Journal of Experimental Biology and Agricultural Sciences

http://www.jebas.org

ISSN No. 2320 – 8694

DESIGN, MANUFACTURING AND CALIBRATION OF A CIRCULAR RING TYPE MONOLITHIC LOAD CELL ADDRESSED TO DRAWBAR PULL TESTING OF THE FARM TRACTOR

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Received – July 07, 2014; Revision – July 31, 2014, Accepted – August 13, 2014
Available Online – August 21, 2014

KEYWORDS

Circular Ring Type Load Cell

Drawbar Pull

Farm Tractor

ABSTRACT

A circular ring type monolithic load cell was designed to be used in the farm tractor pulling tests; its maximum capacity is 58.86 kN of load. Its spring element is 4140 steel, which has a Rockwell hardness of 42. Its weight is 79.46 N. The maximum working stress is 169.79 MPa, factor of steel safety, normal strain, factor of strain gage safety, momentum and displacement were 4.06, 819.87 $\mu\varepsilon$, 1.83 and 506.03 Nm and 161 μm, respectively. The calibration test showed high significance between applied load and unit strain measured by strain indicator; the linear equation by regression analysis was y= 0.1327x+0.0953, and its determination coefficient was 0.99.

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Peer review under responsibility of Journal of Experimental Biology and Agricultural Sciences.

Production and Hosting by Horizon Publisher (www.my-vision.webs.com/horizon.html).

1 Introduction

Farm Mechanization in developing countries has lagged behind, because of the technical, economic, social, political and human issues have not been satisfactory (Agribusiness Worldwide, 1987). The tractor is the most important source of power within the agriculture and can be described as the conventional symbol of agricultural mechanization. In any system of farming, the tractors acquired by the farmers should be selected with precise technical criteria in order the tractors can be used efficiently. One of the most important parameters to consider in selecting a farm tractor is the power of its engine and its relationship with drawbar power and power take off (PTO). The power at the drawbar is a very important factor to consider for proper performance of the tractor and implement configuration, to match better with the working conditions and expected use, and thus fully utilize their potential efficiency (Sakurai, 1999).

In the country there is a lack of reliable data on tractors and farm machinery, making it difficult and even impossible somehow making decisions about which models should recommend. Currently different Mexican institutions of research, teaching, and operation in the areas of engineering and agricultural machinery, are dedicated to the development of laboratory testing and evaluation of agricultural machinery and implements, to verify the behavior of different models, brands commercially available in the country (INIFAP, 2014).

But few universities in Mexico have insufficient research, laboratories, staff and even instruments for field testing instruments. The little or no availability of laboratories in the short term, and the high cost of the instruments found on the market, encouraged to undertake programs for the development of measuring instruments to carry out tests and evaluations of tractors. The Department of Agricultural Machinery Agricultural University Antonio Narro is part of the National Evaluation and Testing of Agricultural Machinery coordinated by the Mexican Center for Standardization of Agricultural Machinery and the Mexican Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food. The Department of Agricultural Machinery of Agricultural University Antonio Narro participated in the development and implementation of Mexican standards for testing and evaluation of agricultural machinery as well as technical training of staff. For testing power drawbar on agricultural tractors Agricultural Machinery Department of Agricultural University Antonio Narro required to have a force transducer instrument. Present study was aimed to develop a circular ring type monolithic load cell or force transducer at lower cost for future use in testing and evaluation of agricultural tractors.

2 Materials and Methods

2.1 Load cell capacity

The capacity, given in Newtons, of transducer is determined by consulting directly with the manufacturers of agricultural tractors such as New Holland and John Deere companies. For the selection of the diameters of the holes in the ends of the transducer, we revised the Table 4 of appendix A from OECD (OECD, 2000), Figure 1 and ASAE (American Society of Agricultural Engineers, 1999) has provided specifications in ASAE 5482 DEC98 standard for the Category II tractors. For the selection of material information provided by the company Measurements group (1992) was used.

2.2 Manufacturing of load cell

After completing the design and material selection, proceeded for machining the transducer in machine shops and local tools for this specification using the plane generated and the metallic material chosen. Later, selected strain gages were installed at 90 ° and the system was assembled. Least squares method was used in this study to estimate the probability of occurrence of del min and med in the month of the series.

2.3 Test and calibration of the load ring

Strain indicator was connected with the transducer, it happened according to the instructions released from Measurements group (2000):

1. Gauges were connected according to the indicator diagram of full bridge.
2. AMP ZERO (zero amplification) button was pressed, and were allowed five minutes of warming and adjusted to a reading of + / - 0000. GAGE FACTOR Button was pressed (gauge factor). The gauge factor was adjusted according to study specifications and desired sensitivity of the instrument and finally the lock was fixed on the micrometer knob GAGE FACTOR button.
3. RUN button was pressed (run). It was adjusted with the know BALANCE. For the present study load were applied from 0 to 1082 kg (10614 N). The strain indicator reading unit was in microstrain (με) with a resolution of 1 (με).

The set appropriate gauge factor is calculated as follows.

$$\boxed{GF = \frac{4000\,x\,\frac{mV}{V}}{FS}}$$

where

GF = gauge factor to be set on the indicator strain.

FS = full scale value of the transducer expressed in engineering units (Pascals or Newtons).

Scatter plots were obtained of data from a load of 0 kg to 1000 kg (9810 N) versus indicated strain to obtain the best fit to a model of the hysteresis, repeatability, size and weight tables were generated and compared between design data set and adjusted. The conditions of temperature and relative humidity were monitored.

3 Results and Discussion

3.1 Selection of material for spring element, moments, deformations and stresses

The 4140 selected steel was heat treated, which has a Rockwell C hardness of 22.2 and which was given a mild to 815.55 ° C and tempered to increase its hardness to 42 Rockwell (402 Brinell) and obtain a resistance tension of 1380 MPa (200,000 lb/in2) and fatigue of 690 MPa (100,000 lb/in2). The elastic modulus of 207 GPa is (30,000,000 lb/in2).

The maximum stresses generated in the axis of the ring were calculated using the theory of curved beams (Hoag & Yoerger, 1973; Dally & Riley,1978) through the analysis of the diagram in Figure 2. The maximum moment obtained was as follows:

$$M = \frac{F\bar{r}}{2}\left(sen90° - \frac{2}{\pi}\right) = 0.181F\bar{r}$$

$$R = \frac{A}{\int_A \frac{dA}{v}} = \frac{A}{\int_{r_1}^{r_2} \frac{2dr}{r}} = \frac{A}{2\left(\frac{\ln r_2}{\ln r_1}\right)}$$

$$R = \frac{(0.74)(2)}{2\ln\left(\frac{2.24}{1.5}\right)} = \frac{0.74}{0.401} = 1.845$$

Inches (4.699 cm) of radius –

$$\bar{y} = \bar{r} - \frac{A}{\int_A \frac{dA}{v}} = \frac{r_1}{r_2} - R$$

$$\bar{y} = 0.025$$

Inches (0.635 mm) to centroid axis

$$M = 0.181F \cdot \bar{r}$$

$$M = (0.181)\cdot(13215.86)\cdot(1.87)$$

$$M = 4473.172$$

pounds-inches (506.027 Nm (positive))

The distance from neutral axis to extremous fiber is given by the equation (Cernica, 1983).

$$z_1 = \left(\frac{r_{2-}r_1}{2}\right) - \bar{y}$$

$$z_1 = \frac{2.24 - 1.5}{2} - 0.025 = 0.37 - 0.025 = 0.345$$

inches (8.763 mm)

$$z_2 = \left(\frac{r_2 - r_1}{2}\right) + \bar{y}$$

$$z_2 = 0.37 + 0.25 = 0.395$$

inches (10.03 mm) distance from neutral x is to extremous fiber.

The yield maximum strain was –

$$\delta = 1.79\frac{F\bar{r}^3}{Ebt^3} = 1.79\frac{(13215.86)(1.87)^3}{(30x10^6)(2)(0.74)^3}$$

$$\delta = 6.36x10^{-3}\ pu\lg = 636.mpu\lg = 161\mu m$$

The maximum estimated unit strain is (Cook,& Rabinowics, 1963).

$$\varepsilon = 1.09\frac{F\bar{r}}{Ebt^2}$$

$$\varepsilon = 1.09\frac{(13215.86)(1.87)}{(30x10^6)(2)(0.74)^2}$$

$$\varepsilon = 8.198x10^{-4} \quad \varepsilon = 819.87\mu\varepsilon$$

Estimated maximum tensile stress is as follows,

$$\sigma = (30x10^6)(8.198x10^{-4})$$

$$\sigma = 24596.31$$

lb/pulg^2 (169.79MPa).

The elastic stress of 4040 steel is $\sigma = 690MPa$ and tensile maximum stress of predicted is $\sigma = 169.79MPa$, thence the factor of safety of the load cell is

$$F.S. = \frac{\sigma_{elástico}}{\sigma_{trabajo}}$$

$$F.S. = \frac{690\,MPa}{169.79\,MPa} = 4.06$$

Elastic unit strain of gage is $\varepsilon = 1500\mu\varepsilon$ y predicted unit strain $\varepsilon = 819.87\mu\varepsilon$ thence the safety factor of the strain gage

$$F.S. = \frac{\varepsilon_{elástica}}{\varepsilon_{trabajo}}$$

$$F.S. = \frac{1500\mu\varepsilon}{819.87\mu\varepsilon} = 1.83$$

Of these results, the working stress is 4.06 times the fatigue limit of 4140 steel. Moreover, the unit strain of strain gage in working conditions is 819.87 με, that is 0.54658 times yield maximum unit strain.

3.2 Characteristics of the load cell

Circular ring type monolithic load cell (Figure 3) has been developed and sent it to the machining center to manufacture the transducer. According to computer assisted software designing , the load cell has a volume of 1030 cm3 and a centroid whose coordinates are in inches were X :7.6, Y: 3.74, Z: 1. The load cell and strain gauge are shown in Figure 4. The density of 7.84 g cm-^{3} is 4140 steel and according to software the circular ring type monolithic load cell has a weight of 8.082 Kg. To confirm this result, the load cell was weighed on a scale whose maximum capacity is 125 Kg, obtaining and reading a weight of 8.100 kg (79.46 N).

3.3 Selection of the strain gage, cellophane tape, adhesives, and cable

It was selected type of CEA-XX-062 UW-350 resistive strain gauge. The terminal area was 1.8 mm by 1.0 mm. It has a length of 1.57 mm. The gauge was $350 \pm 0.4\Omega$. Their gauge factor is 2.0 and the temperature range in which work is -100 to 175 ° C. The coefficient of thermal expansion in the range 0 to 100 ° C is 11.3 and the range of 32 to 212 ° C is 6.3. The deformation is ± 5 percent. The level of fatigue deformation is en $\mu\varepsilon$ is ± 1500 for 1,000,000 cycles. This gauge can be used in the analysis of static load and dynamic.

3.4 Selection of sand paper, degreaser, conditioner and neutralizer

It was chosen 220 grit silicon carbide paper and for final abrasion, it was used 320 grit silicon carbide paper. CSM Degreaser was chosen because it is better to use spray applicator to prevent back contamination from the solvent. M-Prep A Conditioner and MN Prep 5A-2M-16 neutralizing was selected to provide optimum alkalinity for adhesives. To avoid contamination of the bonding surface or reaction with, we used an adhesive tape certified by the company Micro-Measurements. The adhesive chosen was the M-Bond, it is a cyanoacrylate alkaline compound, and it can operate in temperatures from 30 to 65 ° C. In addition, it was used a catalyst used for the M-Bond 200 that controls the rate of reactivity of this adhesive. Since this adhesive weakens is exposed to high humidity, a M-coat A protective lacquer was used.

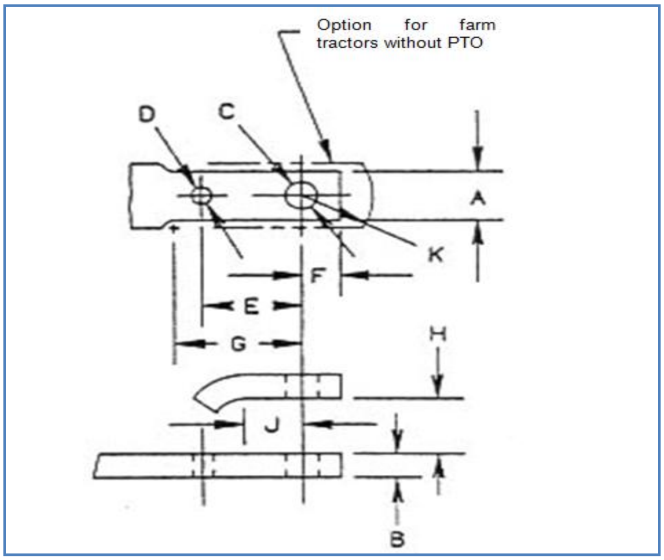

Figure 1 Drawbar tool of a farm tractor (Reprinted with permission from ASAE Standard S482 DEC98: Drawbars -- Agricultural wheel tractors. Copyright 1998 American Society of Agricultural Engineers. St, Joseph, Mich.: ASAE).

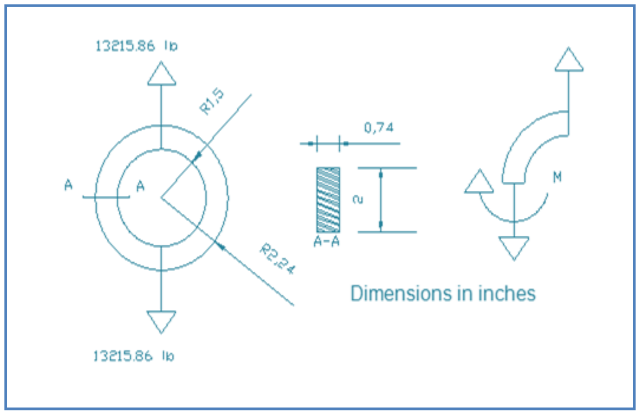

Figure 2 Stress analysis of load cell.

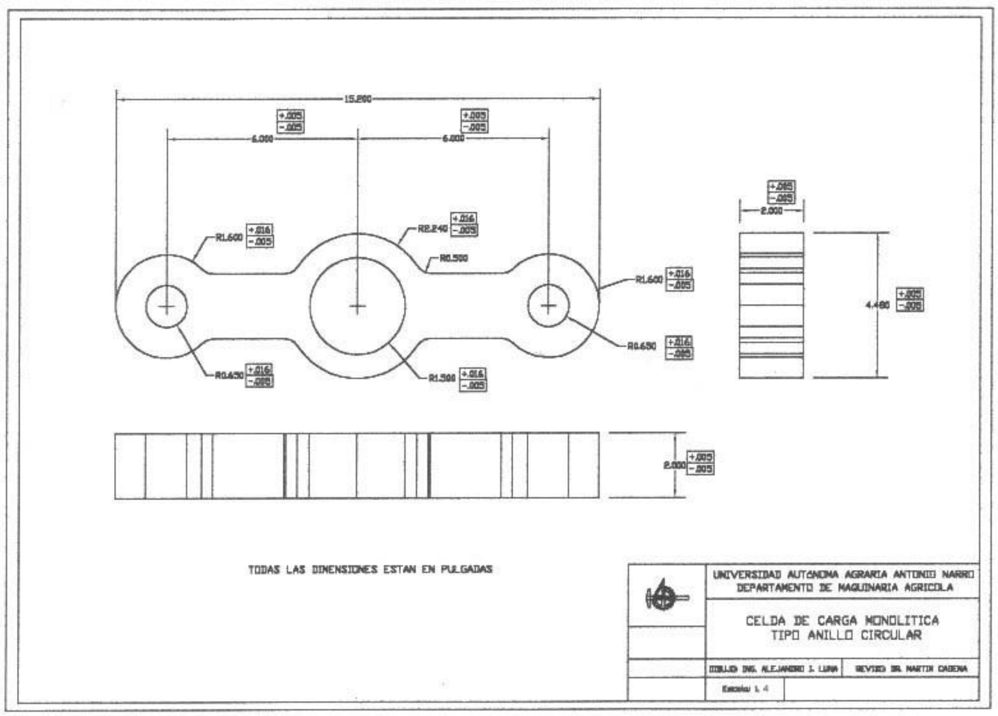

Figure 3 Circular ring type monolithic load cell.

Figure 4 Circular ring type monolithic load cell and strain indicator.

Figure 5 shows the scatter points and the calibration curve obtained with the data read from the strain gauge actual loads applied on the load cell monolithic. Table 1 shows the load applied in relation to the estimated strains indicated and adjusted. It can be observed very close values between the different strains. The hysteresis was zero, since the strains in loading and unloading were the same.

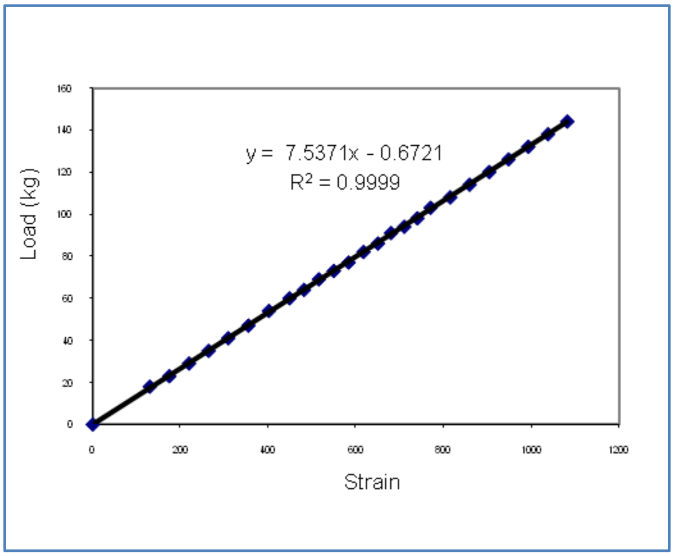

Figure 5 Calibration curve of a circular ring type monolithic load cell.

3.5 Tests

426-DFV wire, 26 gauge 4 lines and 4.4 m in length was selected and P-3500 model strain indicator was used in the form of full Wheatstone bridge through the posts for connecting gauges. It introduced a gauge factor of 6 to produce a sensitivity of 1.5 mV / V. The calibration test was made at an average temperature of 20.6 ° C and a relative humidity of 55 percent. The regression coefficients obtained by the method of least squares are B_0 = 0.09, B_1 = 0.13, so the equation is y = 0.13x +0.09 and the determination coefficient was found to be R^2 = 0.99. The variance analysis shows that the calculated correction factor is greater than tabulated, 95 and 99 percent of significance, so the charge in relation to deformation is highly significant. Confidence intervals of 95 percent for the coefficients B_0 = B_1 = 0.09 and 0.13 are in the lower limit -0.12 to 0.31 and the upper limit from 0.13 to 0.13. Confidence intervals of 99 percent for the coefficients B_0 = B_1 = 0.09 and 0.13 are in the lower limit -0.19 to 0.38 and the upper limit from 0.13 to 0.13.

4. Conclusions

The load cell monolithic circular ring type is a transducer that measured forces with a 99 percent confidence. The sensing device has a sensitivity of 1.5 mV / V and is suitable for mounting to drawbar tractor category II and which was designed according to ASAE Standard 5482. It was found that the repeatability, linearity and hysteresis freedom is very high in a monolithic load cell.

Acknowledgements

We would like to thank the Mexican Ministry of Education, the Department of Farm Machinery at Universidad Agraria Antonio Narro and the Agricultural Research Centre of the Faculty of Agronomy of the Universidad Autonóma de Nuevo Leon.

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