TechGuide

Measuring Draft Power:
A Low-Cost Dynamometer for Field Use

by David Kramer and Richard Roosenberg
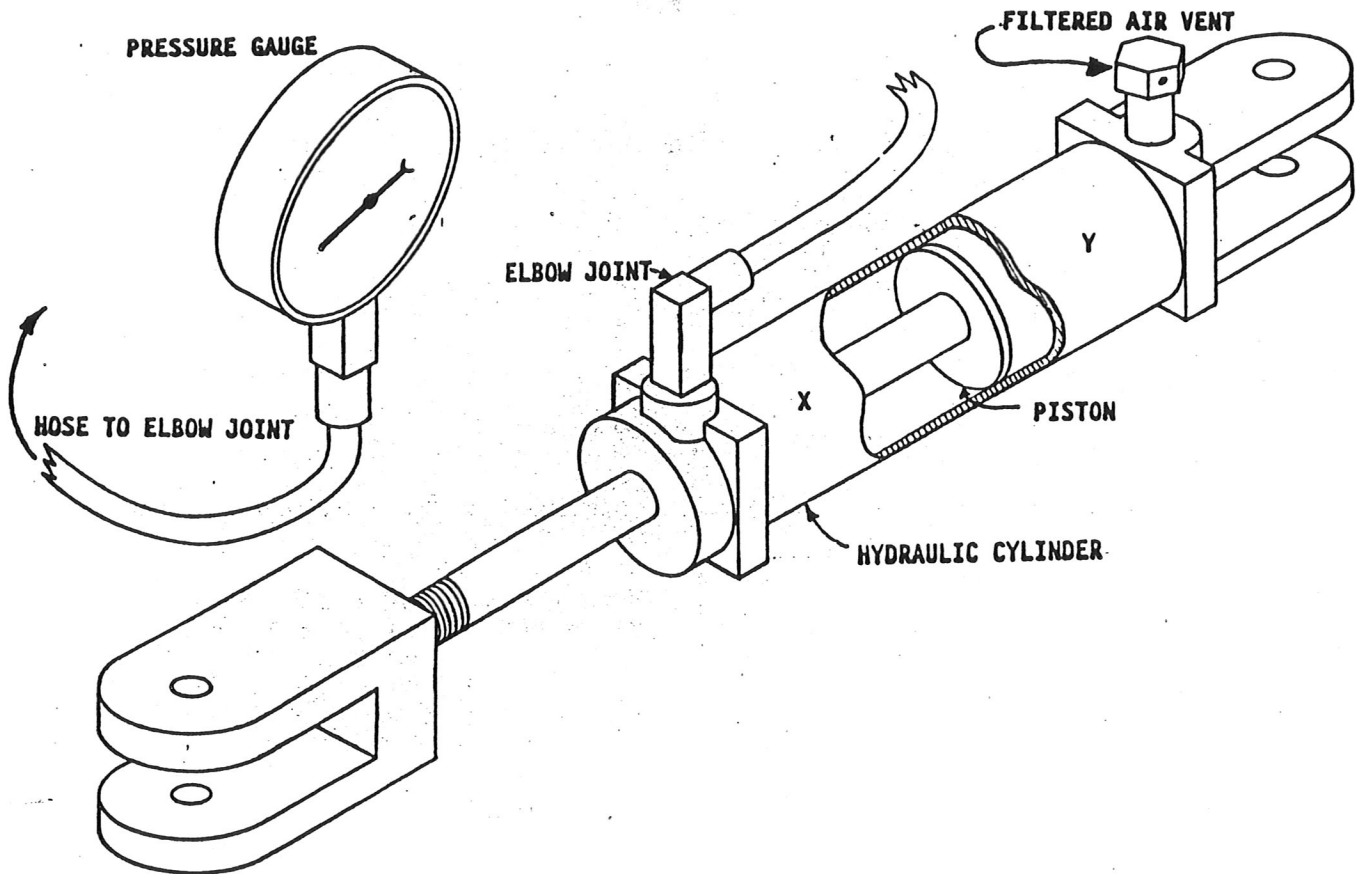
PRESSURE GAUGE

FILTERED AIR VENT

ELBOW JOINT

Y

HOSE TO ELBOW JOINT

X

PISTON

HYDRAULIC CYLINDER

Figure 1: Pressure Gauge and Hydraulic Cylinder with Cut-Away to Show the Piston

Introduction

Measuring draft is essential to most research of animal-powered farming. Without a dynamometer to measure force, an exchange of quantitative descriptions is not possible.

The ability and willingness of animals to pull varies with the efficacy of yoking or harnessing and

with the size, conditioning, training, and temperament of the animals. A dynamometer permits a relatively objective description of the resulting differences. With this information, farmers and projects can begin to match the power of their animals to particular tasks -- pulling implements designed for local soil and surface conditions. Without comparative measurements we grope in the dark.

Although a dynamometer takes much of the guesswork out of field-level decision making, electronic load cells connected to a computer are both too expensive and too easily damaged for general field work. In searching for an inexpensive and durable field unit, we first tried a simple spring-loaded linkage (4 discarded valve lifter springs on a heavy eye-bolt within a pipe sheath), Figure 2. Calibrations were marked on a flattened area of the bolt shaft. Though the price of this design was very low, it proved difficult to read in the field. Animal draft power is characterized by a pulsating movement. This causes variation in draft readings. While an average and range of readings is adequate for most field measurement purposes, this spring-loaded unit was too lively to read.

Robert Wilkinson, Professor of Agricultural Engineering at Michigan State University, suggested the use of a hydraulic cylinder and pressure gauge instead of springs. Extending a hose from the pressure generating cylinder to a remote gauge facilitates readings and the oil in the hose and the cylinder dampens the sharpness of the variations in draft. The dampening affect averages peaks and eases the interpretive task of the person taking readings. While

hydraulic cylinders are not cheap by Third World standards, they are within the means of most projects and cooperatives. (We have found cylinders from $25 to $50, hose and connectors for about $30, and pressure gauges for about $12 each; a system for about $150.) Most cylinders are certainly robust. It is hard to imagine conditions that would damage them.

Set-up

Most hydraulic cylinders used as dynamometers can measure force either in tension or in compression modes since most are designed for two way action. Set-up differs for tension or compression modes.

For the more usual tension mode, fit a hose with a pressure gauge to the end of the cylinder from which the shaft, or rod, extends (end "X" in Figure 1). Attach the hose to the cylinder with an adjustable elbow joint to reduce bending or kinking of the hose in field use. A sharp bend in the hose will eventually cause a leak and may restrict flow. The other end of the cylinder (end "Y") should be fitted with a filtered air vent so air can easily pass in and out of the "Y" end of the cylinder. Without a vent, movement of the piston will generate air pressure or vacuum behind the piston. This resistance will offset and distort oil pressure in the opposite end.

The cylinder must be partially filled with motor oil or hydraulic fluid. The Tillers International
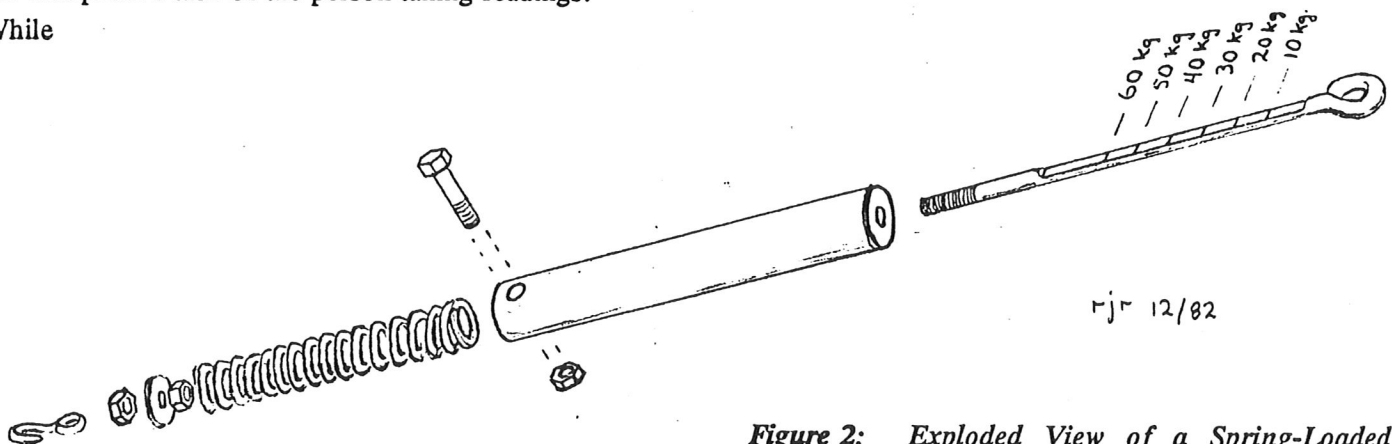

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Figure 2: *Exploded View of a Spring-Loaded Dynamometer.*

dynamometer comes charged with standard 10W-40 motor oil. To put in the fluid, remove the gauge from the end of the hose, leaving the other end of the hose attached to the cylinder. Extend the shaft as far as possible to close the X end of the cylinder. Place the open end of the hose into a container of fluid and draw it in by slowly pushing the shaft about half way back in. This will suck the fluid into end X of the cylinder. The cylinder should be about half full. Air trapped in the fluid will increase movement of the shaft under a load. To bleed out any air, elevate the hose while keeping its end submersed in the fluid container slowly move the shaft back and forth until few bubbles exit with the fluid. Finally, attach the pressure gauge back on the hose, checking to be sure the hose is filled to capacity with oil.

The dynamometer is now ready to measure a pulling (or tension) force. One end of the dynamometer can be hooked to the yoke and the other to the traction chain that is attached to a cart, plow, or other implement.

Reading the Dynamometer

In most cases a reading from the pressure gauge must be multiplied by a constant factor to give a measurement of draft in commonly used units; namely, pounds or kilograms. Direct readings from a pressure gauge must be converted because the surface area of the piston which compresses the oil usually is not the same as the area to which the gauge was calibrated (1 square inch or 1 square centimeter). For example, the pressure gauge used by Tillers measures PSI, pounds per square inch, but the piston's surface is greater than 1 square inch.

Determining the area of the piston's surface that compresses fluid can be a little tricky since you must exclude the area covered by the end of the shaft. Refer to Figure 3. First, find the total area of the piston's face, A. To find the area of a circle use the formula πr^2. Next, find the cross section area of the shaft, B. Finally, subtract B from A to find C -- the factor by which the gauge reading must be multiplied to determine pounds of force transferred through the
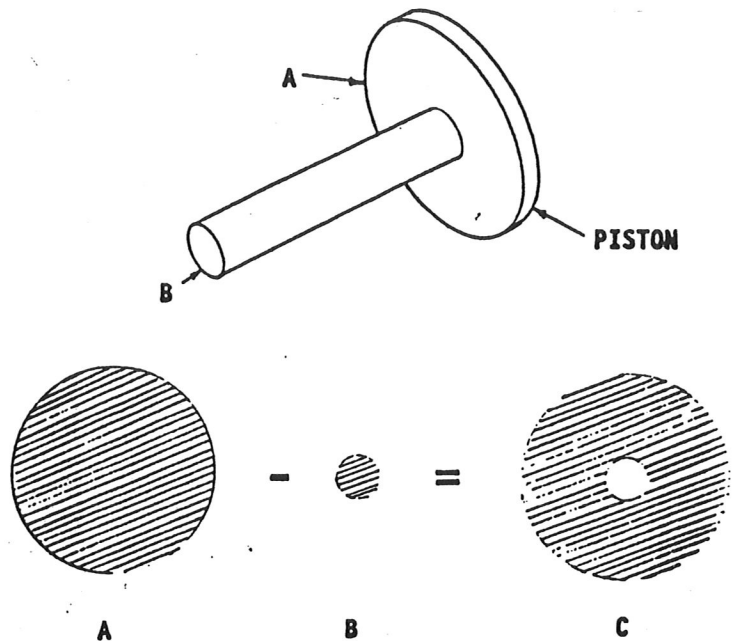

Figure 3: Finding the Working Surface Area of the Piston

piston's working surface. This should be close to a true reading of draft. The accuracy of all dynamometers should be determined before use by suspending known weights from the cylinder.

An Example

Assume that as a team of oxen pull a log the pressure gauge reads 280 PSI on the average. The diameter of the cylinder's piston is 2 inches, and the shaft connected to the piston is 1 inch in diameter. What is the actual force in pounds that the oxen are exerting?

First, find the surface areas of the piston and of the shaft's cross section. (πr^2 = Area of a circle, where r is the radius.)

A = Area of the Piston = πr^2
= 3.142 X 1 X 1 = 3.142 square inches

B = Area of the Shaft = πr^2
= 3.142 X .5 X .5 = 0.786 square inches

C = Area of Piston that compresses fluid
= A-B = 3.142 - 0.786

= 2.356 square inches

= Factor by which the reading is multiplied to obtain Force (lbs)

Gauge Reading x C = Force (lbs)

280 PSI x 2.356 = 659.68 Pounds of Force

Thus, the oxen are exerting 659.68 pounds of force to pull the log in this example.

The dynamometer supplied by Tillers should be read in pounds by multiplying the gauge reading by the factor of 2.356 as shown in the preceding example. This will yield the force applied by the animals in pounds (lbs).

Tillers' dynamometer can also be approximately read in kilograms without converting the gauge reading. The conversion factor of 2.356 used to determine force in pounds is nearly equal to the conversion factor of pounds to kilograms, 2.2. Thus, the gauge can be read directly in kilograms rather than converting the reading to pounds.

The Compression Option

If the cylinder has a two-way hydraulic capacity, it can also be used to measure a compression, or pushing, force instead of the tension mode described above. This is particularly useful with horses where the force is applied behind the animals without enough room for the cylinder in the tension mode.

To set up the dynamometer for compression, empty the fluid from the shaft end, X, switch the air vent and hose positions on the cylinder, and refill the other end, Y, as above. You will need to build a sturdy holder to keep the cylinder in line while under compression. Finally, the factors used to convert your gauge readings to pounds or kilograms will also need to be changed. Since there is no shaft in the Y end of the cylinder, the factor for pounds will be the full area of the piston's face (3.142). The conversion factor for kilograms will be 1.43 (3.142/2.2 = 1.43).

Materials

Used hydraulic cylinders should be adequate as they will operate at significantly lower than design pressure. If the seals leaked under high pressure pumping they are not as likely to leak when used for a dynamometer. Plan ahead in the selection of pressure gauges. They come in differing ranges of calibration.
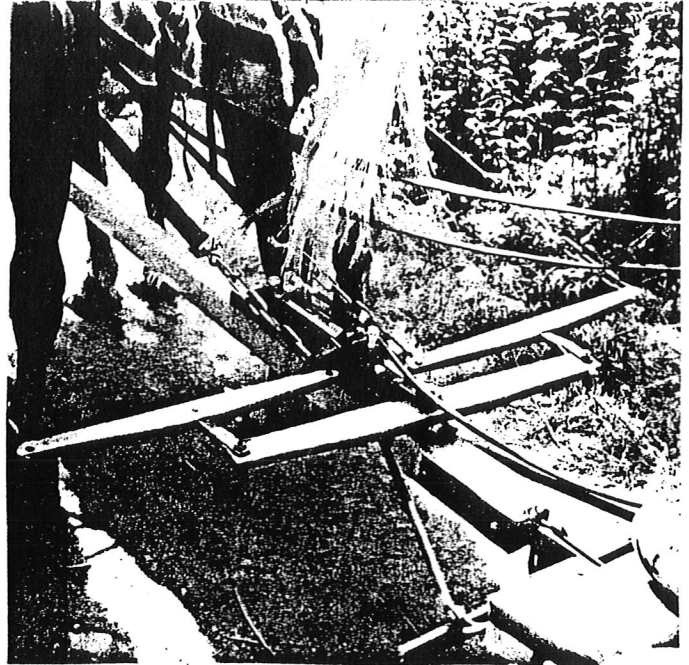

Figure 4: A Cylinder Arranged in the Compression Mode

We found that 1,000 PSI gauges which measure to 2,300 pounds of force through a 2 inch cylinder are not sensitive enough to satisfactorily show variations in normal working loads -- 200 to 600 pounds. We also use a 300 PSI gauge. However, our 3,600 pound team of oxen can break a 300 PSI gauge if we catch an implement on an immovable object when they are moving with momentum. Care needs to be taken in matching gauges to anticipated peak work loads. If gauges are difficult to find in your area, you can protect them with a shear pin or break away in the line.

Comments On Use

When used in a traction chain, we have found that oxen tolerate the cylinder better if it is light and is attached at the yoke end of the chain. At the implement end it causes the chain to hang so low that the animals step over the chain or bump their ankles on the cylinder. For implements with tongues, we mount the cylinder at the implement end of the tongue and connect the shaft end to a chain from the staple of the yoke. We allow the tongue to move relative to the yoke by slipping it through a large slide ring on the staple. (For safety, the tongue must have a stop

behind the ring to keep the implement from moving forward into the heels of the animals. In addition, the traction chain linking the dynamometer cylinder to the implement must be tight enough to keep the implement's tongue from escaping the slide ring.

There are some problems in reading the pressure gauge. The pulse of eight legs pushing out in discrete steps shows up as considerable movement of the needle on the gauge. The amount of load affects the movement of the needle. A lightly loaded cart on a hard gravel surface bounces the needle erratically. Usually the needle is more stable with heavier loads. The range of movement is perhaps as significant as the average. It is frequently easier for the reader to note the range of the needle's movement than to determine an average in the field. Under constant conditions the needle will generally flutter in a fairly clear range. Glycerine-filled gauges help dampen vibrations but are a little more expensive. Glycerine can also leak from the gauge and react with the oil in the hose and cylinder, rendering the dynamometer inoperable.

Calculating Power

Except for a few tasks such as pulling stumps, short maximum exertions are not as valuable as sustained efforts. If you want oxen to plow for 4-6 hours a day, do not match them to a tool that they can pull handily for only 10 minutes. Readings should be taken under normal working conditions. Measuring the work accomplished is a much closer reflection of profitability than is a measurement of instantaneous or maximum force. Work is defined as force multiplied by distance. The concept of power makes measurements more comparative. Power is defined as Work/Time. With animals that need rest, the longer the time period of measurement the more realistic the result.

Horsepower is defined as: 1 HP = 33,000 foot-pounds of work per minute. Thus, if our oxen pull a log at 660 pounds force for 176 feet in 1 minute they will produce 3.52 HP.

$$HP = \frac{Force\ (660\ pds)\ X\ Distance\ (176\ ft)}{Time\ (1\ min)\ X\ Constant\ (33,000)}$$

$$= \frac{116,160}{33,000} = 3.52\ HP*.$$

* 1HP = 746 joules/sec
= 4,615 meter-kg/min
= 0.746 kw

That would be more power than you should expect from a team for a long period of work. Generally, you can expect a team to produce a force of about 10-14 percent of their bodyweight over several hours of work (Goe and McDowell, 1980:20). That will vary considerably by temperature and working conditions. The work will also vary with the soil or surface conditions.

A dynamometer checks your animals and equipment against the results of others. It will permit you to select implement designs more realistically. You will know what power is available and what power your implements require. This field unit can give you that information within reasonable accuracy.

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