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Design and Calibration of a Direct Mounted Strain Gauged Lower Links System for Measurement of Tractor-Implement Forces

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ABSTRACT

A bi-axial direct mounted strain gauged lower links system for the measurement of tractor-implement forces was designed and calibrated for coincident and perpendicular loads up to 10 kN. No lateral force or moment was considered. The system was tested for its Sensitivity, Cross-Sensitivity, Hysteresis, Linearity and Repeatability. The results of the calibration tests revealed that the system was well working for a range of draught and vertical forces up to 20 kN. The results showed a high degree of linearity between bridge output voltage and force applied. The minimum co-efficient of correlation, R^2, was found to be 0.9996. The hysteresis effect between the calibration curves for increasing and decreasing applied coincident and perpendicular force was very small (<1.20%). The interactions of the applied forces on the orthogonal force bridges were less than one percent. Maximum difference from the mean value for applied coincident and perpendicular force respectively was 1.75% and 1.3%. If the lower link arm 793/1 is considered as an example, the sensitivity for coincident and perpendicular force respectively was found to be 1.28×10^{-4} $\mu VN^{-1}V^{-1}$ and 6.80×10^{-4} $\mu VN^{-1}V^{-1}$. The system could best be used for the measurement of draught (horizontal) and vertical forces where medium type equipment is attached with a tractor.

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

INTRODUCTION AND BACKGROUND

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.

An idea was to mount strain gauges directly on to the lower links of the tractor, calibrate and test this system and the results compare with that of the octagonal ring transducer.

A B.Eng. student worked initially and got developed the direct mounted system. He calibrated the system with a small load amounting up to 100 kg. or about 1 kN. A strong need was felt to raise the applied load up to at least 10 kN. The author was involved in this moment.

After starting calibration tests with the static weights (up to 90 kg.) on the same pattern as the B.Eng. student did, it was found that one of the gauges of one link was faulty and wires cut under the protective cover. The faulty gauge was removed, a new gauge mounted and re-wired the system and protected again.

LITERATURE REVIEW

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. The first attempts to measure the forces between tractor and mounted implement were made by measuring the forces in the links themselves (Volkov, 1958). This required simultaneous recording of at least three forces which involved very complicated instrumentation.

In 1961, Reece developed strain gauged pins for measurement of draught of a three-point-linkage implement. These pins could only measure longitudinal component of force in each link and were only suitable for free linkage systems.

In 1964, Scholtz improved the system proposed by R. Lal in 1959. Lal's system was using instrumented ball joints. This ball joints system had friction induced cross-sensitivity problems. Scholtz reduced this effect by using self aligning ball bearings and longer beam length. This caused the equipment heavier, displaced the implement backwards and thus increased the bending moment. Moving the implement back from its nominal position affects the tractor-implement geometry and hence it's operating characteristics. The instrument could not fit on many tractors. Modification to the tractor was required to fit the system. The use of P.T.O. was also obstructed.

Scholtz later developed a three point hitch dynamometer which could be used with hydraulic linkages providing position and draught control, unlike his previous design which was for un-restrained linkages. The shape was such to permit P.T.O. use. Friction was minimized by use of self-aligning ball bearings. Cross-sensitivity was 2% on horizontal draft force and 0.5% on vertical forces. Modifications were needed if the instrument was to be used with mounted implement and was not fit to category I implements. The construction was bulky 120 kg. The implement shifted back by 23 cm from its nominal position.

Baker et al (1981) used six load cells mounted at different points within an A frame to measure horizontal, vertical and lateral forces. These measured with little error. The implement moved back by 19 cm.

Chung in 1983 developed a quick attachment coupler using pins mounted as strain gauged cantilever beams. It eliminated the need for modification in either tractor or implement since it could be used with category II and III hitch dimensions. This dynamometer gave minimum sensing errors but the disadvantage was pushing the implement back by 21 cm.

Many other designs were developed. Some measured all the forces acting between the implement and tractor by using a six point dynamometer suspension system using load cells (Baker et al, 1981; Chaplin et al, 1987). Other systems measured longitudinal and vertical forces only, assuming lateral forces as zero (Reid et al, 1985; Garner et al, 1985).

Blake (1993) directly mounted strain gauges on to the lower links of the tractor. He mounted these gauges on the link arms to get tension and differential cantilever bridges. This system was calibrated for horizontal and vertical forces while applying load only up to 100 kg. The test results showed a cross-sensitivity of 2% in the differential cantilever (vertical force) bridge while 12.5% in the tension (horizontal force) bridge.

MATERIALS AND METHODS

Calibration Procedure

A test-rig used for two-dimensional analysis was available in the Field Engineering Building (FEB) at Silsoe College.

Each gauged lower link arm was individually calibrated by applying coincident and perpendicular forces. To apply coincident force (FC), the link arm was hung with the hook of the crane using D-shackles (plate 1). Load was applied on the implement side of the link arm.

A load cell was incorporated in to the system to measure the applied load through a Statimeter. The load was applied using a hydraulic ram operated by a power pack (plate 2).

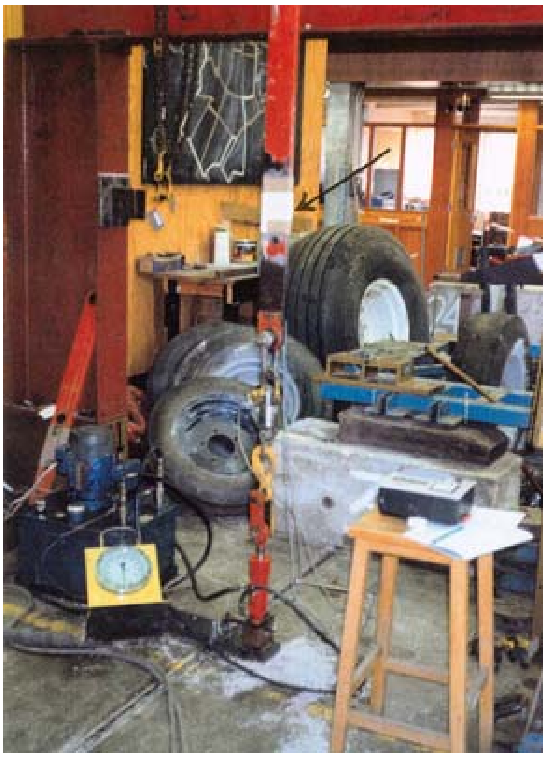

Plate-1: Calibration Test- Coincident Force

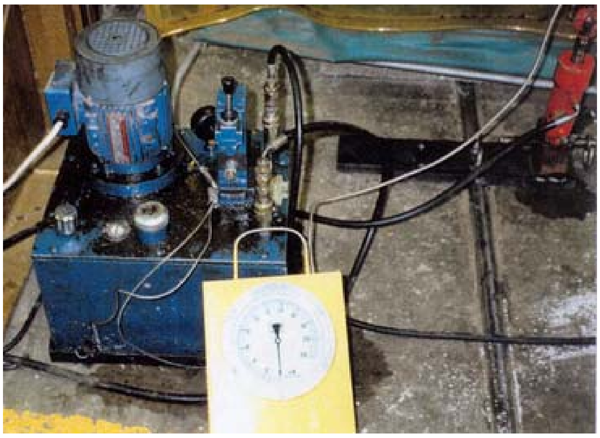

Plate-2: Hydraulic Power Pack

To apply perpendicular force (FP), the link arm was attached with the gantry using mounting brackets and pins. The arm was supported by a chain to make it horizontal. A load cell was incorporated using D-shackles and the applied force measured using the statimeter. Load was applied on the implement side of the link arm. Hydraulic ram system was used to apply the force.

A Campbell scientific ltd. 12x data logger was used in this experiment. The data logger excited the bridges with 5 volts and recorded the output of the channels. Instruction six (6) was used to programme the data logger.

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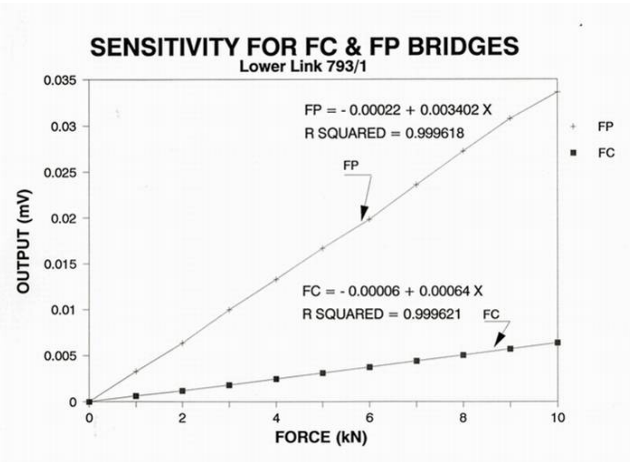
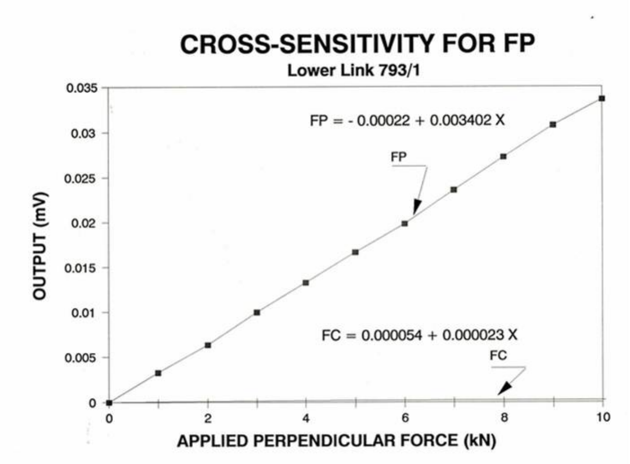
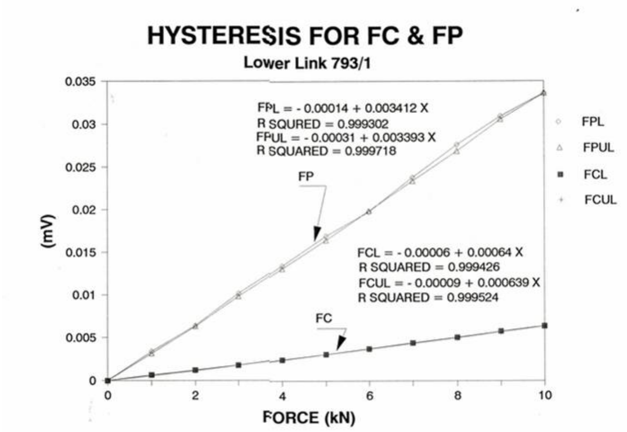
For the above two cases, the force applied (horizontally and vertically) ranged from 0 to 10 kN with intervals of 1 kN. Calibrations were conducted for both increasing and decreasing loads to determine any hysteresis effects. The two output channels (FC & FP) were recorded simultaneously to see the level of cross-sensitivity. The experiment was repeated at least three times. Data obtained for all calibration tests were analysed for sensitivity, cross-sensitivity, linearity, hysteresis and repeatability.

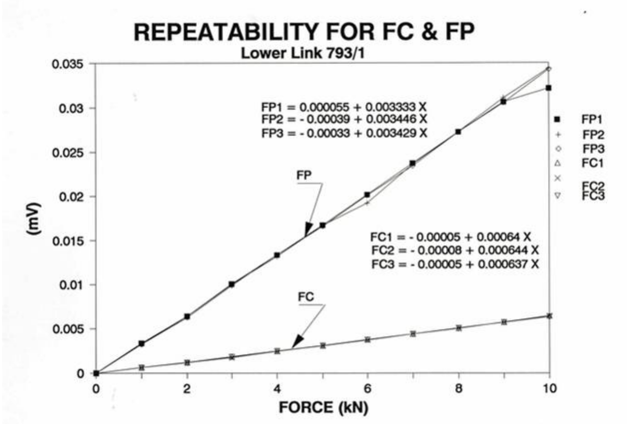
RESULTS AND DISCUSSION

Data obtained from the experiment was analysed using computer software (spreadsheet). 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 lower link arm 793/1 in graphic form for sensitivity, cross-sensitivity, hysteresis and repeatability.









The bi-axial direct mounted strain gauged lower link system for a tractor was calibrated for the two perpendicular forces i.e. draught (horizontal) and vertical force. No lateral force or moment was considered. Each link arm was gauged in such a shape to get tension and cantilever bridge format. The tension and cantilever bridge output was recorded respectively for the applied coincident and perpendicular (bending) loads. These gave sensitivities for respective bridge. The second channel (passive bridge) was monitored to see the level of cross-sensitivity.

Calibrations were also conducted for both increasing and decreasing loads to determine any hysteresis effects. All the calibration showed a high degree of linearity between bridge output voltage and force applied. The co-efficient of correlation, R^2, for the relationship between voltage output and force was equal to 0.9996 (minimum) for both of the link arms.

For the link arm 793/1, 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 0.75% and 1.19% respectively at a load of 8 kN.

Similarly the hysteresis effect for the link arm 793/2 for increasing and decreasing applied coincident and perpendicular force was found to be 0.87% and 0.70% respectively at 8 kN load. The sensitivity, cross-

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sensitivity and hysteresis of both the link arms for FC and FP bridges found are summarized in table-1.

Table-1

	Sensitivity μVN^{-1}V^{-1}	**Cross-Sensitivity (%) at Full Scale**	**Hysteresis (%) at 8 kN load**
Lower Link 793/1			
Coincident Force (FC)	1.28x10^{-4}	0.252	0.75
Perpendicular Force (FP)	6.80x10^{-4}	0.840	1.19
Lower Link 793/2			
Coincident Force (FC)	1.258x10^{-4}	0.382	0.87
Perpendicular Force (FP)	6.430x10^{-4}	0.940	0.70

Table-1 shows that the sensitivities for two link arms for coincident force (FC) had a small difference in value of 1.71% while that for perpendicular force (FP) was 5.44%. This difference in value may be attributed to the positioning of the gauges or the slight differences in link cross-sectional areas as reported by J. Blake (1993).

Sensitivity of the coincident bridge was 5 times less than the perpendicular bridges on the same arm.

The cross-sensitivity for both the arms was very small (<1%). The cross-sensitivity can be compensated for by a computer programme provided it is small.

The analysis of the data for the link arm 793/1 for coincident and perpendicular force respectively showed a maximum difference from the mean value of 0.31% and 0.41% for the three replications of each test while that for the link arm 793/2 for FC and FP respectively 1.75% and 1.3%.

CONCLUSION

The calibration tests for the bi-axial direct mounted strain gauged lower links system revealed that the system was well working for a range of draught and vertical forces up to 20 kN. 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 0.9996. The hysteresis effect between the calibration curves for increasing and decreasing applied coincident and perpendicular force was very small (<1.20%).

The interactions of the applied forces on the orthogonal force bridges were less than one percent. Maximum difference from the mean value for applied coincident and perpendicular force respectively was 1.75% and 1.3%.

If the lower link arm 793/1 is considered as an example, the sensitivity for coincident and perpendicular force respectively was found to be 1.28x10^{-4} μVN^{-1}V^{-1} and 6.80x10^{-4} μVN^{-1}V^{-1} .

The system is best suited where medium type equipment is used with a tractor.

However, the system needs to be further tested in the field.

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