AN INSTRUMENTED TEST CHAMBER TO COMPACT FODDER AT HIGH PRESSURE

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An instrumented compression chamber was fabricated to study the behavior of hay under high compressive loads. The system satisfactorily measured wall forces, friction forces on walls, applied load, and piston displacements.

INTRODUCTION

In Northern latitudes it is necessary to store large quantities of fodder to support livestock through the winter months. However, in Australia this has not been necessary and as a result, regional droughts periodically decimate the livestock industry, mainly because of feed shortages. Fodder is usually available in other regions of the country but is unobtainable because of purchase, transport, and storage problems. During the 1964-1966 drought, a select committee was instituted by the New South Wales Legislature to study the effects of drought on the rural community and the agricultural industry in general. One recommendation was that a study be made of the compression of hay with a view to reducing transport and storage costs of emergency fodder supplies (Australian Meat Board 1969; Commonwealth of Australia Bureau of Census and Statistics 1968; Select Committee of the Legislative Assembly 1966).

Several studies have been made of the compression of hay, particularly for the production of wafers and pellets (Bellinger and McColly 1961a, b; Bruhn 1955; Hill 1959; Hundtoft and Buelow 1971; Reece 1966; Shepperson and Grundey 1962; Yang 1968), but they did not consider the relationship of lateral wall force to applied force. Mewes (1958) studied the compression of parallel and interlaced straw samples, and the relationship between applied pressure and lateral pressure for low pressures (<686 kPa).

To study the compression of fodder to high bulk densities so as to provide a source of energency feed supplies, an instrumented laboratory compression chamber was needed. Lateral and frictional wall forces and piston displacements had to be measured so that friction coefficients, friction losses, bulk density, and energy requirements could be calculated for applied loads up to 11,200 kPa. This paper describes the design of such a chamber.

DESIGN

Because the major source of fodder for drought relief would be on-farm-produced bales which would be recompressed, the chamber dimensions selected were of the same ratio as field bales and were 8.64 X 9.75 cm and 16.6 cm deep. The hay particles, of course, could not be scaled and the measured forces are therefore not applicable to larger bale chambers. The chamber was designed to separately measure the forces acting on each pair of opposing walls. The chamber was closed-end type and the walls were cut from 0.952-cm steel plate.

Each pair of opposing walls was laterally restrained by four 0.635-cm diam high-tensile steel rods. To minimize bending effects owing to slight misalignments of the walls, the ends of the rods were seated on spherical washers in chamfer seats. Two 120 ohm wire resistance strain gauges were mounted on each rod, diametrically opposite one another, and were connected in series, thus cancelling any resistance change caused by bending. The four rod transducers were wired in parallel and connected in one arm of a Wheatstone bridge to provide an averaging circuit for the forces acting on each pair of opposing walls. Temperature-compensating gauges were mounted on a dummy 0.635-cm diam rod and were connected in the adjacent bridge arm (Figure 1). The bridge output was connected to a UV galvanometer recorder and the circuit theory for this arrangement is as follows.

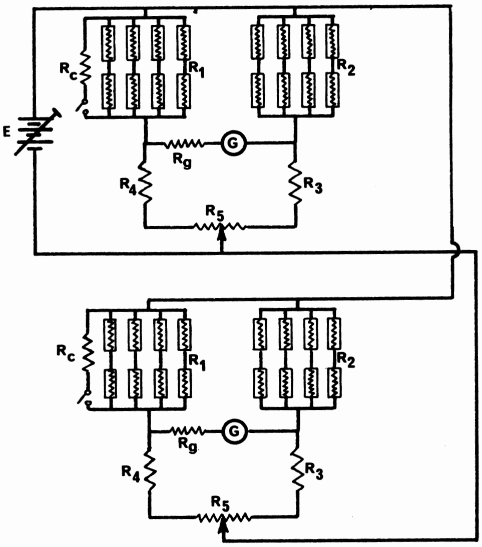

Figure 1. Circuit diagram for lateral force transducers. Power supply E = 7Vdc; shunt resistor Rc = 112 kohms; active gauges R_1 = 120 ohms; temperature compensating gauges R_2 = 120 ohms; bridge arm resistors $R_3 = R_4$ = 60 ohms; galvanometer resistance R_g = 42 ohms; balancing potentiometer R_5 = 5 ohms; galvanometer G.

List of Symbols Used in Circuit Equations

R	gauge resistance
R'	equivalent arm resistance
R_s	shunt resistance
R_g	galvanometer resistance
ΔR	change in resistance under load
E_r	applied voltage to rod transducers
E_m	Young's modulus
I_g	galvanometer current
C_g	gauge factor
S	sensitivity
D_s	shunt calibration deflection
P	lateral load on walls
P_a	apparent lateral load on walls
P_f	frictional load on walls
P_{fa}	apparent frictional load on walls
A	cross-sectional area of rod
M	bending moment on beam
ϵ	strain
I	area moment of inertia
d	lateral distance between top and bottom knife edges
c	half depth of beam

Equivalent Resistance of Bridge Active Arm

$$\frac{1}{R_{eq}} = \frac{1}{R_A + \Delta R_A} + \frac{1}{R_B + \Delta R_B} + \frac{1}{R_C + \Delta R_C} + \frac{1}{R_D + \Delta R_D}$$

where R_A, R_B, R_C and R_D are the gauge resistances of the four transducers

But

$$R_A = R_B = R_C = R_D$$

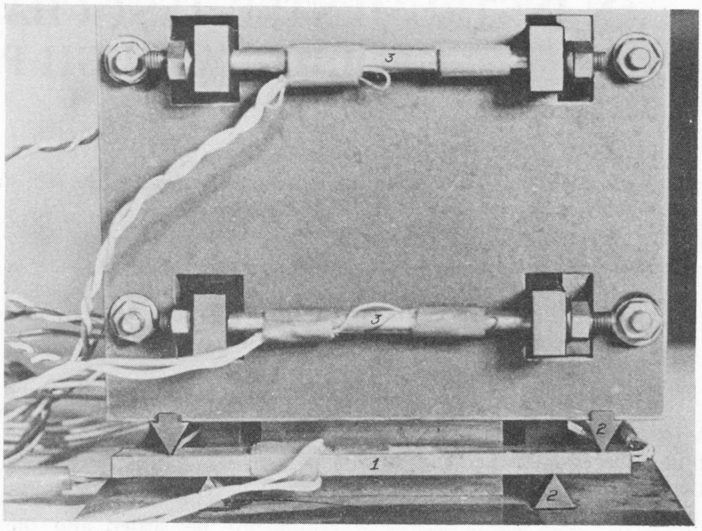

Figure 2. Force transducers showing (1) beam transducer, (2) knife edges, (3) rod transducers.

Therefore

$$\frac{1}{R_{eq}} = \frac{4R^3 + 3R^2\Delta R}{R^4 + R^3\Delta R}$$

Dropping $3\Delta R$ as negligible gives

$$R_{eq} = \frac{R + \Delta R}{4}$$

Now let

$$R' = \frac{R}{4}$$

Therefore

$$R_{eq} = R' + \frac{\Delta R}{4} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

Substituting (1) in the equation for galvanometer current I_g in an unbalanced Wheatstone bridge circuit, as derived from Kirchhoff's second law gives:

$$I_g = \frac{E_r \frac{\Delta R}{4}}{4R'(R' + R_g) + \frac{\Delta R}{4}(3R' + 2R_g)}$$

Dropping $\frac{\Delta R}{4}$ $(3R' + 2Rg)$ as negligible gives

$$I_g = \frac{E_r \frac{\Delta R}{4}}{4R'(R' + R_g)} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

But

$$\frac{\frac{\Delta R}{R}}{\epsilon} = C_g$$

and for a rod in tension

$$\epsilon = \frac{P}{AE_m}$$

Therefore, for four rods in parallel under a total tensile load P

$$\frac{\Delta R}{4} = \frac{R'C_gP}{4A\,E_m} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3)$$

Substituting (3) in (2) and noting that

$$I_g = \text{DS}$$

gives a bridge sensitivity of

$$S = \frac{PC_gE_r}{16(R' + R_g)\,AE_mD} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (4)$$

The strain gauges, resistors, voltage, and rods were selected to give a sensitivity suitable for the wall loads anticipated and was calculated from (4) as 1.23 kN/cm.

To calibrate the rod transducers during testing, a 112 kohm shunt resistor (R_s) was connected in parallel across each of the active bridge arms to obtain a galvanometer deflection. The bridge sensitivities for each test were calculated as follows:

$$\epsilon_a = \frac{R'}{C_g(R' + R_s)}$$

For four rods in parallel under a total tensile load P

$$\epsilon = \frac{P}{4AE_m}$$

Letting

$$\epsilon_a = \epsilon$$

and simplifying gives an apparent load when the shunt resistor is inserted into the circuit of:

$$P_a = \frac{4AE_mR'}{C_g(R' + R_s)} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (5)$$

The bridge sensitivity under test conditions is then:

$$S = \frac{P_a}{D_s} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (6)$$

where D_s is the shunt calibration deflection in cm.

To measure the wall friction forces, each wall was supported by two knife edges and rested on a 1.270 × 0.635-cm cross-section hardened steel beam. Each beam in turn rested on two knife edges so as to be subjected to a pure bending moment when a vertical load was placed on the wall (Figure 2). The position of the bottom knife edges could be adjusted so as to provide either a 0.635-cm or a 1.270-cm moment arm to each beam. Two 120 ohm wire resistance strain gauges were attached to each beam, one each on the top and bottom surfaces, and were connected in adjacent arms of a Wheatstone bridge circuit (Figure 3). This provided temperature compensation with doubled transducer sensitivity (Perry and Lissner 1955). The outputs from the four bridges were connected to four channels of a galvanometric recorder. For calibration of the transducers prior to each test, a 22 kohm shunt resistor was connected in the circuit to obtain a calibration deflection, and the bridge sensitivity was calculated as follows:

For a beam in pure bending

$$\delta = \epsilon E_m = \frac{M\,c}{I}$$

but

$$M = \frac{P_f\,d}{2}$$

For shunt calibration

$$\epsilon = \frac{R}{C_g(R_s + R)}$$

Therefore

$$\frac{P_f\,d\,c}{2E_m\,I} = \frac{R}{C_g(R_s + R)}$$

or

$$P_f = \frac{2E_m\,I\,R}{C_g\,d\,c\,(R_s + R)}$$

Since the sensitivity is doubled by the two active bridge arms, the apparent load P_{fa} during shunt calibration is:

$$P_{fa} = \frac{E_m\,I\,R}{C_g\,d\,c\,(R_s + R)} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (7)$$

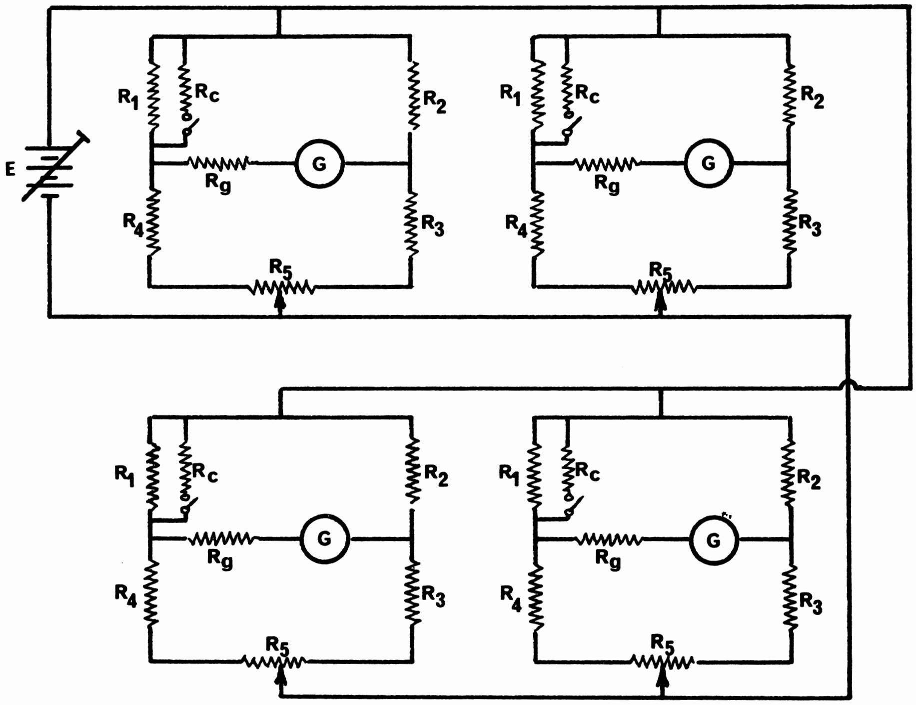

Figure 3. Circuit diagram for friction force transducers. Power supply E = 5 V; active gauges R_1 and R_2 = 120 ohms; bridge arm resistors R_3 and R_4 = 120 ohms; galvanometer resistance R_g = 9 ohms; balancing potentiometer R_5 = 5 ohms; galvanometer G.

The transducer sensitivity S therefore is

$$S = \frac{Pfa}{D_s} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

where D_s is the shunt calibration deflection.

A test assembly was constructed to check the lateral force transducers. The four rods were mounted in the assembly in the same manner as on the chamber. The assembly was then mounted in the universal testing machine, a shunt calibration test made, and a tensile load applied to a maximum of 8,900 N. The operation was repeated for the other transducers. The recorded applied loads were compared to the loads calculated from the transducer deflections using equation 5 and showed a difference of less than 2%. When one set of rods was loaded, there was negligible response from the other set. When only two or three of the four rods in one set were loaded, there was negligible difference between the applied load and the calculated load.

The friction force transducers were checked by applying a vertical load to the walls with the universal testing machine and comparing the applied load to that calculated from the transducer signal using equations 7 and 8. The difference between actual and indicated load was less than 2% and again there was negligible interaction between active and inactive transducers.

Because the beam transducers and rod transducers were on separate circuits, no interaction between them was possible.

During a hay compression test, the load to the compression piston was applied by a Shimadzu Model REH50 universal testing machine. A continuous recording of applied load and piston displacement was made throughout the compression sequence and was related to the test chamber friction and lateral force measurements. Because the wall knife edges in contact with the top surfaces of the beam transducers could support a lateral force equivalent to the frictional force acting on the wall times the coefficient of friction of steel on lubricated steel, the lateral force readings were corrected by this amount. A friction coefficient of 0.23 was used (Standard Handbook for Engineers).

With the readings of applied load, piston displacement, lateral wall force, frictional wall force, and sample weight, it was possible to calculate the total work done, the frictional losses, the coefficient of friction of hay on steel for a range of contact pressures, and the bulk density of the sample under compression at any applied load. The effect of hold time at load could also be considered.

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