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INSTRUMENTATION FOR IN-FIELD AGRICULTURAL MACHINERY TESTING

by

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SUMMARY

Much of the work of engineering is associated with measurement and its related data collection, storage and analysis. In agricultural research and development, measurement typically occurs on machinery operating in a time critical and hostile environment over which the engineer has little control. The ideal data acquisition setup for such an environment is necessarily different than that required for a lab test setup. This paper discusses the needs, design criteria, and development of a general purpose field data acquisition system for the Alberta Farm Machinery Research Centre.

KEYWORDS

Data, Instrumentation, Measurement, Sensors, Vehicles

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INTRODUCTION

The process of measurement and the related collecting, storing and analyzing of data is a fundamental part of the engineering design process. As efforts are made to simplify and enhance the process, many electronic methods are continuing to evolve and improve. The testing and development of agricultural equipment places significant demands on measurement systems in the areas of flexibility, ease of setup, ease of use and reliability. As engineers we want to measure, record and analyze information with as little measurement overhead or hassle as possible. We want the portability, reliability and ease of use of a pencil combined with the power and flexibility of a Cray computer. This paper explains the process of developing a general purpose in-field data acquisition system intended to simplify and improve measurement capabilities at the Alberta Farm Machinery Research Centre.

The Alberta Farm Machinery Research Centre (AFMRC) was established in 1988 as an improvement to the Prairie Agriculture Machinery Institute (PAMI) station originally set up in 1975. The AFMRC has a mandate to test, evaluate and report on existing farm machinery, and to provide assistance to manufacturers in the development of new farm machinery. The areas of expertise of AFMRC are tillage, seeding, spraying, traction, ventilation and aeration, pumps, and wind and solar energy conversion systems. In these and related agricultural areas, AFMRC conducts tests and makes performance measurements to be used in preparing PAMI/AFMRC Evaluation Reports. Additionally, AFMRC provides contracted engineering, testing and development support to farm equipment manufacturers. This support is usually in the form of engineering measurements on prototypes or test fixtures.

AFMRC uses a broad range of transducers to provide as universal as possible measurement capabilities in agricultural areas. Our transducers include load cells, accelerometers, inclinometers, flow meters and position, shear, pressure, torque, velocity, temperature, proximity, moisture, humidity and other custom sensors. The various transducers have differing characteristics, power requirements and outputs. Each time a test is set up there can be different requirements for measurements, resulting in a wide diversity of measurement requirements and a need for flexible and easy to use measurement systems.

AFMRC DATA ACQUISITION HISTORY

AFMRC measurement techniques progressed through the standard industrial measurement growth path. A measurement typically starts with a transducer, which is a device that accepts a quantity you are interested in that is inconvenient to measure and produces some proportional quantity that it is convenient or at least possible to measure. For electronic measurements, most transducers take the quantity of interest and produce a proportional voltage or current. A measurement system consists of a combination of transducers with some form of recording mechanism.

Early PAMI/AFMRC measurement work was relatively simple, using transducers with some form of analog readout and a pencil and paper as the recording device. This was simple and reliable but it was also slow and error prone. The first step up came with strip chart recorders, which were effectively a fancier method of moving the paper under the pencil. These sped up the taking of data and reduced the transcription errors but did little to assist in analysis and were difficult to use in the agricultural environment. The next step was to record the transducer data on magnetic tape and play it back later for analysis. This further increased the speed of taking data and improved our ability to analyze the data after testing but it still provided no immediate interpretation of the data. The next big step was to move to digital storage with a computer based recording and calculation system built into a dedicated van. This greatly improved both the speed and amount of analysis that could be done. The disadvantages were the signal conditioning and calibration that was needed, the cumbersomeness of having a separate vehicle connected to the field implement during the tests and the additional manpower required to run tests.

All of these systems worked but none were ideal for our operation. In 1990, we began a project to produce the best possible system for our specific test needs. The project went through three stages, first, the identification of our major needs; second, the determination of what needs could realistically be met; and finally, the development of a system that incorporated the features that made it through the first two stages.

IDENTIFICATION OF REQUIREMENTS

As we considered what system would be the best for our needs, it was important to first understand and define our measurement environment. The AFMRC runs two distinct types of tests, each type having different requirements.

The first type of tests are performance measurements using standard, well defined, machinery performance measurement sequences. These are used in preparing information for our machine evaluation reports and require the taking of data both in the field and lab under a set of predefined test conditions. The equipment used in the tests needs to be easily moved between the field and lab and needs to be flexible and easily reconfigured for different test setups. As an example, an air seeder evaluation may require three load cells, a torque transducer, a rotational speed sensor and a ground speed transducer, while a sprayer evaluation may require two flow meters, four pressure transducers and a ground speed transducer. Both of these test setups could be used on the same or alternate days over several weeks depending on weather, ground or crop conditions and machinery availability.

The second type of tests are short term research and development measurements for manufacturers. These are usually custom setups intended to provide specific measurement results on test bed or prototype machines that can assist in developing the machine performance. They are usually one-of-a-kind tests and often require creativity in determining what and how much or how little to measure.

For either type of test, we are usually most concerned with average performance as a function of some parameter, adjustment or condition, rather than with instantaneous load levels or time critical histories. Usually the desired end result is an average performance value or a distribution of the time at level for some value. High sample rates and large volumes of data are typically not required or expected.

Since our tests are related to agricultural machinery, our measurements are conducted in and influenced by the weather. The test environment contains major variables that we cannot control or change. Speed is important in making comparisons since environment and weather conditions are constantly changing. Additionally, most of our tests cannot be directly repeated since the test material or condition is consumed or changed by the running of the tests. All of these factors tend to reduce the resolution of our measurements. This is compensated for or at least offset in that agricultural equipment is usually more forgiving than equipment in some disciplines. It is not necessarily lower technology but is usually lower precision in usage and our measurement systems reflect this. We are not NASA precise but we have acceptable accuracy for agricultural measurements.

Considering this general testing regime and our previous measurement systems experience, we identified the requirements for a data acquisition system that would be of maximum benefit to us. These requirements, in their approximate order of priority to us, are listed below.

1. The entire system must be able to function reliably and quickly in the agricultural test environment.

2. The entire system must be portable and self-contained.

3. The system must be flexible, allowing for multiple types of test setups, and be able to be switched between different test setups quickly and easily.

4. The system must handle multiple types of transducers and allow direct connection to those transducers with built-in or no signal conditioning.

5. The system must be easy to use and smart enough to assist the operator in setting it up.

6. The system must have built-in real time display and calculation capabilities and provide quick and easy post test data analysis.

7. The system should be affordable and replaceable.

REVIEW OF THE AVAILABLE HARDWARE

Once these requirements were agreed on, we set out to determine which could be realistically achieved. We first arranged to use several different systems representative of what is available. We attempted to used each of these in our regular tests to evaluate how well they met our needs. This paper mentions several products by manufacturer or brand name. This is not meant to be an endorsement or advertisement nor is it meant to suggest that there are not other products from other manufacturers. There are many products and many manufacturers and we evaluated only a few of the possibilities.

The first system we looked at was a Campbell Scientific 21X with a 12 bit A/D. This is a relatively unsophisticated but very complete datalogger. Its advantages were that it was flexible, reliable and low in cost, about $3,000. On the disadvantage side, this system was difficult to adapt quickly to different test setups, had relatively slow sampling rates (5 to 10 samples/sec maximum) and had no built in analysis capabilities.

The second system we used was a custom built eight channel 12 bit system leased from the John Deere Technical Center. This was a system that Deere had developed in-house for their specific measurement needs. It is not commercially available. Its advantages were that it was very flexible, had fast sampling rates (up to 10000 samples/sec) and could provide some data analysis on site. The disadvantages of this system were the concerns about availability (Deere is in the business of making farm equipment rather than leasing data acquisition systems), the concerns about long term reliability and support and the rudimentary data display capabilities.

The third system was a commercially available stand alone 8 bit data acquisition system from Somat. The advantages of this system were excellent portability, adequate sample rates (2000-3000 samples/sec) and an interface to a PC for immediate display and analysis. The disadvantages were the high cost ($15,000 for an eight channel system), inflexibility to be quickly customized for different tests and the limited resolution of the 8 bit A/D.

As we worked with each of these three systems we realized that the features we needed and liked most would require a system based around some form of a computer. A laptop or notebook computer seemed the natural choice so we investigated options that were based on such computers.

We first considered a notebook combined with a separate commercially available data acquisition box connected to the serial port. Systems like this were available for a total cost of around $8,000 and had the advantage of working with any computer and being immediately available. Their disadvantages were the increased number of pieces, a lessening of the flexibility and portability and the requirement to work with two separate manufacturers. Examples include almost any laptop or notebook combined with data acquisition systems like the Keithley Metrabyte 575 box or the Adac Midas 100 box.

We then considered notebooks combined with separately available bus data acquisition cards, either in an internal bus slot or an external docking station card slot. Systems like this were available for a total cost of around $5,000 to $7,000 and had the advantage of being very flexible. Their disadvantages were the increased number of pieces, the need for a portable computer that had a standard bus slot or expansion stations and the requirement to coordinate with several separate manufacturers. Additionally, we judged these systems to require the most initial set up work. Examples of systems include any portable computers with internal bus slots or external expansion stations combined with data acquisition cards like the Metrabyte or Analog Devices products.

We finally considered notebooks with custom internal cards. A few of these were available for around $4,000 to $6,000, total cost. The advantages to systems like this were that they required the least effort to set up, involved working with only one manufacturer, were relatively low cost and were small and portable. The disadvantages were the limited selection and some lack of flexibility. Examples of systems like this include the Elexor TD4000, based on a Toshiba 1000.

REFINEMENT OF THE REQUIREMENTS

Following evaluation of these various systems, we moved into the second phase of our decision process. Here we carefully reviewed our list of needs and wants. For each item we analyzed what it was we were asking for, what it was we really needed and based on our experiences, how much of what we wanted that we could realistically achieve.

1. We decided that the requirement of being able to function reliably in the agricultural environment would be adequately met if the system was rugged enough to function inside the operator's cab of a moving agricultural vehicle while powered from the vehicle.

2. For the portable and self-contained requirement, we decided the system had to be moveable, in a briefcase sized package and fit into the operator's station of self-propelled agricultural vehicles with no significant modifications to the cab.

3. The requirement of handling multiple types of transducers and of being able to connect directly to those transducers with minimum signal conditioning led us into detailed considerations of A/D performance and resolution, particularly 12 bit vs 16 bit A/D's.

   In general, A/D performance is a tradeoff. The greater the number of bits, the greater the resolution, but also the greater the conversion time. For our system, we felt the sample rates and hence the conversion times that we needed could be lower than what is current state of the art. For our field measurements, we commonly sample in the hertz range (usually around 100 to 250 hz), rarely in the kilohertz range, and never in the megahertz range. Accordingly, we attempted to trade off speed for increased resolution by using a 16 bit A/D. This had the added benefit of allowing us to do away with signal amplification and thus remove the calibration uncertainties amplification can introduce.

   We feel it is acceptable for us to measure to ± 0.5 percent of a transducer's range. In the case of a 20,000 lb load cell, this would mean we would be able to measure to the nearest 100 lbs. To accomplish this we feel that the measurement system should resolve to or have a count of at least one order of magnitude less than that minimum measurement, that is, at least 0.05 percent of full scale.

If we use thermistors for temperature measurement rather than thermocouples, the lowest voltage levels that we encounter as signals are those from our strain gauge transducers. With our standard 5 volt excitation these signals are in the range of 8 to 10 millivolts at full scale output. The A/D's that we looked at typically worked in the range of either ± 5 or ± 10 volts full scale. Based on our transducers, we concluded that we could accept the requirement that the transducer output signals would always be within the -5 to +5 volt range. This allowed us to plan for an A/D that worked in that range rather than in the -10 to +10 volt range, effectively doubling the resolution for a given A/D.

A 12 bit A/D has a theoretical least count of 1/4096 or 0.02 percent of its full scale. A 16 bit A/D has a theoretical least count of 1/65536 or 0.001 percent of the same voltage. A 12 bit A/D with ± 5 volts full scale and a gain of 1 has a least count measurement of 2.4 millivolts. This is 30 percent of the 8 millivolts (0.008 volt) full scale signal of our strain gauge set and is insufficient resolution for our needs. A 16 bit A/D with ± 5 volts full scale and a gain of 1 has a least count measurement of 0.15 millivolts. This is 2 percent of the 8 millivolts (0.008 volt) full scale signal of our strain gauge set and is still not adequate for us. By going to an internal gain of 100 on the 16 bit A/D unit, or in other words mapping ± 0.05 volts across the full scale of the A/D, we reach a least count of 0.0015 millivolts which is .02 percent of an 8 millivolts full scale signal. This is more than adequate for our measurement needs and would allow us to measure our strain gauge transducers outputs without external signal amplification.

Accordingly, we planned for a 16 bit A/D with an internally adjustable gain up to at least 100. Boards that we saw with adjustable gain typically were either 1, 8, 64, 128, or 1, 10, 100, 1000, so this was well within the range of possibility. It was also important for us that this gain be software selective since we typically mix various types of transducers in our test setups.

Another area of signal conditioning concern was pulse inputs like speed pickups and switches. Most commercial boards have some form of pulse counting but do not handle it in the same way as the A/D reads multiple channels of voltage. To keep things common, we decided to construct selectable frequency to voltage converters on each of the input channels. Doing this allowed us to always measure a standard voltage input whatever the transducer. The F/V's that we built reflect the realities of our test needs. They produce a linear 0 to 5 volt output over a series of frequency ranges typical of those that we encounter in our test work. Included with the F/V's is a variable frequency oscillator to allow calibration.

The last area of signal conditioning concern was filtering of the signals. To date we have done nothing on the analog side to filter. For those instances where we require filtering we produce a digital equivalent by performing multiple readings on the channel and averaging those readings to produce one value. This has been acceptable for our current needs but is an area that we may change in the future.

4. The requirement of flexibility for multiple types of test setups and the requirement of being easy to use and quick to set up needed to be met both by construction and by programming. To achieve this goal, we felt the system had to be able to be set up and used by any of our employees in a minimum amount of time without an intensive course in electronic measurement.

On the construction side, we defined a single standard connector and cable for all our transducers. We selected a setup that had sufficient lines (seven) to be able to carry all of our excitation voltages as well as the signal and the ground. Each transducer was then wired with a standard connector so that the correct excitation was automatically connected when the transducer was plugged in. This simplified the connection procedure; you select the transducer you want and plug it in to the channel you want to read it on.

On the programming side, we outlined an interactive program that would define, edit, save and recall multiple test setups, prompt the operator through calibration procedures and provide real time display of data values.

5. The requirement for built-in and immediate display and calculation capabilities was achieved by specifying that a complete laptop computer be part of the system and by planning for the program to provide this feature.

6. The low cost requirement was relative, depending on how well the system met the other requirements. The general goal was decided to be that the system be priced low enough that we would not be afraid to use it vigorously and would be able to afford to replace it if it failed. For us, this meant the total system cost needed to be less than $10,000.

DEVELOPMENT OF THE SYSTEM

After our hardware review, we concluded that nothing that we had found was quite right for us but we also saw that all of the things we wanted seemed possible. We decided that the best solution would be to combine some development of our own with some existing products. We proceeded to specify and develop a two-part eight channel system. This consists of a front end or a transducer connection box and a top end or a data processing head. The transducer connection box provided the power supplies for the transducers, performed frequency to voltage conversion and calibration, and served as a central cable connection point. This box then fed the signals to the data processing head which was a purchased and slightly modified notebook with a custom A/D card.

THE FRONT END

The combination power supply, F/V and connector interface box is shown in FIGURE 1. It was designed and built in-house and has the following specifications and characteristics:

As a power supply, it can provide power for all our transducers, supplying concurrently 2 amps of 5 volts (strain gauge circuits), 2 amps of 9 volts (computers), 2.5 amps of 12 volts (radar guns, switches), 0.25 amps of -12 volts (some special transducers) and 0.25 amps of 24 volts (pressure gauges). All of this comes from a single 12 volt input.

As a frequency to voltage converter, it can convert frequencies ranging from 10 to 10,000 hz into voltages from 0 to 5 volts. All eight channels are switchable between frequency to voltage conversion and straight voltage input. There is a built-in frequency generator that can be set to produce known frequencies to facilitate calibration for the F/V's.

As a connector interface, the box has eight input channel connections with our defined standard connector. All our transducers are modified to use the same 9 pin plastic Canon connectors and the wiring is arranged such that any transducer hooked to the box automatically receives its correct powering voltage and returns the signal on the correct lines. A single cable then carries all the signals from the box to the data head. The box also contains a separate connector for manual control of the test start and stop. A switch can be connected with a standard cable and placed wherever it is most convenient to use.

FIGURE 1. Combination Power Supply, F/V and Connector Interface Box.

THE DATA PROCESSING HEAD

The data head is shown in FIGURE 2 and is somewhat of a hybrid. We selected a custom internal card that had been designed to fit in the modem slot of a specific notebook and modified it so we could attach it to other notebooks and laptops. We have attached it either underneath the computer in a custom built cradle as is shown in FIGURE 2, or in some cases inside the computer in the space for the modem or some other proprietary card. The basic requirements for the computers that we used were that they have disk storage, the ability to display plots on the screen, and some way to connect to the internal computer bus.

FIGURE 2. Data Head.

The card that we adapted has eight channels of low level voltage inputs (differential input). This can be switched internally to 16 channels of higher level voltages (single ended inputs) but we left it in the differential mode and planned our system around eight data channels. The card has four amplification gain levels or voltage measurement ranges: X1 or ± 5 volts (high level signals), X10 or ± 0.5 volts (miscellaneous transducers), X100 or ± 0.05 volts (strain gauges, pressure transducers) and X1000 or ± 0.005 volts (strain gauges). The voltage ranges are software selective. The A/D is 16 bit giving a theoretical resolution of 1 in 65,536 parts. At the highest amplification range, this is 0.15 microvolts per part. Conversion time for the A/D limits the maximum number of A/D conversions to about 1500/second at the highest gain level, to about 6000 conversions per second at the next highest level and to about 12000 conversions per second at the lower levels. Theoretically these become the systems maximum sample rates, although in actual use our controlling software cannot achieve these rates and is thus the speed limiting factor.

The card also has seven digital I/O lines that can be used as inputs or outputs. These allow both switching and switch sensing at TTL level voltages and one line is used as the test start/stop switch. There are also two channels of analog output with 12 bit resolution that allow computer controlled 0 to 5 or -5 to +5 volt outputs.

THE SOFTWARE

The software for the system was a major element in achieving the ease of use that we desired. We felt the program should do everything the operators wanted but should not make them do anything they did not want to unless it was critical to obtaining good data. Balancing completeness against ease of use can be a problem for a general purpose program but we feel we struck an acceptable compromise.

At start-up, a main menu allows the selection of previous test setups, the definition of new test setups, or the modification or continuation of testing with the current test setup. Test setups can be stored and recalled at will. They include information that defines the test goals and conditions, the instrumentation setup, the calibration values and optional additional calculations made with raw data values.

When a test setup has been selected or defined, the operator is prompted through the voltage scaling measurements for the zero values and the calibration values. The program is designed to check that impossible conditions do not exist and that appropriate ranges are selected for the expected loads.

The program has a real time display of the incoming data. The operator can select between a strip chart plotted format or a tabular printed format. Display occurs both before, during and after a test run.

Sampling is done as scans, maximum speed samples taken sequentially from all specified channels followed by a pause. The scan rate is adjustable down from a maximum value. As the number of channels read increases, the maximum attainable rate decreases. If the channel readings are displayed, this additionally reduces the scan rate. Since the programming is the speed limiting factor, the maximum attainable rate is also affected by the speed of the computer; the faster the processor, the faster the maximum rates. For a 12 mhz 80C286 processor, the following maximum scan rates are attained:

8 channels, all displayed - 90 scans per second
8 channels, only 1 displayed - 100 scans per second
8 channels, no display - 110 scans per second
1 channel, displayed - 200 scans per second
1 channel, no display - 650 scans per second

Test data sampling can be started, stopped, restarted, or ended when the operator desires, either directly with a keystroke, remotely with a switch, or logically when a specified channel reaches a specified level. During a test run the data is held in the computer memory. At the completion of a test run a summary of the data is displayed. The test data can be immediately stored on disk or it can be plotted and reviewed first then stored or discarded.

The program stores data in a standard AFMRC test file format, as ASCII comma delimited values, prefaced by a test description header containing the set-up information. These data files interface with existing AFMRC data acquisition programs, plotting programs and file structures. They can also be read with standard spreadsheet, database or word processing programs.

The plotting programming is designed to quickly create the plots that we most commonly use. Most often this is either a time history plot as shown in FIGURE 3 or time at level histogram as shown in FIGURE 4. Additionally, the program can produce X-Y plots and perform regressions on the data as shown in FIGURE 5. On all graphs, multiple channels and multiple test files can be plotted together.

The program is written and compiled in Microsoft Quickbasic with some of the speed critical areas done in assembler or C.

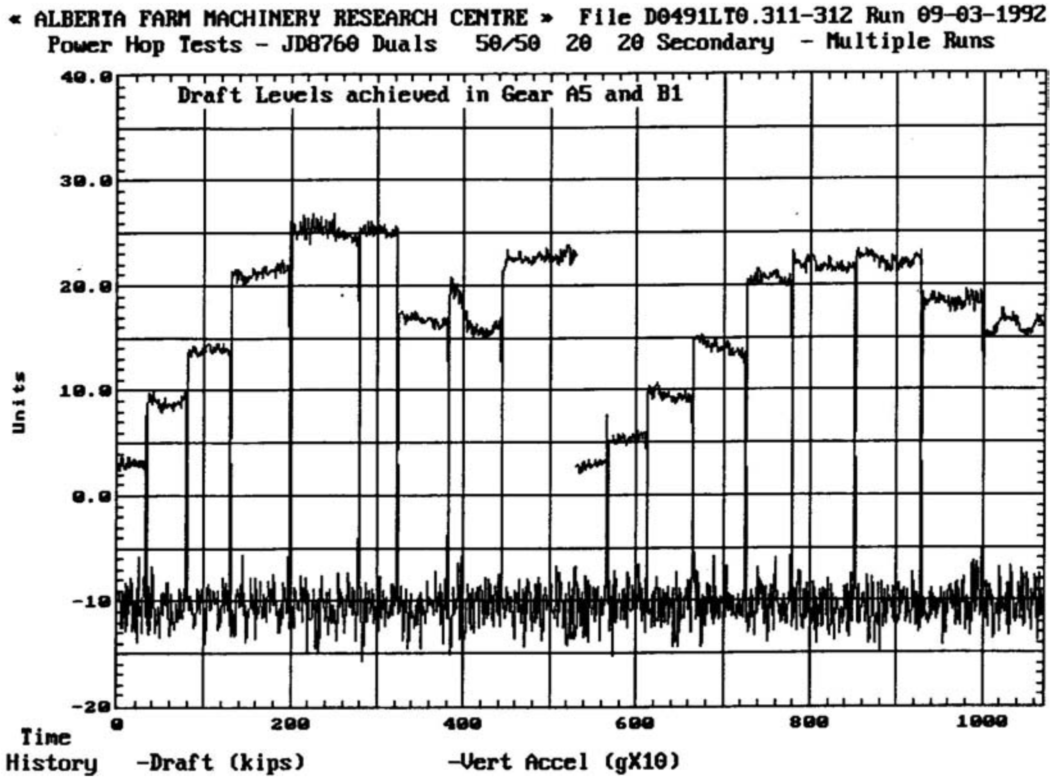

FIGURE 3. Time History Plot.

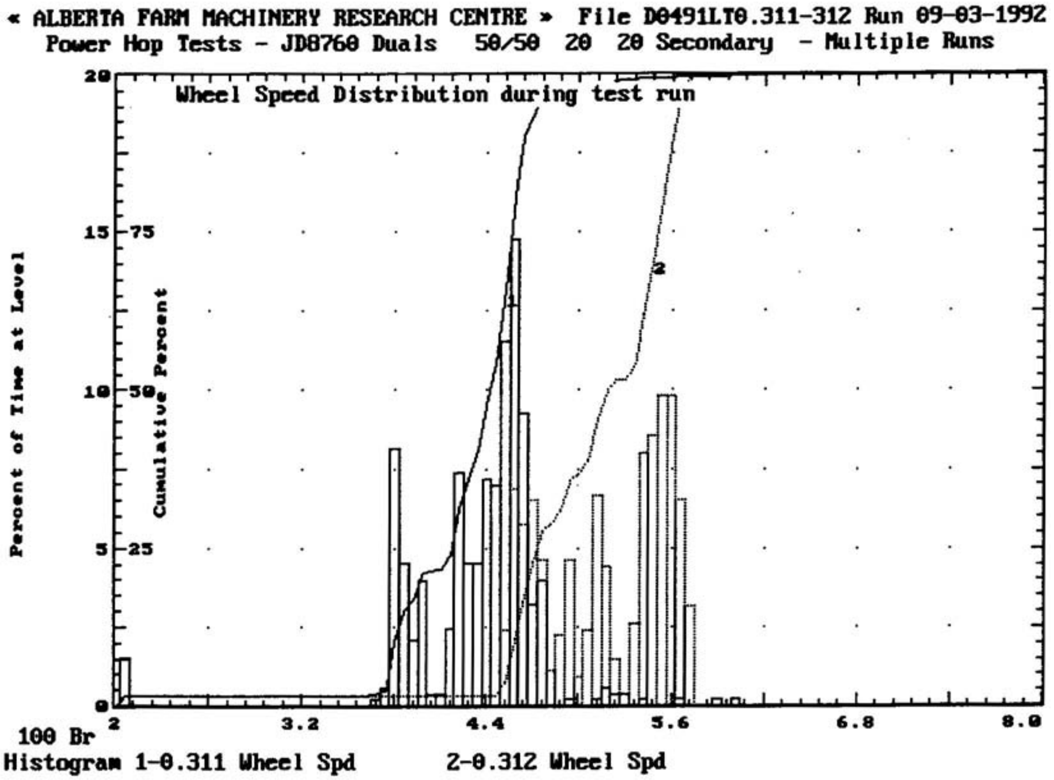

FIGURE 4. Time at Level Histogram.

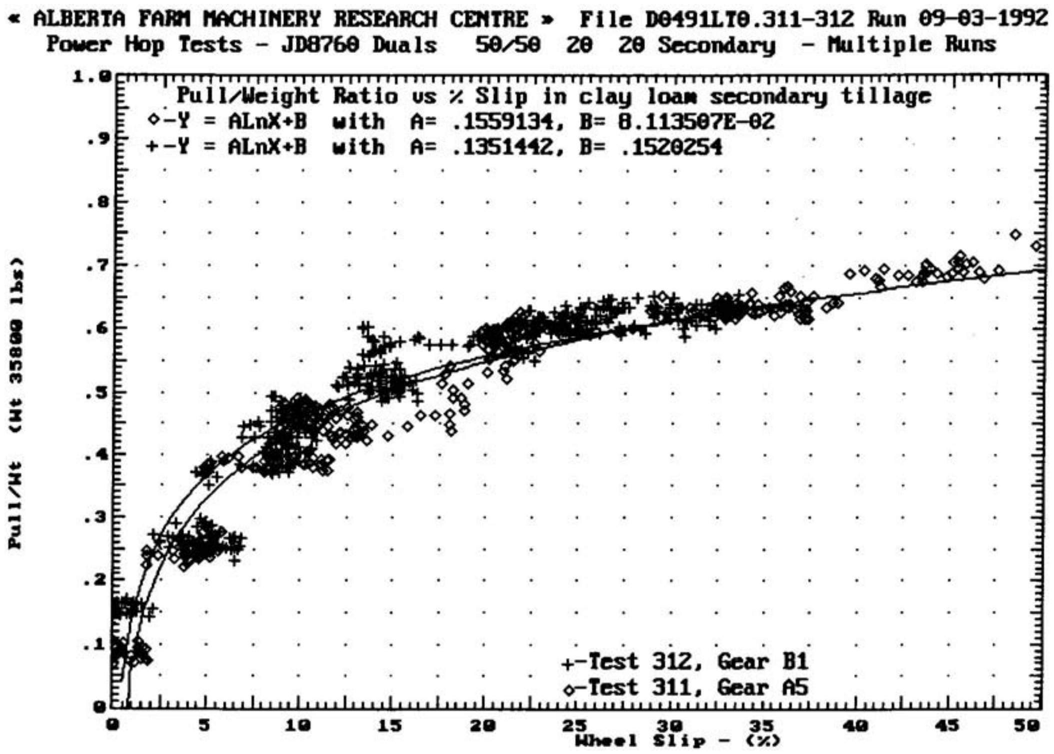

FIGURE 5. X-Y Plots and Regressions on Data.

USE EXPERIENCES AND CONCERNS

As AFMRC staff have integrated this system into our test and measurement work, we have noted several benefits.

First, we have successfully entered a "plug and chug" measurement mode where all our staff can run their own tests directly. The staff members needing the data determine what they want, select the transducers needed, plug things together, take the data and determine immediately if the results are accurate and adequate.

Second, the data acquisition process is more transparent than in the past. This allows our staff to spend more time and effort working with the data, rather than working on the measurement process. At the same time, the staff feel that they better understand the data acquisition process now than they have in the past. This has reduced the tendency to request or plan impossible things.

Third, our staff have a better understanding of their data and of the quality of their data. This is the result of direct involvement in the taking of the data and the ability to see and interpret results as they are being taken.

Fourth, the quality of the data being taken has improved. The availability of computerized assistance during setup removes several common errors that tend to degrade the data. Additionally, the ability to review and interpret freshly taken data allows the operator to notice and correct any measurement setup problems immediately.

Fifth, there is now a greater tendency to measure something rather than just to wonder about an effect. When the setup and measurement process is simple and fast it often takes less time to measure an effect than it does to speculate about what it is.

Finally, as a side benefit, we no longer need our electronic support person to be present and assisting when we are running tests. This has freed up this individual to concentrate on maintaining and improving our abilities to test and to measure.

FUTURE ENHANCEMENTS

As we have gained experience with the system, we have also observed changes that we have either made or would like to make in the future.

On the hardware side, we quickly wanted a more powerful laptop; no matter how fast things happen, it seems they are not fast enough. Our first system was based on an 4.7 mhz 8088 laptop with a floppy disk for storage. While sample rates on this system were acceptable, the time required for the computation and storage produced a 2 to 4 minute delay between test runs. Review of the data was equally slow and the overall test rate was only marginally acceptable on complex multiple channel tests. Our second system is based on a 12mhz 80286 laptop with a hard disk for storage. With this system there is negligible delay between tests and data can quickly be displayed and reviewed. We continue to store the data on floppies as a backup but the hard disk has proved reliable thus far.

A major concern with both the first and the second system has been the difficulty in reading the laptop display in bright sunlight. The first laptop has a reflective non-backlit passive matrix screen which is small, low contrast, and only CGA (640x200) resolution. This display is marginal for plotting but is still easier to read than the larger and higher resolution screen of the second laptop. This second screen is a high quality backlit nonreflective DCGA (640x400) passive matrix screen. While this screen works well in dim or indirect light, it is very hard to read in bright direct light. Unfortunately, almost all modern laptops now have screens similar to this one. We are investigating the possibility of changing both units to reflective active matrix screens. Although these are not common, they offer a much higher contrast image under bright light.

On the programming side, we expect to continue improving the ease of use of the system. In our existing program, we plan a link to our transducer database so that current zero, calibration and setup data will be entered automatically when the transducer part number is specified on setup. We also expect to add additional error checking capability, including the ability to highlight probable errors during the actual test run instead of just during the setup. We are presently working on a simpler and more accurate control of the scan timing and expect that this will allow us to increase the maximum sample rates.

Longer range, we expect to add additional data acquisition modes to the program. The current program handles straight time history acquisition. We expect to add histogram or time at level acquisition both one and two dimensional, rain flow counting, peak-valley or max-min counting and burst mode time histories. As we migrate to faster laptops we also plan to add additional "during the data acquisition" data analysis capabilities.

CONCLUSION

Has this project been a success? For us, the answer is an unqualified yes. We are presently using two systems almost continuously, both in the field and in our laboratory tests. Work on the first system began in the winter of 1990. By the summer of 1991, we were productively using this first prototype in the field. During the winter of 1991, we built a second system that incorporated refinements in overall speed and ease of use. This system has been in use since the spring of 1992. We also built and supplied a third system to the Northern Montana College for use in the Northern Tractor Resource Center. Other agricultural manufacturers that we work with have also inquired about obtaining systems for their own tests.

No data acquisition system can be perfect, but the system we have developed certainly works well for us. It is simple, reliable and meets all of the goals we set. The payoff for developing it has come both in the ease with which we make measurements with it and in the quality of the information that we obtain from it.