# Instrumentation for the measurement of draught animal performance

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## SUMMARY

AN INSTRUMENTATION *package has been developed to monitor the performance of draught animals and implements while work is in progress. The prototype has been used successfully on research stations and farms in Africa and India to collect data on selected physiological and mechanical variables which were previously inaccessible. Based on these successful trials, an electronically advanced modular version has been developed. Because of its small size and powerful electronics, the modular package is more versatile under field conditions than the prototype and simpler to operate, while at the same time enabling better data handling.*

## INTRODUCTION

The need to measure accurately and reliably the work done by draught animals is widely recognised. Comprehensive assessment of animal performance must include information on the energy expended by the animal in doing useful work and on the physiological responses of the animal to work.

The power demand of a cultivating implement is the product of the horizontal draught force and the speed of progression. The most important physiological responses to work that can be measured on working animals without causing them too much discomfort are changes in heart rate, breathing rate and temperature (Pearson, 1985; Rautaray, 1987). Oxygen uptake is the most direct measure of energy expenditure (Brody, 1964), but is difficult to measure.

The Institute of Engineering Research of the Agriculture and Food Research Council (subsequently referred to as AFRC Engineering), UK, has developed an instrumentation package to monitor as comprehensively as possible the performance of animals working in the field (O'Neill et al,1987). The package has been tested in various animal traction programmes of the Overseas Division of AFRC Engineering.

Trials in Ethiopia, Burkina Faso, Botswana and India focused on oxen working with cultivation implements. The instrumentation package can, however, be easily adapted for use with other draught animals, such as equines and camels which have been investigated in Morocco, and is readily applicable to research programmes designed to investigate diversified uses of animal draught power. The versatility of the package has led AFRC Engineering to collaborate with other research institutions; for example, the International Livestock Centre for Africa (ILCA) commissioned it to develop an instrumentation package to suit ILCA's research needs.

# DESCRIPTION OF THE INSTRUMENTATION PACKAGE

## Requirements

To be able to measure the performance of draught animals and cultivation implements while work is in progress, the package must be portable, durable and cause a minimum of interference with normal working practices. The sensors must be easy to attach and acceptable to the animals, i.e. they must not hurt them or subject them to stress, and farmers must be convinced that the sensors are harmless to their animals.

The package should be able to operate at high environmental temperature and humidity for periods of up to 4 hours. It should also be able to display performance data while the animals are working, i.e. it must function as a monitor as well as a logger. And last but not least, there must be a facility for processing and summarising data immediately after acquisition to enable rapid decisions on test or experimental procedures.

## Design

### The prototype package

The instrumentation package designed by AFRC Engineering combines three subsystems—the sensors, the signal conditioning circuits and a powerful microcomputer that acts as the logger/monitor. To provide the monitoring capability, sensor outputs are converted to digital format before inputting to the logger. This also facilitates the processing of logged data in the field. Although the method is more complex than, for example, recording analogue signals on magnetic tape, its complexity is fully justified by the immediate access to the data.

The variables chosen as indicators of animal-implement performance are shown in Table 1 together with some information on sensor operation. They have been grouped under 'mechanical' and 'physiological' variables and are described in more detail below.

**Table 1**. *Variables describing animal-implement performance and methods of sensing.*

| Variable | Method of sensing | Location of sensor |
|---|---|---|
| **Mechanical** | | |
| Draught force | Strain-gauge load cell | Between yoke and implement in draught chain |
| Draught angle | Potentiometric inclinometer | Suspended below load cell |
| Distance travelled | Radar device relying on Doppler shift of microwave radiation[1], or trailing wheel | Fixed to implement |
| **Physiological** | | |
| Heart rate | Detection of infrared absorptance of blood[1] | Arrays of emitters and receivers clipped to animal's ear |
| Breathing rate | Differential temperature signal during inhalation and exhalation[1] | Tube adjacent to animal's nostril |

| | | |
|---|---|---|
| Body temperature | Thermistor | On rectal probe |
| Stepping rate[2] | Accelerometer sensitive to fore-and-aft movement of leg | Front lower leg |

[1]Sensor designed and developed by AFRC Engineering.
[2]Two channels available.

Sensing the draught angle eliminates the need to include in the load cell a device measuring the horizontal pulling force, and this in turn simplifies the incorporation of the cell into the draught chain. Furthermore, by measuring the actual force in the load cell and its angle of application it is possible to determine the vertical load on the yoke.

Distance is measured using either a microwave radar device (excitation frequency 24 GHz) or a trailing wheel. The radar is more convenient than the wheel because it is compact and does not come in contact with the soil surface. Tests have shown the accuracy of the radar to be at least equal to that of the wheel, except where the ground is obscured by moving vegetation (Howell et al, 1986).

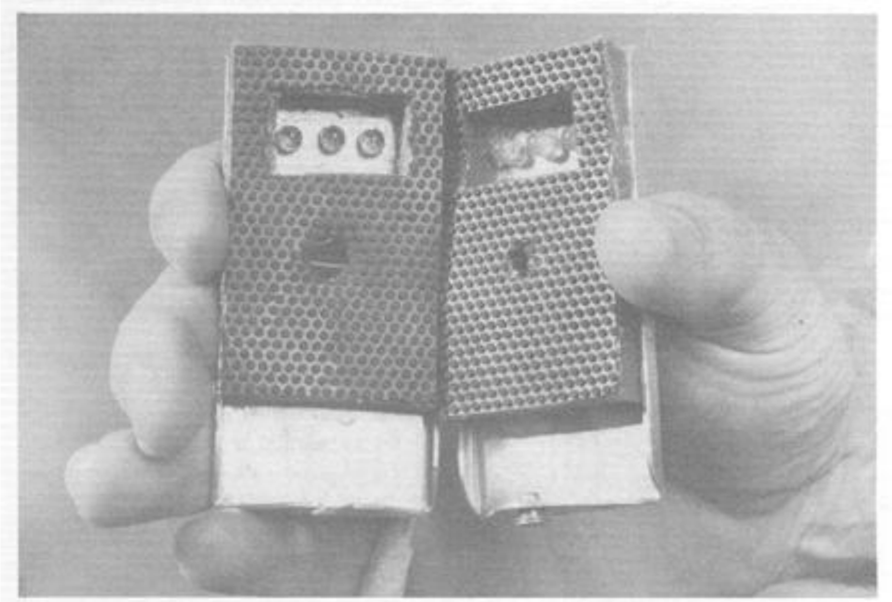
The radar sensor is usually set up to give a pulse at nominally 80-mm intervals. These pulse signals are used to compute three variables—work done, speed between pulses and instantaneous power.

Work done is computed in the logger by taking the average force observed between distance pulses, multiplying it by the distance travelled and summing the results. Because each distance pulse is recorded at the exact time at which it occurs, speed of travel during each pulse interval (i.e. every 80 mm or so) is computed using the time between pulses. The third variable, instantaneous power, is computed as the product of speed and average force between distance pulses.

A major criterion in the choice of physiological variables was acceptability of sensors, both to the animals and to their owners. The variables selected as suitable and useful were heart rate, breathing rate, stepping rate and body temperature.

Heart rate is measured by detecting the change in infrared absorptance of the ear as blood pulses through. This is done using an earclip sensor comprising two arrays of three diodes (Figure 1): one array emits near-infrared radiation and the other, on the other side of the ear, is sensitive to it. A signal conditioning circuit was made to give an electronic (‘square’) pulse coinciding with the peak surge of blood (i.e. maximum absorptance).

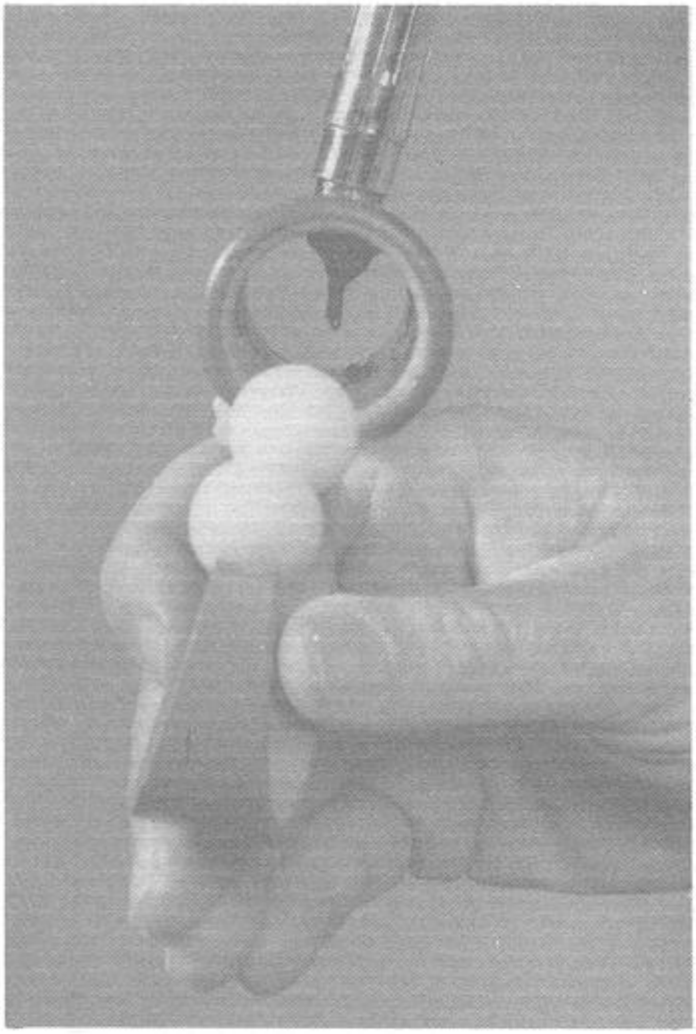
**Figure 1.** *The emitter (left) and receiver (right) of a bolt-on heart rate sensor.*



The sensor may be attached to the ear by a spring-loaded, clamp-type or bolt-on clip. The clamp and bolt-on types make it possible to control the compression on the ear, but they are more difficult to attach. The bolt-on clip is probably the most reliable, although it can only be used on animals with punched ears. Its other attraction is that it can remain in the ear for long periods of time, causing no more distress to the animal than an ear tag.

Breathing rate is determined by sensing air movement through a tube fixed near one of the animal's nostrils. Inside the tube there are two thermistors, one on either side of a small heater (Figure 2), which yield differential temperature signals dependent on the direction of the air flow during inhalation and exhalation. The differential temperature data obtained are then used to calculate the number of breaths per minute. This indirect technique of measuring breathing rate is preferable to using a flowmeter approach, because it avoids problems in the sensor caused by mucus and other foreign matter on a delicate mechanism.

**Figure 2.** *A view through a breathing sensor tube with the heater/thermistor assembly at the top and the nose clip in the foreground.*



The instrumentation package is equipped with two channels for measuring stepping rate, thus enabling both animals of a pair to be monitored. Stepping rate is measured by an accelerometer strapped to one of the animal's lower forelegs. The sensitive axis of the accelerometer is parallel to the direction in which the animal moves, and the peak acceleration in the stepping cycle is identified by a signal conditioning circuit. The peak generates an electronic (square) pulse signal which is logged in real time.

Earlier attempts to measure stepping rate included the use of a shock sensor to identify footfall and an infrared device which generated a signal when the legs crossed. Both devices were, however, found to be insufficiently reliable in the field.

The on-farm testing of the prototype package indicated a number of improvements that would considerably enhance its performance and increase its usefulness under field conditions. These are being incorporated into a modular instrumentation package described below.

## The modular instrumentation package

The microcomputer used in the prototype system has proved adequate for the logging and monitoring operations required and will continue to be used in the improved package. Similarly, the sensors will be retained. But the signal conditioning unit and the data management software are being modified.

**The signal conditioning unit.** During the developmental phase, the signal conditioning unit was carried in a back pack by the researcher. However, the pack is heavy and the researcher needs to walk alongside the animal, which can interfere with the work in progress.

To avoid these practical problems, the signal conditioning circuits have been miniaturised, divided into those dealing with mechanical and physiological variables, and housed separately in two small modules. Each module will be able to operate independently of the logger, accumulating up to 30 kbytes of data. Thus, in addition to processing signals, the modules will perform as low-capacity slave loggers programmed by the master logger (i.e. the microcomputer).

Data recorded by the modules will be transferred to the master logger at intervals ranging from perhaps 15 minutes to several hours, depending on the routine adopted. The researcher will thus need to approach the animals and implement under study relatively infrequently, leaving them to work undisturbed during data collection.

**Data management.** Analysis of the data gathered with the prototype package has suggested that work performance comparisons can be made with acceptable accuracy by studying only data related to important events, such as the physiological responses to changes in work output and the time taken for the responses to appear. It is therefore intended to include in the software an interactive capability, so that specified events can be recognised and data on them stored in detail. In those cases where specific events are highlighted, a less comprehensive record of the general progress of the work would be retained.

When operating in this ‘intelligent’ mode, it will be necessary for the slave loggers to be interconnected by a communications link. The link could also serve as a programming and data unloading facility, enabling the master logger to handle several slave loggers through a single port. However, where exact synchronisation or intelligent logging are not required, the slave loggers can work independently and the number of leads and their lengths can be reduced.

Partial communication between the slave loggers is also feasible. This would allow, for example, a detailed study of both animals of a pair—or indeed any number working together—in order to establish the animals' reaction to each other, while their collective output is recorded independently related through a real time base. The total effort of a team could also be logged to support an exhaustive study of an implement, where depth of work, angle of approach, rotor speed and wheel loading might be recorded in addition to the standard mechanical parameters.

Accommodating more powerful electronics in a smaller format will increase the versatility of the instrumentation package and make it more convenient to use in the field. Specifically, the advantages derived from miniaturisation are:

- Increased convenience and realism without the researcher being in continuous proximity to the animals;

- Ability to monitor mechanical and physiological variables separately; and
- Scope for expansion, e.g. to multiple animal monitoring or to detailed studies of implements.

The benefits of using advanced electronics in the package are:

- Increased data handling power and provision of slave memory;
- Ability to log independently of master logger;
- Capacity to program for special events ('intelligent' operation); and
- Easy operation in the field (less skill required from field operators).

## Applications

### Prototype package

The instrumentation package was developed specifically to improve the effectiveness of ox-powered cultivation, and because of this it had to be capable of logging reliably the performance of animals and implements in farmers' fields. Such logging was carried out successfully in July and October 1986 and 1987 by a team of researchers from AFRC Engineering and the Central Institute of Agricultural Engineering in Bhopal, India.

Further trials were conducted in cooperation with ILCA in the Ethiopian highlands. Their objective was to determine the performance of a pair of oxen pulling a traditional plough *(maresha)* or a broadbed maker or a sledge loaded with weights for calibration purposes. The performance of a single ox pulling a modified *maresha* was measured as well. All the trials, except the one involving the sledge, were carried out under true field conditions. Valuable data were collected on implement/soil interactions and the animals' physiological responses to the workload.

In general, a trial lasted 2 hours and data were recorded about every 20 minutes when the conditions of the trial were judged to be typical. These periods of data recording (or runs) lasted about 2.5 min and provided samples of representative information for about 10% of a trial.

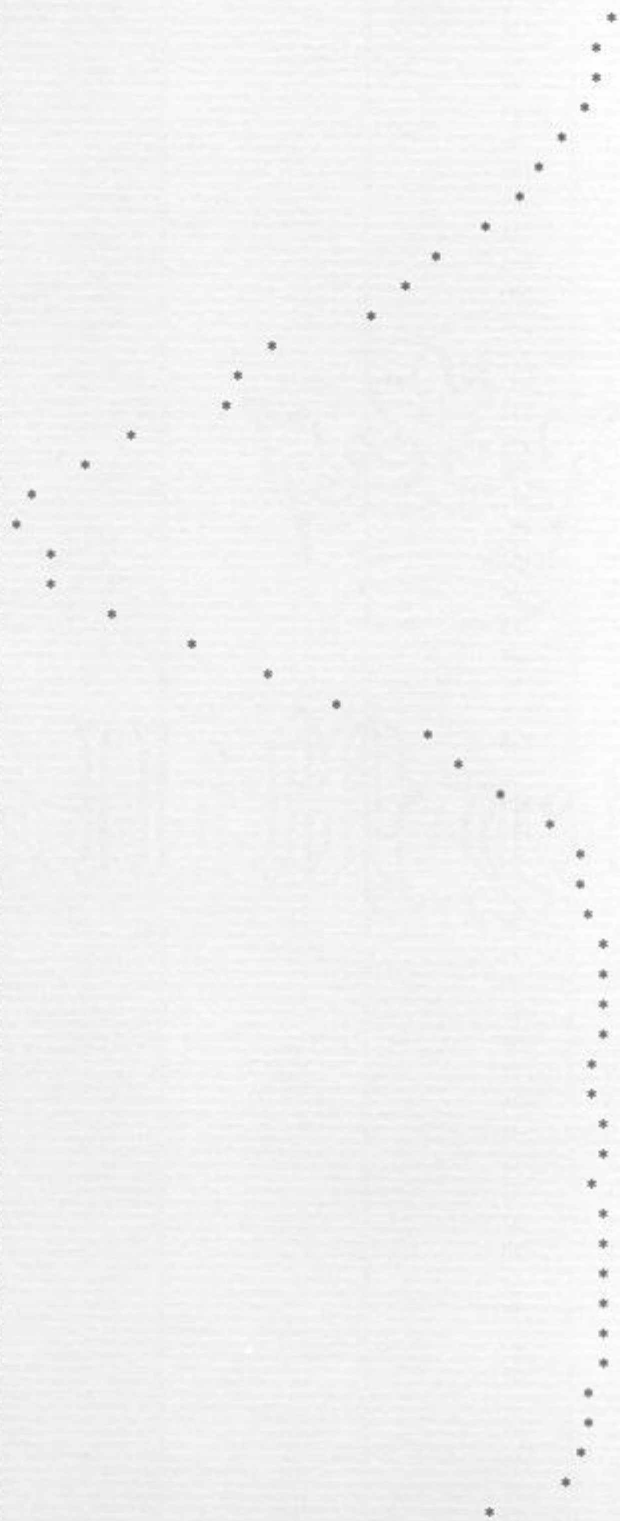
The results on the horizontal and vertical draught forces exerted through the harness, and on mechanical energy and instantaneous power requirements (averaged over 15 or 30 s for short runs of 2.5 min during each trial), indicated accurately the levels of effort required from the oxen. Figures 3 and 4, which are reproduced in the form available in the field, show how the pattern of force can change with different implements and under different soil conditions.

**Figure 3.** *Load-cell force for a pair of oxen pulling a* bakhar *plough, Bhopal, India, July 1986.*

| Load (N) | Number of observations |
|---|---|
| 2117.8 | 6 |
| 2671.3 | 12 |
| 2624.8 | 29 |
| 2578.4 | 58 |
| 2531.9 | 95 |
| 2485.4 | 99 |
| 2439.0 | 142 |
| 2392.5 | 143 |
| 2346.0 | 181 |
| 2299.5 | 248 |
| 2253.1 | 230 |
| 2206.6 | 334 |
| 2160.1 | 276 |
| 2113.7 | 292 |
| 2067.2 | 274 |
| 2020.7 | 292 |
| 1974.3 | 250 |
| 1927.8 | 239 |
| 1881.3 | 176 |
| 1834.9 | 134 |
| 1788.4 | 164 |
| 1741.9 | 116 |
| 1695.5 | 134 |
| 1649.0 | 166 |
| 1602.5 | 176 |
| 1556.1 | 183 |
| 1509.6 | 127 |
| 1463.1 | 129 |
| 1416.7 | 131 |
| 1370.2 | 98 |
| 1323.7 | 77 |
| 1277.3 | 59 |
| 1230.8 | 59 |
| 1184.3 | 80 |
| 1137.9 | 71 |
| 1091.4 | 64 |
| 1044.9 | 72 |
| 998.5 | 45 |
| 952.0 | 44 |
| 905.5 | 24 |
| 859.1 | 53 |
| 812.6 | 37 |
| 766.1 | 40 |
| 719.7 | 32 |
| 673.2 | 45 |
| 626.7 | 36 |
| 580.3 | 65 |
| 533.8 | 86 |
| 487.3 | 65 |
| 440.8 | 42 |
| 394.4 | 38 |
| 347.9 | 33 |
| 301.4 | 35 |
| 255.0 | 13 |
| 208.5 | 12 |
| 162.0 | 10 |
| 115.6 | 6 |

**Figure 4.** *Load-cell force for a pair of oxen pulling a broadbed maker, Debre Zeit, Ethiopia, June 1986.*

| Load (N) | Number of observations |
|---|---|
| 1958.4 | 23 |
| 1919.6 | 35 |
| 1880.8 | 54 |
| 1842.0 | 76 |
| 1803.2 | 111 |
| 1764.5 | 145 |
| 1725.7 | 195 |
| 1686.9 | 265 |
| 1648.1 | 355 |
| 1609.3 | 424 |
| 1570.5 | 495 |
| 1531.8 | 681 |
| 1493.0 | 754 |
| 1454.2 | 776 |
| 1415.4 | 951 |
| 1376.6 | 1039 |
| 1337.8 | 1155 |
| 1299.0 | 1162 |
| 1260.3 | 1091 |
| 1221.5 | 1102 |
| 1182.7 | 992 |
| 1143.9 | 847 |
| 1105.1 | 679 |
| 1066.3 | 553 |
| 1027.6 | 375 |
| 988.8 | 301 |
| 950.0 | 230 |
| 911.2 | 127 |
| 872.4 | 75 |
| 833.6 | 59 |
| 794.9 | 44 |
| 756.1 | 28 |
| 717.3 | 28 |
| 678.5 | 30 |
| 639.7 | 19 |
| 600.9 | 41 |
| 562.2 | 34 |
| 523.4 | 28 |
| 484.6 | 29 |
| 445.8 | 46 |
| 407.0 | 33 |
| 368.2 | 27 |
| 329.4 | 20 |
| 290.7 | 14 |
| 251.9 | 16 |
| 213.1 | 27 |
| 174.3 | 41 |
| 135.5 | 37 |
| 96.7 | 59 |
| 58.0 | 93 |
| 19.2 | 240 |



Results of the physiological monitoring reveal the animals' reactions to the combined effects of workload and environmental conditions. The rise in heart rate above the resting level gives an indication of the effort expended during work (Astrand and Rodahl,1970; Pearson, 1985; Upadhyay and Madan, 1985; Rautaray, 1987; Premi and Singh, 1987). The time taken for the heart rate to return to the resting level after work is a measure of the level of fatigue induced by the work (Grandjean, 1980).

A summary of results for mechanical and physiological parameters around the end of work is shown in Table 2. If necessary, these data can subsequently be processed on more powerful computers, using statistical procedures. The time histories in Figure 5 are useful in examining the results, particularly for the identification of time dependencies between the measured variables.

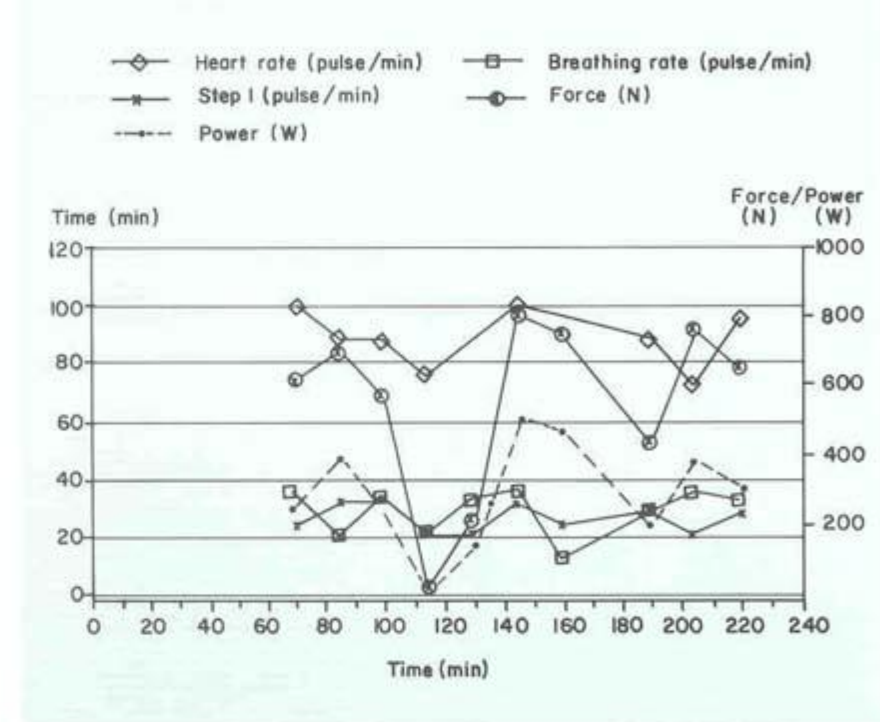
**Table 2**. *Output results for a period around termination of work, Bhopal, India, 7 October 1987.*

| Time (h, min, s) | Average Horizontal force (N) | Average angle (degrees) | Average distance (m) | Energy (kJ) | Average speed (m/s) | Average power (W) | Heart rate | Breathing rate (pulse/min) | Steppingrate[1] 1 | 2 | Temperature (ºC) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 15 36 | 1593 | 19 | 15.0 | 23.05 | 1.00 | 1537 | 136 | 100 | 44 | 0 | 37.0 |
| 16 15 51 | 1318 | 19 | 14.9 | 19.60 | 0.99 | 1307 | 132 | 92 | 40 | 0 | 37.0 |
| 16 16 6 | 1527 | 19 | 11.5 | 17.19 | 0.77 | 1146 | 136 | 92 | 40 | 0 | 37.0 |
| 16 16 21 | 0 | 19 | 0.0 | 0.00 | 0.00 | 0 | 136 | 112 | 4 | 0 | 37.0 |
| 16 16 36 | 0 | 19 | 0.0 | 0.00 | 0.00 | 0 | 116 | 104 | 0 | 0 | 37.1 |
| 16 16 51 | 0 | 19 | 0.0 | 0.00 | 0.00 | 0 | 108 | 100 | 0 | 0 | 37.0 |
| 16 17 6 | 0 | 19 | 0.0 | 0.00 | 0.00 | 0 | 92 | 88 | 0 | 0 | 37.0 |
| 16 17 21 | 0 | 19 | 0.0 | 0.00 | 0.00 | 0 | 80 | 100 | 0 | 0 | 37.0 |
| 16 17 36 | 0 | 19 | 0.0 | 0.00 | 0.00 | 0 | 80 | 104 | 0 | 0 | 37.0 |
| 16 17 51 | 0 | 19 | 0.0 | 0.00 | 0.00 | 0 | 72 | 100 | 0 | 0 | 37.0 |
| 16 18 6 | 0 | 19 | 0.0 | 0.00 | 0.00 | 0 | 72 | 72 | 0 | 0 | 37.0 |
| 16 18 21 | 63 | 19 | 0.1 | 0.04 | 0.01 | 3 | 72 | 88 | 0 | 0 | 37.0 |
| 16 18 36 | 0 | 19 | 0.0 | 0.00 | 0.00 | 0 | 76 | 84 | 4 | 0 | 37.0 |
| 16 18 51 | 0 | 19 | 0.0 | 0.00 | 0.00 | 0 | 68 | 84 | 0 | 0 | 37.0 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 19 6 | 0 | 19 | 0.0 | 0.00 | 0.00 | 0 | 68 | 84 | 0 | 0 | 37.0 |
| 16 19 21 | 0 | 19 | 0.0 | 0.00 | 0.00 | 0 | 64 | 92 | 0 | 0 | 37.0 |

[1] As measured in channels 1 and 2.

**Figure 5.** *Performance variables plotted against time, Bhopal, India, October 1987.*




In addition to the studies of animal–implement systems described above, the instrumentation package has been used in studies where cultivation implements themselves are the object of scrutiny and the draught animals (and their physiological responses to work, particularly heart rate) are part of the evaluation method. Two cultivation implements have been evaluated—a rolling tiller and a set of single-blade tines developed specifically for animal draught by the Centre d'études et d'expérimentation du machinisme agricole tropical (CEEMAT) in France.

The design of the instrumentation package permitted two simple modifications to be made which greatly facilitated the implement evaluations. To test the rolling tiller, one of the channels available for monitoring stepping rate (see Table 1) was converted to receive a signal from the tiller, enabling the speed of one of its rotors to be determined. When testing the single-blade tines, the inclinometer was fixed to the tool frame, rather than the draught chain, and after an appropriate modification of the data processing software, the angle measured was used to compute the depth of penetration.

### Modular package

Because of its greater versatility, the modular package is expected to be particularly useful for evaluating implements, harness designs and work routines. Data collected by this package would also enable a more accurate analysis of the draught potential of *Bos indicus* and *Bos taurus* oxen under different environmental and management conditions, and of other species such as donkeys, buffaloes and camels.

Beyond these uses there are other research topics related to animal draught power to which the data acquisition techniques developed by AFRC Engineering can be applied directly or with some adaptation. For example, the modular package being developed for ILCA will enable the monitoring of the animal's energy metabolism and thus extend the range and precision of data collection and analysis carried out by the Centre's Animal Traction Thrust.

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