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Tractors and Tillage Implements Performance

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Abstract

An instrumentation system was developed and mounted on an MF 3090 tractor to measure the various performance parameters of the tractor and attached implements. The system was intended to be used for the formation of a database of draft requirements of most of the tillage implements. The system is designed to measure: drawbar pull, three-point linkage forces, rear and front wheel forces, PTO torque, ground speed, tillage depth, fuel consumption, engine speed, and fluid temperatures. Two precision wheel torques and weight transducers three-point linkage-implement force and depth transducer were also developed as part of the tractor data acquisition system. The wheel torque and weight transducers measures the torque and forces acting on the tractor wheels, whereas the other transducer was used to measure the vertical and the horizontal forces on mounted implements of categories II and III. Field tests were conducted with the developed tractor data acquisition system to measure draft of four primary tillage implements on sandy loam soils. The effects of speed and depth on draft of the implements were investigated and a general regression equation to predict draft of the implements was also developed.

Introduction

Performance data from various tractors and implements are essential for farm machinery management and manufacturers alike. Proper selection of tractors and implements for a particular farm situation can be determined from these performance parameters. These data can also be used to evaluate various farm machinery systems to determine the relative merits of each system. As field machines contribute a major portion of the total cost of crop production systems, proper selection and matching of farm machinery is essential to reduce significantly the cost of ownership and operation of farm machinery. Also, efficient operation of tractors and implements is a main concern for farmers because of the rising cost of fuel and other operating costs.

A number of instrumentation systems based on datalogger and microcomputers to determine the performance of tractors and implements have been reported in literature. Al-Suhaibani et al. (1994) has made an extensive review on different instrumentation systems to measure the performance parameters of tractors and implements. Majority of them were designed exclusively for a particular tractor and not easily adoptable to other tractors. And also, most of the developed systems were used to measure major parameters like drawbar pull, ground speed, and drive wheel speed.

A fully instrumented tractor was developed and tested by agricultural engineering department at King Saud University. A mobile instrumentation system was developed for tractors up to 150 kW covering the range of the most common agricultural wheel tractor in use in Saudi Arabia. A drawbar dynamometer, two wheel torque transducers, and a three-point linkage dynamometer were developed as part of the instrumentation system to measure drawbar pull, wheel forces, and three-point linkage forces, respectively. The developed system was mounted on an MF 3090 tractor to monitor and record its various physical parameters. Also, other transducers were

mounted on the tractor to monitor ground speed, implement working depth, fuel consumption, engine speed, temperatures (engine oil, transmission oil, front axle oil, engine coolant, and engine fuel), PTO torque, right and left position of front wheel steering, and angular position and indication of the lifting position of the three-point linkage. The transducers were calibrated using the relevant standard load cell and a Novatech indicator. For each calibration test, load was applied in equal steps from zero to the maximum allowed load for the transducer under test and then reduced in approximately the same steps back to zero. A linear regression analysis was carried out on the data collected for each transducer under calibration using the lotus software package. Field tested were conducted with the instrumented tractor, and various work was published describing in details the various stages of this project, these works include Al-Suhaibani et al, (1994), Al-Janobi A; Al-Suhaibani S A (1995), Al-Janobi A; Al-Suhaibani S A (1996), Al-Suhaibani S A; Al-Janobi A (1997), Al-Janobi A, et al (1997).

Objectives

The objective of this paper is to review the various works, which had been carried out to develop an instrumented tractor at the department of agricultural engineering, King Saud University, Riyadh, Saudi Arabia which will include the following:

1. Development of a tractor instrumentation system
   - a). General setup of the instrumentation system,
   - b). Development of a wheel torque and weight transducer,
   - c). Development of a three-point linkage-implement force and depth transducer,
   - d). Setup of a calibration rig in the mobile instrumentation laboratory,
   - e). Further development by gradate student
2. Conducting field experiments.

Tractor Instrumentation System:

General Setup of the Instrumentation System:

An instrumentation system was developed and installed on a Massey Ferguson (MF) 3090 tractor to measure tractor and implement performance parameters. A drawbar dynamometer, two wheel torque transducers, and a three-point linkage-implement force and depth transducer were developed as part of the instrumentation system to measure drawbar pull, wheel forces, and three-point linkage forces, respectively. The developed system was mounted on the MF 3090 tractor to monitor and record its various physical parameters. Also, other transducers were mounted on the tractor to monitor ground speed, fluid temperatures (engine oil, transmission oil, front axle oil, engine coolant, and engine fuel), PTO torque, right and left position of front wheel steering, and angular position and indication of the lifting position of the three-point linkage.

The block diagram of the instrumentation system is shown in Figure 1. The drawbar dynamometer consists of two load sensing clevis bolts. The force exerted by the implement can be measured by a strain gauge bridge within the clevis bolts. Tractor ground speed was measured using a fifth wheel attached to a suitable position underneath the tractor. An RS shaft encoder of 360 pulse/rev mounted on the fifth wheel was used to measure the distance traveled and hence the actual ground speed. Fuel consumed was measured by a fuel flow unit. The unit gave a single output pulse per revolution of the wheels. Engine speed was measured by an RS optical proximity sensor mounted at the front of the tractor near to the crankshaft pulley. Fluid temperatures were measured by using platinum resistance thermometers. A torque meter was used to measure the torque required to operate the Power Take Off (PTO) driven implements; Two inductive proximity sensors mounted on brackets attached to the left and right bump stops on the front axle were used to indicate right and left position of front wheel steering. Development of wheel torque transducers and three-point linkage-implement force and depth transducer will be discussed in the following sections.

A datalogger mounted on a platform to the left of the tractor operator was used to scan and record the output signals from the transducers in the system. The strain gauge transducers in the instrumentation system were connected to the datalogger through amplifier boxes, which also provided a regulated power supply for giving excitation to the transducers. The activity unit was used to provide excitation to both the datalogger and transducers with input supply from the tractor 12 V battery and also it was used to indicate the activity performed during field tests. The design and setup of the strain gauge amplifier and activity units are presented in Al-Suhaibani and Al-Janobi (1996).

Development of Wheel Torque and Weight Transducers

Most of the wheel torque and weight transducers developed are designed to work in specific tractors for the required precision and usually are quite expensive. There is need for a general precision wheel torque transducer suitable for the most common agricultural tractors in the field. To fulfill this requirement, two wheel torque and weight transducers, one for the front wheel and the other for the rear wheel suitable for any common agricultural tractors had been developed. These transducers were used to measure the torque and weight acting on the tractor wheels. The developed transducer has to replace the standard wheel center of the tractor under consideration and connect the wheel hub to the wheel rim. Figure 2 shows the tractor wheel fitted with the developed wheel torque and weight transducer. The transducer incorporated three load sensing clevis bolts. Its force measurement on the revolving wheel combined with the measurement of angular position of the wheel by a position transducer, shaft encoder is used to determine the total horizontal and vertical components of forces. The design details and other aspects of the transducer can be found in Al-Janobi et al. (1997). The system performed well during the field operation and results obtained show the transducer accuracy is acceptable.

Development of a three-point linkage-implement force and depth transducer

A three-point linkage–implement force and depth transducer was developed for the MF 3090 tractor as a tool for measuring the draft forces. It was designed specifically for use with mounted implements of categories II and III, measuring forces in the longitudinal and vertical planes. The lower links of the three-point linkage dynamometer were modified to accommodate the sensing elements by preserving the original geometry and the use of the P.T.O. shaft was not restricted. The details concerning the design and other aspects of the transducer can be found in Al-Janobi and Al-Suhaibani (1996). Field tests were conducted to monitor the performance of the three-point linkage-implement force and depth transducer. The details of the field experiments and results concerning the performance of the transducer are given in Al-Janobi (2000). The data acquisition system together with the three-point linkage-implement force and depth transducer yielded an effective means of measuring the draft of mounted implements of categories II and III.

Setup of Calibration Rig in a Mobile Instrumentation Laboratory

A self –contained mobile instrumentation laboratory was designed to accommodate all for the transducers in the instrumentation system and the calibration rig for the calibration of the transducers at site. The instrumentation laboratory also includes a personal computer for development of the different datalogger test programs and for the data analysis at site. Figure (3) shows the mobile instrumentation laboratory with the MF 3090 tractor.

A Transducer calibration rig was designed and fabricated to calibrate the major transducers in the instrumented tractor. The rig was used to calibrate the force transducers: drawbar dynamometer, wheel torque meters, PTO torque meters, and three-point linkage-implement force and depth transducer of the instrumented tractor. The rig could be assembled in three different modes to accommodate and calibrate the various force transducers of the instrumentation system. In the first mode, the load sensing clevis bolts, two for the drawbar dynamometer and three for each wheel torque meter could be calibrated against a 100 kN standard load cell. In the second mode, the PTO torque meter could be calibrated against a 5 kN standard load cell on a torque arm. In the third mode, the two EORTs and the top link load cell of the three-point linkage-implement force and depth transducer could be calibrated against a 100 kN standard load cell. The details concerning the design and other aspects of the calibration rig and calibration procedure are given in Al-Janobi and Al-Suhaibani (1995).

Further Development by graduate students

The process of development of the instrumentation package didn't stop. The graduates students have made some development to some parts. Alblaikhi (1998) he had developed a processing unit to monitor drawbar performance, The added system included a laptop computer, two data acquisition cards and a speed signal conditioning circuit. The laptop displayed the measured parameters and analyzed data on the console in a well-designed format. It also signaled on faulty transducers and gave an indication of stability of the tractor. The system was field tested on an asphalt surface and showed acceptable performance. The system provided accurate and reliable results.

Almajhadi (2004) has made substantial development to some parts of the instrumentation package, his contribution was as fallows:

a). Designing on electric circuit to determine the angle of the first transducer on front and rear wheels.

b). Changing the design of the fifth wheel to become smaller and wider and increasing the number of pulses from 20 per turn to become 360 pulses. This design has increased the accuracy of reading of the actual tractor speed.

c). The accuracy of the measurement of the speed of the front and rear wheels of the traction was increscent up to 5 times. That was achieved by increasing the number of pulses from 100 per turn of the wheel to 500 pulses.

d). developed a microprocessor unit for monitoring performance of agricultural tractor with mounted implement. The system has been implemented by MS Visual C++ programming tools and has a visual interaction screens. The program consists of three sub-programs to scan sensors, converting to engineering values, and processing and presenting the results as curves and digital. The system can read up to 10 scan per second. Figure(4)

Field Experiments

As part of forming a database of draft requirements of tillage implements in sandy loam soils, experiments were conducted with the MF 3090 instrumented tractor and data acquisition system to measure draft requirements of commonly used primary tillage implements on sandy loam soils (Al-Suhaibani and Al-Janobi, 1997; Al-Janobi and Al-Suhaibani, 1998).

Experiments were conducted at King Saud University's Agricultural Research and Experimental Farm at Dirab. A set of primary tillage implements comparing three chisel plows of different shanks, an offset disk harrow, a moldboard plow and a disk plow were used in the experiments for evaluating draft requirements over a wide range of speed and depths. These implements are representative of the standard primary tillage implements most commonly used for seed bed preparation in Saudi Arabia. The parameters investigated for the draft measurements were forward speed and tillage depth. For the three chisel plows, four speeds and three depths were used in combination for 36 treatments and for the other three implements six speeds and three depths were used to give a total of 54 treatments. The parameters set and measurements made during the tillage experiments, table (1).

The on-board datalogger in the instrumented tractor measured and recorded implement draft, implement working depth and tractor speed during field operations. The average values for draft of all the implements during the tillage experiment at different speeds and depths are given in table 1. These results showed a significant increase in draft in all the treatments with an increase in tillage depth. For all the tillage implements except the chisel plows, draft was divided by the implement width to obtain specific draft per unit width, whereas draft was divided by the number of tools to obtain specific draft per tool for the chisel plows. An increasing response in specific draft was observed with an increase in tillage depth and speed for all the implements tested in the field (Al-Janobi and Al-Suhaibani, 1998). The biggest changes were

mostly due to the result of changing operating depth of the implements. The effects of soil strength and shape and size of implements were also found to be significant in all these implements.
Multiple regressions were performed on the calculated values of specific drafts of all the implements using a General Linear Model (GLM) procedure in SAS (1986). A number of different best-fit unit draft equations were formulated for each implement. The general form of the equation used in this analysis was a function of travel speed and tillage depth. The regression equation giving a good fit with a maximum coefficient of regression, R2 and variables that have significant effect on the draft of all the implements is:

$$UD = \beta 0 + \beta 1 * D + \beta 2 * D2 + \beta 3 * S + \beta 4 * S2 + \beta 5 * D * S \qquad (1)$$

Where as:
UD = Unit draft, N/mm or N/tool
D = Tillage depth, cm
S = Travel speed, km/h
β0, 1, 2,3,4,5 = Regression coefficients

The data presented in equation form would enable anyone to prediction of unit draft for all the implements tested on sandy loam soil within the ranges of speed and depths used. Shows an example prediction of unit draft for the chisel plow 1, where the data points correspond to all the tillage depths used. The least square fit with an R2 of 0.998 indicates that the model has overestimated draft/tool for the chisel plow by approximately 0.115 % with a constant of 0.61 N/tool. This example shows that unit draft can be predicted reasonably for each of the implements tested.

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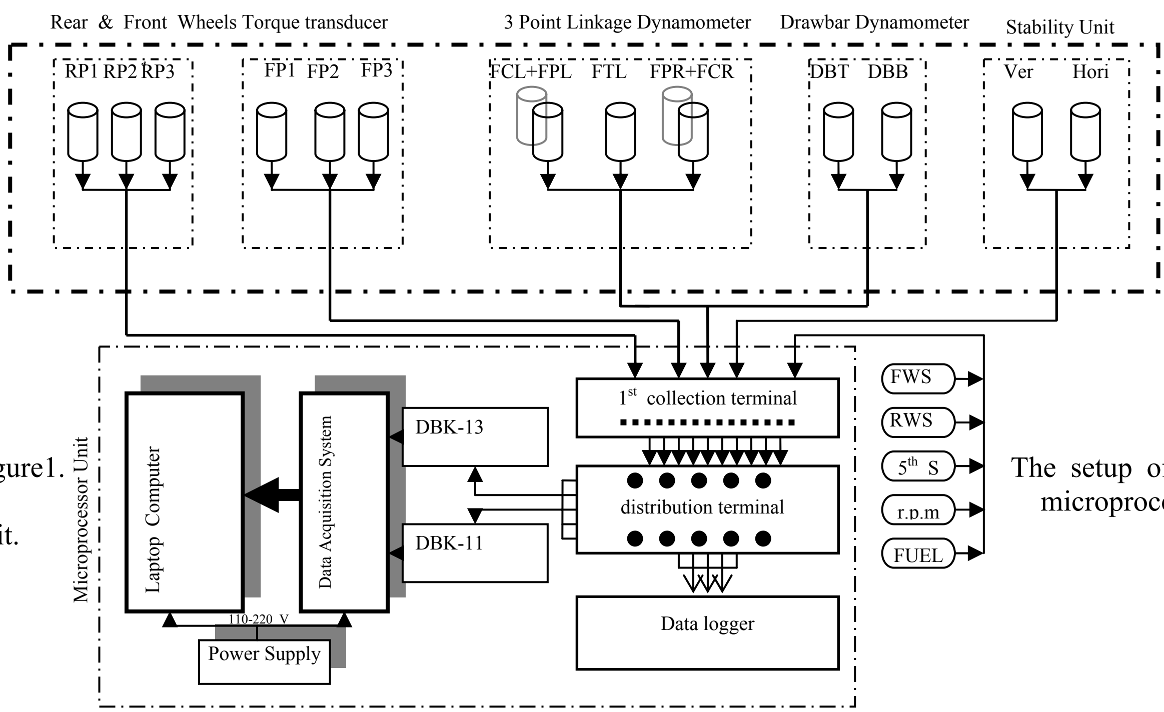

Figure1. The setup of the microprocessor unit.

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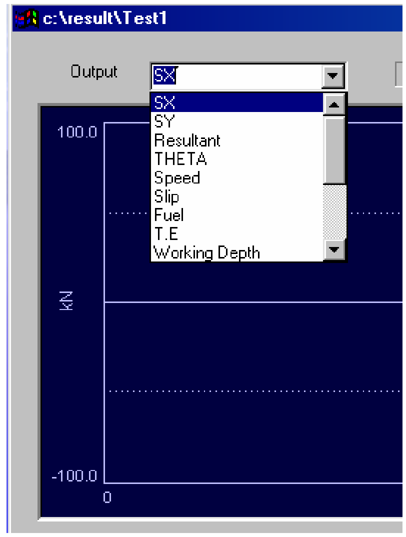
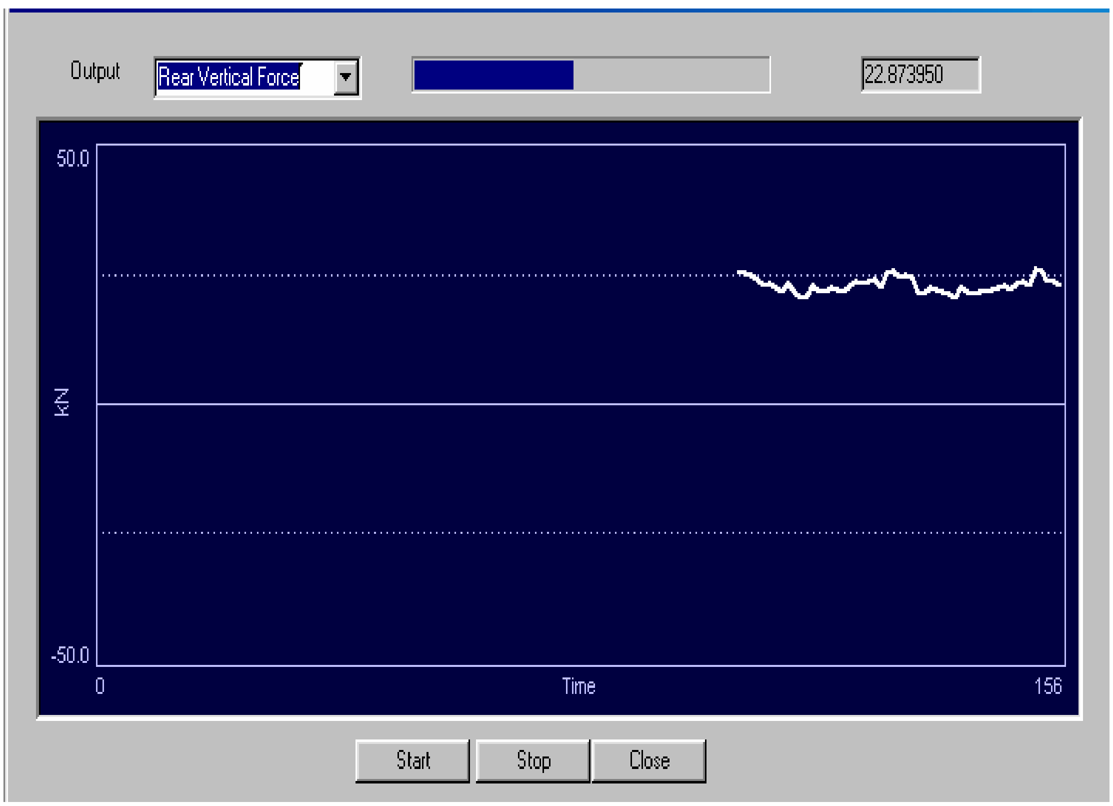
Figure 2. Tractor wheel fitted with the wheel torque and weight transducer.

Figure 3. Overall view of the mobile instrumentation lab and the MF-3090 instrumented tractor.



(a)



(b)

Figure 4. The result can be seen as Indicator, Digital value, and Curve (a) for one of the performance component, which can be selected from the menu (b)

Table 1. Parameters set and measurements made during the tillage experiments

Implement	Speed (m/s)	Avg.draft (kN)	SD* (kN)	Avg. draft (kN)	SD* (kN)	Avg.draft (kN)	SD* (kN)
		for first depth		for second depth		for third depth	
Offset disk harrow	0.84	2.15	0.517	3.08	0.060	5.62	0.456
	1.39	3.26	0.440	4.39	0.410	6.91	0.388
	1.76	4.81	1.735	5.53	0.617	7.40	0.835
	2.02	5.46	0.156	6.57	0.587	9.56	0.656
	2.31	6.25	0.412	7.43	0.637	10.57	0.596
	2.50	6.78	0.498	7.88	0.520	11.37	0.788
Moldboard plow	0.80	4.08	0.110	5.29	0.111	8.03	0.115
	1.32	4.51	0.219	5.99	0.071	8.56	0.364
	1.68	4.99	0.250	6.69	0.298	9.01	0.241
	1.94	5.36	0.093	7.29	0.165	10.02	0.348
	2.23	5.98	0.705	7.97	0.240	11.40	0.172
	2.53	6.79	0.594	9.21	0.100	13.00	0.398
Disk plow	0.86	3.50	0.102	5.34	0.134	6.76	0.078
	1.27	4.15	0.146	5.51	0.173	7.15	0.059
	1.60	5.10	0.185	6.25	0.113	8.09	0.661
	1.90	6.11	0.174	6.96	0.168	8.76	0.308
	2.18	7.30	0.617	7.99	0.449	9.56	0.532
	2.54	8.96	0.225	9.91	0.229	11.13	0.305
Chisel plows							
Plow 1	0.73	3.14	0.521	5.54	0.377	8.33	0.625
	1.23	3.76	0.139	6.56	0.378	9.60	0.841
	1.74	4.11	0.236	7.41	0.142	10.58	0.103
	2.37	4.59	0.247	8.01	0.684	11.92	1.113
Plow 2	0.74	3.01	0.235	5.38	0.338	8.19	0.146
	1.17	3.61	0.172	6.44	0.279	9.47	0.178
	1.82	3.74	0.161	7.11	0.221	10.51	0.754
	2.30	4.37	0.264	7.85	0.296	11.33	0.427
Plow 3	0.72	7.52	0.593	11.00	0.717	15.90	0.841
	1.19	7.86	0.285	11.49	0.421	16.58	0.652
	1.75	8.13	0.112	11.84	0.513	17.13	0.579
	2.30	8.41	0.673	12.34	0.597	18.31	0.979

* Standard deviation