THREE-POINT HITCH-MECHANISM INSTRUMENTATION FOR TILLAGE POWER OPTIMIZATION

H. BENTAHER1*, E. HAMZA2, G. KANTCHEV3, A. MAALEJ3, and W. ARNOLD4

ABSTRACT

The tillage power optimization is a field of interest of many researchers since the sixties. Three categories of tillage force measuring systems were built by several researchers: Sensors incorporated in the tillage tools, a separate frame between the tractor and the tool and the installation of transducers in the three-point hitch-mechanism. In the present work a system from the third category was built, calibrated and tested in the field. The innovation in this system is its ability to calculate the three orthogonal components of the tillage effort in relation with the tool penetration. A dynamic calculus program was developed to take into consideration the changes of the three-point hitch-mechanism geometry during the tillage operation. The calibration results showed a linear proportionality between the applied and the measured forces. The preliminary field tests proved the stability of the system results. The developed system could be a useful tool for the optimization of tillage energy consumption.

Keywords: Instrumentation; three-point hitch-mechanism; power; tillage

INTRODUCTION

Due to the rapid increase of energy cost, power optimization is a common purpose for the majority of researchers around the world. Tillage is the biggest power consumer in an agricultural production system and hence the evaluation of tillage effort is a field of great interest.

1Olive-tree Institute, PB 1087, Sfax-3000, TUNISIA
2National Agronomic Institute of Tunis
3National Engineering School of Sfax, PBW, Sfax-3000, TUNISIA
4Fraunhofer-Institute for Non-Destructive Testing (IZFP), Bldg. E3.1, Univ. D-66123 Saarbrücken, Germany,
*Corresponding author. Tel.: +216-74-241589; Fax: +216-74-241033; E-mail: bentaher.hatem@iresa.agrinet.tn
Researchers proposed and built many systems to measure the effort and power requirements of tillage implements. Developed systems can be classified into three categories in relation to the force transducers location. For the first category, sensors are mounted on the tillage tool (Girma et al., 1989; Formato et al., 2005). These systems give a precise idea about strain distribution on the implement that helps in their design optimization. However, they are expensive because each tested tool has to be equipped with its sensors. Moreover, the transducer’s installation needs some changes of the implement’s global geometry which could modify the interaction soil-tool and make an important change of the tool weight. The second category systems are separate frames in which transducers are mounted. These systems are introduced between the tractor and the implement. Because these systems are interchangeable between different tractors and tools and they are easy to manufacture, the majority of researchers investigated such devices (Reece et al., 1961; Barker et al., 1981; Reid et al., 1985; Clark et al., 1985; O’Dogherty, 1986; Chaplin et al., 1987; Thomson et al., 1989; Palmer et al., 1992; Godwin et al., 1993; Hammada L., 1998; Al-Jalil et al., 2001; Kasisira et du Plessis, 2006). However, this category presents many inconveniences: First, it requires a heavy frame to fix the transducers which causes a change of the global weight and a backward displacement of the implement. Second, the fixation of the transducers and the frame to the tractor necessitates many extra elements at the articulations that are a source of error in the measurements. For these reasons, the second category did not reflect the real work conditions. Thus it is not useful for the studies of the tractor stability.

The third category consists of the installation of transducers in the three-point hitches system of the tractor. Despite the fact that this category preserves the real conditions of field work, little research has been focused on it. The efficiency of these systems is highly related to the position of the sensors. On the one hand, some researchers mounted the transducers on the top and two lower links (Bandy et al., 1985; Upadhyaya et al., 1985; Al-Janobi et al., 2000; Bentaher et al. 2003). The load of the lower links is complex. It entails tension, compression, and flexure which is not suitable for the installation of force sensors. As a result, with such systems they were unable to measure the lateral effort generated by unsymmetrical
implements. On the other hand, the installation of force transducers on the top and two lift links seems to be the best solution. To our knowledge, the unique work that has been done on this type of system is that of McLaughlin et al., 1993. In that work, the three-point hitch system was considered as static during tillage. The changes of its geometry during field work were not taken into consideration, so they were a source of measurement errors.

The present work extends the use of the last model with a dynamic program calculating the three orthogonal components of the tillage effort. This program takes into consideration the changes of the three-point hitch system geometry. The coordinates of each articulation of this system is continuously calculated as a function of the rockshaft arm position detected by an angular sensor.

**MATERIALS AND METHODS**

1 **Theoretical Background (Cinematic Study):**
In the majority of published work, researchers considered the three-point hitch mechanism as planar system. This system was modelled in two dimensions to represent the forces in the original geometric configuration between the tractor and the implement (Bandy et al., 1985; Aljanoubi, 2000). This approximation hypothesis can be accepted, with a relative error, for the studies of symmetric implements.

In order to evaluate the three orthogonal components of a non-symmetric tillage tool (longitudinal, vertical and lateral forces), a three-dimensional cinematic study of the tractor linkage mechanism is needed. This mechanism consists of seven articulated beams. During the field work, this system is isostatic with one degree of freedom. The angular position of the rockshaft is sufficient to determine the exact geometry of this system.

To make the force calculation simpler, the three-point hitch system is modelled by ties and pin joints. The coordinates of each joint are calculated in a Cartesian coordinate system \((I_0, X_0, Y_0, Z_0)\) related to the rear wheel axis and the tractor mid plane (Fig.1). The position of the tillage application point \((G)\) in reference to this coordinate system is given by these equations:
\[ x_G = x_D + IH \frac{z_K - z_D}{IK} + HG \frac{x_D - x_K}{IK} \]  \quad (1)

\[ z_G = z_D - HG \frac{z_K - z_D}{IK} + IH \frac{x_D - x_K}{IK} \]  \quad (2)

For a definition of the variables in these equations, see fig. 1.

An Excel computer program \((CP1)\) was developed to determine these coordinates. The inputs of this program are:

- Tractor characteristics: Cartesian coordinates of: \(O\), \(O'\), \(B\), \(B'\), \(E\) and the distances: \(AA'\), \(L_1\), \(L_1'\) and \(L_3\);
- Adjustable lengths: \(L_2\) and \(L_4\);
- Tool triangular chassis characteristics: distances \(DD'\), \(IK\), \(IH\) and \(HG\);
- Rockshaft angular position \(\phi\) which is the unique variable parameter during the field-work.

The tractor characteristics are measured and compared to the OECD restricted code test report \(N°\ 10617\) \((CEMAGREF 1995)\). The computation equations of all the pin-joint positions are developed and an Excel spreadsheet \((CP2)\) was developed to evaluate the three orthogonal components of the tillage effort. The inputs of this program are the outputs of the first program \(CP1\) and the reaction efforts in the top link and the two lift links. The cinematic study of the three-point hitch mechanism showed that the voltage response of three force transducers located in these parts are sufficient to identify the tillage effort. The equilibrium of the left lower link arm gave this system of equations:

\[
\begin{align*}
R_{Dx} + R_{Bx} + R_{Cx} &= 0 \\
R_{Dy} + R_{By} + R_{Cy} &= 0 \\
R_{Dz} + R_{Bz} + R_{Cz} &= 0 \\
(y_c - y_b)R_{Cx} - (z_c - z_b)R_{Cy} + (y_d - y_b)R_{Dx} - (z_d - z_b)R_{Dy} &= 0 \\
(z_c - z_b)R_{Cx} - (x_c - x_b)R_{Cz} + (z_d - z_b)R_{Dx} - (x_d - x_b)R_{Dz} &= 0 \\
(x_c - x_b)R_{Cy} - (y_c - y_b)R_{Cx} + (x_d - x_b)R_{Dy} - (y_d - y_b)R_{Dx} &= 0 \\
\frac{R_{Cx}}{(x_A - x_C)} = \frac{R_{Cy}}{(y_A - y_C)} = \frac{R_{Cz}}{(z_A - z_C)} = \frac{R_C}{L_2}
\end{align*}
\]  \(3\)
The equilibrium of the right lower link arm gave a similar system of equations. From the equilibrium of the tillage tool chassis, this system of equations is derived.

\[
\begin{align*}
W_x &= R_{Dx} + R_{D'y} + R_K \frac{(x_K - x_E)}{L_4} \\
W_y &= R_{D'y} + R_{D'y} \\
W_z &= R_{Dz} + R_{D'z} + R_K \frac{(z_K - z_E)}{L_4} + mg \\
y_D (R_{D'z} - R_{Dz}) &= W_y (z_G - z_D) + mg (y_{cg}) \\
\left[(z_K - z_D)(x_K - x_E) - (x_K - x_D)(z_K - z_E)\right] \frac{R_K}{L_4} &= W_y (z_G - z_D) - W_z (x_G - x_D) \\
W_y &= \left(\frac{R_{D'z} - R_{Dz}}{x_G - x_D}\right) y_D
\end{align*}
\]

The last equations of these two systems are derived from the knowledge of the direction of the reactions in the two lift links and the top link: They are bi-articulated beams, so their reactions are parallel to the beams direction. The flow-diagram of the two computer programs is illustrated in Fig.2.

The resolution of these systems gave the expression of the three orthogonal components of the tillage force:

\[
\begin{align*}
W_x &= M\left[R_c + R_{c'}\right] + NR_K + Omg \\
W_y &= P\left[R_c - R_{c'}\right] + Qmg \\
W_z &= R\left[R_c + R_{c'}\right] + SR_K + Tmg
\end{align*}
\]

The coefficients M, N, O, P, Q, R, S and T were determined experimentally from the calibrating curves.

2 Instrumentation

The three-point hitch mechanism of a “Massey Ferguson 6120” tractor was instrumented to evaluate the orthogonal components of tillage implements. The dimensional characteristics of this mechanism were preserved. Two HBM-U2B force transducers with a capacity of 200 kN were incorporated in the two lift links. Four simple thread shells were designed and constructed to make the assemblage of these transducers possible. A third
load cell with the same capacity and a lower weight was designed and constructed. The incorporation of this transducer should not change the weight of the link greatly (Fig. 3). More detailed information concerning the design of this sensor and its calibration are presented in Bentaher et al. 2006. A rotary position transducer functioning as a potential divider was mounted on the rockshaft and operated of its movement. This transducer was used to measure the implement depth and the angular position of the hitch mechanism.

3 Data-Acquisition System

The three load cells and the rotary position transducer were connected to the differential channels 1 to 4 of 21X scientific Campbell data logger. This data logger was connected to the RS232 port of a notebook computer via an optically isolated interface SC32A. The whole acquisition system was mounted on a platform to the back of the driver seat. This system worked either on its own batteries or on the 12V power supply of the tractor (Fig. 4). The data logger was used to excite the transducers and to sample and record their responses. The notebook was utilised for developing the program, its transfer to the data logger and to start and stop the sampling on field. In fact, the F1 button of this computer was programmed as the flag of the programmable data logger. In addition to that, it was used to collect the stored data and to calculate the tillage effort using the developed computer programs CP1 and CP2. The software (PC208) was used to prepare the data logger program and to run and test its validity and the proper functioning of the acquisition system.

4 Calibration

The instrumented three-point hitch-mechanism was calibrated using a separate HBM-U9B force transducer with a capacity of 20 kN. The simulated effort was applied and varied with a chain-hoist attached to a fixed point from one side, and to the force transducer from the other side. This transducer was fixed to the force application point (G) of the triangular chassis with a cable. The direction of the applied effort, given by the sheared cable, was verified by a standard air level, its modulus was controlled by an MVD 2510 control panel measuring amplifier. Three
principal efforts, related to the orthogonal directions, were applied: Longitudinal, vertical and lateral effort. The applied efforts were increased gradually and for each value, the acquisition of the three sensors responses was logged on for a period of one minute. The results of the calibration are presented in figures 5, 6 and 7.

The field tests were executed in the Tunisian agriculture Institute farm, where the soil was loamy consisting of 63.69 % loam, 36.16 % sand and 0.15 % clay. The mean of the water content, dry basis, and the cone index for the upper horizon (0-20 cm) were 14% and 2.2 MPa, respectively.

A 20 inches AMS mouldboard with one ploughshare was used to make the preliminary tests. The tractor speed used for these tests was 1 km/h with a sliding lower than 2%. A tillage depth of 20 cm was chosen.

RESULTS AND DISCUSSIONS

The results of calibration showed a linear proportionality between the applied force and the responses of the three force sensors. The registered and the treated data are represented in figure 8. This figure shows a good stability of the three orthogonal components of the tillage force. The mean of the horizontal, lateral and vertical forces generated by the tested mouldboard are respectively 4105N, -40N and -295N. The negative values indicating that the forces are in the opposite direction of the Cartesian coordinate system.

CONCLUSION

Instrumentation of the three-point hitch-mechanism allowed us to evaluate the force generated by tillage implements. The system was calibrated and tested in the field and the results showed its capability to measure the three orthogonal components of the tillage force. This system could be used in the design of tillage tools and the optimisation of their energy consumption. The developed calculus programs gave this system flexibility in the interpretation of the logged data in relation with the tool penetration in the soil. More investigations are needed to study the influence of several work parameters such as tillage speed, tillage depth and soil type on the measured forces.
Acknowledgements

The authors would like to thank the “Agence Universitaire de la Francophonie” for the financial support of the researcher’s mobility between the two laboratories: LASEM in Tunisia and IZFP in Germany.

Figures

Figure 1: Rear view (a), side view (b) and upper view (c) of the three-point hitch mechanism showing lower link 1; lift rod 2; lift arm 3; upper link 4; tillage tool triangle 5; longitudinal component of tillage force Wx; lateral component of tillage force Wy; vertical component of tillage force Wz.
Figure 2: Flow-diagram of the computer programs showing the distance between the two lift arm joints AA’; distance between the joints of the lower link L1; distance from the lower link joint to the lift rod joint L’1; lift rod length L2; lift arm length L3;

Figure 3: Instrumented three-point hitch mechanism.
Figure 4: Data acquisition system.

Figure 5: Longitudinal logged data.
Figure 6: Lateral logged data.

Figure 7: Vertical logged data.
REFERENCES


Hammada L., Mise au point d’une cellule dynamométrique adaptée à l’attelage trois points de tracteurs, Thèse de Doctorat non publiée de la Faculté universitaire des sciences agronomiques de Gembloux, 1998;


الملخص العربي

تجهيز آلية شد المحاريث في مؤخرة الجرار لترشيد استهلاك الطاقة

إن قياس قوة الحرف محطم اهتمام عدد الباحثين منذ الستينات. الألابات المصنوعة لهذا الغرض يمكن تقسيمها إلى ثلاثة أنواع: تركيب محسات القوة في المحاريث أو صنع هيكل يحمل المحسات يقع تركيبه بين الجرار و المحاريث أو تركيب المحسات على جهاز الشد الخلفي للجرار. في هذا البحث تم صنع آلية من النوع الثالث و تمت معايرتها و تجربتها. هذا الجهاز قادر على قياس القوى الأفقية و الرأسية و الجانبية للمحاريث مع أخذ التغير في عمق الحرف بعين الاعتبار. النتائج الأولية للتجربة في الحفل أثبتت استقرار آلية قياس القوى المصنوعة وإمكانية استعمالها لترشيد استهلاك الطاقة في عملية الحرف.