyne Model 1240T fuel flow transducer and a Fluidyne Model 1240D fuel display unit, similar in design and function to those used by Smith et al. (1981) and Williford (1981), were installed on the tractor to measure fuel consumption. The fuel transducer consisted of a positive displacement piston motor that rotated an optical encoder sensor. A square wave signal was produced by the sensor to indicate fuel flow. The transducer also included a fuel filter, a vapor eliminator, pressure and temperature sensors, and an audible vapor detector alarm when incorporated with the 1240D display. The fuel transducer was capable of measuring flow to the nearest 0.1 cc with 0.5% accuracy. The 1240D display had electronic circuitry that summed and displayed fuel measurements from the transducer. The display unit included LED displays for fuel consumption, elapsed time in seconds, and a switch-selectable display for fuel temperature or pressure. The fuel flow transducer was installed in the fuel system of the tractor using two solenoid-actuated values as shown in Figures 1 and 2. The purpose for using the solenoid-actuated values was twofold. First, the valves routed fuel through the transducer only when measurements were desired. Secondly, valves rerouted return fuel flow from injectors and injection pump to the downstream side of the fuel transducer so that only fuel consumed by the engine was measured. Activation of the solenoid values was accomplished with a toggle switch located in the cab of the tractor. Fuel flow signals produced by the flow transducer were routed to the display unit and forwarded to the data handling and

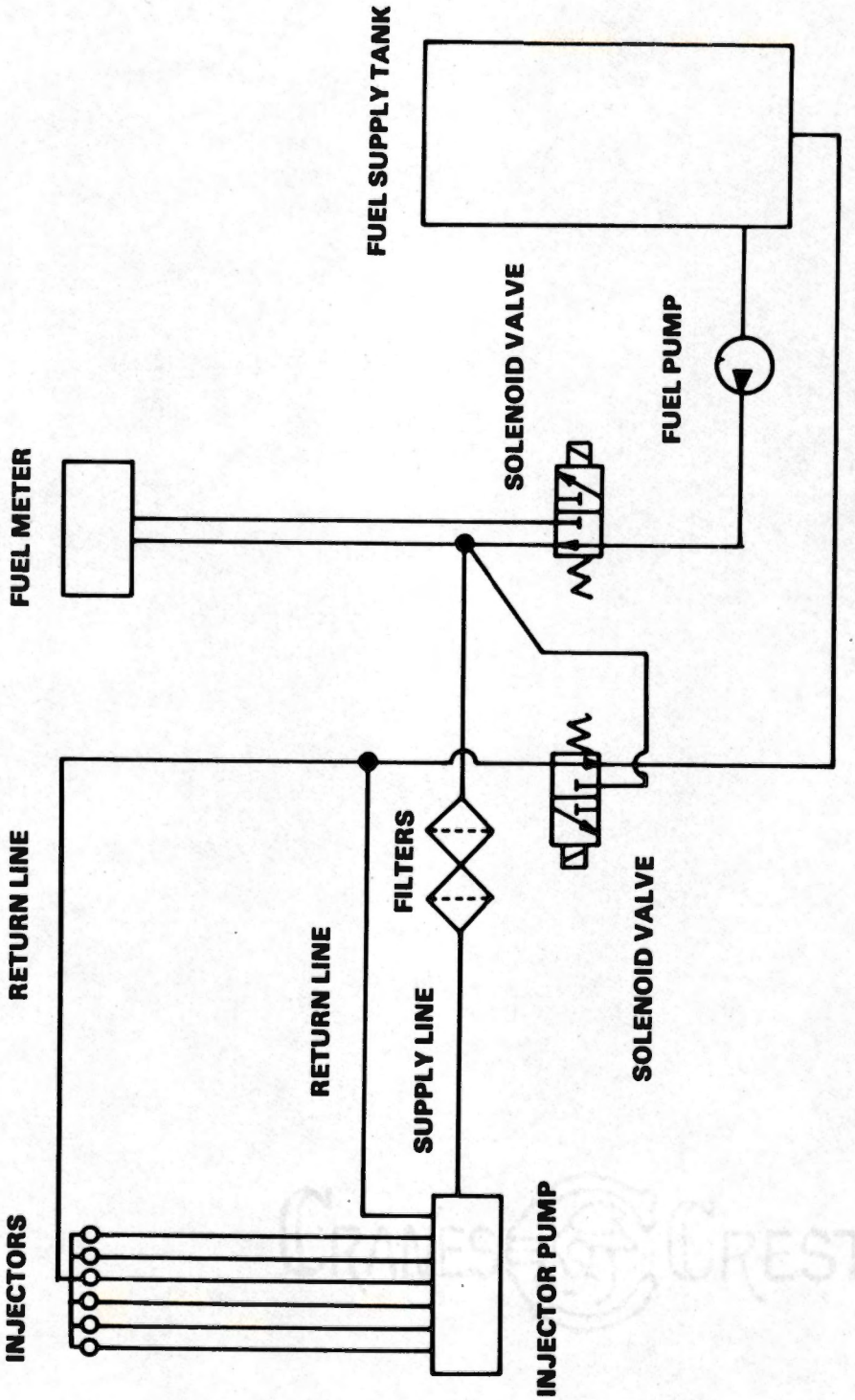


Figure 1. Schematic of the tractor fuel system as modified to accommodate the fuel transducer. Solenoid values are shown in deenergized position.

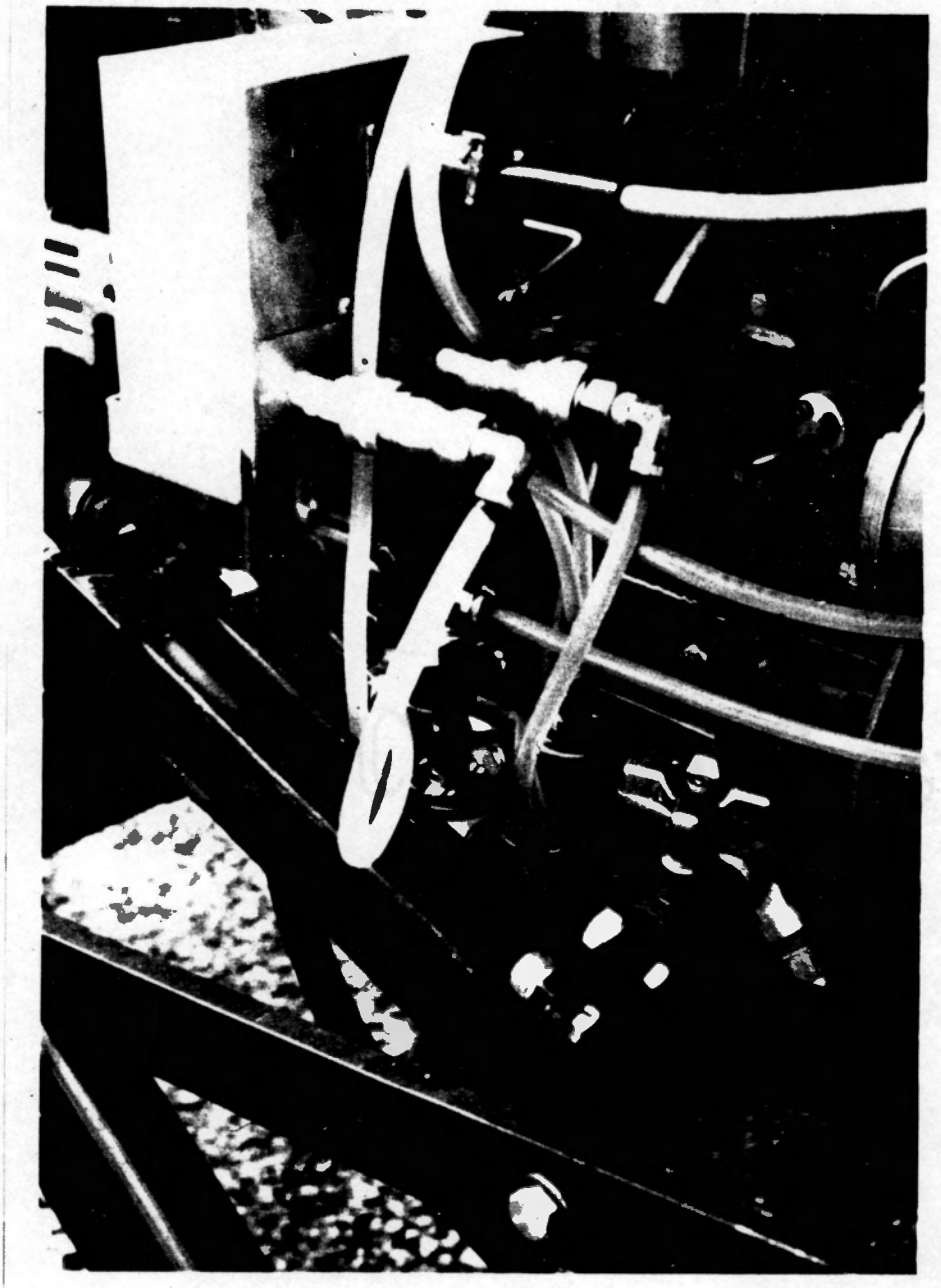


Figure 2. Fuel transducer installed on the instrumented tractor.

storage system. Each group of 100 pulse signals represented one cc of fuel flow. Power for the fuel monitoring system was supplied by the 12-volt electrical system of the tractor.

Fifth Wheel Assembly

A free-rolling fifth wheel assembly, shown in Figure 3, was designed and fabricated to measure ground speed and travel distance. Researchers such as Lyne and Meiring (1976), Shelton and Bashford (1977), Clark and Gillespie (1979), and Smith et al. (1981) determined ground speed and travel distance by measuring the angular velocity of the front wheel on their tractors. However, there are some disadvantages associated with this methodology. First, due to the loading imposed by an implement, the apparent weight transfer of the tractor can be expected to change the effective diameter of the front tire. Also, by changing the weight distribution on the front of the tractor some wheel slippage would be expected. Thus, the effective rolling circumference of the tractor tire would not remain constant. Secondly, since the tractor was expected to be operated in large field applications that involved operating through curves and around field obstacles, a true indication of mean distance traveled would not be obtained from measurements using the front tractor wheel. Therefore, an independent free-rolling fifth wheel, similar in function to those used by LePori and Stapleton (1965), Reid (1978), and Garner et al. (1980) was used. The main frame of the fifth wheel assembly was constructed from 2-inch x 4-inch steel tubing and 1/4 inch x 4-inch flat stock. A 18.0-inch outsider diameter flotation type tire was used as the ground wheel. The tire and rim unit was bolted to a 1-inch diameter axle.



Figure 3. Free-rolling fifth wheel assembly used to measure ground speed and travel distance.

The wheel-axle assembly was then attached to a yoke equipped with two self-aligning flanged bearings. A hinge joint incorporated into the support assembly allowed the wheel free lateral movement to track the tractor while operating along curved fields. The complete fifth wheel mechanism was raised and lowered with a hydraulic cylinder. A yoke attached to the cylinder rod allowed the tire to move freely in the vertical plane to conform to ground surface conditions encountered in field operation. Monitoring equipment included a 72-tooth split gear that attached to the axle of the ground wheel. An aluminum housing, shown in Figure 4, enclosed the gear to maintain it in a clean environment. A magnetic sensor (Airpax Model 085-101-0001) screwed into the housing to sense rotation of the split gear. The sensor produced a rectified sine wave output for each gear tooth that passed. These sine wave signals were converted to TTL-compatible digital signals using an in-house designed Schmitt trigger circuit. Ground speed and travel distance were computed by summing the number of digital signals over a given period of time and relating that sum to the effective circumference of the ground wheel.

Rear Axle and Drive Wheel Speed Sensing

Angular velocity of the rear axles was measured in a manner similar to that used for the fifth wheel assembly. However, in this particular instance 120-tooth split gears were used with the magnetic sensors (Airpax Model 087-304-0052). These split gears attached directly to each rear axle of the tractor, as shown in Figure 5. Magnetic sensors were mounted on 5/8-inch x 5-inch metal plates. The rear of the plates attached to the cab mounts of the tractor and

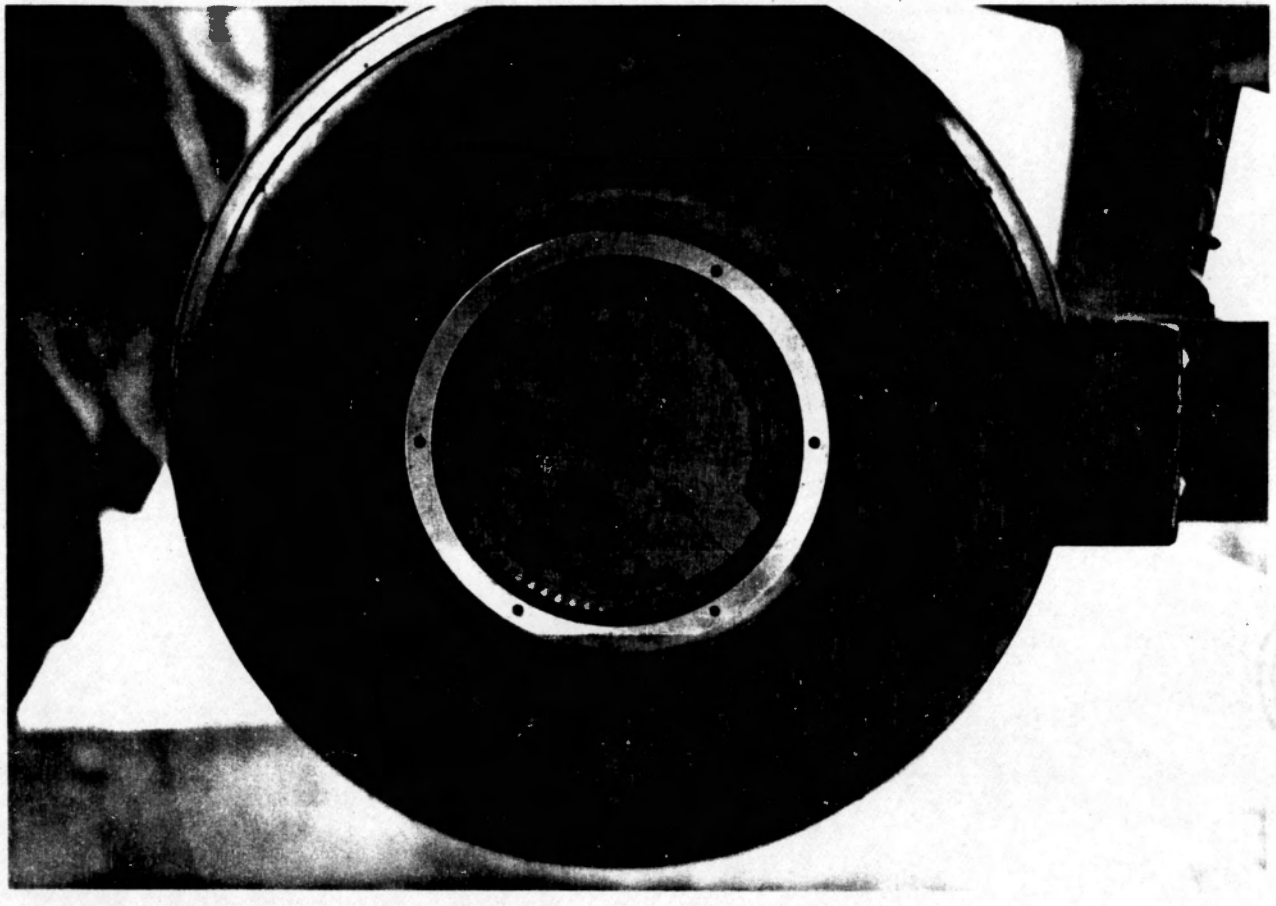


Figure 4. Aluminum housing enclosing the 72-tooth split gear on fifth wheel axle.

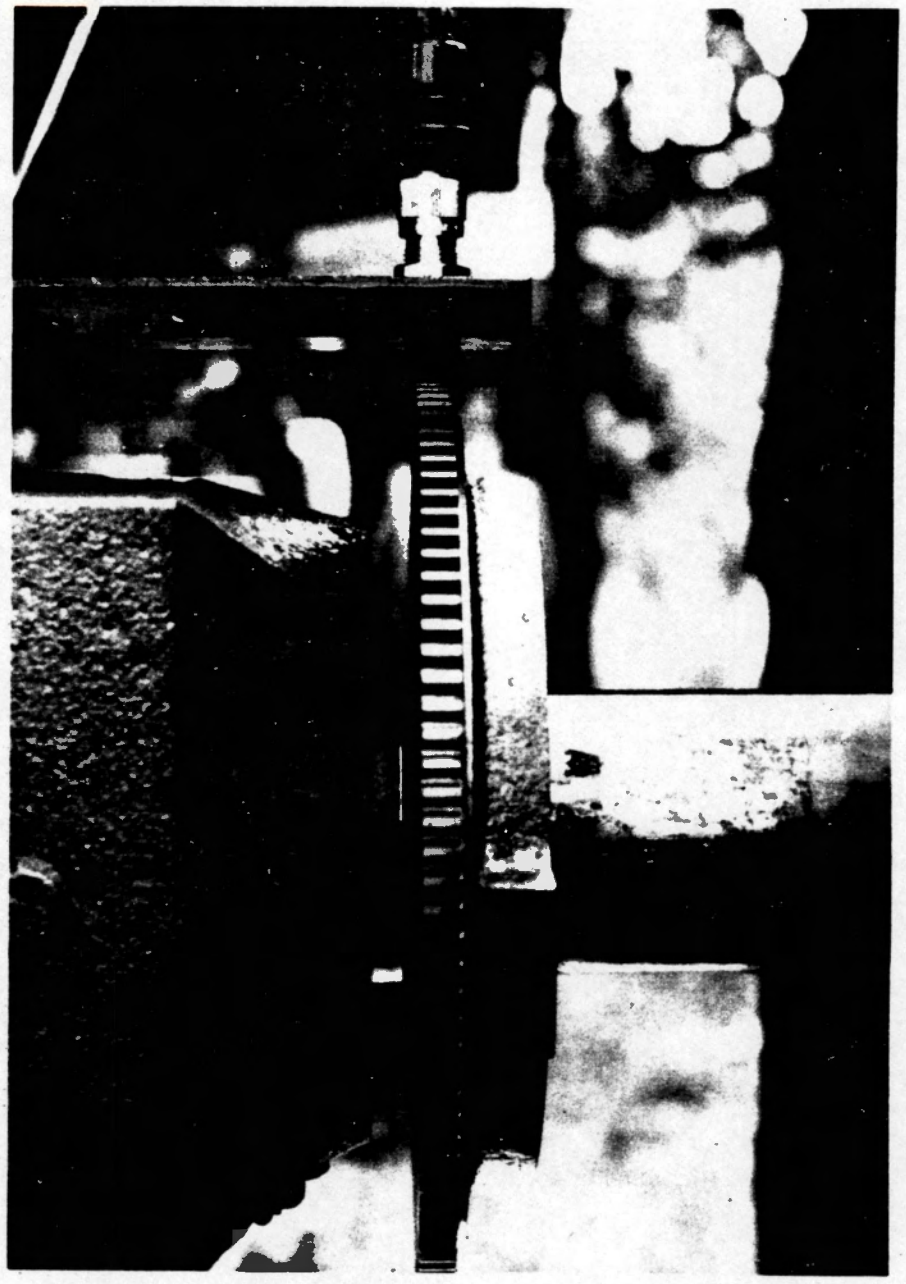


Figure 5. Magnetic sensor and 120-tooth split gear mounted on rear axle of tractor for determining angular velocity.

protruded outward to position the magnetic sensors directly over the split gears. As with the fifth wheel, the rotational speed was measured by "counting" the teeth on the gears as they passed in front of the sensors. Rectified sine wave signals produced by the sensors were converted to compatible digital signals and forwarded to the data handling equipment. Rear axle speed was computed by summing the number of digital signals from the magnetic sensors over an elapsed time. Drive wheel speed was calculated based upon the rotational speed of the rear axles and the effective circumference of the rear tires.

Axle Torque Sensing

Strain gauge rosettes were applied directly to both rear axles to measure torque, as shown in Figure 6. Rosettes were mounted on opposite sides of each axle 90° from the center of the axle keyway. Gauges used were Micro-Measurements EA-06-125TK-350 with factory connected leads. Gauges were mounted onto the axle surface in the following three generalized steps. First, the axle surface was cleaned thoroughly and sanded to remove any pitted areas so that gauges would be in firm contact with the metal. Second, gauges were applied to the axle surface with Micro-Measurements M-Bond AE-10/15 strain gauge adhesive cement. Third, the cemented gauge rosettes were covered with Micro-Measurements M-Coat G polysulfide/epoxy protective coating to ensure that gauges would not be harmed during field operation. Using an approach similar to Lin et al. (1980), gauges were wired to form wheatstone bridge circuits to measure torque in both clockwise and counter clockwise directions. Gauges were temperature compensating and measured only axle torque, with all bending forces canceling.

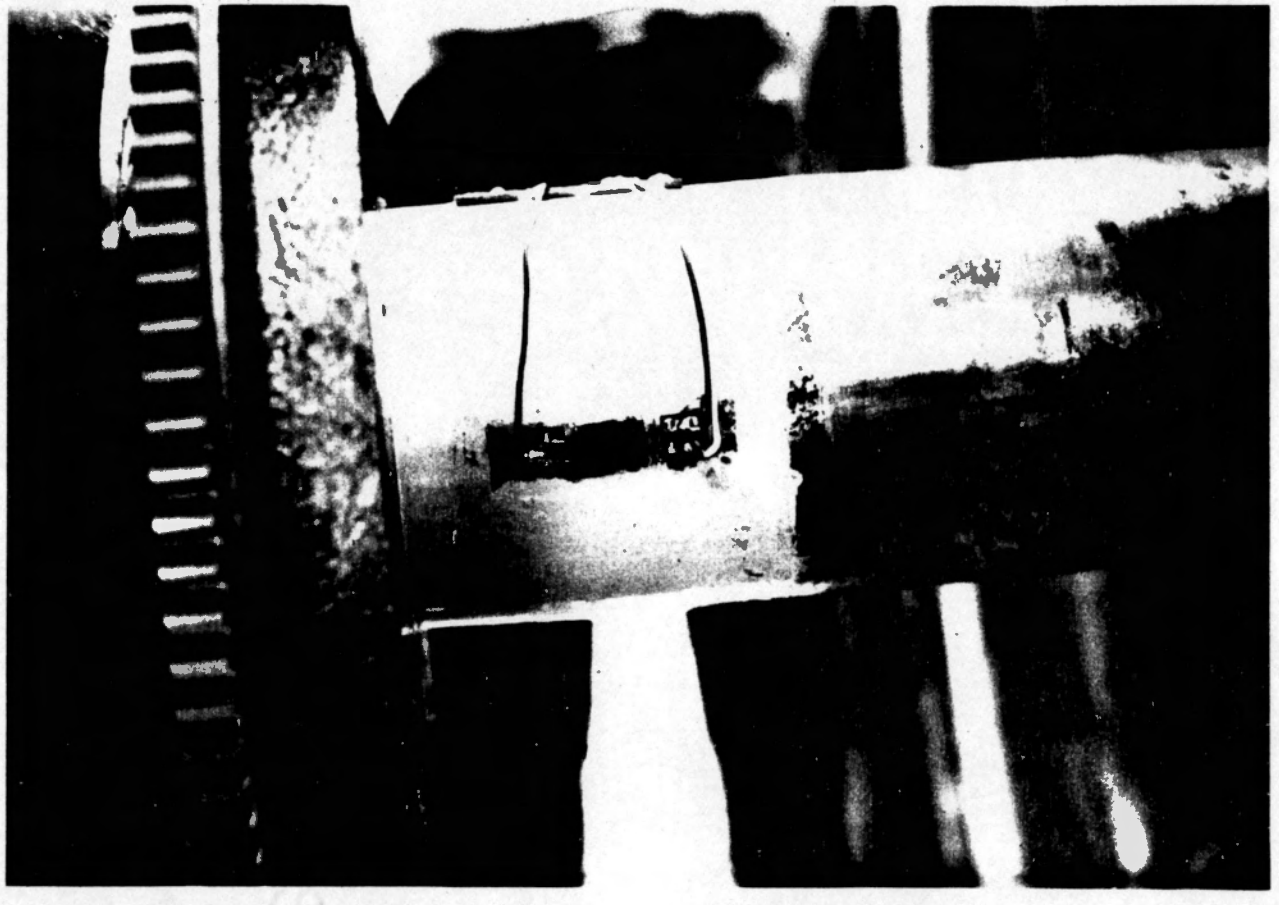


Figure 6. Strain gauge rosettes mounted on rear axle of tractor for torque sensing.

Analog signals produced by the gauges were routed to a set of slip rings (LeBow Model 6118-111-4) installed on the end of the axles. Slip rings were attached to the axles by specially designed aluminum cups with various spindle diameters, shown in Figure 7. The signals were forwarded from the slip rings to the data handling equipment through a set of slip ring support arms. These support arms were constructed from 1½-inch square tubing which attached to pillow block bearings located beside the slip rings. The arms extended upward and across the rear drive wheels and attached to the 5/8-inch x 5-inch metal plate that held the magnetic sensors. The construction is shown in Figure 8. The strain gauge power supply and signal conditioning equipment (Vishay Model 2100 System) were located inside the tractor cab.

Three-point Hitch Dynamometer

Implement loading was measured with a three-point hitch dynamometer, similar in function to dynamometers described by Scholtz (1966), Garner et al. (1980), and Barker et al. (1981). The dynamometer, shown in Figure 9, was patterned after a design described by Johnson and Voorhees (1979) with some modifications. Rectangular metal tubing was incorporated into the design instead of welded channel iron and some dimensions were updated for this particular application (refer to review of literature for design description). In addition to the basic dynamometer, a sway drawbar was constructed from 2-inch x 4-inch rectangular tubing. The drawbar could be attached to the lower links of the dynamometer quick hitch to allow operation with towed implements. This dynamometer design was chosen for the versatility of dual load sensing and the ability to measure draft, vertical force, and



Figure 7. Slip ring attached to tractor axle with specially designed aluminum cup.



Figure 8. Slip ring support arm mounted on pillow block bearing and magnetic sensor base plate.

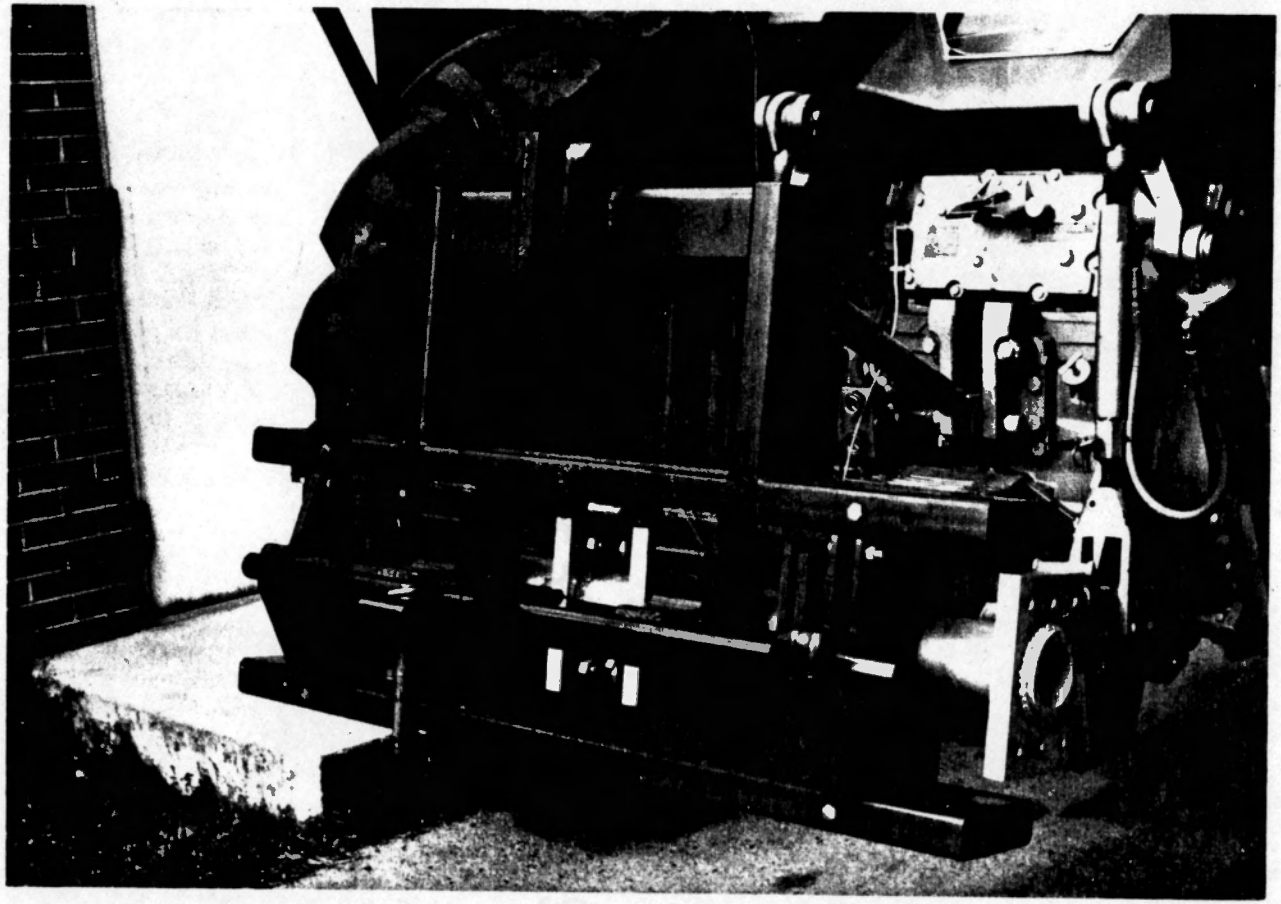


Figure 9. Three-point hitch drawbar dynamometer equipped with lower link swaybar.

torque simultaneously and independently. However, only the strain gauge bridge circuit that measured the horizontal component of force, or draft, associated with implement operation was installed on the sensing tube of the dynamometer. Strain gauges (Micro-Measurements EA-13-250BF-350) were mounted on the sensing tube using the same procedures as previously outlined in the axle torque sensing section. Gauges were connected in a wheatstone bridge circuit for draft sensing. The same power supply and signal conditioning equipment used with the axle gauges was employed with the dynamometer gauges.

III. DATA HANDLING EQUIPMENT

Microcomputer

The data handling system was centered around a Digital Equipment Corporation (DEC) PDP11/03-LK microcomputer equipped with 32K words of RAM memory. A BDV11 diagnostic, bootstrap terminator module was included as a standard feature on the microcomputer. This module provided bootstrap programs and diagnostic aids to help the user determine various operating conditions of the system. The module also contained 4K words of ROM designated specifically for DEC diagnostic aid and bootstrap programs. In addition, the module furnished user-available space for 2K words of EPROM and 16K words of ROM. An important feature of the module incorporated into the data handling system was the versatile application of this 18K of user-added memory. This ROM (or EPROM) could be accessed directly or loaded into RAM for later execution by the central processing unit (CPU). Also, the user could choose the location of program execution by altering specific jumper

configurations on the module. Specifically, when power was turned on, program execution could be initiated from the 4K words of diagnostic/ bootstrap ROM or directly from a user-added system ROM or EPROM. In this particular application an automatic bootstrap program developed specifically for the data handling system was stored on user-available system EPROM. When the system was turned on, this bootstrap initiated the bootup procedures between the microcomputer and associated peripheral devices. Other boards or modules installed in the backplane of the PDP11 microcomputer included a DEC DLV11-J four-port serial interface board, a DEC VK170 serial video module, and a Data Translation DT1761-SE-PG analog-to-digital converter (ADC) board equipped with 16 single-ended input channels and two digital-to-analog (D/A) output channels.

The microcomputer was installed in the tractor cab on a custom fabricated metal rack above the head of the operator. The rack was constructed from 1-inch x 2-inch rectangular tubing and bolted to the metal framework of the cab. Rack framework included a hinge assembly to allow easy installation and removal of the microcomputer. Padding installed on the rack frame along with the existing foam rubber of the cab ceiling provided a cushioned fit that damped vibration and shock loads to the microcomputer during field operation.

Microprocessor Counter Box for Digital Signals

Transistor-to-transistor logic (TTL) pulse signals were measured with a single-board microprocessor counter box developed specifically for this system. The microprocessor received and summed the digital pulse signals produced by the speed and fuel flow

transducers until processed by the PDP11 microcomputer. A Motorola 9600A single-board microprocessor and a 6840 programmable timer module were incorporated into the design of the microprocessor board. This board controlled a counter board with eight 16-bit channels. Seven of these 16-bit channels were designed to accept digital pulse input signals from transducers. However, only four of the channels were used to receive the digital pulse signals from the Fluidyne fuel transducer and the three magnetic speed transducers (fifth wheel and both rear axles). The eighth 16-bit channel was connected to the inverted binary coded decimal (BCD) output of three thumbwheel switches used to select test numbers to identify each set of collected data. Also included on the microprocessor box was a rotary switch to select a desired counting interval from 0.1 second to five minutes. A RS232 connector was used to interface the microprocessor counter box to the DLV11-J serial interface board of the PDP11 microcomputer. The microprocessor was installed in the forward right corner of the cab floor for easy operator accessibility.

Strain Gauge Conditioner and Amplifier

Strain gauge bridge circuits installed on the rear axles and drawbar dynamometer produce analog input signals to the PDP11 microcomputer. These bridge circuits were connected to a Vishay Model 2100 System strain gauge conditioner and amplifier. This unit provided supply voltages to the strain gauges and conditioned analog signals to input directly to the analog-to-digital converter board of the microcomputer. The strain gauge conditioner unit was mounted on the left side of the operator in a rack constructed from 1-inch angle iron.

The rack was bolted to the cab floor and was lined with rubber strips to provide some shock absorption during field operation.

System Program and Data Storage

A DEC TU58 cassette tape system incorporating dual tape drives was used for system program and data storage. Tape drives were designated as drive zero and drive one. Tape drive zero was used to store a comprehensive system program that controlled various data collection and system testing routines. Tape drive one was used exclusively for data storage in binary code. The TU58 cassette tape had a storage capacity of 480 blocks comprised of four 120-block tracks. The tape drive system was interfaced with the DLV11-J serial interface board in the microcomputer. The tape drive system was wired to transmit and receive at a 19.2K baud rate, although other speeds were possible by different wire wrap configurations. Twelve-volt and five-volt power to the tape drive system was supplied by the PDP11 microcomputer. The two tape drive unit was screw mounted to the tractor cab, just to the right rear of the operator for easy installation and removal.

Operator Control and Power Supply

Communication between the operator and the data acquisition system was through a DEC VK170 serial video module. The module consisted of a small 64-key keyboard and a DEC M7142 board which was installed in the backplane of the PDP11 microcomputer. With appropriate cables supplied by DEC, the module was interfaced with the DLV11-J serial interface board. A compact Electrohome V14 cathode ray tube (CRT) was connected to the board video port for external monitoring of

program and data display. Physical dimensions of the CRT allowed it to be placed on the right window ledge of the tractor cab adjacent to the operator for ease of reading. The keyboard was placed in the lap of the operator during field use and was stored conveniently on the instrument console of the tractor when not in use.

A Black and Decker Model 3625 AC portable gasoline generator (2.5 kW), was used to supply 120-V power to the sensing and data handling equipment on the tractor (excluding the fuel transducer and display, which were powered directly from the 12-V electrical system of the tractor). The generator was equipped with two 3-prong receptacles and an automatic idle control. A metal rack was constructed to mount the generator to the suitcase weights on the front of the tractor, as shown in Figure 10. Generator fuel tank capacity allowed approximately two hours of continuous data collection. The complete system including sensing transducers and the data handling equipment is shown schematically in Figure 11.

IV. SOFTWARE PACKAGE

A comprehensive software package was developed specifically for the data acquisition system. The program was written primarily in MACRO assembly language. However, the main program and some subroutines were written in Fortran. A modular format consisting of a three-line main program and numerous subroutines and general purpose miniroutines enhanced the versatility and simplicity of program operation. The main program allowed the operator to select any one of the many functions available by entering a two-character code. The program



Figure 10. Portable gasoline generator mounted on tractor suitcase weights with removable metal rack.

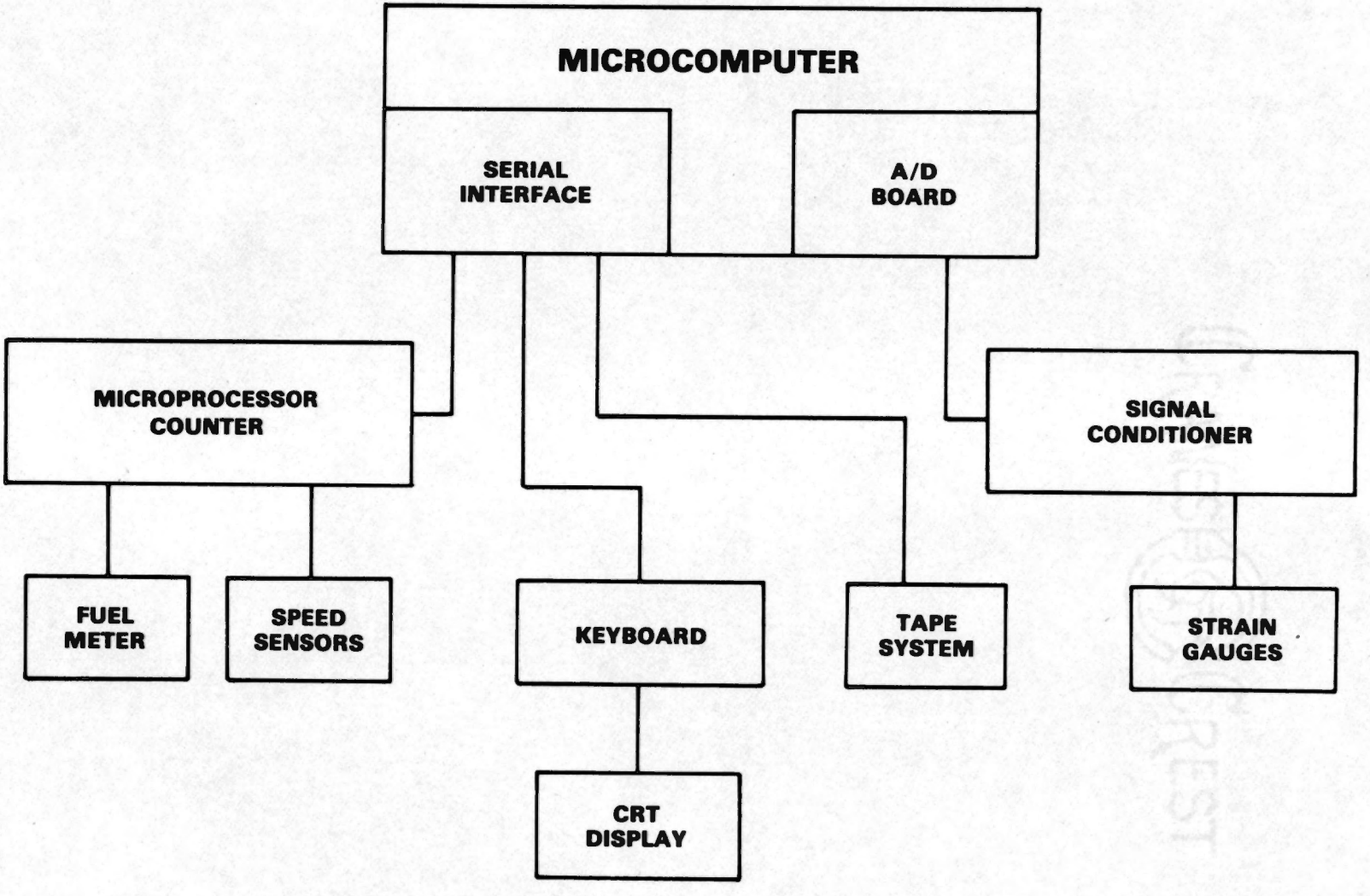


Figure 11. Block diagram of the microcomputer-based data acquisition system installed on the tractor.

required 22K bytes of space which included 1.5K bytes of buffer used for data storage until recorded on TU58 tapes (Wilhelm et al., 1981).

Program execution was initiated by switching on the PDP11 microcomputer. Two EPROM chips installed on the BDV11 diagnostic bootstrap terminator board allowed the system to automatically boot up from drive zero of the TU58 drive unit, which stored the source program. The first step of the program involved the execution of the main or option template subroutine. This subroutine was the entry point for the macro program and subsequently called the powerup subroutine. The powerup routine, in turn, called other routines such as TULKUP, JNLOAD, and ENGIN. These combined routines opened appropriate input/output channels to various boards and peripheral devices, loaded the instruction program into the microprocessor counter box, located the first empty block on the TU58 data tape, set up extra queue-elements, and accessed calibration factors to be used in calculations. At the completion of the power-up procedure, the option template routine displayed a selection table that listed all functions available to the operator. Routine functions were selected by typing an appropriate two-character code followed by a carriage return. (Refer to Table 1 for a listing and brief functional description of the selection codes available.) The system automatically returned to a selection mode, which displayed the three line main program for option selection, along with the function table at the completion of a given operation (with the exception of QUIT, which terminated program execution and closed open channels). Functions or operations developed within this software package could be divided into four major categories:

Table 1

Selection Code Listing and Description of Routine Options Available on the Data Acquisition System

Selection Code	Routine	Description
NS	NOSLIP	Calibrates ground distance and speed measurement sensors
CL	CALLAX	Calibrates left axle torque sensor
CR	CALRAX	Calibrates right axle torque sensor
DR	CALDYN	Calibrates drawbar dynamometer draft sensor
CF	CALFAC	Lists the current calibration factors stored in the source program on the CRT
DT	DATA	Displays data in engineering units on CRT and records raw data on TU58 tape
CN	CONTIN	Displays data in engineering units on CRT without storing on TU58 tape
IN	INITTU	Initializes TU58 data tapes
RP	REPLAY	Displays the last data test in engineering units on the CRT
IW	IMPWID	Allows implement width to be entered from the keyboard
QU	QUIT	Performs termination procedures for exiting the source program
RD	RANDRD	Displays data for any selected block of a TU58 tape
RL	ATOOCT	Converts real numbers to octal numbers
AT	ADTEST	Reads and displays readings from specified A/D channels at one-second intervals
AD	DT1761	Internally checks the A/D board using a backloop through the D/A channels to the A/D channels
JN	JNLOAD	Loads the counter program from the source program to the microprocessor counter box
JT	JNTEST	Displays output from the microprocessor counter box on the CRT
AP	APATCH	Stores calibration factors and permits software editing
DE	DMPENG	Allows recorded data to be printed in engineering units from the TU58 tape
DM	DMPRAW	Allows recorded data to be printed in raw form from the TU58 tape

Calibration and Testing, Data Acquisition, Data Examination, and Support Routines (Wilhelm et al., 1981).

Calibration and Testing Routines

Calibration and Testing routines were incorporated into the software package to make the complete system as versatile and reliable as possible. These routines provided a means to check, and if necessary recalibrate analog and digital signal output of the sensing transducers. Specific routines for calibration of transducers included the following: NOSLIP, CALDYN, CALLAX, and CALRAX.

The routine NOSLIP was used to calibrate the distance counters (magnetic sensors and split gears) on the fifth wheel assembly and the rear axles of the tractor. Distance calibration involved driving the tractor over a predetermined 100-ft course. The procedure for distance calibration was as follows: the NOSLIP routine was accessed by the operator by typing the appropriate two-character code from the option table. Once the system acknowledged, the tractor was brought into position for operation over the course. To initiate the calibration procedure, a carriage return on the keyboard was hit at the starting point of the course. While operating the tractor through the course, the program counted the pulse signals from each of the three sensors. Another carriage return was hit upon completion of the course to end the calibration routine. Immediately following the carriage return the total number of counts and the theoretical counts (based upon effective tire circumference), for each sensor were displayed on the video monitor to the operator. A decision was then made to either accept or reject the collected calibration factors. Upon acceptance the new

calibration factors were automatically patched (APATCH) to be stored as a calibration table for use in data acquisition computations. However, if rejected the system allowed the operator to exit the routine and default to the calibration factors stored previously in the calibration table.

The routine CALDYN was used to calibrate the output from the sensing elements on the drawbar dynamometer. The procedure consisted of developing a calibration curve by comparing the outputs of a laboratory calibrated tensile transducer and the dynamometer when loaded in series. A double-acting hydraulic cylinder anchored to a stationary structure provided the means for loading the sensors. Signals from the transducer and the dynamometer were connected to the microcomputer through the Vishay signal conditioning unit. Once the loading assembly was connected in-line with the dynamometer and tensile transducer, all operating functions were performed from the cab of the tractor. Actual calibration consisted of loading the dynamometer by retracting the hydraulic cylinder until the tensile transducer indicated a maximum load of 8000 lbs force. Once that load was reached, the gain on the signal conditioner was adjusted to produce a maximum signal of 8V for the dynamometer sensor. The load was then released at a slow uniform rate over a period of 10 to 15 seconds. While releasing the load, the calibration routine read and stored 16 signals from both the dynamometer and the transducer. These values were used to determine a calibration curve (refer to Figure 12). The first values were read at the maximum calibration load of 8000 lbs force, which was 80 percent of the maximum design load of the drawbar

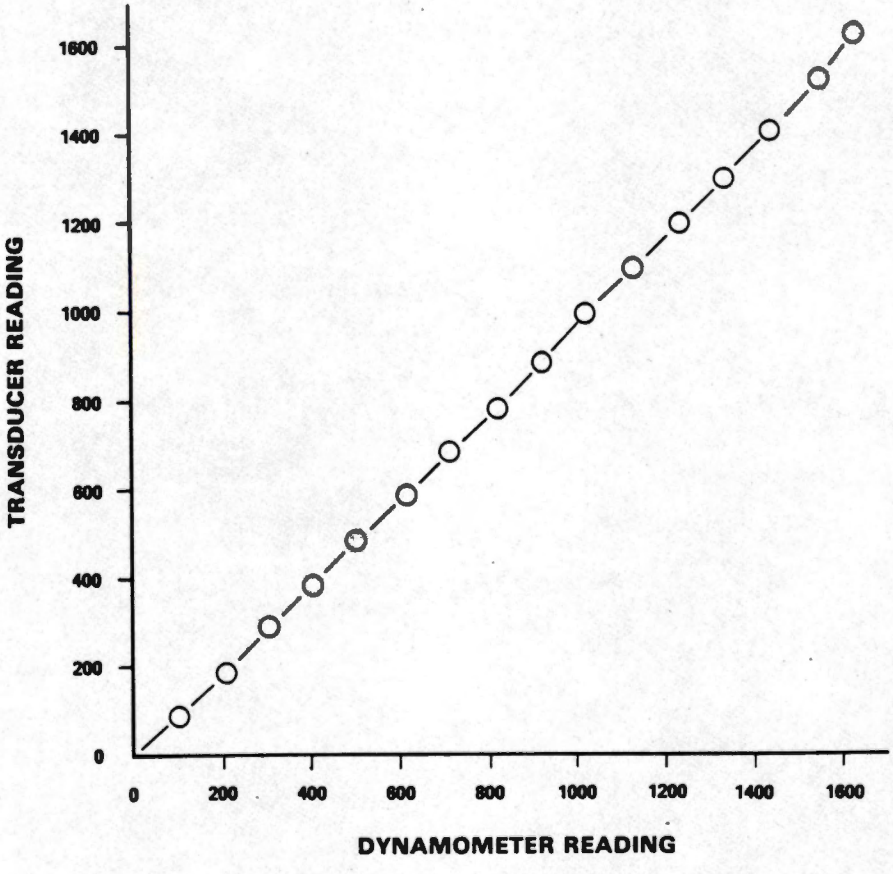


Figure 12. Typical drawbar dynamometer calibration curve plotted from recorded calibration factors. Numbers represent unconverted output values read from the 12-bit A/D board.

dynamometer. Additional values were read at 5 percent intervals (80, 75, 70, etc.) until the 16 points were obtained. Throughout the calibration routine all values for the sensors were displayed to the operator as they were read. After all points were collected, the operator had the option of accepting or rejecting the calibration values. As in the NOSLIP calibration routine, if accepted, the new calibration factors were automatically saved and patched (APATCH) into the program as the new calibration table. If rejected, calibration values stored previously were retained and the calibration routine ended. During data acquisition routines, a linear interpolation subroutine was used to automatically determine dynamometer force readings from the calibration table.

The routines CALLAX and CALRAX were used to calibrate the torque sensors on the left and right rear axles of the tractor. Calibrations for the axle torques were accomplished in the same manner discussed previously in calibrating the dynamometer. However, each axle was calibrated separately. Thus, when the transducer was loaded, the calibration routines divided the force reading of the transducer by a factor of two (theoretically, the load was distributed equally on each axle). Also, since the torque was measured as ft-lbs, the distance from the center of the axle to the ground was used as the lever arm. The transducer was loaded to a maximum load of 8000 lbs force which produced approximately 10,700 ft-lbs of torque on each axle. Gain on the axle sensor was then adjusted to produce a maximum signal of 8V. Once the gain and the maximum load were obtained, the load was released at a slow uniform rate over a period of 10 to 15

seconds. As with the dynamometer, 16 values were automatically read and stored from each of the sensors to determine the calibration curve for the axle being calibrated. As mentioned earlier, calibration values could be accepted or rejected and calibration routines could be repeated as often as thought necessary. Torque readings from axles during data acquisition routines were obtained by using a linear interpolation of the calibration table.

In addition to the four calibration routines, various testing routines were incorporated into the software package to check the output of specific components of the system. Some of these test routines were ADTEST, DT1761, and JNTEST. The routines ADTEST and DT1761 were used to test the outputs from the A/D board. ADTEST read and displayed the raw readings from the four A/D channels connected to the left axle sensor, right axle sensor, dynamometer sensor, and tensile transducer. These values were displayed and updated approximately every one second. The routine DT1761 was an internal check of the A/D board. An octal value was input on one of the two D/A channels and was systematically reproduced on the 16 single-ended A/D channels in the same octal form. This particular routine was only used in the developing stages of the system software package. JNTEST was a routine which displayed the raw pulse counts from the eight counter channels (only four contained digital signals) on the microprocessor counter box. Signals from the test routine were also displayed to the operator and updated at one-second intervals.

Data Acquisition Routines

Data acquisition was accomplished with two routines, DATA and CONTIN. DATA was the routine used exclusively in the data collection and storage process. This routine read the raw values from the sensing transducers, displayed collected information in engineering units on the video monitor, and recorded the data on the TU58 tapes in binary form. The routine CONTIN performed the same functions as DATA with the exception of recording data on tape. CONTIN was used primarily to review the data acquisition procedure before storing any data on tape. Therefore, only the routine DATA will be discussed. Execution of the DATA routine required a minimum of input from the operator. To initiate the data acquisition procedure, the appropriate two-character code was entered from the keyboard. Once acknowledged by the system the following procedure was required for data collection. The desired scanning interval and test number were selected on the microprocessor counter box by positioning the rotary switch and three thumbwheel switches. Data collection was then started by entering a carriage return from the keyboard. The collection routine continued to scan until a second carriage return was entered. At that time the test number was manually updated and the data collection routine continued with additional carriage returns to start and stop each test. To exit the DATA routine the character "Q" was entered from the keyboard during a data collection sequence. Upon completion of that test run the system automatically stopped and returned to the option template routine awaiting additional instructions from the operator. During data acquisition, the routine DATA read sensor inputs at the selected

scanning rate. These readings were converted, using various subroutines, to engineering units for display on the video monitor. At the same time the raw readings were recorded in binary form on the TU58 data tape. Storage in binary form permitted more efficient use of the tape system and allowed higher acquisition rates. The writing procedure allowed data to be written to adjacent blocks on the four tape tracks, rather than filling each track consecutively. This procedure eliminated the anticipated loss of time for tape rewinding and reduced the possibility of losing data. Each tape block had the capacity to hold data for approximately 21 scans (i.e., 21 seconds of recording at a one-second scan interval). Total storage capacity for tapes depended on the length of data tests. If a test consisted of continuous recording, each tape could hold approximately 2.8 hours of data. However, if short tests were used, considerably less storage space was available because only whole blocks were allocated for each test. In addition to recording the raw data on the tapes, the routine also recorded the calibration factors in the first block of each data set.

Engineering units for the raw data were displayed on the video monitor during either data acquisition routine. The monitor continuously displayed a template (Figure 13) comprised of variables computed using the raw data. The template used a no-scroll procedure which allowed each variable to be positioned at an assigned line location. During data acquisition, computed values were updated as often as new data values were collected (one-second scan interval). The computed values provided a means for the operator to determine the

RIGHT AXLE SPEED	(MPH)	XX.XX	DTB
LEFT AXLE SPEED	(MPH)	XX.XX	TID
FIFTH WHEEL SPEED	(MPH)	XX.XX	
LEFT WHEEL SLIP	(%)	XX.XX	
RIGHT WHEEL SLIP	(%)	XX.XX	
FUEL TEMPERATURE	(°C)	XX.XX	
FUEL CONSUMPTION	(GPH)	X.XX	
DRAFT	(LBS)	XXXX.XX	
RIGHT AXLE TORQUE	(FT-LBS)	XXXX.XX	
LEFT AXLE TORQUE	(FT-LBS)	XXXX.XX	
ACRES PER HOUR		X.XX	
GALLONS PER ACRE		X.XX	
HORSEPOWER THROUGH AXLES		XXX.XX	

Figure 13. Template of monitored parameters displayed on the CRT screen during data acquisition routines. Values represented by XX's indicate converted engineering units which are updated according to the data sampling interval. The values DTB and TID indicate the current data tape block and test identification numbers.

reliability of collected data from sensing transducers and to insure that all transducers and data handling equipment were functioning properly.

Several equations were used to analytically calculate the values displayed on the monitor screen. The speed parameters (right drive wheel speed, left drive wheel speed, and fifth wheel speed) were computed using variations of the equation expressed as:

$$V = KND \tag{3.1}$$

where

V = linear velocity in miles per hour,

K = constant for unit conversion,

N = raw counts from the appropriate speed indicator (cnts/sec), and

D = calibration factor which related distance traveled to gear teeth counted (ft/cnt).

Drive wheel slip was determined from the calculated speeds of the rear axles and the fifth wheel. The equation used to express drive wheel slip was of the following form:

$$SL = \frac{R - F}{R} \times 100 \tag{3.2}$$

where

SL = drive wheel slip expressed as a percentage,

R = linear velocity of the designated rear drive wheel in miles per hour, and

F = linear velocity of the fifth wheel in miles per hour.

Fuel consumption was determined directly from the pulse signals produced by the fuel transducer. The following equation was used to convert transducer counts to the consumption rate expressed as a volume per unit time:

$$Q = TCK_1 \tag{3.3}$$

where

Q = fuel consumption rate in gallons per hour,

T = pulse counts produced by the fuel transducer (cnts/sec),

C = conversion factor relating transducer counts to cc of fuel flow (cc/100 cnts), and

K_1 = constant for unit conversion.

Theoretical field capacity was determined from the actual speed of operation (as computed from measurements obtained from the fifth wheel) and the effective implement width as follows:

$$C_T = \frac{S \times W}{K_2} \tag{3.4}$$

where

C_T = theoretical field capacity expressed as acres per hour,

S = computed travel speed measured by the fifth wheel in miles per hour,

W = effective width of the implement expressed in feet, and

K_2 = constant for unit conversion

Fuel consumption per unit area processed was a function of the computed fuel consumption per hour and the theoretical field capacity. The equation used to relate these variables was as follows:

$$GA = Q/C_T \qquad (3.5)$$

where

GA = fuel consumption per unit area processed in gallons per acre,

Q = computed fuel consumption rate in gallons per hour, and

C_T = computed theoretical field capacity expressed as acres per hour.

Axle horsepower was derived from the rotational speeds of the axle and the measured torque of axle sensors. The equation used to compute axle horsepower was of the form:

$$HP = ((RT \times RC) + (LT \times LC)) \times CF \qquad (3.6)$$

where

HP = horsepower transmission through the axles of the tractor,

RT = measured torque from the right axle sensor expressed as ft-lbs,

RC = raw counts from the right axle speed indicator (cnts/sec),

LT = measured torque from the left axle sensor expressed as ft-lbs,

LC = raw counts from the left axle speed indicator (cnts/sec), and

CF = conversion factor which related torque and angular velocity to horsepower.

The remaining variables displayed on the video monitor included draft, right axle torque, and left axle torque. Analog signals used to measure these variables were conditioned and digitized. The digital outputs were routed through a linear interpolation routine and converted to force and torque readings for monitor display.

Data Examination Routines

Four data examination routines were provided to allow the operator to review recorded data in two forms. Both raw data and data converted to engineering units could be displayed on the video monitor or printed to provide hard copy. These routines included RANDRD REPLAY, DMPRAW, AND DMPENG.

The routines RANDRD and REPLAY displayed recorded data on the video monitor. RANDRD permitted the operator to review raw data from any specified tape block by entering the desired block number from the keyboard. The routine REPLAY allowed data from the last test run to be displayed in engineering units. This routine presented the data in the same template form displayed on the monitor during data acquisition routines. REPLAY permitted the operator to systematically step through the data set (pausing at each scan) by entering carriage returns from the keyboard. The routine automatically returned to the option template selection routine after displaying the last data scan or could be terminated by entering the character "Q" followed by a carriage return.

The routines DMPRAW and DMPENG allowed recorded data to be printed as either raw or engineering unit form. As with the routine RANDRD, data printout could be initiated at any specified tape block. However, to use these routines, a line printer was required in addition to the regular data handling equipment.

Support Routines

Many support routines were included to make the comprehensive software package complete. These routines performed many functions indirectly associated with the data acquisition process. Some of these routines were INITTU, APATCH, IMPWID, and QUIT.

INITTU performed an initialization procedure to new TU58 data tapes. This procedure encompassed filling all data tape blocks with zeros. This routine was required to establish the correct format for recording data in binary code.

APATCH automatically stored calibration factors in the main program during the four calibration routines. This routine also permitted the operator to edit software while in the field.

IMPWID permitted the operator to input different implement widths from the keyboard. These values were used throughout the program in calculating variables such as theoretical field capacity and fuel consumption per acre.

The final routine (QUIT) was used by the operator to terminate program execution. This routine closed all opened input/output channels to peripheral devices, located the last block written on the data tape, and initiated steps to exit the program to the monitor mode.

In addition to the routines displayed on the option template (Table 1, page 52), several minisubroutines were incorporated throughout the program. The minisubroutines (Table 2) shortened the source program and enhanced the overall performance of the main program by performing specific functions associated with the routines discussed previously.

Table 2

Miniroutines Used Throughout the Source Program to Perform Specific Routine Functions

Routine	Description
CLRBUF	Clears input buffer
ENGIN	Calculates engineering units for data using conversion factors
HOLD	Awaits input and carriage return from terminal before proceeding with operation.
SLOW	Performs a delay of approximately 0.5 second
STUFF	Stores data in buffer
TIMWT	Waits for a specified timing interval
TTINR	Inputs control character from terminal if present
TUMAP	Identifies number of next free TU58 tape block
UNSTUF	Transfers data from buffer to memory
VTCLR	Clears the CRT display screen
VTPOS	Position curser on CRT display screen

CHAPTER IV

INSTRUMENTATION FIELD TESTS AND SYSTEM MODIFICATION

I. FIELD TESTS

Preliminary field tests of the instrumentation package were conducted during September 1980 at the Milan Experiment Station in West Tennessee. Tests provided a means to evaluate the overall ability of the system to collect reliable data and determine the capability of electronic components to function properly in harsh field conditions. The instrumented tractor was used to monitor the energy inputs to five tillage implements. (Refer to Table 3 for a detailed description of implements.) Implements were operated at various speeds to simulate a range of cultural practices associated with seedbed preparation.

Plot Description

Tests were conducted in a level field comprised of Memphis silt loam soil. A conventionally grown corn crop had recently been harvested from the field. Residue from the corn crop had been cut with a rotary mower, leaving a firm surface free of vegetative cover with some scattered stalk residue. The field was divided into two 200-ft length plots with approximately 50-ft between plots. Soil moisture content of the test area averaged between 7 and 8 percent, which was below the level for optimum tillage conditions.

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Table 3

Description of Tillage Implements Operated by the Instrumented Tractor During Preliminary Field Tests at the Milan Experiment Station

Implement	Effective Width (ft)	Description
Chisel plow	9.0	9 shanks equipped with 2-inch chisel points 3-point hitch mounted
Heavy tandem disk harrow	14.0	22-inch notched disk blades in front gang 22-inch smooth disk blades in rear gang 10-inch disk blade spacing
Light tandem disk harrow	12.0	20-inch notched disk blades in front gang 20-inch smooth disk blades in rear gang 7-inch disk blade spacing
Soil pulverizer	13.0	19 field cultivator tines plus rotary clod pulverizer plus spike-tooth harrow section
Subsoiler	6.7	2 curved plow standards spaced 40 inches apart 1.5-inch flat plate cutting point 3-point hitch mounted

Test Procedure

The data acquisition system was calibrated before data collection was initiated using the procedures outlined previously. A data acquisition test consisted of operating an implement with the instrumented tractor over a 200-ft plot as shown in Figure 14. The various energy-related inputs discussed earlier were monitored and recorded with the instrumentation package. The tillage implements were operated on the 200-ft plots in the following order: chisel plow, heavy tandem disk harrow, light tandem disk harrow, soil pulverizer, and subsoiler. The chisel plow was operated at a depth of approximately eight inches and the subsoiler was operated at a depth range of 12 to 14 inches. The remaining implements (two tandem disk harrows and the soil pulverizer) were operated as deep as the implements would penetrate the hard, cloddy soil.

Each implement, except the subsoiler, was operated through the 200-ft plots at three predetermined no-load speeds. The subsoiler was only operated at two speeds due to the extremely hard soil conditions. An operating speed was established by selecting an appropriate gear setting and maintaining an engine speed of 1800 rpm regardless of implement load. Tests for each implement-speed combination were replicated three times in each 200-ft plot.

Field Test Results

Chisel plow operation produced an extremely rough, irregular surface comprised of large clods. This type of soil fragmentation was attributed to the low moisture content of the soil. Additional trips with the tandem disk harrows and the soil pulverizer only resulted in



Figure 14. Instrumented tractor operating a 9-ft chisel plow through a measured 200-ft test plot in energy study.

partial size reduction of the large soil fragments. After completion of the tillage tests, a desirable seedbed still had not been obtained. Therefore, one could expect that the energy measurements taken did not typify normal tillage conditions.

Specific energy parameters observed from the field test data included travel speed, drawbar pull, drawbar horsepower, drive wheel travel reduction, fuel consumption per hour, and fuel consumption per acre. These values were analytically computed from the data recorded during field tests as follows.

Travel speed was computed based upon the time required to traverse a 200-ft plot with the operating implement. Time was determined by counting the number of data scans (one-second sampling intervals) plus any fractional portion of a scan period occurring at the end of the test run. Travel speed was derived in this manner, rather than averaging the speed indicated by the fifth wheel, due to irregular signals produced by magnetic sensors.

Drawbar pull was determined directly from the drawbar dynamometer readings. All one-second readings were averaged to obtain an overall representation for each test run.

Drawbar horsepower values were derived from the computed travel speed and the average drawbar pull for each test. This relationship was expressed as

$$DBHP = \frac{CS \times DF}{375} \qquad (4.1)$$

where

DBHP = drawbar horsepower,

CS = computed travel speed expressed in miles per hour, and

DF = average drawbar pull for a given test expressed in pounds of force.

Drive wheel travel reduction was computed with the data acquired by comparing fifth wheel speeds to rear drive wheel speeds. However, irregular counts from the magnetic sensors (speed indicators) resulted in inconsistent values. Therefore, travel reduction was subsequently derived by comparing the time required to travel across a 200-ft plot with the implement in the raised position (no-load) to that required to operate the functioning implement through the same plot (Collins et al., 1980).

Fuel consumption per hour was computed from the volume of fuel consumed while operating an implement through the 200-ft plots. The recorded fuel transducer counts were related to a volumetric consumption rate in the following expressions:

$$Q = \frac{TC \times C \times K_1}{TI} \qquad (4.2)$$

where

Q = fuel consumption rate in gallons per hour,

TC = total number of fuel transducer counts in a test,

TI = time in seconds required to traverse the 200-ft plot with the functioning implement,

C = conversion factor to relate fuel counts to a volumetric measure (1 cc/100 cnts), and

K_1 = constant for unit conversion.

Fuel consumption per acre was determined by relating the computed fuel consumption per hour to the theoretical field capacity of the functioning implement. This relationship was expressed by equation 3.5.

Tractor operating parameters and the computed energy inputs to each tillage implement are presented in Table 4 (Tompkins and Wilhelm, 1981b). These tabulated values are averages for the data acquisition tests performed on the two 200-ft plots at each operating speed.

The following trends were apparent from the summarized data shown in Table 4.

1. The drawbar pull or draft required to operate an implement consistently increased as the travel speed increased. Consider the draft requirement of the heavy tandem disk harrow as an example. As the speed of operation increased from 4.01 mph to 6.07 mph implement draft increased from 4650 lbs to 5090 lbs. However, these draft readings tended to be higher than the range given by Hunt (1977) for the Midwest Region. An explanation for these higher draft values was attributed to a combination of two things. First, the extremely low moisture content of the soil may have increased the amount of draft required to propel the tillage implements. Secondly, due to inadequate calibration equipment,

Table 4

Tractor-implement Operating Parameters and Computed Energy Requirements of Selected Tillage Implements from Preliminary Field Tests

Implement[a]	Gear Setting	Ground Speed (mph)	Drawbar Pull (lbs)	Drawbar Power (dbhp)	Travel Reduction (%)	Fuel Consumption	
						Gal/hour	Gal/Acre[b]
Chisel plow	3L	1.86	6780	33.6	15.8	3.60	1.78
	4L	2.60	6820	47.2	17.2	4.40	1.56
	5L	2.99	7010	55.9	19.5	5.03	1.54
Heavy tandem disk harrow	4I	4.01	4650	49.8	2.0	4.20	0.618
	5I	4.55	4980	60.4	4.7	4.87	0.631
	6I	6.07	5090	82.4	7.6	6.25	0.607
Light tandem disk harrow	4I	4.10	3240	35.4	1.0	3.33	0.558
	5I	4.62	3600	44.4	3.1	3.79	0.564
	6I	6.30	3670	61.7	4.5	4.53	0.494
Soil pulverizer	4I	4.06	4500	48.7	4.0	4.07	0.636
	5I	4.62	4750	58.6	4.2	4.55	0.625
	6I	5.96	5160	82.0	11.4	5.81	0.621
Subsoiler	2L	1.30	6030	20.9	10.5	2.71	2.58
	3L	1.84	6450	31.6	13.6	3.39	2.29

[a]Refer to Table 3, page 69, for a description of tillage implements.

[b]Computation based on theoretical field capacity of implements.

proper calibration of the drawbar dynamometer may not have been achieved.

2. Drive wheel travel reduction tended to increase as the speed of operation increased. This increase in travel reduction was attributed to the higher drafts associated with operating the implements at faster ground speeds. To illustrate this point consider the data for the light tandem disk harrow. As travel speed increased from 4.10 mph to 6.30 mph the drive wheel travel reduction increased from approximately 1.0 percent to 4.5 percent, corresponding to a 430 lb increase in implement draft.
3. Drawbar horsepower required to propel the tillage implement consistently increased as the speed of operation increased. This increase in drawbar horsepower was a function of both the increased speed and the increase in draft associated with higher operating speeds. However, it should be noted that the drawbar horsepower values for the heavy tandem disk harrow (82.4) and the soil pulverizer (82.0) were approaching the maximum drawbar horsepower (87.47) of the tractor as reported in Nebraska Tractor Test No. 1309 (Implement and Tractor 1982). This further substantiates the possibility of error in draft values read due to inaccurate calibration of the dynamometer.
4. Fuel consumption per hour with a given implement tended to increase with increases in drawbar horsepower required to operate the implement at higher travel speeds. Consider the

heavy tandem disk harrow as an example. Fuel consumption increased approximately two gallons per hour as the drawbar horsepower requirement increased from 49.8 hp to 82.4 hp.

5. The amount of fuel required to till an acre of ground tended to decrease slightly as the speed of operation increased. For example, increasing the operating speed of the chisel plow from 1.86 mph to 2.99 mph reduced the fuel requirement from 1.78 gpa to 1.54 gpa. A total fuel reduction of 0.24 gallons per acre.

System Performance

Overall the data acquisition system performed as expected during the two weeks of preliminary testing. The electronic hardware components of the system functioned satisfactorily throughout the extremely hot and dusty conditions encounted during field operation. However, some disadvantages associated with the system were discovered and a few malfunctions developed with some of the hardware sensing equipment.

The major disadvantage associated with operating the data acquisition system was using the TU58 tape system as a system device for booting the PDP11 microcomputer and loading the system program. This procedure proved to be very reliable; but the process was extremely slow. System bootup required approximately five minutes, plus an additional four to five minutes were required for loading and executing the system program. Although this system was very time consuming, there were not problems due to the tape unit after the system was booted and operating.

A second disadvantage of the system dealt with the microprocessor counter box. The microprocessor box functioned correctly; however, the manual selection of test numbers added considerably to the workload of the operator. Also the space required by the operator for manipulating the brake pedals was reduced substantially by the physical dimensions and bulky wire connection of the counter box.

The magnetic sensors used to indicate speed and travel distance proved to be a major trouble area with the data acquisition system. Inconsistent pulse signals from the sensors were detected frequently throughout field operation. The signals were fairly uniform during the initial field tests, but tended to become more sporadic as data acquisition tests progressed. These sporadic signals were attributed to resident vibrations associated with the tractor operation and underdesigned magnetic sensors. Upon conpletion of the field tests, the magnetic sensors had partially or completely lost their magnetism.

Finally, parameters measured with the fifth wheel assembly (travel speed and travel distance) were also inconsistent and unreliable. Inconsistency in these values were from a combination of two things: first, as mentioned earlier, irregular signals produced by the magnetic sensors resulted in the transmission of inaccurate information to the data handling equipment. Secondly, excessive wheel slippage and bouncing of the flotation tire was observed frequently during field operation. This nonuniform ground contact was due to the light weight of the fifth wheel assembly and the extremely rough surface conditions encountered in the test area.

II. SYSTEM MODIFICATIONS

Several components of the data acquisition system were modified or replaced after the preliminary field test. Specifically, alterations were performed on the following components:

1. Microprocessor counter box;
2. Slip ring support arms;
3. Fifth wheel assmbly;
4. Magnetic sensors;
5. Fuel meter;
6. Calibration equipment;
7. Panel meters.

Microprocessor Counter Box

Modifications of the microprocessor counter box involved completely replacing the unit. The microprocessor was used to accept, sum, and transmit all digital pulse signals from transducers to the PDP11 microcomputer. In addition to summing digital signals, the microprocessor was used to manually select data sampling intervals and data test identification numbers. The microprocessor unit was abandoned due to the construction of a DEC interface foundation module board (DRV11-P) which inserted into the cardslots of the PDP11 microcomputer. The board was developed to accept and sum digital pulse signals until read and cleared by the PDP11 microcomputer. Also, the board included a software-programmable clock for selecting data sampling intervals. The board was designed to handle eight 16-bit channels. Five channels were equipped with up/down counters for transducers, such as the fuel

transducer, which required bi-incremental sensors (number and direction count). Another channel was used by the software-programmable clock, which allowed a data sampling range between 0.01 second and 4.5 minutes. The programmable clock allowed time to be measured to the nearest 1/120 second after the last data sampling interval of a data collection test. Two channels without up/down counters were left open for additional digital transducers.

Installation of the DRV11-P module board changed the methods used to select data test identification numbers and the data sampling interval. System software changes allowed the data collection routine (DATA) to automatically assign and increment test identification numbers. Provisions were also made to allow the operator to change test identification numbers from the keyboard. In addition to test numbers, the system allowed the data sampling interval to be software controlled. Additional software routines were developed and incorporated in the main option selection template to allow the operator to check output from the counter board module. Specific routines included CNTTST and TIMTST. The routine CNTTST replaced the routine JNTEST which tested the microprocessor box. CNTTST was used to perform basically the same function as JNTEST by displaying raw counts from digital output transducers on the CRT unit at the rate of data sampling. The routine TIMTST was used to display a signal on the CRT unit to provide a visual check of the programmable clock used to select data sampling intervals. Installing the DRV11-P module board improved the overall reliability and efficiency of the data acquisition system and increased the amount

of space available in the tractor cab by eliminating the microprocessor counter box and associated wiring.

Slip Ring Support Arms

The slip ring support arms secured the slip rings and housed the cable connecting the slip rings to the data handling equipment. Support arms were attached to the pillow block bearings and the metal plates that positioned the magnetic sensors above the split gears (refer to Figure 8, page 42). Attachment to the metal plates proved inappropriate as axle deflections were transmitted through the support arms causing bending of the plates. This bending altered the vertical position of the plates and changed the clearance between the magnetic sensors and the split gears used to measure drive wheel speed. Clearance between the magnetic sensors and split gears had to be maintained at 0.005 inch to obtain correct signal response. Therefore, movement of the plates was unacceptable. To correct the problem, the attachment points of the arms were relocated from the metal plates to points on the rear of the tractor cab as shown in Figure 15. Also additional bracing was installed to increase the rigidity of the arms.

Fifth Wheel Assembly

The fifth wheel required modifications in two areas. First, additional ballast was attached to the frame assembly to reduce the excessive bouncing and wheel slippage observed while operating on rough, irregular surfaces. This was accomplished by attaching two 1-foot sections of railroad rail to the wheel assembly frame and filling the pneumatic tire with fluid. These additions increased the



Figure 15. Rear view of the instrumented tractor showing relocated slip ring support arms attached to tractor cab.

normal force exerted by the wheel approximately 110 lbs. Secondly, the flanged bearings that held the axle of the fifth wheel proved to be inadequate. The bearings allowed excessive movement of the axle, which permitted the 72-tooth split gear to occasionally come into contact with the magnetic sensor. The excessive movement was corrected by the installation of a set of double roller flanged bearings. (Refer to Figure 16 for wheel modifications.)

Magnetic Sensors

Modification of the magnetic pickup included replacement of the old magnetic sensors. The loss of magnetism observed during the system testing was attributed to the hot, dusty environment encountered during field operation and underdesigned sensors. The problem was resolved with the purchase of new magnetic sensors from another manufacturer (DI-MAG Model 58426). The DI-MAG sensors were more compatible with the data acquisition system than the formerly used AIRPAX sensors. The DI-MAG sensors produced TTL digital pulse signals which were compatible with system counter inputs, eliminating the necessity of having the Schmitt trigger circuit developed to convert sine wave output from the AIRPAX sensors to digital pulse signals for the data handling equipment. Moreover, the DI-MAG sensors required an air gap clearance of 0.040 inch between the split gears, rather than the 0.005 inch gap recommended by the AIRPAX manufacturer. This allowed considerably more latitude in sensor adjustment and minimized the possibility of contact between the sensors and split gears.



Figure 16. Modified fifth wheel assembly equipped with ballast and double roller flanged bearings.

Fuel Meter

The fuel transducer required only slight modification. The transducer contained a small disc divided into equal pie-shaped transparent and opaque sections. This disc was attached to a shaft which connected to a small piston motor. As fuel flowed through the transducer, the motor rotated the shaft. A pair of optical encoders were used to monitor the direction and speed of the disc. During winter storage of the tractor the opaque sections were removed from the plastic disc for unknown reasons (possibly fuel vapors discolored the disc). Hence, the fuel transducer malfunctioned. The problem was corrected by replacing the plastic disc with a metal replacement disc obtained from the manufacturer. The metal disc contained pie-shaped slots for the encoders to monitor.

Calibration Equipment

A hydraulic cylinder and a tensile transducer were used to calibrate the axle torque sensors and the drawbar dynamometer. The concept worked satisfactorily, but the 10-inch stroke of the hydraulic cylinder was too short to provide the loading necessary for calibration procedures. A more precise method for releasing cylinder loads at a uniform rate was also required to allow the calibration routines to read transducer outputs correctly. To eliminate these problems a 36-inch stroke hydraulic cylinder and a flow control valve were acquired. The hydraulic cylinder and flow control valve permitted accurate transducer calibration with precision loading and unloading.

Panel Meters

The final modification made on the data acquisition system was the installation of panel meters for continuous display of selected monitored parameters. The panel meter unit consisted of two 0-10 vdc meters, three LED displays, and an audible alarm. The voltmeters were connected to the two D/A output channels of the A/D converter board. Software programs allowed any two monitored parameters to be displayed on the voltmeters using the 0-10v range as the full scale. Parameters available for display included: right drive wheel speed, left drive wheel speed, fifth wheel speed, fuel temperature, fuel consumption, implement draft, right axle torque, left axle torque, acres processed per hour, fuel requirement per acre, and axle horsepower. The routine PANELS was used to select desired parameters for display. Selection of parameters was accomplished by typing an appropriate three-character code followed by a carriage return (refer to Table 5 for a list of parameter codes). Parameters were displayed and updated continuously during both data acquisition routines CONTIN and DATA.

In addition to displaying parameters to the operator, the panel meter unit included a warning system. The three LED displays and audible alarm were used to indicate drawbar dynamometer overload, full TU58 data tapes, and malfunctions in the counter system. Other routines used with the panel meters included LIGHTS and CLHORN for testing/clearing LED displays and audible alarm.

A block diagram of the modified system including transducers and data handling equipment is shown in Figure 17. Also, an updated list of the options available to the operator, along with the two-character

Table 5

Three-character Codes Used to Select Monitored Parameters for Panel Meter Display

Selection Code	Description
RAS	Right drive wheel speed
LAS	Left drive wheel speed
FWS	Fifth wheel speed
RWS	Right drive wheel slip
LWS	Left drive wheel slip
APH	Acres processed per hour
RAT	Right drive axle torque
LAT	Left drive axle torque
HPW	Horsepower transmission through drive axles
DRF	Implement draft
FTM	Fuel temperature
FCN	Fuel consumption per hour
GPA	Fuel consumption per acre

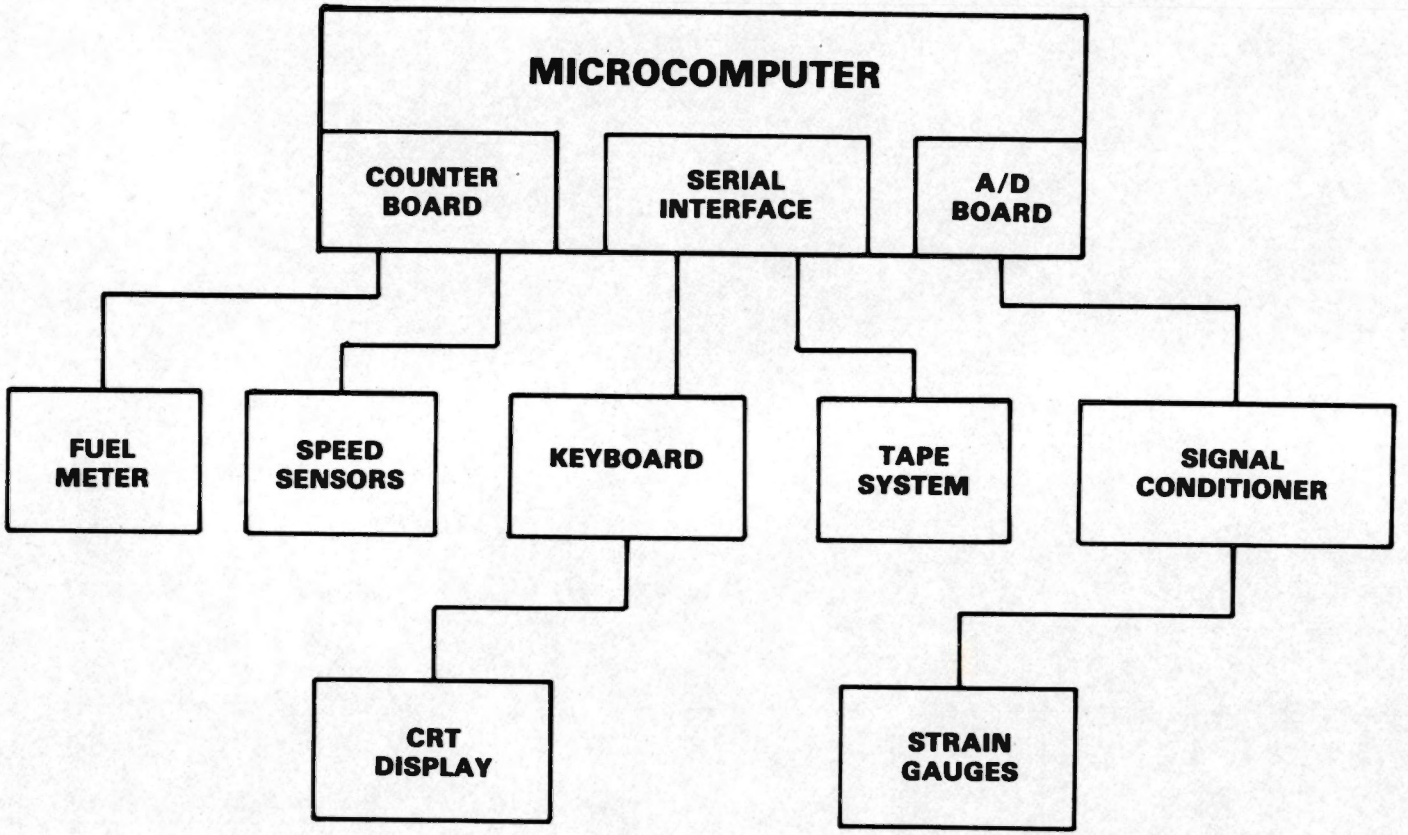


Figure 17. Block diagram of the revised microcomputer-based data acquisition system.

selection codes are listed in Table 6. The complete revised data acquisition system as mounted on the tractor is shown both schematically and pictorially in Figures 18 and 19.

Table 6

Revised Listing of Selection Codes and Option Routines Available on the Modified Data Acquisition System

Selection Code	Routine	Description
NS	NOSLIP	Calibrates ground distance and speed sensors
CL	CALLAX	Calibrates left axle torque sensor
CR	CALRAX	Calibrates right axle torque sensor
DR	CALDYN	Calibrates drawbar dynamometer draft sensor
DT	DATA	Displays data in engineering units on CRT and records raw data on TU58 tape
CF	CALFAC	Lists the current calibration factors stored in the source program on the CRT
CN	CONTIN	Displays data in engineering units on CRT without storing on TU58 tape
IN	INITTU	Initializes TU58 data tapes
RP	REPLAY	Displays the last data test in engineering units on the CRT
IW	IMPWID	Allows implement width to be entered from the keyboard
QU	QUIT	Performs termination procedures for exiting the source program
RD	RANDRD	Displays data for any selected block of a TU58 tape
RL	ATOOCT	Converts real numbers to octal numbers
AT	ADTEST	Reads and displays readings from specified A/D channels at one-second intervals
AD	DT1761	Internally checks the A/D board using a backloop through the D/A channels to the A/D channels
CT	CNTTST	Tests the counters by displaying raw counts from transducers at one-second intervals
TT	TIMTST	Tests the internal clock of timer circuit
PM	PANELS	Allows operator to select parameters for display on the two voltmeters
PT	PANTST	Tests the panel meters over the full scale
LT	LIGHTS	Tests and sets up warning lights and audible alarm on panel meters
HC	CLHORN	Turns off warning lights and alarm
AP	APATCH	Stores calibration factors and permits software editing
DE	DMPENG	Allows recorded data to be printed in engineering units from the TU58 tape
DM	DMPRAW	Allows recorded data to be printed in raw form from the TU58 tape

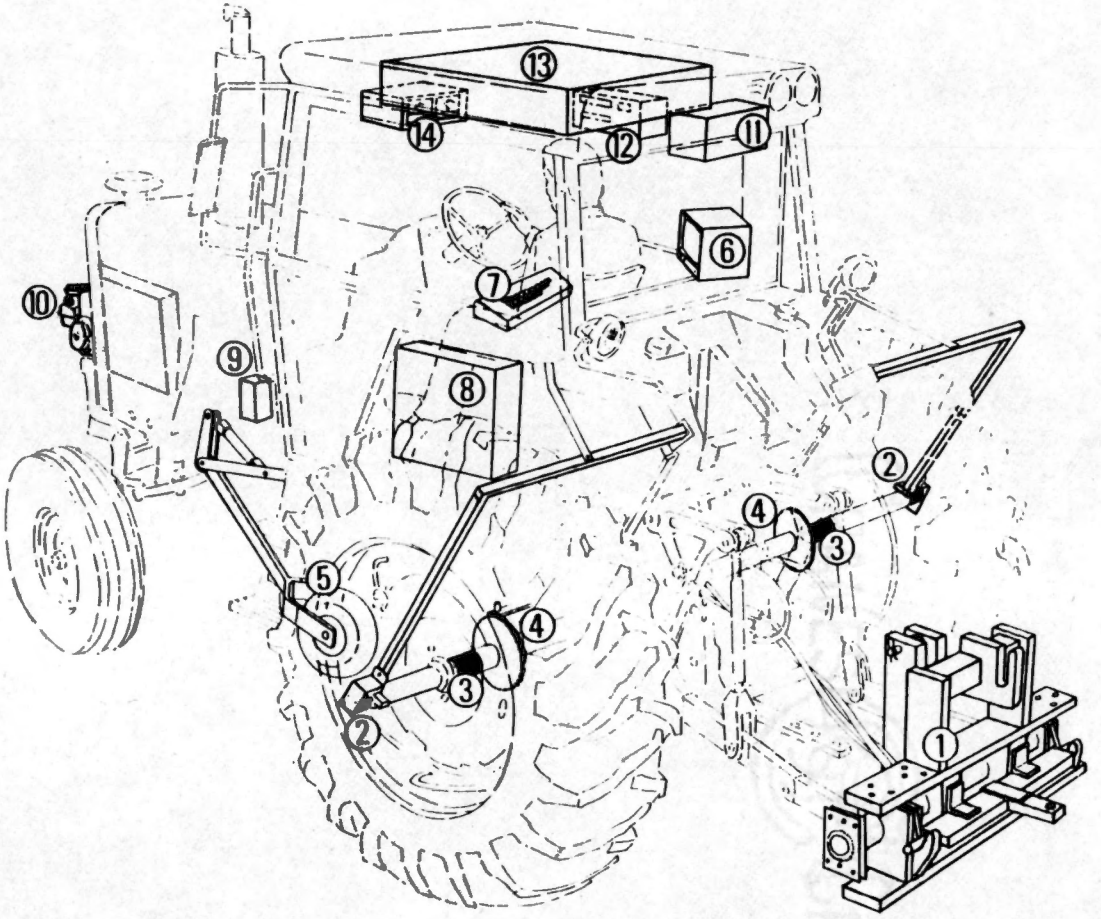


Figure 18. Schematic of the microcomputer-based data acquisition system mounted on the instrumented tractor. System components include (1) three-point hitch drawbar dynamometer, (2) slip ring, (3) strain gauge, (4) magnetic sensor and split gear, (5) fifth wheel assembly, (6) video monitor, (7) keyboard, (8) signal conditioner/ amplifier, (9) fuel transducer, (10) generator, (11) magnetic tape drives, (12) fuel meter display, (13) microcomputer, and (14) panel meter displays.



Figure 19. Instrumented tractor equipped with microcomputer-based data acquisition system for monitoring energy inputs to implements.

CHAPTER V

RESULTS AND DISCUSSION

I. PERFORMANCE OF SELECTED IMPLEMENTS

The modified data acquisition system on the instrumented tractor was used to monitor energy inputs to seven tillage and planting implements. Tests were conducted at the Milan Experiment Station in West Tennessee during July and August of 1981. Implements were operated with the instrumented tractor at various speeds to obtain a range of operating parameters similar to those used in current farming practices. The seven implements used in the energy study are described in Table 7.

Plot Description

Energy requirements of the implements were evaluated on one of two field locations. Soil moisture content in the test areas was of a value typical for tillage and planting operations. All of the implements listed in Table 7, with the exception of the no-till row-crop planter, were operated on a level field which initially had a firm soil surface with sparse vegetative cover. The field was divided into two 200-ft-length plots end-to-end with approximately 40-ft between plots and 60-ft turn strips at either end. The top soil in the test area contained mixed fill materials including a moderate amount of sand. This fill material overlaid Henry and Calloway silt loam soils.

The no-till row-crop planter was operated on a nearby level wheat stubble field divided lengthwise into three 200-ft plots with

Table 7

Description of Tillage and Planting Implements Operated by the Instrumented Tractor in Energy Study

Implement	Effective Width (ft)	Description
Chisel plow	9.0	9 shanks equipped with 2-inch chisel points 3-point hitch mounted
Heavy tandem disk harrow	14.0	22-inch notched disk blades in front gang 22-inch smooth disk blades in rear gang 10-inch disk-blade spacing
Light tandem disk harrow	12.0	20-inch notched disk blades in front gang 20-inch smooth disk blades in rear gang 7-inch disk blade spacing
Soil pulverizer	13.0	19 field cultivator tines plus rotary clod pulverizer plus spike-tooth harrow section
Cultimulcher	13.6	25 field cultivator tines plus 2 rows of rollers
Row-crop planter	13.3	4 rows equipped with 16-inch diameter ripple coulters plus 14-inch diameter double disk furrow opener plus 12-inch diameter double press wheels 3-point hitch mounted
No-till row-crop planter	13.3	8 rows equipped with 16-inch diameter straight coulters plus 18-inch diameter, 2-inch fluted coulters plus 12-inch diameter double disk furrow openers plus 18-inch diameter center rib press wheel trail type equipped with 1200 lbs ballast

approximately 60-ft aisleways between each plot. Soil in the wheat stubble field was comprised of Henry and Collins silt loams.

Data Collection

The collection of test data consisted of operating an implement with the instrumented tractor over a predetermined 200-ft plot. The various energy related parameters discussed in the previous chapter were monitored and recorded at one-second intervals with the instrumentation package. The tillage and planting implements were operated over the 200-ft plots to prepare a well-tilled seedbed and simulate row crop planting in the following order: chisel plow, heavy tandem disk harrow, light tandem disk harrow, soil pulverizer, cultimulcher, and row-crop planter. As mentioned earlier the no-till row-crop planter was operated over the undisturbed surface of a nearby wheat stubble field.

Due to the sequential operation of implements, the chisel plow and the no-till row-crop planter were the only implements operated on a firm untilled surface. The chisel plow was maintained at a plowing depth of approximately 8 to 10 inches. The two tandem disk harrows were allowed to run as deeply as they would penetrate to thoroughly till the soil surface. The soil pulverizer and cultimulcher were operated at depths which permitted the field cultivator tines to penetrate five to six inches so that a well-tilled, uniform seedbed would result.

Each implement, except the row-crop planter, was operated through the 200-ft plots at three predetermined no-load speeds. An operating speed was established by selecting the appropriate gear

setting and maintaining a constant engine speed of 2000 rpm regardless of implement loading. Tests for each implement speed range were replicated approximately 14 times, with the exception of the heavy tandem disk harrow which was replicated 30 times at each field speed. (The heavy tandem disk harrow was operated over the entire test area twice to produce uniform surface conditions for subsequent implements.)

Implement Performance Results

Specific energy-related parameters observed from the data recorded during field operation included travel speed, drawbar pull, drawbar power, drive wheel slip, implement energy input, fuel consumption per unit time, and fuel consumption per unit area processed. These parameters, with the exception of drive wheel slip and implement energy input, were analytically computed using methods similar to those described in the previous chapter. Drive wheel slip and implement energy input were determined as follows:

Drive wheel slip was continuously computed and displayed to the operator by the data acquisition system by comparing fifth wheel speeds to rear drive wheel speeds. However, the new magnetic sensors occasionally produced spurious counts due to resident tractor vibrations and unsatisfactory fifth wheel performance. These inconsistent signals from the speed indicators resulted in the transmission of inaccurate information to the data handling equipment. Therefore, drive wheel slip was subsequently determined by comparing the times required to transverse the 200-ft plots with the functioning implement to the time required to drive the instrumented tractor 200-ft on a hard nondeformable surface (asphalt road) as described by Collins et al. (1980).

Implement energy input per unit area tilled was determined by relating the computed drawbar horsepower required to propel the functioning implement to the theoretical field capacity of the implement at the measured travel speed. This relationship was expressed as follows:

$$EN = \frac{DBHP}{C_T} \qquad (5.1)$$

where

EN = energy input to a given implement expressed as drawbar horsepower-hours per acre,

DBHP = drawbar horsepower required to propel the functioning implement, and

C_T = theoretical field capacity of the implement expressed as acres per hour.

Tractor-implement operating parameters and the computed energy inputs required by each tillage and planting implement are presented in Table 8. These tabulated values are averages of the numerous replications performed over the 200-ft plots at each operating speed. The reduced data were generally within the ranges reported by Hunt (1977), Reid (1978), and Frisby and Summers (1978) on similar implements. However, specific comparisons were not applicable due to the broad spectrum of soil types, soil moisture levels, implement sizes and various operating parameters. Based on the summarized data presented in Table 8 the following trends and generalizations were apparent:

1. Drawbar pull or draft required to operate an implement consistently increased as the speed of operation increased. Consider the drawbar pull for the chisel plow. As the speed

Table 8

Energy Requirements of Selected Tillage and Planting Implements Operated at Various Ground Speeds with the Instrumented Tractor

Implement[a]	Gear Setting	Ground Speed (mph)	Drawbar Pull (lbs)	Drawbar Power (hp)	Slip of Drivers (%)	Energy Input (dbhp-hr/acre)	Fuel Consumption	
							Gal/hour	Gal/acre[b]
Chisel plow	3L	1.94	6350	32.7	11.1	15.40	4.06	1.92
	4L	2.75	6650	48.6	11.7	16.20	5.32	1.79
	5L	3.18	6990	59.0	10.7	17.00	5.78	1.67
Heavy tandem disk harrow	3I	2.81	3470	26.0	7.2	5.45	4.07	0.85
	4I	3.94	3690	38.7	8.3	5.79	5.07	0.76
	5I	4.57	3690	44.9	7.8	5.79	5.99	0.77
Light tandem disk harrow	4I	4.13	2370	26.1	4.0	4.34	4.22	0.70
	5I	4.67	2440	30.4	5.6	4.48	4.64	0.68
	6I	6.19	2640	43.5	9.2	4.83	6.23	0.69
Soil pulverizer	3I	2.94	3460	27.2	2.8	5.87	3.93	0.85
	4I	4.09	3610	39.3	4.8	6.10	4.77	0.74
	5I	4.69	3720	46.4	5.2	6.28	5.41	0.73
Cultimulcher	4I	4.22	2060	23.2	1.8	3.33	4.03	0.58
	5I	4.81	2150	27.6	2.8	3.48	4.37	0.55
	6I	6.49	2440	42.2	4.9	3.94	5.75	0.54

Table 8 (Continued)

Implement[a]	Gear Setting	Ground Speed (mph)	Drawbar Pull (lbs)	Drawbar Power (hp)	Slip of Drivers (%)	Energy Input (dbhp-hr/acre)	Fuel Consumption	
							Gal/hour	Gal/acre[b]
Row-crop planter	3I	2.94	310	2.4	1.4	0.51	2.34	0.49
	4I	4.23	380	4.3	1.7	0.63	2.68	0.39
No-till row-crop planter	2I	2.03	1000	5.4	1.6	1.65	2.42	0.75
	3I	2.96	1140	9.0	2.4	1.89	2.72	0.57
	41	4.17	1080	12.0	3.0	1.78	3.09	0.46

[a]Refer to Table 7 for a description of tillage and planting implements.

[b]Computation based on theoretical field capacity of implements.

of operation increased from 1.94 mph to 3.18 mph the drawbar pull increased from 6350 lbs to 6990 lbs.

2. Drive wheel slip tended to increase with increases in the speed of implement operation. Observe the slip of the drive wheels in relation to operating speed as illustrated by data for the light tandem disk harrow. Drive wheel slip increased 5.2 percentage points as the speed of operation increased from 4.13 mph to 6.19 mph.
3. Drawbar power required to propel implements through the field increased as the speed of operation increased. Consider the chisel plow as an example. As speed increased from 1.94 mph to 3.18 mph the drawbar power requirement increased by approximately 26 horsepower.
4. The energy input required by each implement to process a unit area of land consistently increased with increases in operating speeds.
5. The fuel consumption rate per unit time with a given implement tended to increase with increases in the drawbar horsepower required to operate the implement at higher travel speeds. To illustrate, observe the fuel consumption rate associated with operating the heavy tandem disk harrow. Fuel consumption increased approximately two gallons per hour as the drawbar power requirement increased from 26.0 DBHP to 44.9 DBHP.
6. The amount of fuel required to process an acre of ground decreased slightly as the speed of operation increased.

Consider the no-till row-crop planter as an example. The quantity of fuel required to plant one acre decreased from 0.75 gallon to 0.46 gallon as the speed of operation was increased from 2.03 mph to 4.17 mph.

7. Finally, due to increasing the speed of implement operation conditions were apparently created which increased the operating efficiency of the instrumented tractor. This concept was noted by Tompkins and Wilhelm (1982) who observed that energy input per acre for a given implement operation increased as travel speed increased while the fuel requirement per acre gradually decreased. Greater energy input to the implement operation, while decreasing the quantity of fuel consumed, can possibly be attributed to an increased efficiency in power production and/or more efficient transmission of power through the drive train of the tractor.

CRANES CREST

CHAPTER VI

SUMMARY AND CONCLUSIONS

I. SUMMARY

A microcomputer-based data acquisition system was designed, fabricated, and installed on a 100-PTO horsepower agricultural tractor to monitor energy inputs to selected tillage and planting implements. Sensing hardware on the instrumented tractor was used to monitor fuel consumption, implement draft, actual travel speed, angular velocity of drive axles, and torque on drive axles. Objectives of the study included: (1) fabrication and installation of the data acquisition system on the agricultural tractor, and (2) field test and evaluation of the performance of the instrumented tractor in monitoring energy inputs to selected tillage and planting implements.

The data acquisition system was installed on a 2675 Massey-Ferguson (two-wheel drive) agricultural tractor. The system was centered around a DEC PDP11/03-LK microcomputer that was installed in a rack above the head of the operator. A DEC TU58 cassette tape system, which incorporated dual tape drives, was used for system program and data storage. Communication between the operator and data acquisition system was through a 64-key keyboard and a compact CRT unit for external monitoring of program execution and data display. Other components of the data-handling system included a microprocessor counter box for summing digital signals and a strain gauge signal conditioner/amplifier. All electronic data handling components were mounted within

the confines of the tractor cab. The sensing hardware on the instrumented tractor consisted of a fuel transducer and display, a three-point hitch drawbar dynamometer, a free-rolling fifth wheel to indicate travel speed, axle speed indicators, and axle torque sensors. Power for the data handling equipment and sensing transducers was supplied by a portable gasoline generator which mounted on the front of the tractor.

Preliminary field tests of the instrumentation package were conducted during September 1980 at the Milan Experiment Station in West Tennessee. The instrumented tractor was used to monitor the energy inputs to five tillage implements. The system performed satisfactorily and proved its ability to collect reliable data. Based on the field evaluation results the following modifications were performed on the system:

1. The microprocessor counter box was replaced with a DEC interface foundation module board that plugs in the backplane of the PDP11 microcomputer.
2. Slip ring support arms were redesigned for cab mounting.
3. Additional ballast and double roller flanged bearings were installed on the fifth wheel assembly.
4. The magnetic sensors (speed indicators) were replaced with similar sensors from another manufacturer.
5. A small plastic optical disc housed inside the fuel transducer had to be replaced with a metal replacement disc from the manufacturer.
6. Some new components were acquired to perform system calibration procedures correctly.

7. A panel meter unit was constructed and installed to allow the operator to have a continuous display of monitored parameters.

Modifications were performed on the data acquisition system during the spring and early summer of 1981. Upon completion of these modifications the instrumented tractor was used to monitor the energy inputs to seven selected tillage and planting implements. Tests were again conducted at the Milan Experiment Station in West Tennessee during July and August 1981. Tests consisted of operating the various implements over predetermined 200-ft plots at three speed ranges to simulate cultural practices associated with seedbed preparation and planting. Tests for each speed range were replicated at least 14 times. Data were reduced by averaging information obtained for each speed range for a given implement.

II. CONCLUSIONS

Performance of the data acquisition system and examination of the reduced data resulted in the following conclusions:

1. The data acquisition system performed satisfactorily even in the harsh conditions associated with field operation.
2. The TU58 cassette tape system performed well as a system device and storage medium. However, the system had the major disadvantage of being slow. Booting the system and executing the source program required approximately nine minutes.

3. Magnetic sensors used as speed indicators performed rather poorly. Although the second set of magnetic sensors performed better than the first set, overall both brands of magnetic sensors produced spurious, irregular signals at various operating speeds. From observing the sensors, an explanation for unsatisfactory performance could be the transmission of vibration from mechanical components on the instrumented tractor at certain operating conditions.
4. The fifth wheel assembly used for distance and speed measurement did not produce reliable data when operated on rough surfaces (e.g., chisel plowed ground). The wheel assembly was observed to bounce and slip when operated on hard, cloddy surfaces. However, the wheel performed satisfactorily on well tilled soil surfaces and on hard non-deformable surfaces.
5. Information collected by the instrumented tractor indicated that drawbar pull, drawbar power, drive wheel slip, fuel consumption per unit time, and the energy input per unit area all tended to increase for each implement as travel speed was increased.
6. Reduced data also indicated that the quantity of fuel required to process a unit area tended to gradually decrease for a given implement as the travel speed was increased.

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