A data acquisition system to monitor a potato digger

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Misener, G.C., Gerber, W.A. and McLeod, C.D. 1992. **A data acquisition system to monitor a potato digger**. Can. Agric. Eng. **34**:227-232. A micro computer based data acquisition system was developed to monitor draft, hydraulic pressure, forward speed, and primary chain speed of a potato digger. The operating system was MS-D0S 3.3 with a C language program being used for controlling and interfacing the data acquisition process. From data collected under field conditions, relationships were developed between forward speed and draft of the digger and the required hydraulic pressure of the primary chain drive motor.

Un système d'acquisition de données fonctionnant sur micro-ordinateur a été élaboré pour enregistrer l'inclinaison, la pression hydraulique, la vitesse d'avance et la vitesse de la chaîne principale d'une arracheuse de pommes de terre. On a utilisé le système d'exploitation MS-DOS 3.3 et un programme de langage C pour contrôler le processus d'acquisition des données et assurer l'interface. À partir des données recueillies dans des conditions réelles, on a établi des rapports entre la vitesse d'avance et l'inclinaison de l'arracheuse et la pression hydraulique nécessaire du moteur d'entraînement de la courroie principale.

INTRODUCTION

The development of lighter, more efficient potato harvesters requires accurate information on the forces acting on the blade and the primary chain of a harvester to design the minimum size soil digging and sieving components. In recent years, a number of instrumentation systems have been developed to monitor agricultural equipment. Upchurch and Peterson (1987) developed a data acquisition system for recording experimental data on mobile equipment. Owen et al. (1987) described an instrumentation system for collecting data on a deep tillage machine. Other researchers have developed systems that are an integral part of a tractor and its hitching system (Graham et al. 1987; Marshall and Buckley 1984; McLaughlin et al. 1989; Summers et al. 1986; Grevis-James et al. 1983; Smith and Barker 1982; Green et al. 1985; Grogan et al. 1987; Wolf et al. 1981). Most of these systems were developed to study different variables that could be used for measuring the performance of soil-engaging implements. McLaughlin et al. (1989) took the approach of using a fully instrumented tractor to measure the energy consumption and related parameters on a variety of field equipment. Lackas et al. (1991) developed a portable data acquisition system for measuring the energy requirements of field operations using a laptop computer.

Only a limited amount of literature was found on instrumentation systems used to collect data on a potato harvester. Verma et al. (1977) developed and tested an experimental potato digger equipped with an oscillating blade. The machine was tested with the blade vibrating at frequencies up to 9 Hz with amplitudes to 30 mm. The draft required for the vibrating digger was as low as 24% of a standard two-row harvester draft requirement. Harvester draft measurements were also made by Johnson (1973) using a modified tractor drawbar instrumented with strain gages with the necessary recording equipment on it. The draft for a prototype harvester was measured and compared to that for commercial harvesters. Under laboratory conditions, Singh and Pandey (1981) studied the influence that selected parameters, such as the length and speed of the elevating conveyor and the forward speed of the potato digger, had on power requirements of diggers fitted with conventional and oscillating blades. They found that although the blade draft was lower when using an oscillating blade, the total power requirement was comparatively higher due to the additional power required to oscillate the blade. Hyde (1986) compared draft and PTO power for potato harvesters equipped with a rotary and fixed digger blade. Draft was measured with a simple strain gage force transducer fabricated from a 38 x 76 mm rectangular cross section steel bar bolted to the tractor draw bar. The PTO torque and speed were measured with shaft torque and speed sensors, and the sensors were scanned every 14 seconds by a recording instrument. Data were transferred from the instrument's memory to an audio magnetic tape for later analysis.

The objective of this study was to develop a data acquisition system to monitor the performance of a prototype two-row potato digger. The blade on the digger was similar to that on a commercial harvester while the digger chain was approximately one half the length of a primary chain.

INSTRUMENTATION SYSTEM DESCRIPTION

The data acquisition system consisted of three major components; transducers, signal conditioners, and a microprocessor. The system was connected to a three point hitch mounted digger (Fig. 1).

Transducers

Digger variables measured and recorded were draft, tractor engine speed, forward speed, primary chain speed, and hydraulic pressure drop across the primary chain drive motor.

Draft was measured at the three-point hitch with clevis pin

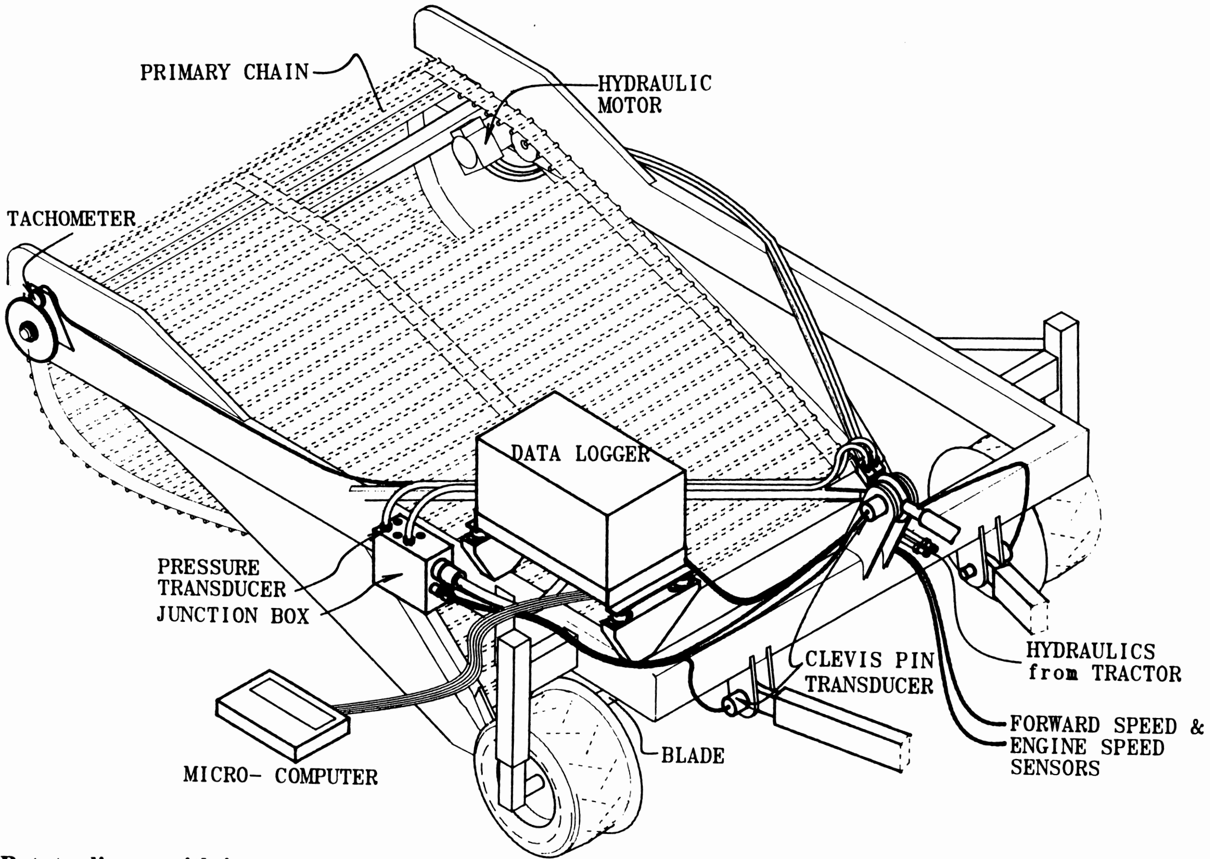

Fig. 1. Potato digger with instrumentation.

load cell transducers (Strainsert, West Conshohocken, PA). Two 53 kN load cells were used in the two lower hitch points and one 36 kN load cell was used in the upper hitch point. Each pin employed internal strain gages configured to measure transverse shear in the pin. The gages formed a 350 Ω full bridge and the full scale output was 24 mV with a 12 V excitation. To facilitate calibration, a span resistor was placed in parallel with one arm of the bridge which gave an output equivalent to a fixed load. The clevis pin arrangement was more suitable for our application than transducers which formed an integral part of the three-point hitch links (Marshall and Buckley 1984; McLaughlin et al. 1989) because the clevis pin transducers could be easily inserted and removed. The ease of connecting and disconnecting sensors was important because the tractor was not totally dedicated to this use.

A semiconductor pressure transducer (Model 93, IC Sensors, Milpitas, CA) was used to measure the pressure drop across the hydraulic drive motor of the primary chain. This type of transducer had a higher output voltage than strain gage pressure transducers. The semiconductor transducer was also considered to be less susceptible to power supply fluctuations since a constant current source was used for excitation. It was also less sensitive to temperature changes that result from friction losses during pumping of the hydraulic oil. The pressure transducer had a range of 21 MPa and an accuracy of ± 2% of full scale.

A Dickey-john (Dickey-john Corporation, Auburn, IL) tractor performance monitor employing a Doppler radar was installed on the tractor to measure forward and engine speed. The pulse output signals from the monitor were conditioned and recorded in the data logger. The signal from the electronic tachometer installed on the tractor was converted to six revolutions per pulse and the Doppler signal was converted to 28 pulses$\cdot$km$^{-1}\cdot$h^{-1} in the monitor. Both were then converted to voltages in the data logger.

Primary chain speed was measured by an optical encoder (Model CR1060, Electromagnetic, Ville St-Laurent, PQ) which provided a pulse output with frequency proportional to the shaft rotational speed. The encoder had an output of 60 pulses per revolution and operated from a five volt source.

Signal conditioning

Three analog conditioning circuits were utilized in the instrumentation system for output from the clevis pin load cells, the pressure transducers, and the frequency monitoring devices.

Differential instrumentation amplifiers (Model AD624, Analog Devices, Norwood, MA) were employed to amplify the differential millivolt signals from the strain gage bridges in the clevis pin transducers. The amplifier gain was programmable through either an external jumper connection for a number of predetermined gains or the inclusion of an external resistor for custom gains. Both input and output null could be trimmed via external resistors.

The output from the clevis pin load cells was interfered with by harmonic frequencies emitted by the microprocessor system during a bench test. These frequencies distorted the differential output signal which when amplified, created a large error in the final readings. A second order Butterworth filter with a cut-off frequency of one kHz was installed at the output of the clevis pin amplifiers to remove the interfering frequencies. This was the only filtering done in the system.

The pressure transducers were excited by a constant current source (Fig. 2). This circuit helped to limit the erroneous responses of the transducers caused by power supply fluctuations, temperature variations, and noise. The circuit's offsets could be nulled by an one kΩ potentiometer. The circuit used the amplifier in the A/D converter card to amplify the sensor's output.

An Analog Devices hybrid module frequency to voltage converter (Model AD 451) with a range of conversion from 0-10 kHz frequency input generating a 0-10 V voltage output was used to convert pulse trains to an analog voltage. It incorporated a zero and gain adjustment using external potentiometers.

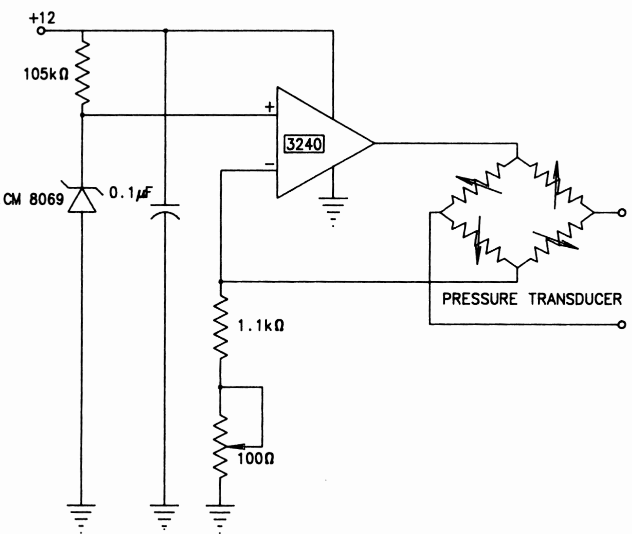

Fig. 2. Schematic of pressure transducer constant current source.

Microprocessor

The microcomputer was an Intel 8088-2 based system (Teknor Microsystems Inc., Ste-Thérèse, PQ) which operated at 8 MHz under the DOS 3.3 operating system on a STD bus. The operating system was located in EPROM. The system automatically booted from this rather than from a disk. The CPU card contained 256 K Byte EPROM, 96 K Byte RAM, and had one RS-232 port, one parallel port, two 8 bit I/O ports, and five 8 bit timer/counters. Additional 640 K Byte of SRAM was provided on two boards which had provision for battery backup. The operating system and main program were accessed via either a floppy disk or an EPROM. The system was accessed through an RS-232 port by a Toshiba (Model T1200) portable microcomputer using a terminal emulator program (Tekterm). Recorded data were stored in memory until acquisition was completed. Data were then downloaded to the microcomputer. It was possible to record up to 300 x 10^3 readings per channel.

The analog to digital interfaces utilized in the instrumentation system were Analog Devices 16/32 channel STD bus compatible plug-in boards (Model RTI1260). Two boards were used, one in single ended mode and the other in differential mode. They could be accessed via the microprocessor through either a port or memory address. The application program was written in Aztec C operating within the DOS system which made it both upgradable and portable.

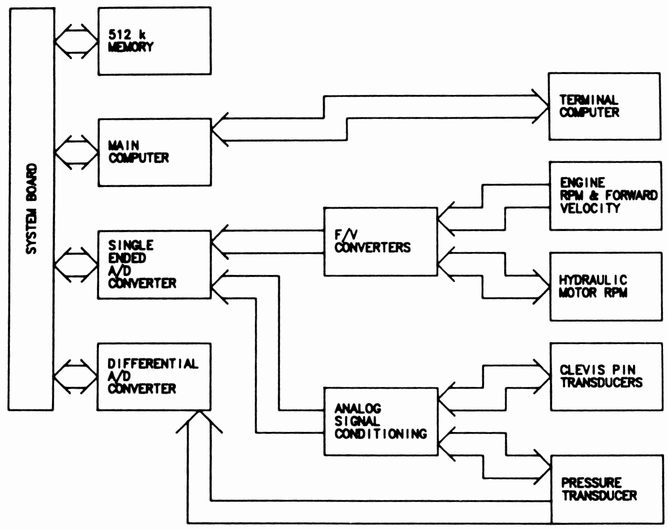

Fig. 3. Schematic of instrumentation system.

A schematic layout of the instrumentation is presented in Fig. 3. Table I lists the type and the accuracy of the transducers used in the data acquisition system.

INSTRUMENTATION VERIFICATION

An industrial standard analog pressure calibrator (Ametek, US Gauge Division, Largo, FL) was used to obtain the calibration curves of the pressure transducers. This unit consisted of a hand powered hydraulic fluid pump connected between a reservoir and the device under test. The output pressure was measured with the analog gage. A bleed valve bypassing the pump was used for setting the precise pressure desired. Pressure readings were taken in 1.5 MPa increments on the standard gage. The output voltage from the pressure sensor was transmitted to the data logger and then recorded for each reading and finally transferred to a spreadsheet. A regression analysis of the data yielded Eq. 1 which was used for interpretation purposes.

$$P = 42.0 + 404.5\,V \qquad (1)$$

where:

P = pressure, measured by the standard gage (MPa), and
V = pressure sensor output voltage (after the conditioning circuit) (mV).

The analysis yielded a standard error of ± 0.04 MPa between predicted and measured pressures.

The clevis pin transducers were calibrated using an universal testing machine (UTM), Model MC-3000 (Nene Instruments Ltd., Wellingborough, England). A test fixture to hold a pin was constructed. The tests consisted of three replications of each test run for each of the three transducers. Each test run consisted of increasing the load on the transducers in 445 N increments from 0 to 4.45 kN and in 2.25 kN increments from 4.45 to 13.45 kN. Equations were developed to relate the output from the transducers to the output from the UTM using the formula:

Table I. Specifications of sensors utilized in instrumentation system

Transducer	Function	Manufacturer	Specifications
Clevis pin load cells	Draft	Strainsert West Conshohocken, PA	0 - 36 kN 0.25% non-linearity F.S. 0 - 53 kN 0.15% non-linearity F.S.
Pressure transducer	Hydraulic motor pressure drop	IC Sensors Milpitas, CA	0 - 21 MPa ±2% of span
Doppler radar	Forward speed	Dickey-john Auburn, IL	0 - 80 km/h ±1% of span
Hall effect	Engine speed	Dickey-john Auburn, IL	0-9999 rpm ±6 rpm of span
Optical encoder	Primary chain speed indicator	Electromagnetic Ville St-Laurent, PQ	0-9999 rpm ±1/60 rev

$$y = a + bx \tag{2}$$

where:

y = force measured by the UTM from a specific transducer, and

x = output from a specific transducer.

Table II lists the regression coefficients for each equation describing the response of the transducers. The standard errors for the predicted forces are also presented. Operation of the encoder was verified on the digger with the data logger connected to it. The digger bed was operated at a constant speed and the output of the encoder on the drive shaft measured by the data logger was compared to the shaft speed as measured by a hand held tachometer (Ametec Model 1726, Mansfield and Green Div., Largo, FL).

Both the engine speed and the Doppler radar speed readings were checked according to the Dickey-john monitor operation manual and the readings taken from the data logger were further checked against the display values on the monitor. The readings were within the accuracy limits of the Dickey-john monitor (± 6 rpm engine speed and ± 1% forward speed).

Table II. Regression coefficients and standard error for Eq. 2

Clevis pin	a	b	Standard error
53 kN transducer, No. 1	271.4	1.0	± 92.8 N
53 kN transducer, No. 2	46.6	1.0	± 40.8 N
36 kN transducer	114.2	1.2	± 191.7 N

FIELD EVALUATION

Plots were planted with the variety, Russet Burbank, and standard recommended crop management practices were followed during the growing season. The soil in the plots was a Fundy Clay Loam, and the average moisture content of the soil during the tests was 19% dry weight basis. Tests were conducted under normal harvesting conditions. The digger blade height was set to slice the row 250 mm below the top of the hill. The primary chain speed was set to operate between 350 and 580 mm/s, and the forward speed ranged from 1.3 to 3.0 km/h. The sample rate of the data logger was 640 ms/channel. The total time of each test was 650 s. This sample size was considered sufficient to account for the effect of aliasing.

After steady state conditions were achieved, the force data collected were averaged for each 40 second interval and included 62 points in each average. A regression equation was then developed from the collected data to relate the draft requirement (the sum of the output of the three clevis pins) of the digger to its forward speed. A second regression equation was developed to relate the hydraulic pressure drop across the drive motor on the primary bed to the digger forward speed. The equations used to describe these relationships are:

$$D = 3.4 + 1.2\,\upsilon \tag{3}$$

$$P = 2800 + 1400\,\upsilon \tag{4}$$

where:

D = draft (kN),

P = hydraulic pressure drop (kPa), and

υ = forward speed (km/h).

The relationships are shown graphically in Figs. 4 and 5. The regression equations accounted for 77.4 and 94.1% of the variation in the draft and pressure, respectively. The magnitudes of draft determined from Eq. 3 within the limits of normal operating speed for harvesters agree closely with the values reported in ASAE standards (Hahn and Rosentreter 1989).

Variation in the draft with time at a forward speed of 2.8

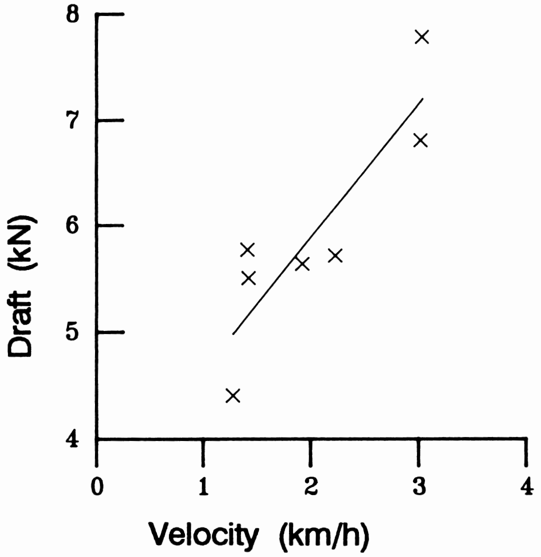

Fig. 4. Effect of forward speed on draft requirements.

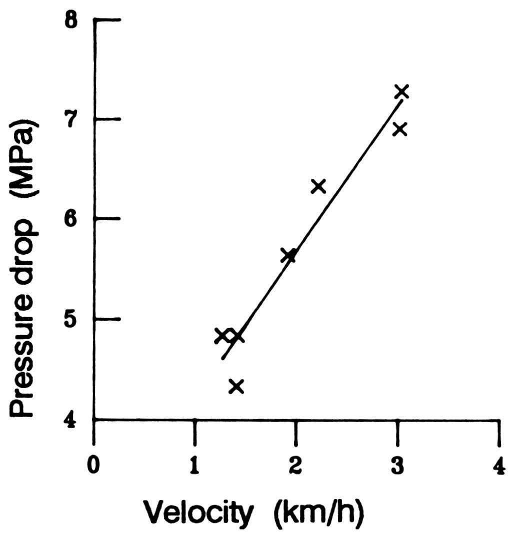

Fig. 5. Effect of forward speed on hydraulic pressure in drive motor of the primary chain.

km/h is depicted in Fig. 6. Variables such as the effect of stones and changes in soil conditions could account for some of the variation in the instantaneous draft measurement during a specific time period.

Given the pressure drop across the hydraulic motor as presented in Eq. 4 and the motor displacement and speed, the theoretical power input can be determined. A detailed treatment of sieving rates, loading, friction, soil moisture, and power inputs is needed before an accurate prediction of their influence on power consumption can be made. Ultimately, it will be necessary to develop this relationship in order to define the efficiency of the primary chain operation in terms of soil elimination and product elevation.

CONCLUSIONS

The data acquisition system developed to monitor the draft and hydraulic requirements of a potato digger functioned well under field conditions. The use of a DOS based system allowed the data to be readily transferred to spreadsheets for

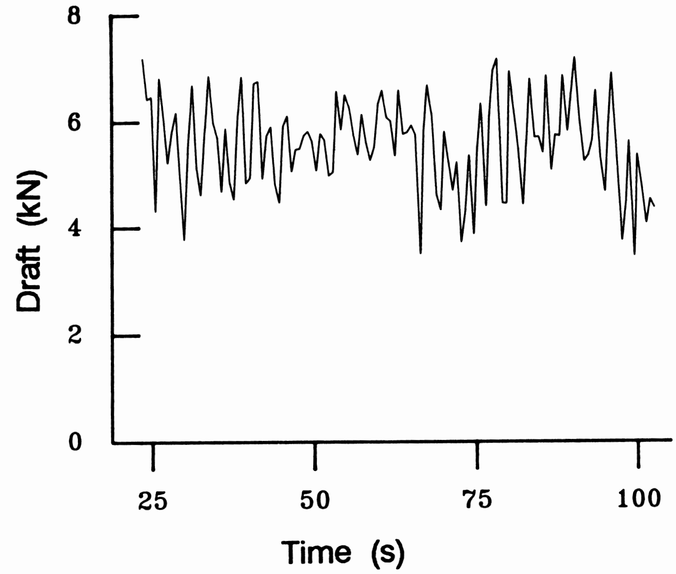

Fig. 6. Variation of draft with time at 2.8 km/h.

analysis. The use of the C language also facilitated the incorporation of several functions and made interfacing with the acquisition boards straight forward.

The field study results showed that both the draft and the pressure required to operate the hydraulic drive motor for the primary chain were a function of forward speed. Regression equations were developed to describe the relationships.

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