# Instrumentation Package for Monitoring Tractor Performance

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## ABSTRACT

AN instrumentation package was developed to monitor tractor performance on a John Deere 4440 tractor. Performance variables measured included front and rear wheel rotational speed, ground speed by Doppler radar, engine speed, differential speed, drawbar pull, axle torque, and fuel consumption.

Speed comparison tests were conducted to determine relative differences between travel speed sensors (front wheel and Doppler radar) and clocked measurements. Travel speeds obtained by using the front wheel sensor were 4 to 15% less than timed speeds. The percent difference between radar ground speeds and clocked speeds were small on smooth surfaces. For infield conditions, radar ground speeds deviated from clocked speeds by an amount approximately equal to the pitch of the tractor.

Results of field performance tests were documented for three tractor/implement combinations. When pulling a JD 230 tandem disk, tractive efficiency and engine load increased 10.6% and 33.4%, respectively, when the operating gear was increased from second to third. Specific fuel energy requirements decreased 24.6%. When "shift up and throttle back" techniques were practiced, specific fuel consumption decreased 14.8% when pulling a JD 340 offset disk and 8.3% when pulling a JD 100 chisel plow.

## INTRODUCTION

Farmers continue to be faced with the double-edged problem of rising production costs and falling market prices. As a result, they need every advantage in order to produce crops as efficiently and cost effectively as possible. Although farmers cannot control many of the variables influencing production costs, there are areas which can be controlled and improved. One such area is the operation and management of agricultural equipment, especially tractors.

Ricketts and Weber (1960), Larsen )1981), and others have performed studies that indicate farmers are not making efficient use of tractors. Larsen reports that even for heavy field operations, Montana farmers use only 60% of the rated engine capacity. At the same time, these farmers are not incorporating "shift up and throttle back" techniques to reduce fuel consumption.

At Texas A&M University, a 3-year project was initiated to document and improve tractor performance for Texas farming operations. Specific objectives of the project are as follows:

1. Document tractor performance (including power and energy requirements) and tractor load use cycles on Texas farms.
2. Provide information to the operator that will assist in improving overall tractor performance.
3. Evaluate economic implications of improved tractor performance (i.e., potential energy savings and economic benefits of better tractor management).

In order to accomplish the stated objective, the project was separated into four phases. The goal of Phase I was to develop and install an instrumentation package for monitoring tractor performance on a John Deere 4440 diesel tractor. Goals of Phase II were to develop a microcomputer-based data acquisition system for monitoring, storing, and processing tractor performance data, and to begin documentation of tractor performance on Texas farms. The goal of Phase III was to develop an operator-feedback system for use with the microcomputer-based data acquisition system. This operator-feedback system would provide information to the operator for optimizing tractor performance. Documentation of tractor performance of Texas farms would then be completed and in Phase IV, the economic implications evaluated. The work reported herein represents achievements made during Phase I of the project.

## LITERATURE REVIEW

Instruments to measure tractor field performance have existed since the early 1900's. Extensive reviews of equipment used to measure and monitor tractor performance have been performed by Langewisch (1976), Grevis-James (1980), and Green (1983). Research emphasis in recent years has been in the development of performance monitors and computer-based data acquisition systems.

### Tractor Performance Monitors (TPM)

Tractor performance monitors developed thus far can be grouped into three categories: engine power, drawbar power, and overall efficiency. Recent examples of each are described below.

Schrock, Matteson, and Thompson (1982) developed a gear selection aid to monitor current tractor performance, predict performance in alternate gears, and inform the operator of the optimum gear and

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throttle setting. Fuel consumption rate and projected fuel savings were also displayed. The monitor used input measurements of engine speed, transmission speed, and injector pump rack position, which had been previously correlated to engine load and fuel consumption rate, to predict performance in alternate gears.

Grevis-James and Bloome (1982) developed a drawbar power monitor for pull-type implements. Drawbar pull, ground speed, and drive wheel slip were measured and processed by system electronics. An analog meter, mounted in the tractor cab, displayed the performance measurements.

Numerous efficiency monitors have been introduced, including designs by Clark and Gillespie (1979), Mertins and Gohlich (1981), and Renault Agriculture (Philippe, 1983).

Clark and Gillespie described an efficiency monitor which provided an efficiency number based on inputs of travel speed, fuel consumption rate, and draft. Using this method, the operator could adjust engine speed and gear setting to achieve the highest efficiency number.

Mertins and Gohlich described an efficiency monitor which measured fuel consumption rate and ground speed. The monitor display showed the operator a graph of cost versus workrate, and by a lighted LED, indicated the actual working point.

Renault Agriculture developed an efficiency monitor known as the Ecocontrol. The Ecocontrol measured engine speed and exhaust gas temperature and related them to engine performance. The operating point of the engine was represented by the intersection of the two needles that crossed over a pattern designating various operating zones of the engine. For economic operation, the operator adjusted engine speed and transmission gear to keep intersection of the two needles within the green operating zone.

**Computer-Based Data Acquisition Systems**

Technical advancements in the development and use of computer-based data acquisition systems have greatly increased the ability to measure and record tractor performance. These systems vary in complexity from the measuring of one or two parameters, as common in performance monitors, to the monitoring of many parameters simultaneously. Their construction, capacity, and versatility varied according to individual data collection needs or requirements. Recent examples are described below.

Grevis-James et al. (1983) reported on a data acquisition and processing system using two Rockwell AIM 65 microcomputers. One microcomputer was installed on the tractor to collect, display, and store data on magnetic tape. The other microcomputer was operated from the laboratory and was used to process and transfer data stored on magnetic tape to an IBM 370 mainframe computer for analysis.

Tompkins and Wilhelm (1982) described an elaborate system with variable sampling rates from 0.01 second to 4.5 minutes. Operator control was through a keyboard and video monitor located inside the tractor cab. Extensive software programs were available for system check, testing, and data collection.

Luth, Floyd and Heise (1978) described a sophisticated microcomputer-telemetry system used in acquiring field data. Their system had the input capability of 31 channels and could scan up to 50,000 samples per second. Data were processed in the field at a mobile receiving station with outputs being immediately displayed, printed, or graphed.

## DEVELOPMENT OF THE INSTRUMENTATION PACKAGE

The principal goal of Phase I of the TPM project was to instrument a tractor and measure overall performance. Sensors were installed to measure ground speed by Doppler radar, engine speed, front and rear wheel rotational speed, differential speed, drawbar pull (draft), axle torque, and fuel consumption.

A two-wheel drive John Deere 4440 diesel tractor equipped with strain gage mounted axles was provided by Deere & Company for the duration of the TPM project. The project also received a commercially available tractor performance monitoring unit from Dickey-john Corporation. The Dickey-john Tractor Performance Monitor II (DjTPMII) consisted of a Doppler radar unit, an engine rpm sensor, a magnetic pickup sensor used for determining drive wheel speed, an implement status switch, and a computerized console which displayed information from the sensors.

Radar ground speed measurement was obtained by using the frequency signal generated from the DjTPMII radar unit. The radar unit and mounting bracket were installed so that the face of the unit projected onto an unobstructed view of the ground when facing rearwards.

Engine speed was obtained by using the frequency signal generated by the DjTPMII engine rpm sensor. The engine rpm sensor fit between the existing mechanical tachometer drive sender and the tachometer cable leading to the operator station. As the sender rotated, the sensor generated a frequency signal proportional to engine speed.

The front wheel rotational speed sensor consisted of a 95 tooth spur gear mounted on the inner-hub of the front right wheel (Fig. 1). The sensor was constructed using a design supplied by Iowa State University (Bedri et al., 1981). Speed was determined by counting the number of gear teeth detected by a magnetic pickup positioned above the gear.

Rear wheel rotational speed was used for determining drive wheel slip. The rear wheel rotational speed sensor consisted of a 95 tooth spur gear which was split and mounted over the right rear axle. Speed was also measured with a magnetic pickup positioned above the gear.

Rotational speed of the differential was measured with a magnetic pickup installed over the final drive reduction gear which drove both axles. Rotational speed of the reduction gear thus represented average rear axle speed.

Draft measurement was achieved with a proving ring load cell mounted on the front end of the existing drawbar. The load cell consisted of a full Wheatstone bridge assembly with 350 Ohm gages located in the proving ring so as to maximize effects of axial forces and minimize effects of bending moments.

Left and right rear axle torques were measured with torque sensors mounted on the rear axles. The torque sensors consisted of strain gage assemblies bonded to the exterior surface of each axle at points located just inside the axle housing. Lead wires from the strain gages were routed through the axle, then soldered to a five-pin connector which was threaded into the end of each axle.

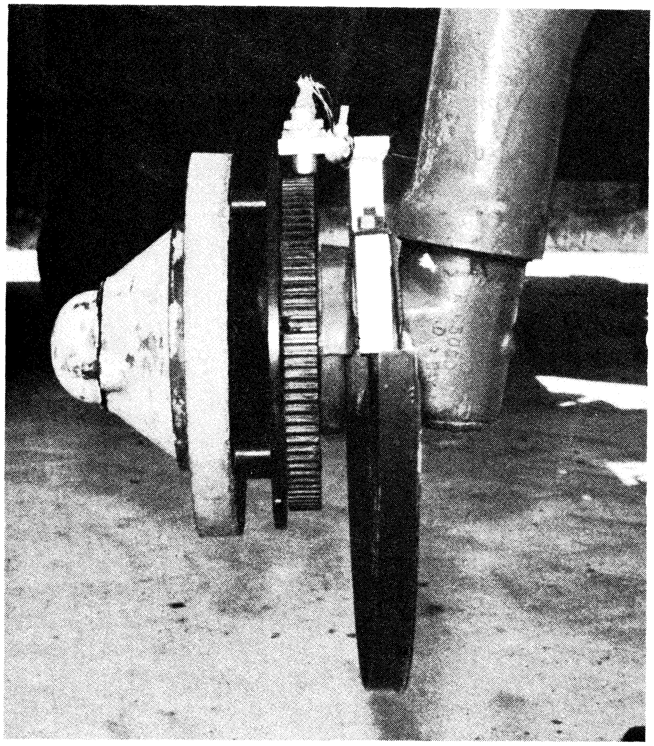

**Fig. 1—Rotational speed sensor consisting of a 95-tooth spur gear mounted on inner hub of front wheel with magnetic pickup positioned above the gear.**

Slip rings were used to provide continuous signal contacts while the axles rotated. Mounting brackets were installed on the tractor to support signal cables leading from the slip rings to the tractor cab.

Fuel consumption was measured with a Fluidyne Instrumentation Model 1214-D flow measurement system (Fig. 2). Primary components of the system were a four-piston positive-displacement flow transducer with two-phase (quadrature output) photo-optical transmitter, a thermocouple probe installed in-line before the flow transducer for sensing fuel temperature, and a flow indicator/totalizer which displayed digital values of average fuel flow (lb/h), fuel temperature (°F), and totalized values of fuel metered (lb).

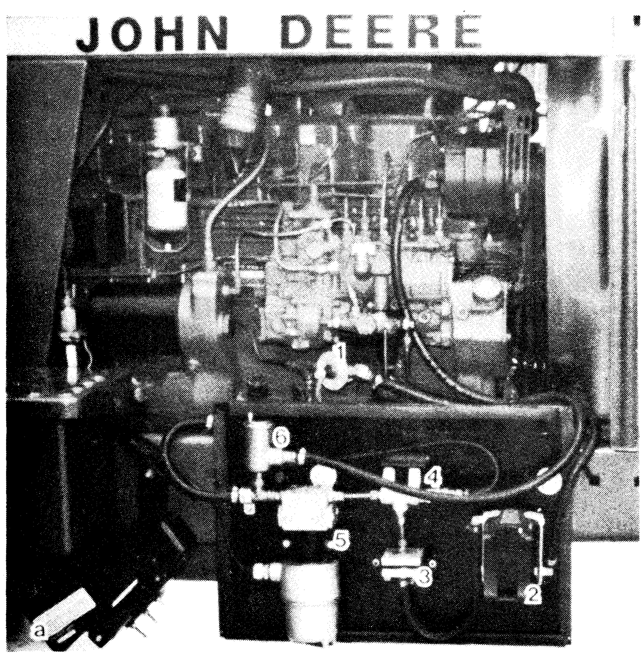


**Fig. 2—Fuel consumption measurement system: (1) A three-way valve which directs fuel in the normal manner or through the metering system; (2) Standard J. D. fuel filter; (3) 100 micron filter; (4) Thermocouple probe installed in-line before the flow transducer; (5) Four-piston positive-displacement flow transducer with two-phase photo-optical transmitter; (6) Vapor eliminator which also serves as routing point for return fuel flow.**

## FIELD PERFORMANCE TESTS

### Recording and Data Handling

Initial checkout of sensors and preliminary field tests were performed while the microcomputer-based data acquisition system was being designed and built. Consequently, a Campbell CR5 digital recorder, manufactured by Campbell Scientific, Inc., was used during Phase I of the TPM project. The recorder was a self-contained field data acquisition unit which mounted in the left window of the tractor cab. It was powered by the tractor's 12 VDC power supply.

The digital recorder consisted of four analog and four digital input channels. Signal conditioning consisted of separate bridge power supply modules for each analog channel and a pulse counter module for each digital channel. Analog and digital channels were monitored at a rate of 10 scans per minute, resulting in 80 recorded measurements per minute. Recorded data represented time-averaged values during each sampling period (0.10 min) and were obtained in a simultaneous process.

Once measured, data were recorded on audio cassette tape in ASCII form. Approximately 160 min of data could be recorded per tape at the scan rate used. Data were later transferred to a DEC PDP 11/34 minicomputer via an audio/cassette terminal interface and stored on floppy disks for permanent storage.

Detailed data analyses were performed on both the DEC minicomputer and an IBM 370 mainframe computer. The Statistical Analysis System (SAS) mathematical and graphical procedures were used extensively for most data analyses.

### Speed Comparison Tests

Following the initial checkout of the instrumentation package, travel speed tests were conducted to determine relative differences between travel speed sensors (front wheel and Doppler radar) and clocked measurements. Except on asphalt surfaces, front wheel speed measurements were consistently less than clocked measurements, with differences varying between 4 to 15% depending on the load. This condition has commonly been referred to as negative front wheel slip.

The percent difference between radar ground speed measurements and clocked measurements was generally small on smooth, flat surfaces. Under field conditions, radar ground speeds deviated from clocked speeds by an amount approximately equal to the pitch of the tractor. This claim is supported by Richardson et al. (1983) who suggested that single beam radar units were affected by translational and rotational motions of a vehicle. Hand held measurements of the radar angle setting, obtained by using the manufacturer's calibrated face plate with plumb bob, showed differences due to weight transfer to vary 1 to 2%, depending on implement load. Actual differences between radar speeds and clocked speeds varied from −2 to +4% during loaded conditions. Compounding errors were caused by slippage of the radar unit on its mounting bracket, thus altering the calibrated measurements.

TABLE 1. TRACTOR SPECIFICATIONS.

| | |
|---|---|
| Tractor: | John Deere 4440 |
| Engine: | Diesel |
| Power: | Rated 97 kW PTO |
| Transmission: | Power shift (8-speed) |
| Tires: | Rear - 18.4 R 38 8 ply<br>Front - 10.0 - 16 6 ply |
| Weight with duals (approximate): | Total - 88.1 kN<br>Front - 26.4 kN<br>Rear - 61.7 kN |

Note: Tractor was equipped with duals during all tests.

TABLE 2. SOIL DATA SUMMARY FOR EACH TESTING DATE.

| Date | Implement tested | Depth, cm | Gravimetric moisture content, % | Bulk density, g/cm$^3$ |
|---|---|---|---|---|
| 06-23-84 | JD 230 disk | 0 - 10 | 18.6 | 1.24 |
| | | 10 - 20 | 24.8 | 1.55 |
| | | 20 - 30 | 23.3 | 1.67 |
| 06-28-83 | JD 340 disk | 0 - 10 | 16.8 | 1.24 |
| | | 10 - 20 | 23.2 | 1.55 |
| | | 20 - 30 | 22.9 | 1.67 |
| 07-28-83 | JD 100 plow | 0 - 10 | 18.6 | 1.21 |
| | | 10 - 20 | 24.3 | 1.51 |
| | | 20 - 30 | 22.9 | 1.66 |

## Field Performance Tests

Upon completion of the travel speed comparison tests, field tests were conducted to determine tractor performance for tractor/implement combinations used locally by Brazos and Burleson county farmers. The test site chosen was a 12 ha field plot located approximately 13 km west of College Station, TX, in Burleson County. The soil classification was Norwood silty clay loam. Implements used during the field performance tests were: (a) a JD 230 tandem disk (7.6 m wide), (b) a JD 340 offset disk (4.9 m wide), and (c) a JD 100 chisel plow (4.9 m wide). Tractor specifications for the field performance tests are shown in Table 1. Soil data for each of the testing dates are summarized in Table 2.

Performance data for the instrumented JD 4440 tractor and three implements are shown in Table 3. When practical, "shift up and throttle back" (SUTB) was used to show effects of gear and throttle setting on performance. The SUTB technique was applied while pulling the JD 340 disk and JD 100 plow. However, the tractor engine would stall when pulling the JD 230 disk at reduced throttle settings.

For the JD 230 disk, tractive efficiency and engine load increased 10.6% and 33.4%, respectively, when the operating gear was increased from second to third. Volumetric fuel consumption increased 14.8%. However, specific fuel consumption actually decreased 14.2% because of the increased engine loading. When SUTB was used, specific fuel consumption decreased

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TABLE 3. TRACTOR PERFORMANCE SUMMARIES FOR SELECTED TRACTOR/IMPLEMENT COMBINATIONS.

| Implement | Gear | Ground* speed, km/h | Drive wheel slip, % | Engine speed, rpm | Engine power, kW | Axle power, kW | Drawbar power, kW |
|---|---|---|---|---|---|---|---|
| JD 230 disk | 2 | 3.3 | 19.3 | 2146 | 55.8 | 45.4 | 29.4 |
| JD 230 disk | 3 | 5.0 | 17.1 | 2090 | 74.4 | 64.9 | 46.5 |
| JD 340 disk | 3 | 5.6 | 10.3 | 2129 | 57.2 | 49.9 | 33.7 |
| JD 340 disk | 4 | 5.7 | 10.8 | 1697 | 59.2 | 52.1 | 38.8 |
| JD 100 plow | 4 | 7.3 | 9.0 | 2148 | 56.6 | 49.8 | —† |
| JD 100 plow | 5 | 7.4 | 6.9 | 1636 | 55.4 | 49.0 | — |

| Implement | Gear | Tractive efficiency, % | Engine load, % | Volumetric fuel consumption, L/h | Specific fuel consumption, g/kWh |
|---|---|---|---|---|---|
| JD 230 disk | 2 | 64.8 | 57.5 | 29.7 | 437.5 |
| JD 230 disk | 3 | 71.7 | 76.7 | 34.1 | 375.2 |
| JD 340 disk | 3 | 67.6 | 59.0 | 29.9 | 429.0 |
| JD 340 disk | 4 | 74.5 | 61.0 | 26.5 | 365.4 |
| JD 100 plow | 4 | — | 58.4 | 26.5 | 365.4 |
| JD 100 plow | 5 | — | 57.1 | 26.9 | 389.4 |

*Ground speed determined by adjusted front wheel speed measurements.
†JD 100 plow was three-point hitch mounted; therefore, draft was not measured.
Note: Mean values represent average of 300 values taken over 30-min sampling periods.

TABLE 4. SPECIFIC ENERGY AND DRAFT REQUIREMENTS FOR TRACTOR AND IMPLEMENTS.

| | | | Energy* | | | | Draft | |
|---|---|---|---|---|---|---|---|---|
| Implement | Ground speed, km/h† | Plow depth, cm | Implement, kWh/ha | Tractor axles, kWh/ha | Engine, kWh/ha | Engine fuel, kWh/ha | Draft force, kN | Draft per Unit width, kN/m |
| JD 230 disk | 3.3 | 15 | 11.7 | 18.1 | 22.4 | 122.1 | 31.9 | 4.2 |
| JD 230 disk | 5.0 | 15 | 12.2 | 17.1 | 19.6 | 92.1 | 33.4 | 4.4 |
| JD 340 disk | 5.6 | 20 | 12.3 | 18.2 | 20.8 | 112.0 | 21.8 | 4.5 |
| JD 340 disk | 5.7 | 20 | 13.9 | 18.7 | 21.2 | 97.1 | 24.6 | 5.0 |
| JD 100 plow | 7.3 | 20 | — | 13.9 | 15.8 | 86.0 | — | —‡ |
| JD 100 plow | 7.4 | 20 | — | 13.5 | 15.3 | 76.1 | — | — |

*Based on theoretical field capacity.
†Using radar ground speed measurements.
‡JD 100 plow was three-point hitch mounted; therefore, draft was not measured.

## Monitoring Tractor Performance

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14.8% when pulling the JD 340 disk and 8.3% when pulling the JD 100 plow.

Specific energy and draft requirements of the tractor and implements are shown in Table 4. For the JD 230 disk, specific fuel energy requirements decreased substantially (24.6%) when operating in third gear. Energy requirements agreed with values determined for the JD 230 disk by Stephens et al. (1981). For implements JD 340 and JD 100, specific fuel energy requirements decreased when SUTB techniques were practiced.

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