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AN INSTRUMENTED SWINGLE TREE FOR DIRECT DRAFT MEASUREMENT OF ANIMAL DRAWN IMPLEMENTS[1]

M. C. Pasikatan & G. R. Quick[2]

ABSTRACT

A direct draft measurement system was developed based on the swingle tree - the rear component of the single-animal harnessing (or yoking) system. The prototype was made from a tube, on which four strain gages were attached. The pull of the draft animal through the flexible pull chains or ropes causes the beam to bend. The bending strain is sensed by the strain gages and the bridge converts this to a voltage signal. Counterweights keep the tube correctly oriented if the angle of pull changes, while end bearings follow the variations in the angle of pull. Hence, the voltage output is proportional to the draft.

The device has highly linear response, acceptable sensitivity, negligible error and hysteresis. It is suitable for electronic data acquisition, non-intrusive, easy to attach and detach and is reasonably priced.

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[2] Senior Research Assistant and Head, Agricultural Engineering Division, IRRI, P.O. Box 933, Manila, Philippines

INTRODUCTION

Conventional draft measurement for animal drawn implements requires two measurements: the pull (F) and the angle of pull (ø), and draft D is measured indirectly by the relationship, D = F * cos ø. Pull is measured by force transducers which link the implement hitch to the ring of the swingle tree, or the yoke and the drawbar, or the yoke and the swingle tree. Angle of pull is usually measured by measuring the length of the rope from the center of the yoke section to the hitch point (L), the height of the center of yoke section from the ground H, and the height of the hitch point from the ground D. *Figure 1* shows these dimensions in a typical single-animal harnessing (or yoking) system. The angle of pull is derived from, ø = arcsin (H - D/L).

Two error-prone assumptions are inherent in this method of angle measurement: the ground is always level, and the distance H is constant. The angle of pull is obtained when the animal is in relaxed stance, but when it pulls, its neck is instinctively lowered, which reduces H. Distance H is further varied when the animal steps on the unplowed land and not on the furrows. A 12 cm change in H for instance could result in an 8^{o} change in angle and a 6 kgf change in draft which may not be reflected in the data (Pasikatan, 1992). Also, tension load cells when hooked between the swingle tree ring and the implement hitch, lengthens the distance (L), thus decreasing the angle of pull. The introduction of the load cell therefore, alters the angle of pull - a case of a transducer changing the measurand.

To overcome this error of constant angle of pull assumption and to permit instantaneous draft measurements, various types of load cells and inclinometers have been used (Lawrence, 1987; O'Neall et al, 1989). These data-capture systems can measure other parameters such as speed, physiological parameters, weather conditions, etc. and offers higher accuracy, but the system may be too costly for researchers in developing countries where draft animal power measurements are most needed.

An alternative technique to the load cell-inclinometer system is a direct draft measurement through an instrumented swingle tree. This offers the following advantages:

(a) non-intrusive - the device does not change the angle of pull ;

(b) more sensitive, since the load tube is in bending, not axial strain;

(c) easily attachable and detachable to the harness system; and

(d) can be manufactured using locally-available material, skills and equipment, hence competitive in cost.

In this study a dynamometer for instantaneous draft measurement of animal drawn implements based on the swingle tree was designed. It was evaluated in terms of linearity, sensitivity, hysteresis, accuracy and overall field performance.

DESIGN OF THE SWINGLE TREE DRAFT DYNAMOMETER

Design Concept

The swingle tree dynamometer consists of a metal tube substituting for the typical wooden swingle tree. Strain gages mounted near the center, on each side, monitors the pulling forces on each end of the tube. Counterweights fix the tube to a reference orientation, and bearings on each end of the beam follow the inclination of the ropes, so that draft is instantaneously monitored.

Design of the Strain Beam

The traditional swingle tree of a single-animal hitch is 480 mm long, so this dimension was retained for the loading beam. A maximum force of 60 kgf was assumed to act on each end of the swingle tree. To test the principle, a tentative material, GI pipe was selected (yield strength, Sy = 34 - 54 kpsi). Using a safety factor of 1.5, for a weaker but more sensitive beam and a 40% assumed reduction in Sy due to substandard pipes, the section modulus is 1510.9 mm^3 (0.0922 in^3). The pipe which has a section modulus closest to this is 26 mm outside diameter (3/4 in nominal) schedule 40 GI pipe.

Principle of the Strain Beam

The analysis of the bending of the beam under the action of the forces on each end and the corresponding conversion to voltage by the strain gage bridge has been derived elsewhere (Pasikatan, 1992). The relationship of the bending force **F** at the gage location **x** (x**1** and x**2** for eight strain gage bridge), to the output voltage $\mathbf{E_o}$ (see *Figs. 3 & 4*) was expressed as

$$F = \frac{E_o E \pi (d^4 - d_i^4)}{16 \times d G E_i} \qquad \text{(for four-gage bridge)}$$

$$F = \frac{E_o E \pi (d^4 - d_i^4)}{16 (x_1 + x_2) d G E_i} \qquad \text{(for eight-gage bridge)}$$

where:

G = gage factor
E = modulus of elasticity of the strain beam
E_i = input voltage
d = outside diameter of the strain beam
d_i = inside diameter of the strain beam

These equations indicate **F** is linearly proportional to voltage $\mathbf{E_o}$. The sensitivity **S** of the strain beam - strain gage bridge system is given by

$$S = \frac{E_o}{F} = \frac{16 \times d\, E_i\, G}{\pi E\, (d^4 - di^4)} \qquad \text{(for four-gage bridge)}$$

$$S = \frac{16\, (x_1 + x_2)\, d\, E_i\, G}{\pi E\, (d^4 - di^4)} \qquad \text{(eight-gage bridge)}$$

The quantity $(x_1 + x_2)$ indicates improved sensitivity as compared to a four strain gage bridge.

DYNAMOMETER DEVELOPMENT AND EVALUATION

The Test Model

The first model, essentially a pull dynamometer was used to test the principle. It was made from 480 mm long, 26 mm outside (3/4 in nominal) diameter schedule 40 GI pipe, in the middle of which a hitching ring welded (*Fig. 2*). Circular plates and round bar strips were welded to both ends of the beam to secure the ropes in place. Four strain gages were attached to the beam as shown in *Fig. 3*. These were covered with moisture proof coating and electrical tape for protection. The lead wires for input voltage and output voltages were wired to an RS232 plug for connection to a Polycorder (a portable data logger). The Polycorder supplied a 5V excitation to the strain gage bridge circuit.

Calibration results showed the kgf-mV relationship was linear ($r^2 = 0.99$). The sensitivity was 1.391 mV/V, slightly lower than the usual 2 mV/V sensitivity of commercial load cells, mainly because of the low elasticity of the tentative material used. Hysteresis and error were 0.6%, and 4% fs respectively. Field tests showed ease of attachment to the ropes and the plow hitch and sufficient protection against water.

The Direct Draft Dynamometer

After the swingle tree dynamometer concept was validated, the second model - a direct draft dynamometer was developed. For trial purposes the circular strain beam was made from unmachined GI pipe, of the same dimensions as the test model. Eight strain gages were mounted for added sensitivity. A counterweight on each side was attached to the beam through a ring and fixed by a set screw. Three bearings - two on each end, and one at the middle of the strain beam enabled the device to follow the changes in the angle of pull. When in use the outer race of the bearings followed the line of pull while the counterweights kept the strain beam and the inner race of the bearings from rotating such that a fixed reference was maintained. Hence the millivolt output of the device was due to the draft, not the pull.

Calibration results showed a linear response (r^2 = 0.99), and a much improved sensitivity (1.778 mV/V). Hysteresis ranging from 0.43% to 1.44%, and error ranging from 0.8% to 1.4% were observed. Both were angle of pull dependent. A machined strain beam was therefore necessary to make accuracy independent of the angle of pull. Field tests proved the validity of the design but these showed the following parts which need improvement: heavier counterweights to prevent rotation out of reference, end bearing housing with easy slip-on rope attachment with a shear pin overload protection device.

The Improved Direct Draft Dynamometer

The improved direct draft swingle tree dynamometer integrated these modifications (*Fig. 5*). The circular strain beam, 152.4 mm long, was machined from mild steel. Eight strain gages were mounted on this. Counterweights on each side were attached to the beam through threaded connection. The middle ring and the end bearings were all easily detachable (and attachable) through retaining rings. For added protection, a strain gage housing made of steel tube was employed.

The direct draft dynamometer was calibrated at angles of pull, ø = 0, 10, 15 and 20° to simulate the range of values which could be expected from the field. For each angle, loads are incremented step by step up to 140 kgf and decremented by the same steps down to zero. Four replications were done for each angle.

The calibration results showed the kgf-mV relationship was linear. The regression equation was MV = 0.041888 * KGF - 0.30268 (r^2 = 0.99). The sensitivity was 1.2 mV/V, less than the previous models because of larger cross-section to permit machining. The hysteresis and error were 0.1% and 0.7% fs, respectively and were angle of pull-independent. Field tests showed the counterweight could keep the strain beam properly oriented while ropes follow the changes in angle of pull.

CONCLUSIONS

A direct draft dynamometer suitable for single-animal harnessing system was developed. The dynamometer was achieved by instrumenting the swingle tree - the rear component of this harnessing system. With a data logger, the dynamometer could be used for instantaneous draft measurements. Calibration showed it has a highly linear response, is reasonably accurate and fairly sensitive. Field tests showed it was non-intrusive and easy to attach to and detach from the implement hitch and harness. It could also be made in workshops using locally available materials and equipment. The bearings and strain gages may be expensive but the dynamometer is still a reasonably priced but application-specific alternative to load cell-inclinometer devices. The probable cost of the device, without recorder is $60.

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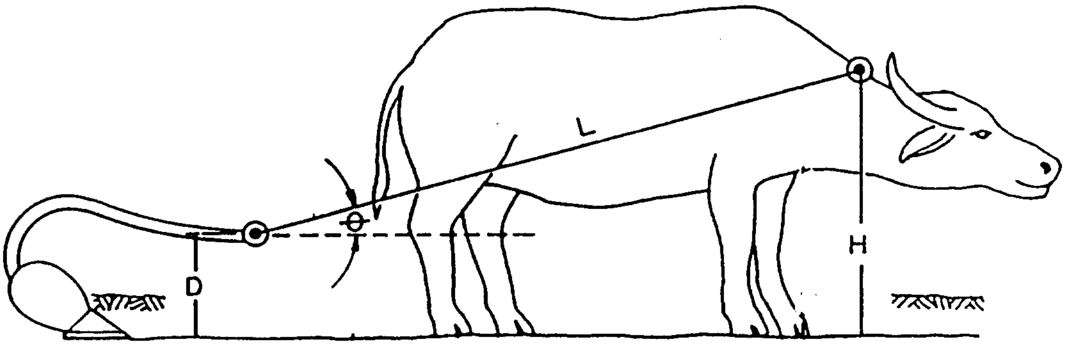
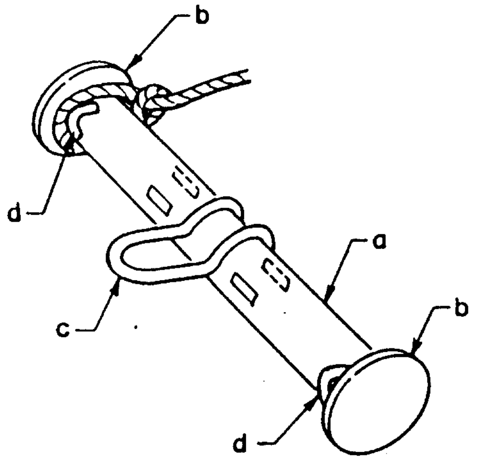


Fig. 1 . Dimensions required in conventional measurement of angle of pull.



a – Strain beam
b – End plates
c – Swingle tree ring
d – Rope securer

Fig. 2. Basic parts of swingle tree pull dynamometer (M_1).

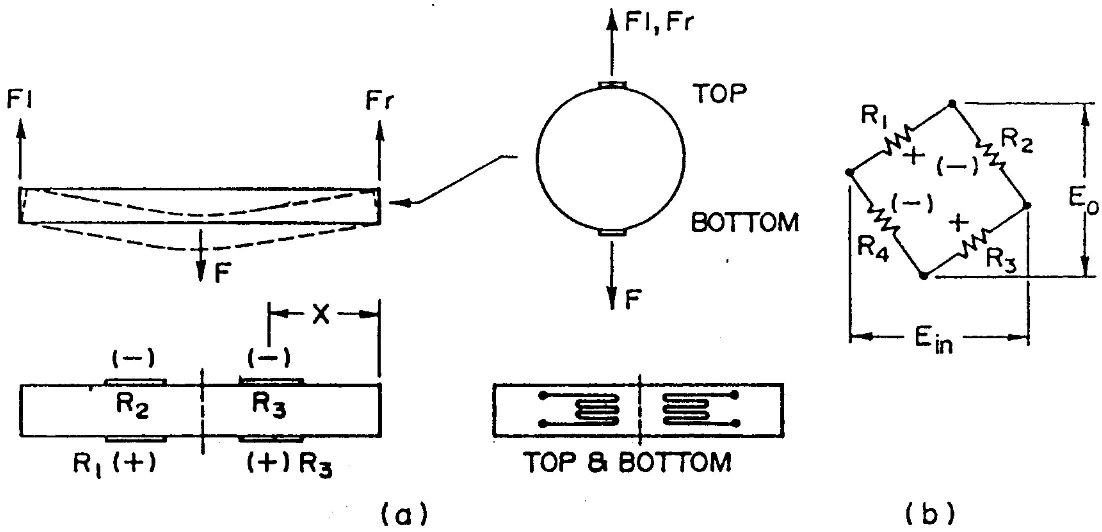


Fig. 3. Forces acting on swingle tree strain beam, orientation of four strain gages on the beam (a) and arrangement of strain gages in a wheatstone bridge (b).

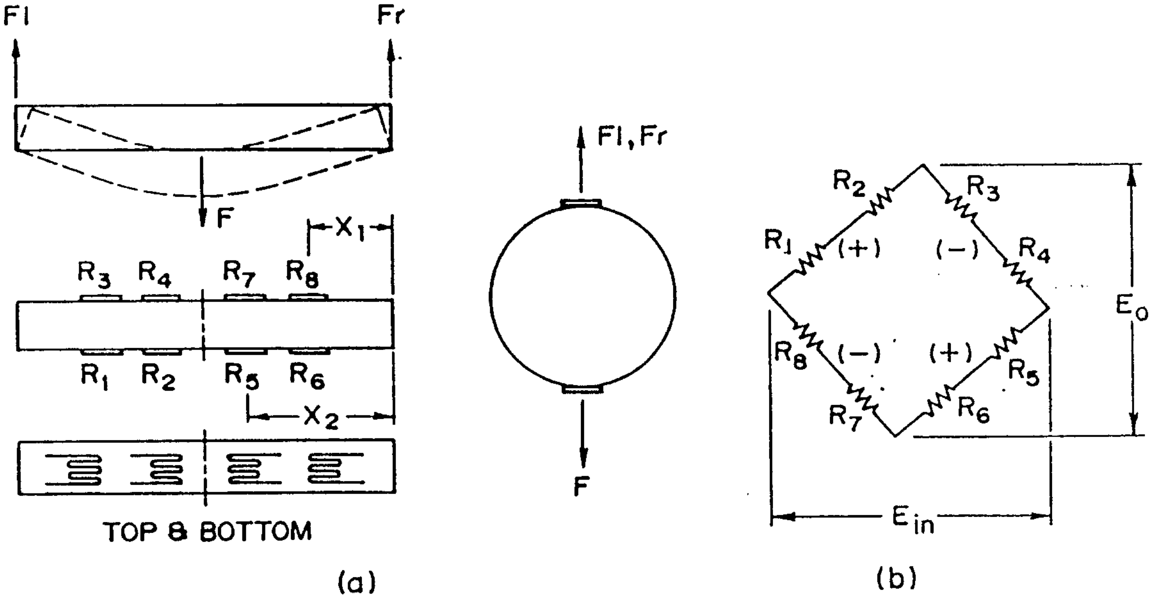


Fig. 4. Forces acting on a swingle tree strain beam, orientation of the eight strain gages on the beam (a) and arrangement of the strain gages in a wheatstone bridge (b).

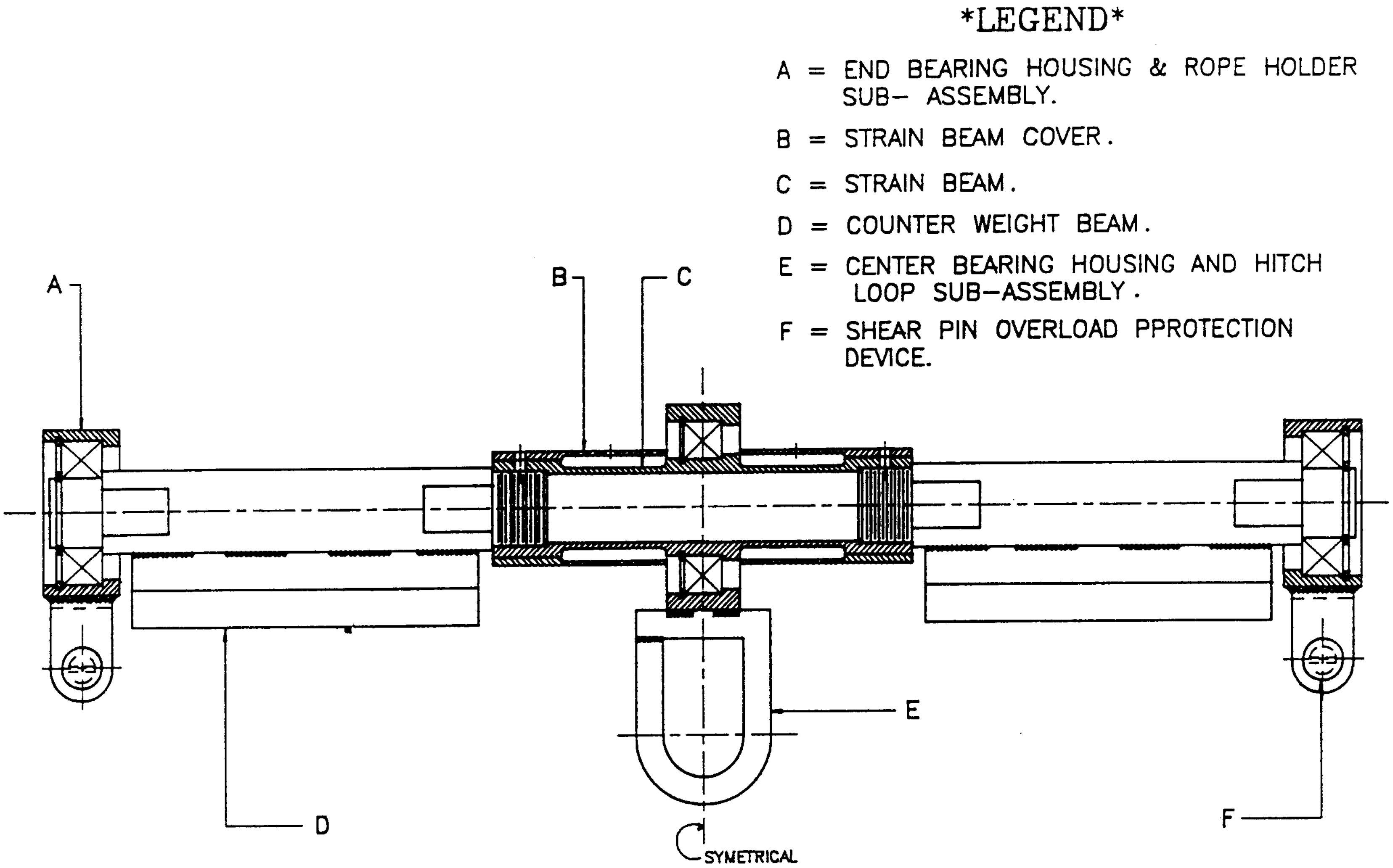


FIG. 5. BASIC PARTS OF A SWINGLE TREE DRAFT DYNAMOMETER