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Using Hydraulics as a Scale on the Farm

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Scales are often used on the farm to weigh things such as feed, lambs, calves, and square bales of hay. Larger objects such as round bales, silage, or livestock are weighed less often, if at all. In many cases, scales for this type of measurement may cost more than $1,000. Using hydraulic cylinders and front-end loaders as scales can be acceptably accurate for most applications for a fraction of the cost.

Basic Principle

"Hydraulics" is a term commonly used to describe the science of transmitting force and/or motion through confined liquids. "Power hydraulics" and "hydrostatics" are more specific terms for the field called "hydraulics" in industry.
In hydraulics, pressure is required for pushing or exerting a force or torque. In a hydraulic system, pressure controls force.

Pressure is defined as a force per unit of area or

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

For example, if a hydraulic system operates at 20 psi of pressure, the hydraulic fluid is under a pressure of 20 pounds per square inch.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} = \frac{\text{20 pounds}}{\text{1 square inch}}$$

Application - Static Hydraulic Cylinders

The terms "force" and "weight" can be interchanged. The formulas discussed previously can be used to determine the weight of an object based on the pressure exerted on a hydraulic system. A single hydraulic cylinder or several cylinders connected in a series with an object hanging below would exert pressure on the system.

Figure 1 illustrates how a single cylinder could be configured to measure the pressure exerted by the weight. It shows the use of a quick coupling system that allows the same gauge to be used with several applications. Make sure that the cylinder is filled with hydraulic fluid before attaching the gauge.

Table 1 provides guidance for using different sizes of cylinders for different weighing capacities.

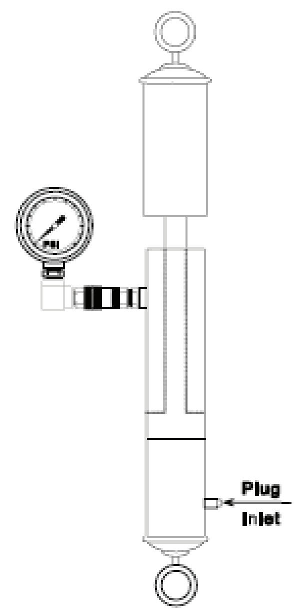

Figure 1

Table 1 - Hydraulic Cylinder Characteristics					
Cylinder Diameter (Inches)	Shaft Diameter (Inches)	Area of Cylinder* (Sq. Inches)	Area of Rod* (Sq. Inches)	Weight per One Pound of Pressure**	Maximum Operational Weight for 3000 psi Rated Cylinder***
1.5	0.750	1.77	0.44	1.33	3,100
2.0	1.000	3.14	0.79	2.36	5,600
2.5	1.250	4.91	1.23	3.68	8,800
3.0	1.375	7.07	1.49	5.58	13,400
3.5	1.500	9.62	1.77	7.85	18,800
4.0	1.750	12.57	2.41	10.16	24,300

1
* The area of a cylinder or rod is determined by multiplying the radius of the circle by itself and multiplying that value by 3.146(pi). (Area of a circle $=\Pi r^2$).
** Area of the Cylinder minus Area of the Rod.
*** The suggested operational maximum weight is approximately 80% of the calculated maximum weight. It is subject to the proper calibration of the cylinder.

Table 2 - Experimental Results with Single Cylinder Weight/Pressure Ratio		
Weight of Tractor Weights (pounds)	**Average Pressure on Gauge (PSI)**	**Ratio of Weight to Gauge Pressure**
190	77.73	2.444
290	120.00	2.417
390	167.27	2.332
490	210.00	2.333
590	250.00	2.360
690	296.36	2.328
790	340.00	2.324
890	380.00	2.342
990	430.00	2.302
1090	470.00	2.319
Average		2.350

Calibration

The figures in Table 1 are based on calculations that assume theoretical values and provide guidance in the design of a weighing device. Only a couple of factors may justify calibration. The accuracy of the gauge and not knowing the correct cylinder or rod diameter can drastically affect the accuracy of the scale. In general, the theoretical values are acceptably accurate for most applications.

To prove this, a 2-inch cylinder with a 1-inch shaft was tested using 1,000 pounds of tractor weights that had been weighed on a certified scale for accuracy. The results are shown in Table 2. The cylinder has a theoretical value of 2.36 pounds of weight per pound of pressure on the gauge. The test comprised 10 replications, starting with the weight of the platform and adding 10 100-pound weights at a time.

The calibration showed an average difference of only .01 pounds of pressure per pound of weight from the theoretical value of 2.36. This cylinder, used to 1,000 pounds without calibration, would give a reading 5 pounds lighter than the actual weight. Another way of evaluating the accuracy would be to say the measurement is 99.58% of the actual weight.

More than one cylinder in a parallel circuit can be used to weigh larger amounts. A parallel connection will divide the load among the cylinders. This would require a gauge on each cylinder, but would allow for increased capacity without increasing the cylinder size. A series connection would use only one gauge, but all cylinders would have the same load, reducing the capacity of the scale in comparison to the same number of cylinders connected in a parallel circuit. **All gauges, fittings, and hydraulic hoses must be rated for hydraulic use at no less than the rating of the cylinders used or the maximum pressure that would be reached by the scale.**

Application - Front-end Loader

Using a hydraulic gauge can also turn a hydraulic front-end loader into a scale. There are differences in calibrating this system compared with a static hydraulic cylinder. A front-end loader uses many feet of hydraulic hose. It has a hydraulic pump and reservoir. Front-end loaders are also different in design among manufacturers and use different attachments to lift. The relationship of weight to pressure will change for the same equipment if different attachments are used. The pressure will be different for a bucket, a fork, a hay spike, and a bucket with a hay spike attached. The farther away the load extends beyond the cylinders or the hinge point (fulcrum), the greater the pressure must be to lift the same weight.

Accuracy

When asked what a round bale of hay might weigh, an individual may use past experience; information in the owner's manual or actually try to move the bale. How accurate is that? How accurate is the use of the hydraulic front-end loader? The results of two small experiments conducted in 2005 are discussed.

The first study involved measuring the weight of nine 4 x 4 bales of alfalfa/brome hay. The measurement took place two days after the bales were made. A pressure reading was taken and recorded. The bales were then weighed with a *Tru-Test SR 3000* and *Tru-Test MP600* weigh bars with an aluminum tub. Table 3 describes the results of this study.

Table 3 - Comparison of Actual Scale vs. Loader Pressure Multiplied by the Average Ratio

Trial #	Scale Weight	Calibrated Loader Weight	Difference (Loader—Scale)
1	830	855	25
2	760	758	-2
3	726	740	14
4	729	734	5
5	744	782	38
6	774	734	-40
7	692	692	0
8	672	674	2
9	722	686	-36
Average	**739**	**740**	**1**

A second experiment was conducted at an in-service training for West Virginia nutrient management consultants. Forty-five consultants were asked to estimate the weight of two 4 x 5 bales and three 4 x 4 bales of hay. The results are shown in Table 4.

Table 4

Trial #	Scale	Loader	Loader Difference	Average Consultant Estimate	Estimate Difference
1	836	806	-30	884	48
2	1285	1088	-197	842	-443
3	688	846	158	477	-211
4	630	685	55	604	-26
5	592	725	133	567	-25
Average	**806**	**740**	**24**	**675**	**-131**

While there was more variability, the number and difference in size may have played a role in that variability. Just like in any statistical effort, the more sampling the better.

Research was conducted in the summer of 2006 by WVU Extension Agent Craig Yohn to expand and validate previous experiments. Ten large round bales were weighed on seven different producer farms. Each bale was weighed twice over 100 days apart with the use of a portable elec-

Figure 2 - Weighing Bale on Livestock Scale

tronic scale.

Each bale was identified and a statistical analysis

Figure 3 - Aluminum Cattle Ear Tag Used

was run to compare the first weighing of the bale to the second.

The loader was then lifted to a consistent height which is an important aspect of calibrating the loader. It is also important to make sure that the

Figure 4 - Bale Raised to a Consistent Height

bale is on the spike consistently.

A pressure was then recorded from an oil-filled gauge. The gauge was divided in increments of

Figure 5 - Oil Filled Hydraulic Gauge

50 pounds of pressure.

The gauge was integrated into the hydraulic

Figure 6 - Side Location on Newer John Deere Tractors

system of the tractor following the line back from the rod in of the lifting cylinders. The pressure was recorded beside the recorded weight. A ratio of weight to pressure was then calculated for each bale after each weighing.

Table 5 shows the calculated ratios for the two weighings and a statistical confidence interval, which can be used to evaluate the variation that can be expected in the observed ratio. The average ratio confidence shows that the front end loader was plus or minus 3.5% of the actual weight of the bale.

Table 5 - Front end Loader Ratio Comparison

Average Weight/Pressure Ratio of 10 Bales

Farmer	Trial 1	Trial 2	Confidence Interval
A	1.16	1.14	3.9%
B	.59	.61	3.6%
C	.94	.92	5.5%
D	1.09	1.01	2.1%
E	.84	.82	3.1%
F	*1.29*	*1.29*	*1.3%*
G	1.34	1.24	5.1%
Average			3.5%

Procedure for Large Round Bales

1. Weigh at least three bales of various size, condition, or species makeup on a certified scale.
2. Lift each bale so that the loader is at the same height and record the pressure on the gauge.
3. Divide the weight of the bale by the pressure reading on the gauge.
4. Calculate an average ratio.
5. Use average ratio of weight to pressure to calculate the weight of other bales.

The following example from a previous trial will provide an overview of the procedure:

Three bales of different sizes and makeup were weighed on a local certified truck scale.

Bale #1
Actual Weight - 880 lbs
Cubic Feet per Bale - 52.0
Grass-Legume
Gauge Reading - 550 psi
Ratio of weight to pressure - 1.60

Bale #2
Actual Weight - 1340 lbs.
Cubic Feet per Bale - 140.8
Grass-Legume
Gauge Reading - 800 psi
Ratio of weight to pressure - 1.67

Bale # 3
Actual Weight - 1720 lbs
Cubic Feet per Bale - 106.5
Alfalfa
Gauge Reading - 1000 psi

Figure 7 - Producer Raised Bales to Same Height

Ratio of weight to pressure - 1.72

An average ratio is determined by taking the three readings, adding them together, and dividing:
1.60+1.67+1.72 = 1.663

The average ratio is 1.663. A table can then be generated for use when weighing bales by

multiplying the pressure times the ratio (ex. 300 * 1.663) and then rounding to a whole number. Table 6 is an example based on the average ratio in the example on the previous page.

Table 6 - Example Reference Table for Producer

Pressure Reading	Weight	Pressure Reading	Weight
300	499	600	998
350	582	650	1081
400	665	700	1164
450	748	750	1247
500	831	800	1330

Application—Three-Point Hitch

Many producers do no have access to a front end loader. An alternative was explored. A hydraulic cylinder replaced the top link of the three-point hitch implement such as a spike or bale carrier.

Figure 8 - Rear view of Cylinder as Top Link

Research conducted in 2006 by WVU Extension Agent Craig Yohn determined that while the accuracy is slightly less, the equipment used properly could be used as an on-farm scale.

Figure 9 - Side View of Cylinder as Top Link

Procedure

1. Attach gauge assembly to tractor hydraulics.
2. Attach rod end of cylinder to implement.
3. Attach other end of cylinder to tractor. (Note: Clevis of cylinder may prohibit a satisfactory hookup. Consider offsetting the connection or preferably use a piece of steel with holes drilled or cut to adapt to the implement and tractor.)
4. Attach hose from rod end of cylinder to gauge.
5. Attach rear hose to tractor hydraulics.
6. Load the bale consistently on the carrier or spike.
7. Pull the cylinder closed after lifting the bale. (Note: Be consistent in lifting the bale to the same height. Use the draft adjustment to be consistent.)
8. Let the cylinder out to a consistent length.
9. Record the pressure.

Figure 10 - Raise Carrier to a Consistent Height

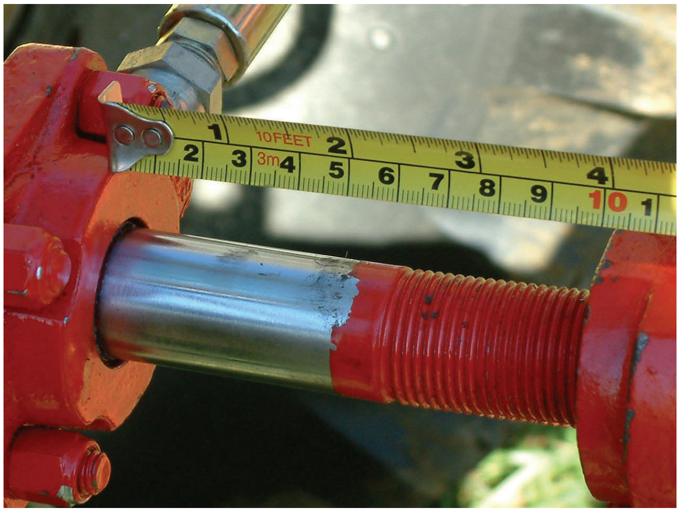

Figure 11- Let out the Cylinder to a Consistent Length

Table 7 shows the results from the weighing of the 10 bales per farm twice during the same trial that evaluated the front end loader.

Table 7 - Three-Point Hitch Ratio Comparison			
Average Weight/Pressure Ratio Comparison			
Farmer	**Trial 1**	**Trial 2**	**Confidence Interval***
A	**1.48**	**1.36**	**4.3%**
B	**1.06**	**1.13**	**4.7%**
C	**.97**	**1.02**	**3.8%**
D	**2.41**	**1.54**	**7.6%**
E	**.92**	**1.14**	**8.5%**
F	**1.55**	**1.57**	**3.5%**
G	**.97**	**1.53**	**5.1%**
Average			**5.4%**

***Can also be described as percent error or percent uncertainty.**

While this trial has been done with large round bales and required the use of a scale, tractor weights, sacks of feed, or other objects of known weight could be used for calibration purposes. The important thing to remember is to place the known weight in the same location on the front-end loader as the commodity being calibrated.

The more samples or items weighed to determine the ratio, the more accurate the hydraulic scale will be. A "quick coupling" system can be built with parts from many suppliers for less than $150. The use of the three-point hitch system adds an additional cost for the cylinder hoses and couplers.

Figure 12 shows how such a system could be constructed to be part of the existing hydraulics of the front-end loader.

Suppliers

There are many suppliers of cylinders, gauges, and hydraulic fittings and hose. These include auto part stores, farm supply and implement dealers, and specialty suppliers such industrial hydraulic and pneumatic system installers.

When considering what to purchase, keep in mind the range of weight that is being measured and the accuracy desired. The larger the cylinder, the more weight capacity, but the larger increment of weight per pound of pressure. For example a 2-inch cylinder, with a pressure capacity of 3,000 psi, has the capacity to weigh up to approximately 5,700 pounds. Each pound of pressure will equal approximately 2.36 pounds of weight. A 3-inch cylinder may have a capacity of more than 10,000 pounds, and each pound of pressure would equal approximately 6 pounds.

The same is true for pressure gauges. An oil-filled gauge is recommended. A gauge that has a 500 psi capacity may have 10 psi increments, and a gauge with a capacity of 1000 psi may have 20 psi increments.

Summary

Hydraulics can be a powerful tool for recording agronomic performance of the farm and provide information related to feeding animals. The construction, configuration, and calibration of the scale are well within the capabilities of most producers.

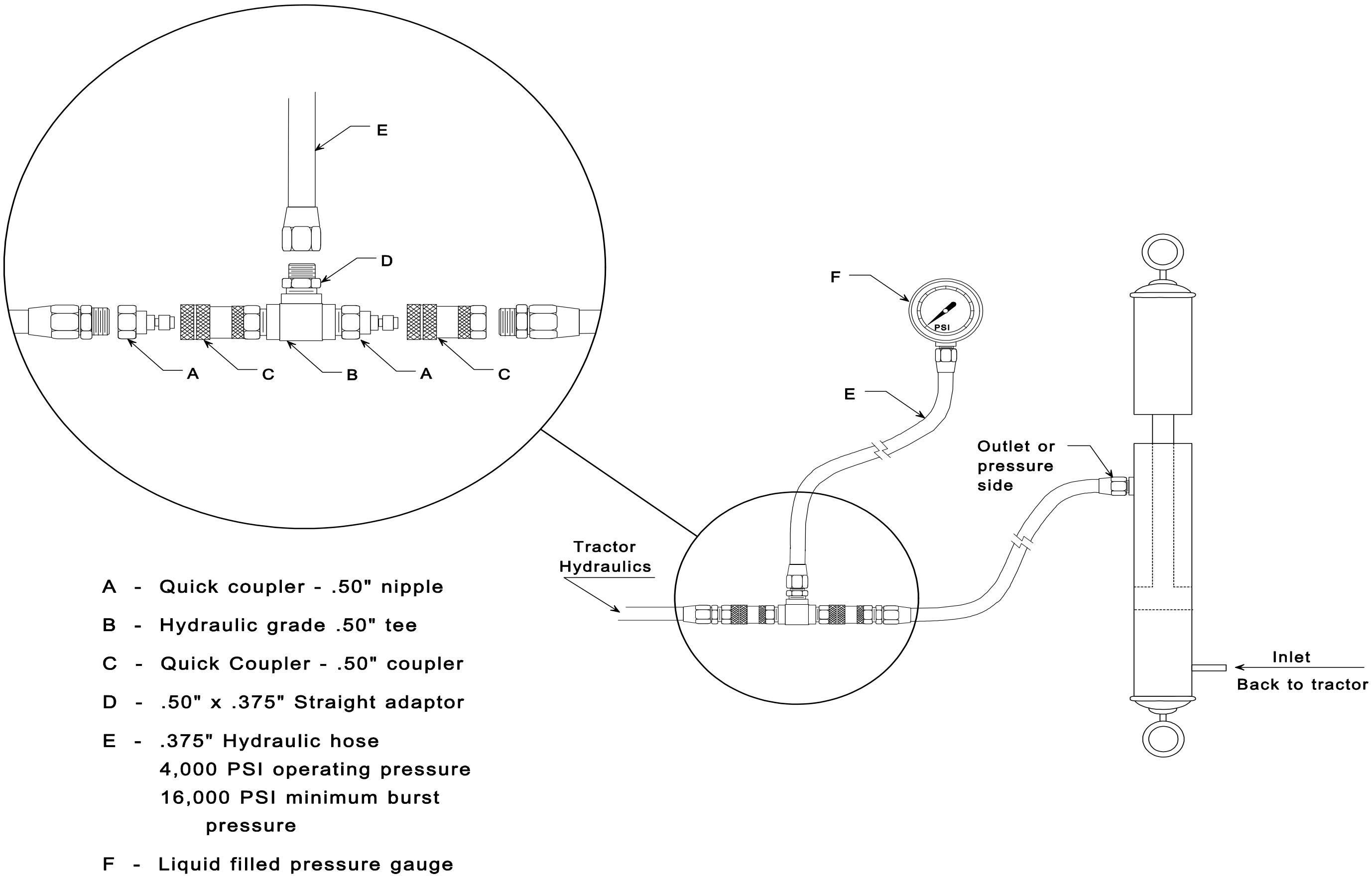

Figure 12— Schematic of Hydraulic Gauge Integration into Tractor Hydraulics

Calibration is a must for different temperatures, apparatus, and age and wear of the cylinder or hydraulic system being used as a scale.

Properly calibrated, the hydraulic scale can be within plus or minus 6% of the actual weight of the bale.

Parts are available through many companies. The pressure gauge capacity and the hydraulic hose and fittings should meet standards greater than the maximum pressure of the hydraulic cylinder, the operating pressure of the tractor, and the maximum pressure generated by the weight to be measured.

Tools

The following page offers a table to record weights, pressures and calculate a ratio. The second table also offers a method to record the pressure on the gauge and the related calculated weight.

An *Excel spreadsheet* is also available that automatically does all of the calculations.

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Hydraulic Scale Calibration Sheet

Hydraulic\Loader Cylinder

Trial Number	Weight of Item	Pressure	Ratio: Weight/Pressure
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
Average			

Pressure Weight Sheet
(Observed Pressure time Ratio)

Pressure	Weight	Pressure	Weight