A Portable Instrumentation System for Measuring Draft and Speed

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ABSTRACT

A portable instrumentation system was developed to measure draft and speed when using either pull type or three point hitch mounted implements. The parameters measured were horizontal and vertical draft, true ground speed and drive wheel speed. The system utilized strain gage load cells with excitation provided by a compact, portable datalogger. Measurements were taken and stored using the datalogger, then transferred via magnetic cassette tape to a microcomputer for further processing. The force dynamometer was designed for tractors up to 80 kW with a maximum draft capacity of 60 kN. Calibration procedures, results from the use of the system and actual tillage energy requirements are presented.

INTRODUCTION

Draft requirements will often dictate the size power unit required on a particular farm. Since the power unit represents a major capitol investment, a better understanding of draft requirements can aid machinery management decisions. Energy management of agricultural machinery will also be increasingly important in the future. Draft requirements will also be required for energy management decisions.

Recent innovations in electronic data acquisition systems have made measurements of draft and speed easier with respect to harsh environmental conditions experienced in the field. In order to measure draft requirements for an implement the system must be able to measure high frequency loads in the field without interference from dust, moisture, or vibration. The ease of making draft measurements has been enhanced through the use of clevis pin strain gage load cells. When the load cells can measure bi-directional forces, the design can be simplified because both horizontal and vertical loads can be measured from one location.

A datalogger can be used to provide the excitation for the load cells and the data storage functions without the need for an auxiliary power source. These devices also make it possible to record data at a high rate, making large data bases possible for a more accurate prediction of implement draft requirements.

LITERATURE REVIEW

Several methods of measuring draft on tractors have been developed, most using mounted strain gages or strain gage load cells. There are two basic types of load dynamometers in use. The most common type uses a subframe assembly between the tractor and the implement. Others have used integral systems with load sensing elements placed on or between the tractor and the implement. These are designed for use on one particular tractor only and proved to be a simple system to incorporate (Bandy et al., 1986). The integral system concept has the advantage of preserving the original geometry with respect to implement hitching location. However, these systems are not interchangeable between tractors.

More common designs have used a subframe assembly with strain gages or load cells incorporated to measure the forces. Johnson and Voorhees (1979) used a subframe assembly involving a torque tube instrumented with strain gages to measure draft, moment, and vertical loads on a three point hitch. This design was based on a “quick-attaching coupler” as defined in ASAE Standard S278.6 for Category II and III hitches (ASAE Standards, 1988), but made simultaneous use of the PTO impossible due to obstructions. A dynamometer designed by Reid et al. (1985) used strain gages mounted on vertically cantilevered aluminum beams to sense the implement loads, including side draft. Designed for use with Category I or II implements, it did not allow quick hitching. Barker et al. (1981) designed a dynamometer using two “calm shell” subframes in which commercially available load cells were oriented to completely determine the resultant forces. This design allowed interchangeability between tractors and was patterned after Category III “quick-attaching coupler” for use on tractors up to 60 kW. A similar rectangular arrangement used six load cells to measure all components of draft (Chaplin et al., 1987). The load frame, for use on tractors up to 90 kW, was susceptible to shock loads during transport due to the large moments imposed on the top link by large mounted implements. A clamp to lock the two subframe assemblies was required to protect the dynamometer during equipment transport. Rearward displacement of the implement causing greater weight transfer and large moments about the top link were noted as common disadvantages of the subframe concept. The subframe concept is advantageous in that it allows the dynamometer to be used on different tractors as tillage draft requirements change.
In order to record the data from the strain gages or load cells, special data acquisition systems have been designed for field use. A datalogger has been used to excite and record the output signals from the load cells (Chaplin et al., 1987; Graham et al., 1987; Green et al., 1985). The data were then transferred from the datalogger memory to magnetic tape for transfer to a microcomputer for final processing.

Microcomputer based systems have also been developed for use on the tractor. Mounting the computer CPU, CRT, and disk drives inside the tractor cab allowed greater versatility in sampling rate, signal conditioning, data processing, and storage media (Clark and Adsit, 1985; Bowers, 1985). A printer was also added to this type of system for a permanent record of the data as they were collected (Wiedmann et al., 1986). On board computers do, however, require much greater space than dataloggers and are more susceptible to the effects of adverse environments.

The designed capacities of the dynamometers all vary according to use and sensitivity desired. The highest draft requirements per unit width or per shank of the common primary tillage implements were used as a design criteria for many of the dynamometers. Nicholson et al. (1984) and Garner et al. (1984) found that a subsoil chisel had the highest draft requirements of the primary tillage tools, averaging about 22.4 kN per shank. Special design considerations must be taken in order to measure the large forces experienced when using a subsoil tillage tool without adverse effects upon the load measuring devices or the tractor stability.

**DESIGN OBJECTIVES**

The objectives of this project were to develop an instrumentation system capable of measuring and recording draft and speed data for common tillage operations performed on Wisconsin farms. From the measurements made with this system it should be possible to calculate wheel slip, tractive power and energy requirements. Specifically:

1. The system must be generally portable and interchangeable, not restricted to a single tractor.
2. The load frame must measure horizontal and vertical components of load imparted through three point hitch or pull type implements by an 80 kW tractor developing 60 kN draft force without damage to the measurement systems.
3. The load frame must be designed such that the use of the tractor’s PTO drive system is not restricted during draft tests.
4. True ground speed and rear wheel speed must be measured in order to determine energy requirements and wheel slip.
5. The load frame should have "quick attaching coupler" capabilities and meet the ASAE Standards applicable.
6. The data acquisition system should interface with a microcomputer for ease of data transfer, manipulation and storage.

**DESIGN RESULTS**

Force measurements between the tractor and implement were made with three Strainsert* strain gage load cells. A subframe arrangement was designed so the front subframe attached to the tractor and the rear frame connected to the implement with a "quick-attach coupler" type hooks (Fig. 1). The two subframes were interconnected by the clevis pin load cells. The two lower cells were bi-directional, measuring horizontal and vertical forces while the top pin measured horizontal loads only. The depth of the pin slot in the top hook was made 1.3 cm greater than that specified in ASAE Standard S278.6 so that the top hook carried only a horizontal force. Therefore, any vertical load imparted

*Reference to a company or trade name is made for identification purposes only and does not imply approval or recommendation by the University of Wisconsin-Madison.
by an implement was carried completely by the lower hooks. At each hook location all three pin connections; tractor to the load frame, load cell connecting the two subframes, and the load frame to the implement, are in the horizontal plane so the horizontal loads are transmitted without binding or geometric distortion.

Major dimensions of the subframe assembly are provided in Fig. 2. ASAE Standard S278.6 (ASAE, 1988) for three-point hitch dimensions was followed in designing the load frame. Note that the center section of the assembly is open and that there is no connection between the lower hooks across the bottom. This facilitates the use of the tractors PTO drive system while draft data is measured. The main structural components of the two subframes were constructed using 7.6 cm x 5.1 cm x 0.64 cm box section steel tubing. Rearward displacement of the implement from the original hitch location was approximately 24 cm. More detailed design data can be found in Thomson (1987).

An additional “A” frame was constructed with a drawbar cross piece which attached in the lower links of the load frame. Two uprights were added to the drawbar to form the top of the “A” and were connected to the top hook to stabilize the drawbar. Draft for pull type implements could then be measured by setting the subframe assembly to normal drawbar height.

Load cell selection was based on the fact that any one load cell may be required to support the maximum pull developed by the tractor, but that large capacity load cells generally do not exhibit the desired sensitivity at small loads (less than 4.5 kN). The Strainsert load cells were chosen because they had ±0.50% non-linearity and ±0.25% error full scale. The two lower bi-directional load cells have a maximum capacity of 67.2 kN and the top uni-directional load cell has a capacity of 80.6 kN. All three load cells have a overload safety factor of 1.5. Only slight dimensional changes from the standard clevis pin load cell dimensions were required. Further details concerning the specific dimensions of the load cells can be found in Thomson (1987).

True ground speed was measured through the use of a Magnavox Work Miser I radar ground speed sensor. The unit consists of a radar speed sensor and a heads-up display module. An input was also available for rear wheel speed which was used in calculating wheel speed, which was displayed along with the ground speed. The heads-up display of true ground speed made it easier for the tractor operator to maintain a constant speed throughout a draft test. An output port was available on the display module which was used by the datalogger to record the voltage pulses corresponding to true ground speed.

Rear wheel speed was measured by rotary encoders driven from axle mounted sprockets through a chain drive. The frequency of the pulse signal was designed to be approximately 37 Hz per km/h to be compatible with the display module. Each rotary encoder was placed in a sealed enclosure mounted on the axle housing of the tractor. Both rear wheels were equipped with encoders. Microcircuitry was used to read the two input signals and send the greater of the two signals to the display module processing unit for wheel slip calculation and display. The signal was simultaneously sent to the datalogger for final storage.

A Campbell Scientific 21XL datalogger was used for a variety of tasks in the system because it has a wide range of program instructions which gave it great versatility. Excitation for the load cells was provided by the datalogger, which eliminated the need for bulky transducer amplifiers, bridge balancing equipment, and 120-VAC power supply. The five strain gage bridges in the load cells, three horizontal and two vertical, were zeroed with an offset command in the datalogger program. The output signal from the load cells was stored in engineering units through the use of a multiplier in the program which converted millivolts to force. The 21XL datalogger can read up to four pulse input channels, so both true ground speed and rear wheel speed pulse signals could be monitored directly. Two channels are still available for additional equipment such as a fuel flow meter or PTO rotational speed measurement. A schematic of the instrumentation system is shown in Fig. 3.

A program was developed for the datalogger which would record the date and time at the beginning and end of each test, the data input signals from the load cells, true ground speed sensor and the wheel speed encoders. A single keystroke initiated and terminated data collection. All strain gage bridge outputs were sampled at a 10 Hz scan rate, which could fill the final memory of 19328 data values in 241 s. The scan rate of 10 Hz appeared to be adequate to provide an “over the field” average of tillage draft and speed. Data sampling rates of approximately 30 Hz were possible, with a corresponding reduction in total sampling time. Faster sampling rates than this could only be achieved by a general change in the data acquisition system. Data was downloaded at the end of each test to a magnetic tape for input into a microcomputer. A data set of 5000 points would take approximately 2 min to download to tape. A special tape read card in a microcomputer was used to translate the data from the tape into an ASCII file which could be manipulated as required.

CALIBRATION PROCEDURE

In order to calibrate the dynamometer three tests were conducted: horizontal, vertical and drawbar loads. During calibration the dynamometer was attached to the tractor to ensure loads were applied as might be applied in the field. The horizontal calibration was accomplished

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by applying a load with a hydraulically powered winch through a previously calibrated load cell. The calibration load cell was calibrated in a MTS Model 5000 universal testing machine. A clevis was connected to either the left, right or top hook of the implement subframe and an eyebolt attached to the clevis. The cable from the winch was also equipped with an eyebolt. The calibration load cell was then placed between the load frame and the winch through the eyebolts. Care was taken to ensure a purely horizontal load. During calibration of each individual load cell located at the left, right or top hook, the output from the two unloaded load cells was monitored. Also, if for instance a horizontal calibration load was being applied to the right hook, the vertical load bridge output at the right load cell was also monitored. Any forces recorded at the two unloaded hooks could be attributed to frame misalignment. The "A" frame drawbar attachment was calibrated by installing the frame and using the same horizontal configuration as above, but applying the load to the drawbar pin of the frame and comparing the sum of all three horizontal sensing load cells with the applied load.

For each calibration a ramp load was applied from 0 to approximately 35 kN, the maximum load which could apply. Because the frame and load cells are capable of handling greater forces, different calibration procedures will be required if greater draft than this is expected. The datalogger was used to excite and record all load cell outputs, including the calibration load cell. Each calibration test was replicated four times.

The vertical loads were applied by a hand powered winch between the tractor mounted load frame and a floor anchor. A ramp load was again applied from 0 to approximately 10 kN, the vertical operating design load. Each calibration test was replicated four times.

The results of the calibration tests are represented in Fig. 4. The measured load exhibited excellent agreement with the applied load. The coefficient of regression ($R^2$) approached 1.000 for all calibration equations. The results of the linear regression calibration analysis are given in Table 1. The percent error in the force measurements was significant ($\pm$ 5%) only at small loads (Fig. 5). The error in the calculated load was generally greater than $\pm$ 5% when less than a 1.5 kN force was applied. Since the full scale error of the load cells is $\pm$ 0.25%, the remaining error can be attributed to load cell misalignment. Generally, the output recorded from the remaining unloaded bridges was less than 0.5 kN during full calibration load.

A multiplier programmed in the datalogger was used to convert the speed pulse voltage from the radar ground speed sensor to engineering units. Rear wheel speed (zero slip speed) was calibrated by operating the tractor on dry pavement and using a multiplier programmed in the datalogger to set rear wheel speed equal to the speed obtained by the radar ground speed sensor. The radar ground speed sensor and the two axle sensors were calibrated by comparing recorded sensor outputs with the speed calculated from the time required to travel a 200m test course. Five speeds from 1.6 to 14.4 km/h, in 3.2 km/h increments were used. The results of the linear regression calibration analysis are given in Table 2.

The dynamometer has been used to record draft forces of a variety of fully mounted subsoil tillage tools, as well

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**TABLE 1. Linear Regression Load Cell Calibration Analysis**

<table>
<thead>
<tr>
<th>Component</th>
<th>Location*</th>
<th>Offset, N</th>
<th>Multiplier, N/N</th>
<th>Observations</th>
<th>$R^2$, %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Horizontal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top hook</td>
<td>96.5</td>
<td>1.019</td>
<td>235</td>
<td>99.99</td>
<td></td>
</tr>
<tr>
<td>Left hook</td>
<td>157.5</td>
<td>0.996</td>
<td>290</td>
<td>99.9</td>
<td></td>
</tr>
<tr>
<td>Right hook</td>
<td>-25.2</td>
<td>1.007</td>
<td>299</td>
<td>99.99</td>
<td></td>
</tr>
<tr>
<td><strong>Vertical</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Left hook</td>
<td>136.9</td>
<td>0.964</td>
<td>145</td>
<td>99.89</td>
<td></td>
</tr>
<tr>
<td>Right hook</td>
<td>81.7</td>
<td>0.987</td>
<td>154</td>
<td>99.96</td>
<td></td>
</tr>
<tr>
<td><strong>Drawbar</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Load cells</td>
<td>-75.1</td>
<td>1.00</td>
<td>290</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

*As viewed from rear of tractor.

**TABLE 2. Linear Regression Ground Speed Calibration Analysis**

<table>
<thead>
<tr>
<th>Location*</th>
<th>Offset, km/h</th>
<th>Multiplier, km/h/km/h</th>
<th>Observations</th>
<th>$R^2$, %</th>
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<tr>
<td>Radar ground speed sensor</td>
<td>0</td>
<td>0.998</td>
<td>14</td>
<td>99.93</td>
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<tr>
<td>Right axle speed sensor</td>
<td>0</td>
<td>0.999</td>
<td>14</td>
<td>99.99</td>
</tr>
<tr>
<td>Left axle speed sensor</td>
<td>0</td>
<td>0.999</td>
<td>14</td>
<td>99.99</td>
</tr>
</tbody>
</table>

*As viewed from rear of tractor.
as pull type tandem offset disks and chisel plows. A sample output from a test with a fully mounted subsoil chisel tool is provided in Fig. 6. The system has also been used on a semi-mounted PTO powered rotary chisel tool. The dynamometer has performed well in the field in all circumstances.

SUGGESTIONS FOR IMPROVEMENT

The designed system worked well, but some improvements are suggested. The radar ground speed sensor used should be made to be easily moved to different tractors. The sensor used was fixed to a tractor and was difficult, although not impossible, to move to other tractors.

A cassette tape was used as a temporary storage media to transport the data from the field to the personal computer. This was a rather slow method for recording and unloading the data. Other storage media with faster baud rates should be investigated in order to increase the speed of the data transfer process. If only the average values over a given test are desired, data processing within the datalogger program could be performed thereby eliminating the need for data transfer.

CONCLUSIONS

A data acquisition system for tillage energy requirements was successfully developed. The design objectives were met and the system was mounted on several two wheel drive tractors. Parameters measured were horizontal and vertical loads of both three point hitch mounted and pull type implements, true ground speed and rear wheel speed (used to calculate wheel slip). Calibration results indicated that the load frame was accurate to within ± 5% for draft forces between 1.5 and 35 kN. The load frame is highly portable, the ground speed sensor slightly less so. The instrumentation for determining drive wheel slip was not made portable. The system performed well in the field with the accuracy needed for a wide variety of tillage tasks.

References