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Research Paper

Front end loader with automatic levelling for farm tractors

Juan I. Latorre-Biel [a,*], Ignacio Arana [b], Tomás Ballesteros [b], Jesús M. Pintor [c], José R. Alfaro [b]

[a] Dept. of Mechanical, Energy, and Materials Engineering, Public University of Navarre, Campus of Tudela, 31500 Tudela, Spain

[b] Dept. of Agricultural Projects and Engineering, Universidad Pública de Navarra, Campus of Tudela, 31500 Tudela, Spain

[c] Dept. of Mechanical, Energy, and Materials Engineering, Public University of Navarre, Campus Arrosadía, 31006 Pamplona, Spain

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One of the most commonly used accessories in multiple applications with farm tractors is the front end loader. There is a broad variety of loaders that can offer a range of possibilities and advantages to the operator. Depending on the task to be developed, the functionality that the operator requests from the loader may be different. Nevertheless, in order to avoid significant loss of product during transport, in most applications it is desirable for the loader to be level throughout its movement. In this paper, a new methodology for achieving a high quality levelling is described. This methodology, when compared to the alternative options that can be found in the market, presented favourable features. The proposed methodology could be implemented at affordable cost by using a reduced set of inexpensive components and can be applied to both new and old tractors.

1. Introduction

Farm tractors are the ubiquitous machine for agricultural applications and front end loaders are one of their common accessories (Ha & Kim, 2015). For example, they can be used for pallet lifting, hay bale handling, manure gathering, and ground levelling (Mukhopadhyay, Gupta, & Howarth, 2008).

Front end loaders contain two long bars, usually bent and welded together forming a boom. The boom is linked to the chassis of the tractor by means of a pivot pin allowing relative rotational motion. Two hydraulic cylinders, called lift-arm cylinders, control the up and down movement of the loader. The loader also contains a mechanism, allowing for the coupling of different accessories or implements. This mechanism is assembled to the boom through pivot pins, as well as

* Corresponding author.
E-mail address: juanignacio.latorre@unavarra.es (J.I. Latorre-Biel).
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Nomenclature

$Ø_{1BORE}$	Bore diameter of the lift-arm cylinder, m
$Ø_{2BORE}$	Bore diameter of the bucket cylinder, m
$Ø_{1ROD}$	Piston rod diameter of the lift-arm cylinder, m
$Ø_{2ROD}$	Piston rod diameter of the bucket cylinder, m
ESL	Electrical self-levelling system
IMU	Inertial Measuring System
PLC	Programmable logic controller
Q	Flow rate, used to represent either $Q_{1OUT}(i)$, $Q_{1IN}(i)$, $Q_{2OUT}(i)$, or $Q_{2IN}(i)$, $m^3\ s^{-1}$
$Q_{kOUT}(i)$	Flow rate of the hydraulic fluid required by a single lift-arm ($k = 1$) or bucket ($k = 2$) cylinder in outward movement and in the *i-th* interval of the trajectory. $m^3\ s^{-1}$
$Q_{kIN}(i)$	Flow rate of the hydraulic fluid required by a single lift-arm ($k = 1$) or bucket ($k = 2$) cylinder in inward movement and in the *i-th* interval, $m^3\ s^{-1}$
$\overline{Q_{kOUT}}$	Average flow rate of lift-arm ($k = 1$) or bucket ($k = 2$) cylinder in a complete outward movement of the piston, $m^3\ s^{-1}$
$\overline{Q_{kIN}}$	Average flow rate of lift-arm ($k = 1$) or bucket ($k = 2$) cylinder in a complete inward movement of the piston, $m^3\ s^{-1}$
r_{ef}	Effective radius of the piston of a cylinder for calculating the flow rate required to move it, m
$S_1(i)$	Relative length of the *i-th* movement for the lift-arm cylinder piston
$S_2(i)$	Relative length of the *i-th* movement for the bucket cylinder piston
$S(i)$	Maximum value of the set $\{S_1(i), S_2(i)\}$
SP_{max}	Maximum value of feasible setpoints for a proportional valve, V or mA
SP_{min}	Minimum value of feasible setpoints for a proportional valve, V or mA
$SP_j(i)$	Setpoint for the proportional valve of the *j-th* cylinder in the *i-th* interval of motion (1st cylinder is the lift-arm one, while 2nd cylinder is the bucket one), V or mA
$t(i)$	Time invested in performing the displacement of the cylinders that correspond to the *i-th* interval, s
t_t	Task time, s
V_1	Volume of the bottom chamber of the lift-arm hydraulic cylinder (opposite to the piston rod side chamber), m^3
V_2	Volume of the bottom chamber of the bucket hydraulic cylinder, m^3
$V_1(i)$	Piston displacement of the lift-arm cylinder in the *i-th* interval, m^3
$V_2(i)$	Piston displacement of the bucket cylinder in the *i-th* interval, m^3
VDC	Voltage (direct current), V
z_1	Stroke of the piston in the lift-arm cylinder, m
z_2	Stroke of the piston in the bucket cylinder, m
$z_1(i)$	Position of the lift-arm cylinder piston at the end of the *i-th* interval, m
$z_2(i)$	Position of the bucket cylinder piston at the end of the *i-th* interval calculated through an interpolating (polynomial) function, m

by one or two hydraulic cylinders (called bucket, tilt or turning cylinders) able to change the orientation of the implement. Depending on the loader type, this system may include additional links, shaping a mechanical parallelogram (Cao & Cleghorn, 2011). In some solutions, an additional pair of compensating cylinders forms a hydraulic parallelogram (Section 2.1).

Three important categories of front end loaders for farm tractors are described below, from the oldest design to the newest.

A classic front end loader is the one lacking mechanical parallelogram. A sketch of this tool can be seen in Fig. 1. This is the simplest of all the loaders, since it contains fewest links and joints or kinematic pairs, which may lead to reduced weight (see Table 1, which will be discussed in Section 2.2). One of the main drawbacks of this type of loader is that the trajectories described by the bucket require manual control of its levelling to prevent significant loss of load (Jain & Issac, 2003). This behaviour makes the operation of the tool complicated and uncomfortable.

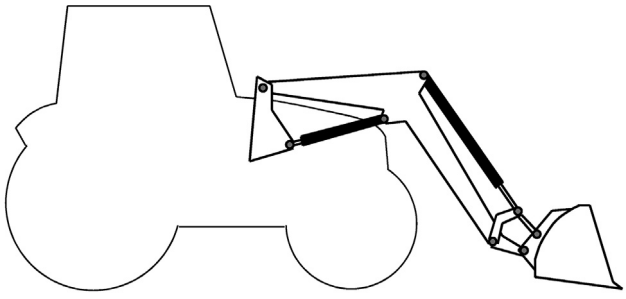

Fig. 1 – Classic solution for the mechanism of a front end loader.

A second important type of front end loaders is that including a mechanical parallelogram (Fig. 2). A significant advantage of these loaders is the possibility of self-levelling of the bucket along trajectories for lifting a given load thereby reducing the risk of losing significant amounts of material. However, this feature is achieved only under certain geometric configurations (Yung, Vázquez, & Freidovich, 2015). Nevertheless, this type of loader can be attached to a broad range of farm tractors and has been commercial successful (Fig. 3, discussed later in Section 2.2).

The third type of front end loader includes a hydraulic parallelogram (Fig. 4). This system requires a hydraulic coordination between bucket cylinders and a third pair of cylinders, called compensating cylinders, which keep the bucket level for a single orientation of this implement. In order to change the orientation of the implement to allow self-levelling, it is necessary to perform mechanical adjustments in the front end loader by modifying its geometry. Currently, not many manufacturers offer this solution.

A very important feature in the operation of a front loader for a tractor is control of the tool. Self-levelling prevents losses