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DESIGN AND CALIBRATION OF A BI-AXIAL EXTENDED OCTAGONAL RING TRANSDUCER SYSTEM FOR THE MEASUREMENT OF TRACTOR-IMPLEMENT FORCES

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ABSTRACT

A bi-axial extended octagonal ring (EOR) transducer system for the measurement of tractor-implement forces was designed for a category II and III MB Trac 1300 tractor. The EOR transducers and a gauged top link were calibrated and the Sensitivity, Cross-Sensitivity, Hysteresis, Linearity and Repeatability were found. The system was tested for 80kN applied coincident load and 60kN perpendicular load. No lateral forces or moment in the plane of the two forces was considered. The results of the calibration tests of the system showed its workability. The system could best be used for the measurement of draught (horizontal) and vertical forces where heavy implements are attached with the tractor.

Keywords: Transducer, strain gauge, calibration, sensitivity, hysteresis, repeatability, draught, vertical, force, tractor, implement.

INTRODUCTION

The developments of different types of mounted implements have led to the demand for an instrument which would measure the forces of a tractor exerted on soil engaging implements.

Transducers have been used for the measurement of forces transmitted through the linkage between tractor and implement for the last so many years. The transducers which have been developed so far and used for the measurement of forces can be divided in to two parts:

1. Those that retain the linkage geometry: Octagonal ring (Bandy, 1986)
2. Systems which distort the geometry: Dynamometer by Scholtz (1966).

Of the above two categories, octagonal ring transducers are now the most commonly used and research work for its continued improvement is going on.

M. J. O' Dogherty designed an extended octagonal ring using electrical resistance strain gauges to measure the cutting and vertical forces acting on a sugar beet topping knife.

Octagonal ring transducers have been part of a continuing research at Silsoe College. A number of transducers were developed, tested and used for different studies; (Kilgour *et al*., 1988; Hughes, 1990 and Kirisci, 1992).

R. J. Godwin *et al*. (1993) designed a triaxial dynamometer for force and moment measurements on tillage implements. The instrument was able to measure the three orthogonal forces acting on the implement and the three moments acting about the orthogonal axis up to a maximum force of 100kN and a maximum moment of 100kNm. A high degree of linearity between the applied forces and moments and bridge outputs were found. The hysteresis effect between loading and unloading was small (<0.5%) and the effect of load position from the dynamometer axis had a small effect on bridge sensitivities (<2%). The Cross-Sensitivity (error in non-active bridge while recording the active bridge) was found to be 4% or less.

MATERIALS AND METHODS

Design of extended octagonal ring transducer

Research has shown that during tillage operations, the implements exert forces and bending moments on the tractor linkages. The top link experiences large forces along its length which tends to lengthen and shorten it. The bottom links experience a force along their length (draught force), a force perpendicular to the link on a vertical plane (vertical force), and a force perpendicular to the link in a horizontal plane (side force). An extended octagonal ring (EOR) transducer can be designed in two ways:

- Designing for the implement
- Designing for the tractor.

Considering case 2,

An EOR transducer system was designed for a category II and III MB Trac 1300 tractor. The EOR's were designed to withstand the maximum estimated force between the implement and the tractor. The maximum force through the link arms was estimated as the maximum pull exerted by the tractor (75% of the tractor weight) multiplied by a safety factor of 3.

Weight of the tractor = 70kN
Maximum pull = 70,000 x 0.75 = 52,000N
Design load = 52,000 x 3.0 =157500N
Horizontal load for each link/ring = 78.75kN
Say 80kN
Vertical load for each link/ring = 40kN
R = SQRT (80 + 40)
= 89.44kN

Figure-1 shows horizontal and vertical forces acting on each link/ring of the tractor.

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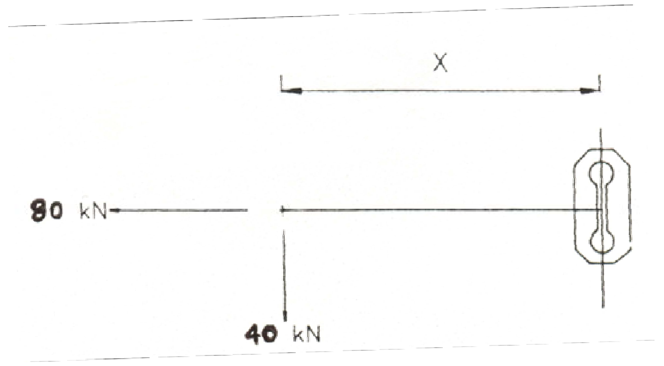

Figure-1. Forces on octagonal ring.

Let X = 180mm
Factor of safety = 3
Bending Moment,
M = 40 x 3 x 0.18
= 21.6kNm
Width of octagonal ring,
b = 90mm
Since, $\sigma = \varepsilon E$
Yield Stress Impax Supreme,
σ_{yl} = 800 N/mm^2
Note: Material Chosen was Uddeholm Impax Supreme Pre-hardened mold steel.

According to Cook and Robinowicz;
When k = L /r = 1.6
$\varepsilon Ebt^2/M = 0.4$
Where,
ε = strain
E = modulus of elasticity
B = width of ring
T = thickness of ring
M = applied moment
2 L = distance between ring centres
r = mean radius of ring
$t^2 = 0.4\ M/\varepsilon Eb$
$t^2 = 0.4 \times 21.6 \times 10^6 /(800 \times 90)$
or t = 10.95mm
For gauging (machining) purposes the hole in the octagonal ring needs to be 60mm diameter, Ø
Mean radius,
r = Ø/2 + t/2
r = 60/2 + 10.95/2
r = 35.48mm
L/r = 1.6
2L = 1.6 x 35.48 x 2
2L = 113.54mm
Overall width of Ring,
W = 2r + t
W = (2 x 35.48) + 10.95
W = 81.91mm
Overall length of Ring,
P = 2L + 2r + t
P = 113.54 + (2 x 35.48) + 10.95
P = 195.45mm

Size of Land,
Q = 1.7 L
Q = 1.7 x 113.54/2
Q = 96.50mm
Check for Land strength,
Area of Land = Q x breadth of ring
A = 96.50 x 90 sq. mm
A = 8685 sq. mm
Yield Stress of Impax Supreme = 800 N/mm^2
Maximum load before yield,
P = 800 x 8685N
P = 6948kN

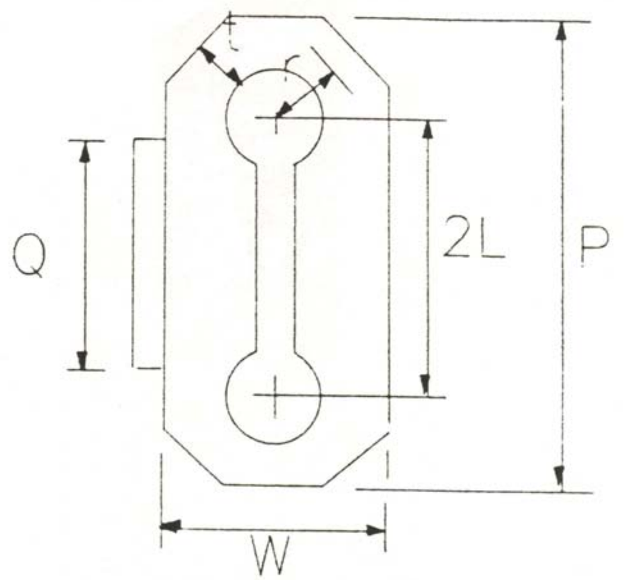

Figure-2. Major dimensions of octagonal ring.

Calibration procedure

The two extended octagonal ring transducers (EORT's) and a gauged top link was calibrated using the Avery Test Machine in the Mechanics Laboratory of Silsoe College. Mounting brackets manufactured for a previous experiment were used for these calibration tests. The EORT's were already developed by the Silsoe College for the design horizontal and vertical loads of 80kN and 40kN, respectively. The two EORT's were calibrated individually. The transducer was fit into the jaws of the Avery Test Machine and supported by the mounting brackets. The transducer was positioned horizontally and vertically respectively to apply coincident and perpendicular loads. Loads were applied up to 80kN in the coincident direction while up to 60kN in the perpendicular direction with intervals of 10kN.

The gauged top link of the MB Trac 1300 tractor was also calibrated using the Avery Test Machine and the above mentioned procedure. The coincident loads up to 80kN in the intervals of 10kN were applied in the tension and compression mode. Output channel of the active bride was recorded to find out sensitivity while the other channel (passive bridge) was monitored for the same load to see the level of Cross-Sensitivity. While for the top link, only one channel (active bridge) was recorded to find out its

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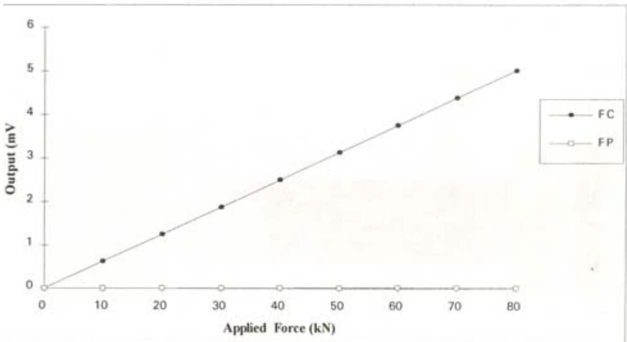
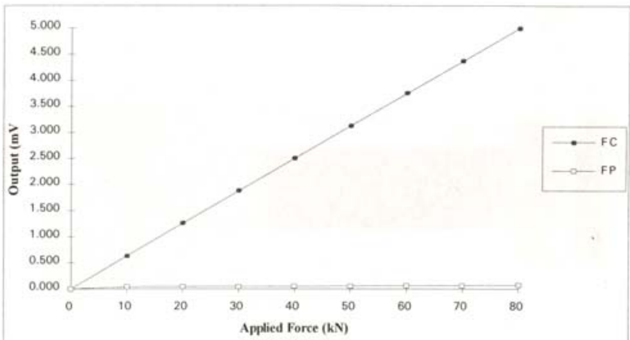
sensitivity. A Campbell Scientific Ltd. 21 X Data Logger was used to record the output of the channels. Data Logger was interfaced with a portable computer. This excited the bridges with 5 volts. The instruction used was 23 Burst mode (high frequency data collection). In this system the data logger was programmed via the computer using a programme called EDLOG. The programme permits instructions to be entered through the computer key board and transferred to set-up the data logger. The output readings were recorded manually from data logger display screen as well as unloaded from the data logger into the computer and were saved on a floppy disk for use of the data analysis using Lotus 1-2-3, Excel and Free Lance.

RESULTS AND DISCUSSION

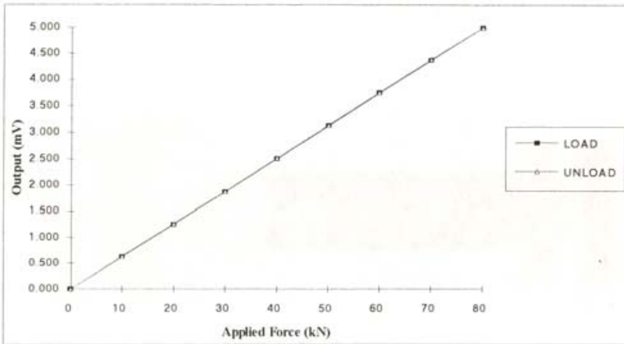
Data obtained from the experiment was analysed using computer software (spreadsheets). The computer produced the best fit line. The statistical method (regression) was used to find out offset, multiplier and co-efficient of determination (R^2) for the equation and linearity of the best fit line. Data was prepared in tabular forms and graphs produced. Figures 1 to 4 represent the experimental data for the extended octagonal ring transducer (EORT) 193/1-2 in graphic form for cross-sensitivity, hysteresis and repeatability while Figures 5 and 6 represent the experimental data for the gauged top link in graphic form for sensitivity and hysteresis.



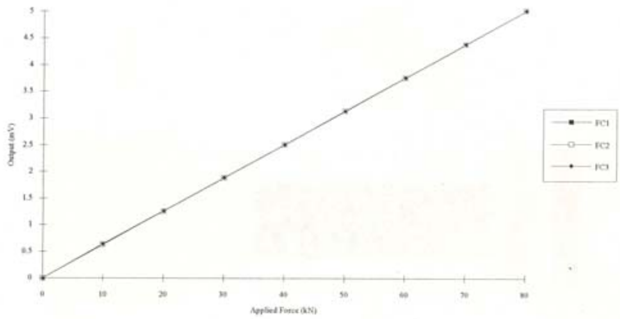
CROSS-SENSITIVITY FOR FC-COMPRESSION (EOR 193/1-2)
FC = - 0.004836 + 0.062780 X ; R SQUARED = 0.999996
FP = - 0.002718 + 0.000305 X ; R SQUARED = 0.971666



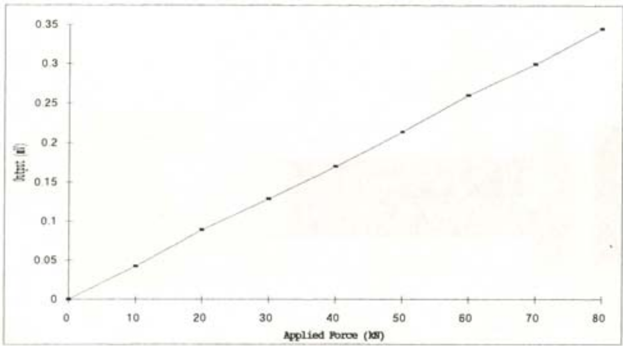
CROSS-SENSITIVITY FOR FC-TENSION (EOR 193/1-2)
FC = 0.005196 + 0.062442 X ; R SQUARED = 0.999997
FP = 0.017984 + 0.000722 X ; R SQUARED = 0.855570



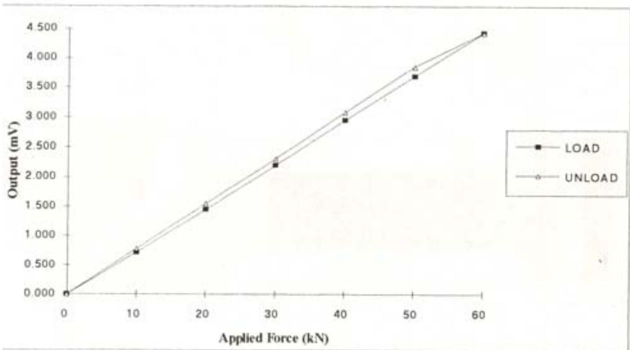
HYSTERESIS FOR FC (EOR 193/1-2)
FCL = 0.000467 + 0.062430 X ; R SQUARED = 0.999998
FCUL = 0.009925 + 0.062454 X ; R SQUARED = 0.99990



REPEATABILITY (EOR 193/1-2)
FC - Tension:
FC1 = 0.001136 + 0.062470 X
FC2 = 0.005287 + 0.062443 X
FC3 = 0.009167 + 0.062413 X



SENSITIVITY FOR FTL-COMPRESSION
FTL= 0.000055+0.004303X;
R SQUARED = 0.999804



HYSTERESIS FOR FTL - TENSION
FTLL = 0.001063 + 0.004227 X ; R SQUARED = 0.999939
FTLUL = 0.002266 + 0.004242 X ; R SQUARED = 0.999728

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The Bi-axial extended Octagonal ring transducers (EORT's) were calibrated for the two perpendicular forces i.e. force Coincident (FC) and force Perpendicular (FP). The lateral force and the moment in the plane of the two forces were considered as zero. Load was applied on each transducer in compression and tension mode for the Coincident force while upward and downward for the perpendicular (bending) force. For the coincident force, the load ranged from 0 to 80kN while for the perpendicular force it ranged from 0 to 60kN in the intervals of 10kN.

The gauged top link was calibrated for force coincident (compression and tension) only. Load applied ranged from 0 to 80kN with 10kN increments.

Output for FC and FP bridges was recorded for the applied coincident and perpendicular loads. The active bridge gave the output value for the respective load from which the sensitivity was found. The second channel (passive bridge) was monitored to find the level of Cross-sensitivity. Calibrations were also conducted for both increasing and decreasing loads to determine any hysteresis effects.

All the calibrations' tests showed a high degree of linearity between bridge output voltage and the force applied. The co-efficient of correlation, R^2, for the relationship between voltage output and force was found to be 0.9995 (minimum) for both of the transducers and top link. The test data for the sensitivity, cross-sensitivity, and hysteresis for both EORT's 193/1-2 and 193/2-2 and the gauged top link for coincident (compression and tension) and perpendicular loading (upward and downward) is summarized in Table-1.

Table-1. Calibration results for EORT's and gauged top link.

	Sensitivity $\mu VN^{-1}V^{-1}$	**Cross-Sensitivity (%) at Full Scale**	**Hysteresis (%) at 40kN load**
EORT 193/1-2			
Coincident Force (FC)			0.417
Compression Tension	0.0125 0.012488	0.432 1.51	
Perpendicular Force (FP)			3.458
Downwards Upwards	0.0149 0.01476	8.686 8.212	
EORT 193/2-2			
Coincident Force (FC)			0.507
Compression Tension	0.012479 0.012497	0.134 1.118	
Perpendicular Force (FP)			2.90
Downwards Upwards	0.01489 0.01490	0.579 0.177	
Gauged top link			
FTL			
Compression Tension	8.6×10^{-4} 8.47×10^{-4}		1.048 1.048

Table-1 shows that the sensitivity values for the two EOR transducers for coincident force (FC) for all the compression and tension tests was almost same i.e. 0.0125 $\mu VN^{-1}V^{-1}$ while that for perpendicular force (FP) for all downwards and upwards tests had an averaged value of 0.01486 $\mu VN^{-1}V^{-1}$. The ratio of the coincident force output to the perpendicular force output was found about 0.84.

The Cross-sensitivity for both of the transducers was very small (<1.5%) except for the perpendicular force (FP) for EOR transducer 193/1-2 which was equal to about 8.5%. A correction can be made for this force during data processing by use of suitable factor.

The averaged value for top link sensitivity was found to be 8.535×10^{-4} $\mu VN^{-1}V^{-1}$.

The three replications for each calibration test showed a negligible difference from the mean.

The hysteresis effect between the calibration curves for increasing and decreasing applied coincident and perpendicular force was small with a difference between the loading and unloading curves of 0.46% and 3.18%, respectively at a load of 40kN.

CONCLUSIONS

The calibration tests for the bi-axial extended octagonal ring transducer system revealed that the system was well working for a range of draught and vertical forces up to 160kN and 80kN, respectively. The results showed a high degree of linearity between bridge output voltage and force applied. The minimum co-efficient of correlation, R^2, found was 0.9995.

The cross-sensitivity for both extended octagonal ring transducers and gauged top link was less than 1.5% except for the perpendicular force (FP) for EOR transducer 193/1-2 which was equal to 8.5%. The test results for repeatability showed negligible difference.

The system is best suited where heavy equipment is used with a tractor. However, the system needs to be further tested in the field.

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