

*The Canadian society for
engineering in agricultural,
food, and biological systems*

**C
S
A
E**



**S
C
G
R**

*La société canadienne
de génie agroalimentaire
et biologique*

Paper No. 05-059

PAPER TITLE

Double extended octagonal ring (DEOR) drawbar dynamometer

Ying Chen

Department of Biosystems Engineering
University of Manitoba,
Winnipeg, MB R3T 5V6

Sylvio Tessier

ST AgriTech,
56 Demers Place,
Winnipeg, MB R3V 1W4

Neil McLaughlin

Agriculture and Agri-Food Canada
960 Carling Ave.,
Ottawa, ON K1A 0C6
mclaughlinn@agr.gc.ca

**Written for presentation at the
CSAE/SCGR 2005 Meeting
Winnipeg, Manitoba
June 26 - 29, 2005**

Abstract

A drawbar dynamometer is required to measure drawbar forces in field research on energy inputs for agricultural field equipment, and tractive performance of agricultural tractors. In this study, a high capacity double extended octagonal ring (DEOR) drawbar dynamometer with a draft capacity of 180 kN was developed. The two extended octagonal rings were oriented vertically on either side of the drawbar which provided a better match of strain to expected drawbar draft and vertical load than could be achieved with previous designs with a horizontal orientation. Strain distributions in the extended octagonal rings were analyzed using a finite element method to locate optimal strain gage positions to minimize cross sensitivity between draft and vertical force measurements. The DEOR was fabricated from high strength ANSI 4130 steel. Vertical and draft calibrations were done in a laboratory universal testing machine. Calibration results show that the dynamometer has a linearity of 0.99 and negligible cross sensitivity for both horizontal and vertical outputs. The DEOR dynamometer was tested in a field to measure the draft and vertical force of a sweep-type manure injector. No mechanical problems were observed for the dynamometer and its draft outputs were comparable to those reported in the literature for manure injectors.

Keywords: Drawbar; Dynamometer; Ring; Finite Element; Strain; Calibration; Test

Papers presented before CSAE/SCGR meetings are considered the property of the Society. In general, the Society reserves the right of first publication of such papers, in complete form; however, CSAE/SCGR has no objections to publication, in condensed form, with credit to the Society and the author, in other publications prior to use in Society publications. Permission to publish a paper in full may be requested from the CSAE/SCGR Secretary, PO Box 316, Mansonville, QC J0E 1X0. Tel/FAX 450-292-3049. The Society is not responsible for statements or opinions advanced in papers or discussions at its meetings.

1. Introduction

Drawbar dynamometers are designed to measure the forces exerted by pull type agricultural implements on the tractor drawbar. Of the three orthogonal forces, horizontal, vertical and side, exerted by an implement on the tractor drawbar, draft (horizontal force) is usually the largest and of greatest interest. Draft measurements are required for many studies including energy inputs for field equipment, matching tractor to an implement size, and tractive performance of the tractor. Vertical force affects weight transfer from implement to tractor, and consequently, affects the tractive performance and dynamic stability of the tractor. Although severe side load can affect tractor steerability, but in most cases, side force is negligible (Godwin, 1975; Leonard, 1980). Pull type implements are connected to the tractor with either a single draw pin in a loose fitting clevis arrangement, or a ball and socket. Moments transferred from the implement to tractor are negligible for either hitch configuration. This is unlike three-point hitch mounted implements where both forces and significant moments in all three directions are transmitted from implement to tractor. Special three-point hitch dynamometers have been developed for these applications (Johnson and Vorhees, 1979; Garner et al., 1988; Palmer, 1992). Two dimensional (draft and vertical) drawbar dynamometers are considered a practical and economical solution for studies on drawbar forces for most pull type implements.

The Canadian Prairies are characterized by large farms, many with more than 400 ha cultivated land base. Many farms have tractors larger than 150 kW, and implements that are at least seven m wide (Chen et al., 2005). Due to the larger sizes of equipment, pull type implements are most commonly used. Many farms are adopting no-till crop production, and many have diversified to confined livestock production, many with liquid manure systems. These two new practices require research on no-till seeding equipment, and manure application systems which inject manure below the soil surface. With ever increasing costs for both tractors and fuel, energy inputs are a critical factor in producer acceptance of any new developments in seeding or manure application equipment. A 2-D drawbar dynamometer with high capacity for draft measurements and low cross sensitivity is required to carry out studies on large scale equipment used for seeding, tillage, and liquid manure application in Canadian Prairies.

2. Literature Review

Kirisci et al. (1993) divided drawbar dynamometers into two groups, frame type and linkage type. A frame type dynamometer consists of transducers mounted on a specially constructed frame which is inserted between the tractor and implement (Kitson, 1987; Thomson and Shinnars, 1989). A linkage type dynamometer has the force transducers built in the hitch links themselves. The main advantage of the linkage type over the frame type is that the position of the implement relative to the tractor is not altered. Linkage types are more suitable for field studies of the interaction of tractor and implement since the hitch geometry, and consequently weight transfer and implement position relative to the soil surface is not altered by the presence of the dynamometer. Several different configurations of link type drawbar dynamometers have been developed in the past. Zoerb et al. (1983) and Kirisci et al. (1993) have been developed instrumented hitch pins to replace the usual implement hitch pin. Strain gages on an inner pin located within an outer split shell with fixed load transfer points provide a linear response to draft when the device is placed in shear in a clevis arrangement on a tractor hitch. Other link

type dynamometers include hydraulic systems, ring load cells, and shear beam elements (Zoerb et al., 1983). Most of these can only measure draft, and many do not have sufficient robustness to accommodate large bending moments, vertical or side loads which are often exerted by the implement on the tractor drawbar. Even though pitch, yaw or roll moments transmitted via a pull type implement are small enough to be of no practical significance, they are often large enough to destroy a link dynamometer based on shear beam or load ring.

Other more robust link type dynamometers, such as plain extended rings (O'Dogherty, 1975; Hoag and Yoerger, 1975) (Fig. 1a) and extended octagonal rings (EOR)(Fig. 1b) have been developed to overcome problems associated with ring and shear beam transducers. Both the extended ring and extended octagonal rings have a massive central section to which loading fixtures can be bolted. Strain gages are mounted on the thinner ring sections for force measurement. EOR's have flat outside surfaces which are easier to machine than the circular outer face on the plain extended ring. EOR's can be made any width, and wider cross sections are more robust and immune to extraneous forces and moments exerted on a drawbar. The EOR's are capable of measurement of draft and vertical forces, and pitch moment. The devices are relatively compact, and offer flexibility in designing mounting fixtures.

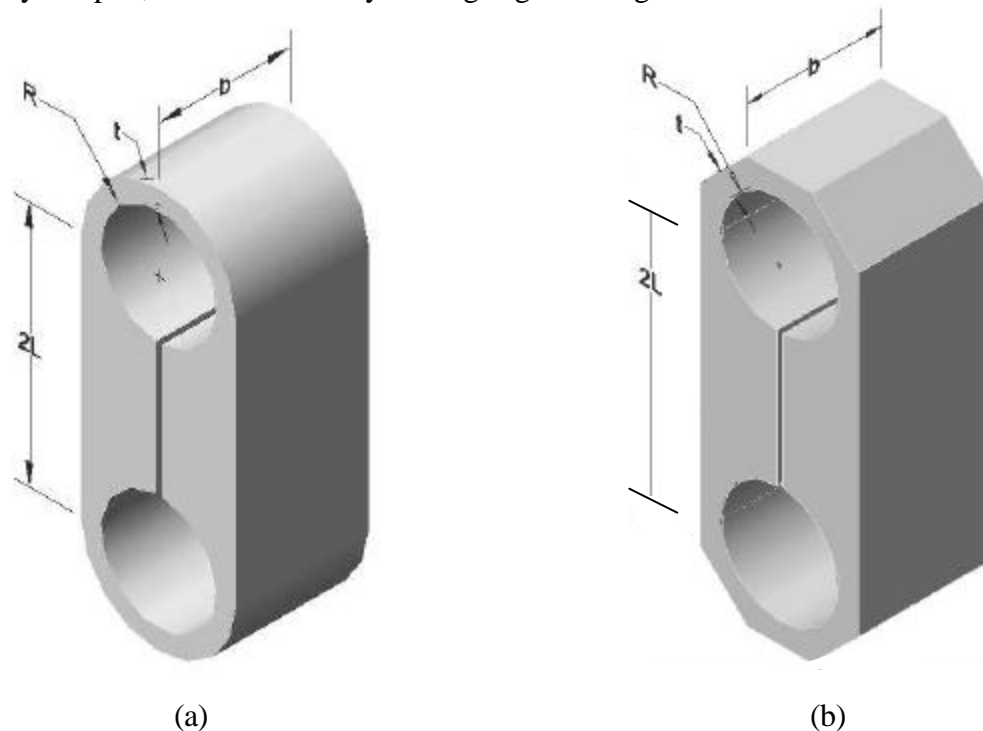


Fig. 1. Plain extended ring (a) and an extended octagonal ring (b) with the basic dimensions.

Godwin (1975) designed and built a 2-D EOR drawbar dynamometer to measure horizontal and vertical loads and one moment. This dynamometer consisted of single EOR and had capacity of 1.26 kN•m for the moment loading. Leonard (1980) designed a 2-D double extended octagonal ring (DEOR) drawbar dynamometer with one EOR on each side of the tractor drawbar. The design capacity was 25 kN for both horizontal and vertical loading. Gu et al. (1991) developed an EOR transducer for measuring vertical and horizontal loads on the wheels of a model tractor. The design horizontal and vertical loads were 3.8 and 2.3 kN

respectively. Tessier et al. (1992) developed a 3-D DEOR drawbar dynamometer with capacities of 45 and 13 kN for horizontal and vertical loading, respectively. An improved version of this 3-D DEOR dynamometer was later developed with the same capacities (McLaughlin et al., 1998). In all these DEOR dynamometers, the two extended octagonal rings were oriented horizontally on either side of the drawbar.

The strain distribution on the ring sections of the EOR is different for vertical and horizontal loads. It is easy to show via curved beam formulae that bending moment and resulting strain for both vertical and horizontal forces are zero at some point on the ring section. McLaughlin (1996) presented diagrams to show the direction of bending moment and resulting strain at various general locations on the ring. The locations of zero bending moment and strain are often called strain nodes, and are at different locations for horizontal and vertical loading. If a strain gage to measure horizontal loading is located at the strain node for vertical loading, then the horizontal strain measurement should be insensitive to vertical loading. Strain from vertical loading is zero at this point for all vertical loads. The same criteria can be applied for locating the vertical strain gages at the strain nodes for horizontal loading. Locating the strain gages at the horizontal and vertical strain nodes should yield minimum cross sensitivity between horizontal and vertical measurements.

Much effort has been devoted to locating the strain nodes on an EOR, and many hypotheses have been presented in the literature. Hoag and Yoerger (1975) presented an elegant analytical solution based on strain energy for strain distribution in the rings of an extended ring transducer with rings of uniform thickness. McLaughlin (1996) noted some typographical errors in the Hoag and Yoerger equations and presented corrected equations (Eq. 1, 2 and 3). These equations have been transformed from those presented by Hoag and Yoerger (1975) to represent the vertical orientation of the EORs in the present device. The sign convention employed in Eq. 1 and 2 is the same as the original Hoag and Yoerger equations: positive horizontal force, F_h , compresses the device, positive vertical force, F_v is upward on the right hand side of the EOR, and positive moment, M_o , is clockwise when applied to the right hand side of the EOR, and positive bending moment, M_ϕ , tends to open or increase the radius of curvature of the rings.

$$M_f = \frac{F_h R}{2} \left(\frac{2}{p} - \sin f \right) + \frac{F_v R}{2} \cos f + \frac{M_o \left\{ \left(2 + \frac{p R}{2L} \right) - \left(\frac{2R}{L} + p \right) \sin f \right\}}{8 + \frac{Rp}{L} + \frac{2Lp}{R}} \quad \text{for } 0 < \phi = p \quad (1)$$

$$M_f = \frac{F_h R}{2} \left(\frac{2}{p} + \sin f \right) - \frac{F_v R}{2} \cos f - \frac{M_o \left\{ \left(2 + \frac{p R}{2L} \right) - \left(\frac{2R}{L} + p \right) \sin f \right\}}{8 + \frac{Rp}{L} + \frac{2Lp}{R}} \quad \text{for } p < \phi = 2p \quad (2)$$

$$e_f = \frac{6M_f}{Ebt^2} \quad (3)$$

Analytical solutions are not available for strain distribution on the rings of an EOR. Many people have used the Hoag and Yoerger equations for the uniform thickness rings to estimate strain in the EOR with rings of varying thickness (Fig. 1b). This along with experimental data has yielded several estimates of the optimum location for strain gages. There is agreement that gages for horizontal force should be located at 90° (Fig. 4), but various locations for the strain nodes for vertical force are given in the literature. These include 45° (O'Dogherty, 1975; Gu et al., 1991), 50° (Leonard, 1980; McLaughlin et al., 1998) and 56° (Godwin, 1975).

Kirisci et al. (1993) suggested that errors in locating the strain nodes due to simplifying an EOR to an extended ring transducer and applying the Hoag and Yoerger equations would result in cross sensitivity and contribute to measurement errors. McLaughlin et al. (1998) devised a method using multiple regression of calibration data to account for any cross sensitivity present. The method requires that both horizontal and vertical loads be applied simultaneously during calibration.

The present work is a follow up to the previous efforts on developing a drawbar dynamometer based on double EORs (Tessier et al., 1992; Tessier and Ravonison, 1997; McLaughlin et al., 1998). The objectives of this study were to (1) design a high capacity 2D DEOR drawbar dynamometer to measure drawbar draft and vertical force, (2) perform finite element analysis on EOR to identify the optimal strain gage locations to minimize the cross sensitivity, (3) calibrate the DEOR drawbar dynamometer, and (4) test the DEOR drawbar dynamometer in a field condition.

3. Materials and methods

3.1. Overall configuration of the DEOR drawbar dynamometer

The design capacities of the DEOR drawbar dynamometer were 180 kN for draft and 35 kN for vertical force. It was decided to use two EORs for such a high capacity dynamometer so that the design loads for each EOR could be reduced to half. Also, with two EOR's spaced some distance apart, the device is more immune to side loads and roll and yaw moments. Thus, each EOR is subjected to 90 kN draft and 17.5 kN vertical force. It was also decided to mount the EORs vertically on either side of the tractor drawbar (Fig. 2a), which enables the EORs to have much higher strength in the draft direction than the horizontal mounting used in previous DEOR designs (Leonard, 1980; McLaughlin et al. 1998). The two EORs were attached together with two 60-mm brackets on which the drawbar adaptor (a simple plate) and the hitch fixture (a clevis) were welded. As the hitch point was offset (127 mm) to the rear of the EOR centre, the design vertical load acting at the centre of the hitch pin induced a moment, M_b , of 2.2 kN mon each EOR.

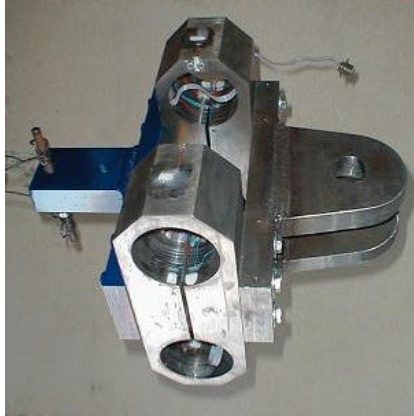


Fig. 2. Double Extended Octagonal Ring (DEOR) drawbar dynamometer with protective shrouds removed.

3.2. Design of the EORs

A maximum design strain of $1500 \mu\epsilon$ ($\mu\text{m}/\text{m}$) was set as a practical design limit as recommended by Measurements Group Inc. (1983) and used by McLaughlin et al. (1998) to ensure long fatigue life of the strain gages and bonding cements. The bending moment and strains in the ring sections of the EORs were estimated using the Hoag and Yoerger equations. A trial and error approach with different EOR dimensions was used to arrive at an appropriate combination of EOR dimensions that would result in near the design strain at the strain nodes as determined from the Hoag and Yoerger equations. As a result of this iteration, the EOR dimensions were selected as thickness (t)=17 mm, width (b) = 114 mm, radius (R) = 50 mm, and centre distance ($2L$) = 228 mm (Fig. 1b). ANSI 4130 steel was chosen, and it has a modulus of elasticity of 207 GPa and yield stress of 537 MPa (78,000 psi). The selected dimensions and material gave a safety factor of 1.5 for the combination of the three design loads.

3.3. Finite element analysis

3.3.1. Element type

Linear and elastic finite element analysis was used to calculate the strain distribution in the EOR to obtain optimal strain gage locations on the rings of the EORs. The ANSYS 8.1 finite element package (ANSYS, Inc. Southpointe, 275 Technology Drive Canonsburg, PA 15317) was used to generate a mesh of SOLID187 type elements for the EOR (Fig. 3). The SOLID187 element is a higher order 3-D, 10-node element. SOLID187 has quadratic displacement behaviour and is well suited to modeling irregular meshes. The global size of the element was 20 mm, resulting four element layers on the face of the ring, six layers along the width of the rings, elements of variable size fitting the irregular shapes of the rings, and a total of 6759 nodes.

3.3.2. Boundary conditions and load application

Uniaxial load was applied to the EOR on the implement side. The horizontal and vertical directions: $F_h = 90 \text{ kN}$ (positive when pulling the ring) and $F_v = 17.5 \text{ kN}$ (downward) were applied separately. Each load was applied directly on the nodes over an area of 60 mm wide

along the depth of the ring at the centre of the front section of the ring (Fig. 3). This was to represent the no-zero width of the mounting bracket attached to the EORs. As the drawbar adaptor was designed to be bolted to the tractor drawbar, the fixed boundary condition (value of strain = 0 in all degrees of freedom) was imposed on an area of 60-mm along the depth of the ring at the centre of the rear section of the ring, representing the 60-mm mounting bracket. The material properties used for analysis were the modulus of elasticity (207 GPa) and Poisson ratio (0.3).

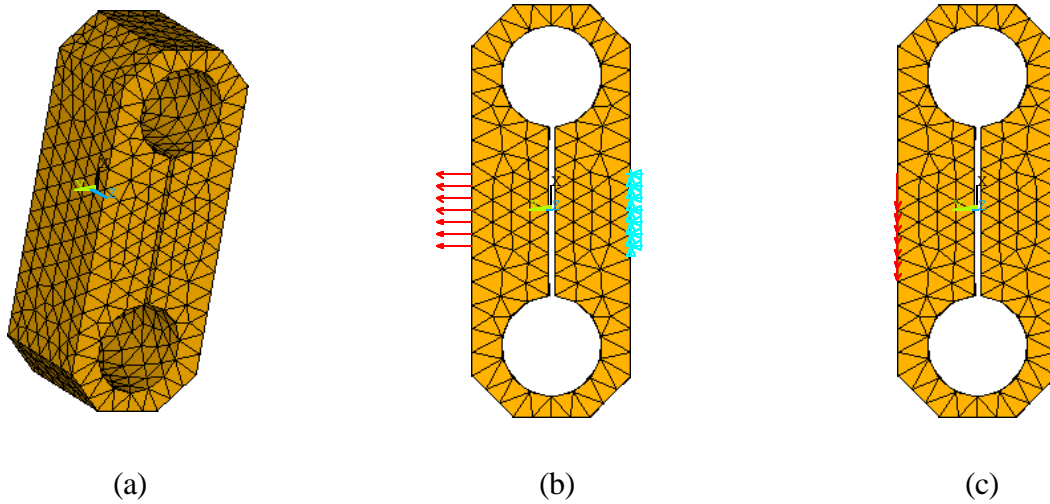


Fig. 3. Mesh, boundary conditions and force applications used for the finite element analysis of the EOR; (a) Mesh; (b) Boundary condition and horizontal load application; (c) Boundary condition and vertical load application.

3.3.3. Strain distributions in the EORs and strain gage locations

The analysis showed a symmetric strain distribution when the EOR was subjected to a horizontal load (Fig. 4 a and b). However, the strain distribution was not symmetric for vertical loading (Fig. 4 c and d). Vertical loading is applied on the outer face of the EOR, and this imposes a moment on the device. It was decided to locate the strain gages for measuring horizontal load, F_h at $\phi = 100^\circ$ outside circumference and $\phi = 105^\circ$ inside circumference (Fig. 5a), because those locations are coincident with the strain nodes from the vertical load. Such strain gage locations will minimise the cross effect from simultaneously applied F_v . These locations are expected to result in reduced the cross sensitivities in measuring F_h when compared to the strain gage location of 90° commonly used for EOR dynamometers.

As mentioned above, the ideal strain gage locations allow for maximum strain levels under the applied load while being totally insensitive to the other load. However, in most cases, including the present case, these requirements cannot be satisfied completely.

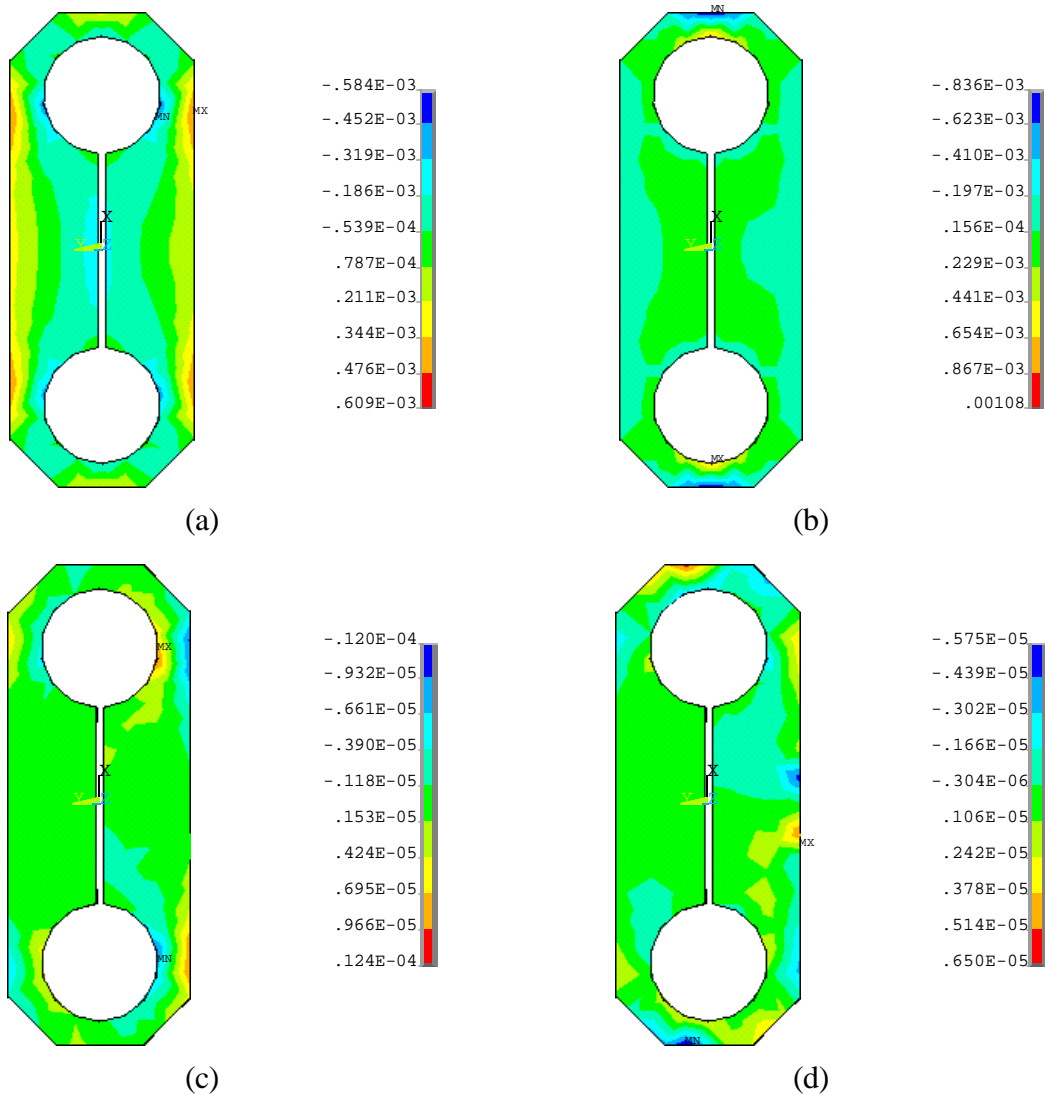


Fig. 4. Strain distribution in the EOR obtained from the finite element analysis; (a) horizontal strain distribution for horizontal load; (b) vertical strain distribution for horizontal load; (c) horizontal strain distribution for vertical load; (d) vertical strain distribution for vertical load.

Diagrams for strain distribution in the x and y directions output by the FEM software showed no apparent strain nodes for vertical load on the inside surface of the rings (Fig. 4 c and d). The strain nodes predicted by the Hoag and Yoerger equations (Eq. 1, 2 and 3) are intermediate between $\phi = 0^\circ$ and $\phi = 90^\circ$. Fig. 4 only shows strain in the x and y directions, and these strains need to be transformed to tangential strain to identify strain nodes lying between $\phi = 0^\circ$ and $\phi = 90^\circ$. Gages measure strain parallel to the surface they are installed on, and except for $\phi = 0^\circ$ and $\phi = 90^\circ$, these strains are different from the horizontal and vertical strains given in Fig. 4. Strain gages for F_v were positioned at four locations on the inside circumference of the rings (Fig. 5a) as these locations provide better mechanical protection than on the outside surfaces. The optimal strain gage locations were considered to be at $\phi = 18^\circ$ and 162° as a compromise to both maximize primary sensitivity to F_v , and minimize cross sensitivity from F_h .

Gages located at 18° and 162° may not be at the exact strain nodes, but do have a good sensitivity. As discussed by McLaughlin et al. (2005), the quest for locating strain gages at strain nodes to eliminate cross sensitivity may be futile. They showed that the effect of strain gage misalignment on cross sensitivity of an extended ring transducer is at its maximum at these so-called strain nodes.

3.3.4. Strain gage installation

Eight strain gages were installed on each EOR at the optimal locations (Fig. 5a) determined via the finite element analysis. Installation was done by Zeus Engineering Ltd. (200-239 Midpark Way SE, Calgary, Alberta T2X 1M2 Canada). The strain gages were bonded to the EORs with M-Bond 610 (Measurements Group, Raleigh, NC). This adhesive utilizes a 165°C curing temperature and is recommended for transducer applications. The strain gages were all 1000 ohm, and the gages on each EOR were connected into two separate Wheatstone bridges (Fig. 5b) for draft and vertical force measurement. Each EOR in the dynamometer had two channels corresponding to the two bridges, and the vertical and draft forces on the DEOR were calculated from the sum of the respective bridges on the two EORs. The strain gages and associated wiring on each EOR were protected by a sheet metal shroud.

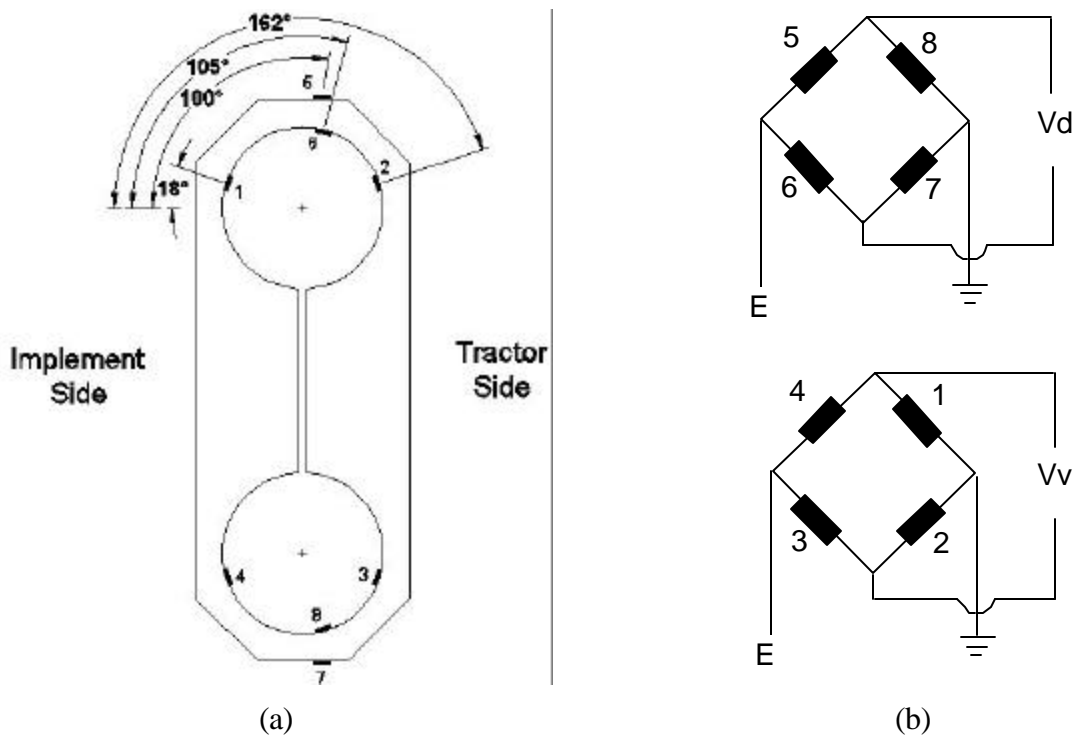


Fig. 5. Diagram of strain gage installation on the EORs; (a) strain gage positions for draft and vertical force measurements; (b) four arm Wheatstone bridges for horizontal draft (top) and vertical (bottom) force measurement.

3.4. Uniaxial calibrations

3.4.1. Calibration equipment

A universal testing machine (Riehle, American Machine and Metals Inc., East Moline, IL, USA) in the Department of Civil Engineering, University of Manitoba, was used to calibrate the dynamometer. The universal machine had a capacity of 267 kN. The adapter for mounting the DEOR on the tractor drawbar, and the clevis for hitching to the implement (Fig. 2a) were used to install the dynamometer in the universal testing machine for horizontal force calibrations. A separate adapter was designed for vertical force calibration. Both of these adapters ensured that the calibration forces were aligned with the design force.

3.4.2. Data acquisition system and calibration procedure

The dynamometer was installed in the universal testing machine, and the four strain gage bridges were connected to four channels of a data logger (ProDAS, Michigan Scientific Corporation, Mifford, MI). The strain gage bridges were excited with 10 V dc. Initial offset readings for the four channels were recorded at zero applied load. These offsets are normal on strain gage bridges and are due to initial bridge unbalance resulting from slight differences in the resistance of the applied gages. Uniaxial load was applied to the dynamometer in steps of 18 kN to a maximum 180 kN draft calibration, and in 4.5 kN steps to a maximum of 35 kN for vertical calibration. The procedure was repeated twice for each force calibration.

3.5. Field tests of the DEOR drawbar dynamometer

3.5.1. Site description and experimental design

Field tests were conducted to evaluate the performance of the DEOR dynamometer under actual field conditions. Draft and vertical force for a 3.7 m wide pull-type liquid manure applicator were measured using the DEOR drawbar dynamometer. The implement had six sweep-type injection tools mounted on C-shanks and spaced at 600 mm (Fig. 6a). The tests were conducted in wheat stubble in a clay soil (59.7% clay, 37.7% silt and 2.6% sand, by weight) at the Glenlea Research Station of the University of Manitoba, southern Manitoba, Canada in the fall of 2000. The soil had high moisture content (42%, dry basis) at the time of field tests. The field condition represented a worst case scenario for implement draft as tilling clay soil required more draft than other soil types (ASAE Standards, 2004).

A factorial experimental design was employed with three injection depths, two travel speeds with four replications for a total of 24 test runs. The travel speeds were 0.87 and 1.40 m s⁻¹. The target injection depths were set at 50, 100, and 150 mm. Actual measured injection depths were 74, 89 and 112 mm.

3.5.2. Force measurements

The DEOR drawbar dynamometer was installed between the tractor hitch and the implement hitch of the injector implement (Fig. 6b). As the tools of the injector engaged into the

soil, draft and vertical force were recorded at a rate of 200 Hz for 30 seconds using the aforementioned Michigan Scientific ProDAS data acquisition system. Means were calculated from the 6000 individual readings in each test run. These means were considered as the dependent variable, and were subjected to Analysis of Variance.



Fig. 6. Equipment used for the field tests; (a) liquid manure injector with six sweep-type tools; (b) DEOR dynamometer installed between the tractor and the injector hitch to measure the drawbar forces.

4. Results and discussion

4.1. Dynamometer calibration

During the calibration, the dynamometer was subjected to two load cycles to design capacity in both horizontal and vertical directions. There was no evidence of yielding as output on the second loading cycle was the same as the first.

The calibration data (Fig. 7a, b) shows an offset of -1.21 mV for F_h and 1.51 mV for F_v at the zero-load. Some initial offset is expected due to slight differences in the resistance of strain gages following installation which results in an unbalanced bridge at zero load. Specialized strain gage signal conditioners usually include a balancing mechanism where the bridges can be balanced at no load to remove the initial offset. Balancing resistors could also be installed on the EOR's to reduce the offset, but this was not done. If balancing at zero load is not done, then the resulting offset can be removed by including an intercept in the regression equation for the calibration data. The calibration curves for the DEOR dynamometer indicate excellent linearity for both horizontal and vertical uniaxial loading. The primary sensitivity was 0.0678 mV/V/kN for horizontal (draft) and 0.2451 mV/V/kN for vertical load.

For the F_h calibrations, the secondary readings (F_v) remained nearly constant, approximately 1.35 mV (Fig. 7a). Similarly, for the F_v calibrations, the secondary readings (F_h) also remained nearly constant at approximately -1.57 mV (Fig. 7b). The flat slope of the secondary readings indicate that the cross sensitivity was very small.

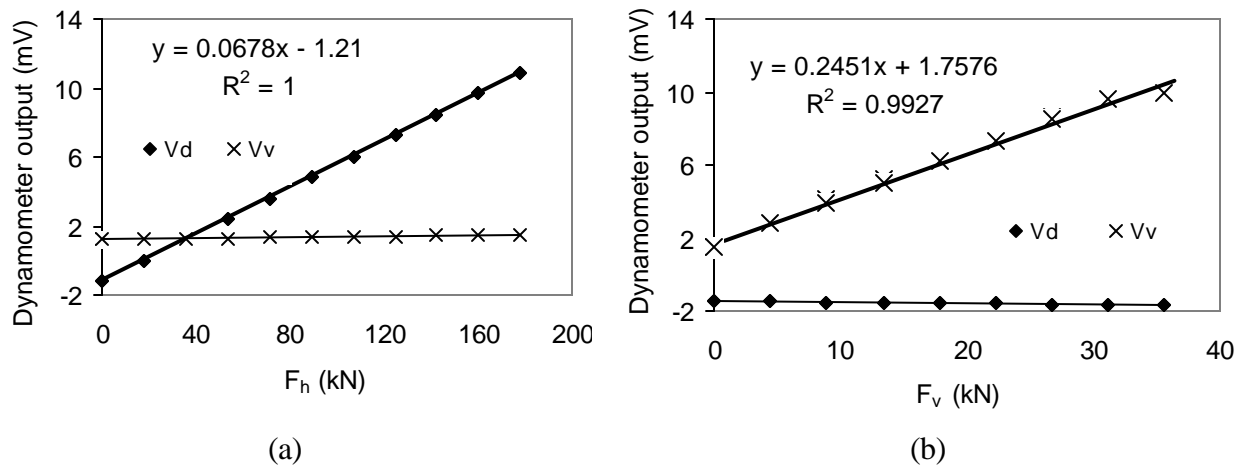


Fig. 7. DEOR dynamometer calibration data; (a) horizontal load; (b) vertical load.

4.2. Field tests

The results of tillage depth effect (Fig. 8a) showed the expected trends with both F_h and F_v increasing with the tillage depth. Higher tillage tool forces usually accompany higher forward speeds (McKyes, 1985). However, little or no speed effect was observed in the tests. This is consistent with the finding from Rahman and Chen (2001) who reported that effects of tool travel speed on forces are less pronounced than those of tillage depth within a speed range of 0.6-1.4 m s^{-1} . The measured draft force per tool at the greatest depth (112 mm) and the highest travel speed (1.40 m s^{-1}) was 4.70 kN per tool in the test field condition. These values are comparable with those reported elsewhere. Laguë (1991) reported that injection of manure into a firm clay soil with a winged injector tool operating at depths up to 203 mm and 0.89 m s^{-1} required between 5.03 kN and 6.19 kN per tool. The range of draft forces of a winged tool reported by McKyes et al. (1977) was up to 6 kN per tool at a 150 mm injection depth and travel speeds up to 2.2 m s^{-1} in soil textures from sand to clay loam.

Draft for liquid manure injectors in a fine soil was calculated with prediction equations published by ASAE (ASAE Standards, 2004). The calculated values were 29% lower than measured values at both travel speeds (Fig. 8a). The depth effect was much less pronounced in the calculated draft values than in the measured draft values (Fig. 8a). Equations from ASAE Standards were developed from a wide range of field conditions and tillage tool types, while data from this field study represent the worst-case scenario in terms of draft. Consequently, direct comparisons with the literature cannot be made. However, the measured draft falls within the broad range of values reported in the literature indicating that the DEOR was providing reliable field measurements.

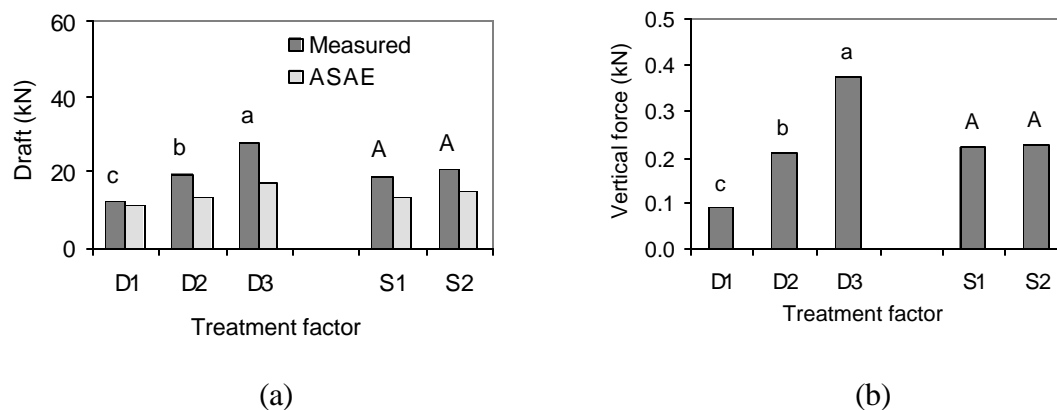


Fig. 8. Draft force (F_h) of the liquid manure injector implement measured with the DEOR dynamometer and predicted using ASAE prediction equations at three depths (D1=74, D2=89 and D3=112 mm) and two travel speeds (S1=0.87 and S2=1.40 m s⁻¹). Measured vertical drawbar loads are shown on the right. Columns with the same letter are not significantly different ($P < 0.05$) according to Duncan's multiple range test.

5. Conclusions

The double extended octagonal ring (DEOR) drawbar dynamometer has the target design capacity of 180 kN for measure drawbar draft. The vertical orientation of two extended octagonal rings provides higher draft capacity than horizontal orientations utilized in previous designs. Finite element analysis of the extended octagonal rings can be used to determine optimal locations of strain gages for high sensitivity and low cross sensitivity between horizontal and vertical loads. As a result of the FEM analysis, strain gage locations different from those normally utilized were chosen. Calibration in a universal testing machine showed excellent linearity and low cross sensitivity. The device performed well under field conditions where draft of a liquid manure applicator was measured. The design was considered successful, and applicable for field research on energy inputs for agricultural field equipment.

Acknowledgements

Financial support for this research was provided by the Natural Sciences and Engineering Research Council of Canada (NSERC). The authors acknowledge Moray McVey and Matt MacDonald, technicians, Faustinus Monero, Graduate Student, University of Manitoba, for their help on calibrations and field tests.

References

- ASAE Standard. 2004. D497.4. Agricultural Machinery Management Data. St. Joseph, MI: ASAE.
- Chen, Y., F. Monero, S. Tessier, C. Cavers and X. Xu. 2004. A survey of crop residue burning practices in Manitoba. *Applied Engineering in Agriculture*. 21(3): 317-323.
- Godwin, R.J., 1975. An extended octagonal ring transducer for use in tillage studies. *Journal of Agricultural Engineering Research*. 20: 347-352.

- Gu, Y., Kushwaha, R.L., Zoerb, G.C. 1991. Cross sensitivity analysis of extended octagonal ring (EOR) transducer. Paper No. 91-3542. St. Joseph, MI:ASAE
- Hoag, D.L., Yoerger, R.R. 1975. Analysis and design of load rings. Transactions of the ASAE 19: 995-1000.
- Garner, T.H., Dodd, R.B., Wolf, D., Peiper, U.M. 1988. Force analysis and application of a three-point hitch dynamometer. Transactions of the ASAE. 31: 1047-1053.
- Johnson, C.E., and W.B. Voorhees. 1979. A force dynamometer for three-point hitches. Transactions of the ASAE 23(2): 226-227,232
- Kirisci, V., Blackmore, B.S., Godwin, R.J., Blake, J. 1993. Design and calibration of three different three-point linkage dynamometers. ASAE/CSAE Paper No. 93-1009. St. Joseph, MI:ASAE
- Kitson, C.I. 1987. Development of a three-dimensional tillage force and moment dynamometer. Unpublished M.Sc. Thesis, Department of Biosystems Engineering, University of Manitoba, Winnipeg, Canada.
- Laguë, C. 1991. Design of a semi-liquid dairy cattle manure spreader/injector. Applied Engineering in Agriculture. 7: 655-660.
- Leonard, J.J. 1980. An extended-octagon rigid drawbar dynamometer. Agricultural Engineering Australia. 9: 3-8.
- McKyes, E. 1985. *Soil Cutting and Tillage*. Elsevier, New York, NY.
- McKyes, E., Negi, S.C., Godwin, R.J., Ogilvie, J.R. 1977. Design of a tool for injecting waste slurries in soil. Journal of Terramechanics. 14, 127-136.
- McLaughlin, N.B. 1996. Correction of an error in equations for extended ring transducers. Transactions of the ASAE. 39: 443-444.
- McLaughlin, N.B., Tessier, S., Guilbert, A. 1998. Improved double extended octagonal ring drawbar transducer for 3-D force measurement. Canadian Agricultural Engineering. 40: 257-264.
- McLaughlin, N.B., Chen, Y. and Tessier, S. 2005. Effect of strain gage misalignment on cross sensitivity in extended ring transducers. CSAE Paper 05-063 Winnipeg, MB:CSAE
- Measurement Group Inc. 1983. Strain gage selection. Technical Note TN-505. Measurement Group Inc., Raleigh, NC.
- O'Dogherty, M.J. 1975. A dynamometer to measure the forces on a sugar beet topping knife. Journal of Agricultural Engineering Research. 20: 339-345.
- Palmer, A.L. 1992. Development of a three-point-linkage dynamometer for tillage research. Journal of Agricultural Engineering Research. 52: 157-167.
- Rahman, S., Chen, Y. 2001. Laboratory investigation of cutting forces and soil disturbance resulting from different manure incorporation tools in a loam sand soil. Soil & Tillage Research. 58: 19-29.

- Tessier, S., Guilbert, A., McLaughlin, N., Tremblay, D. 1992. A double EOR drawbar pull transducer for 3-D force measurement. Paper No. 92-406. Winnipeg, MB: CSAE.
- Tessier, S., Ravonison, N. 1997. Finite element analysis of extended octagonal ring transducers. Department of Soil and Food Engineering, University Laval, Quebec, QC. Research report submitted to Neil McLaughlin, Agriculture and Agri-Food Canada, 960 Carling Ave., Ottawa, ON K1A 0C6.
- Thomson, N.P., Shinnars, K.J. 1989. A portable instrumentation system for measuring draft and speed. *Applied Engineering in Agriculture*. 5: 133-137.
- Zoerb, G.C., Musonda, N.G., Kushwaha, R.L. 1983. A combined drawbar pin and force transducer. *Canadian Agricultural Engineering*. 25: 157-161.