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Combined finite element and multi-body dynamics analysis of effects of hydraulic cylinder movement on ploughshare of Horizontally Reversible Plough

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A B S T R A C T

Hydraulic Cylinder (HC), one of the key components of Horizontally Reversible Plough (HRP), takes the responsibilities for the commuting soil tillage of HRP. The dynamic behaviors of HC surely affect the tilling performances of HRP. Based on our previously related work, this paper further addresses the effects of HC movements during tillage on ploughshare, especially at share-point, of HRP. For HC, uniform motion was considered in this study. A combined finite element and multi-body dynamics analysis (MDA) was implemented to assess both tillage kinematics and kinetics of the ploughshare. These numerical predictions were primarily involved in five different HC movement velocities and two actual HRP tilling scenarios, respectively, where loading data due to the HC movements were obtained from an MDA and applied to load a finite element modal of the ploughshare. Our results show that the importance of performing MDA as a preliminary step FEA to obtain an insight into the actual stress and strain variations at the share-point. Our findings demonstrate that the different movements of HC have no adverse effects on the service life of the ploughshare though they result in the maximum stress and strain at the share-point during HRP tillage.

1. Introduction

In agricultural practices, soil tillage is the largest consuming operation due to so much energy necessary for soil cutting to obtain the desired soil physical conditions for plant growth (Natsis et al., 2008). As for this, the mouldboard plough is generally used and, consequently, development of the ploughs with high efficiency is a domain of interest of many researchers (Shmulevich, 2010; Okayasu et al., 2012). For example, Farid Eltom et al. (2015) adopted the trash-board with mold board plough to reduce the force requirement in tow condition of straw.

Horizontally Reversible Plough (HRP), developed by Xin-Jiang Agricultural Mechanization Institute (XJAMI) of China, is also a novel mouldboard plough. The unique advantage of HRP, compared with the regular mouldboard plough, is that it can perform a continuous and alternative commuting tillage with excellent operation performances (such as steady tilling and orderly soil cutting) (Zhu et al., 2006). Fig. 1 schematically illustrates two different tillage processes of HRP in real field conditions, where symbols I and II separately denote the two different limited tillage positions of HRP. That is, HRP can continuously and alternatively commute between left and right (Fig. 1 (A)), or between left and middle (Fig. 1 (B)). In addition, n in Fig. 1 indicates the rotational speed of Basic Beam (BB) with respect to Main Beam (MB). Note that n is also the rotational speed of the plough body because of it being attached to BB.

In HRP there exists an indispensable component, i.e. a small-cubage hydraulic cylinder (HC) with double functions, which compels Basic Beam (BB) to rotate with respect to Main Beam (MB), and then BB drives the plough body to implement the alternative commuting tillage of HRP (Fig. 1). However, the dynamics behaviors of the alternative commuting due to HC movement surely have an adverse effect on the components of HRP, e.g. BB. As such, it is important to study how HC affects the dynamics behaviors of BB and optimize the motion type of HC. The previous research evidences have demonstrated that uniform motion applied for HC favors HRP, and that the dynamic impact due to the uniform motion has no detrimental effects on the service life of

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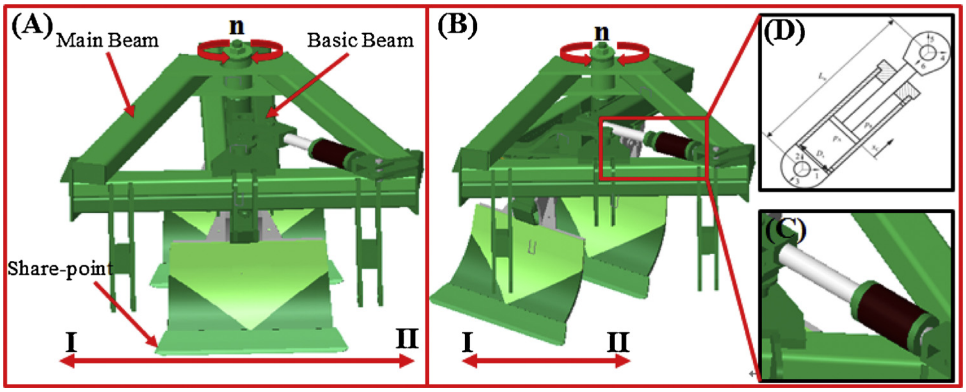

Fig. 1. (A) The first and (B) second commuting tillage processes of HRP, Hydraulic Cylinder (HC) with (C) magnified view and (D) main dimensions and variables: "n" is the speed of rotational pin.

BB (Zhu et al., 2006). But there exists another question whether the foregoing impact loads have an adverse effect on the two essential engaging components of HRP, i.e. ploughshare and mouldboard. This study therefore focuses on the effect of the dynamics of the alternative commuting tillage on the ploughshare, especially at share-point. Generally, the tillage performances of share-point are strongly associated with the service life of ploughshare.

Currently, a combined finite element analysis (FEA) and multi-body dynamics analysis (MDA) approach has received much attention as a strong tool to investigate functional morphology in mechanical design. For example, Kim et al. (2010) used a method combining finite element analysis (FEA) and multi-body dynamics analysis (MDA) to develop a new anisotropic beam finite element for composite wind turbine blades. Aguib et al. (2014) adopted kinematic and kinetic techniques to obtain the dynamic behaviors of a magnet-orheological elastomer sandwich plate. Adriana et al. (2013) employed multi-body dynamics modeling to successfully determine humidity response of kraft papers. The main advantages of using the methods are that the performances of mechanical components can be analyzed on a system level and then the loads acting on these structures can further be predicted and also applied to a modal of theirs (Geradin and Cardona, 2001; Dai et al., 2011; Bilasse and Oguamanan, 2013). Consequently, the patterns of strain and stress across the mechanical components can be obtained accurately. This is very useful to understand the properties and behaviors of more complex and specific structures and, hence, further optimize and improve the performances of these components. However, to the best of our knowledge, so far there are few studies in literature for the performances of HRP by using a combined MDA and FEA approach.

The aim of this study, based on our previously related work, is therefore to use a combined FEA and MDA approach to numerically investigate the effects of various HC movements on the share-point of HRP under the two tillage scenarios.

2. Materials and methods

2.1. Geometric model

SolidWorks was used for the HRP solid model construction. The detailed modeling procedure is depicted as follows: firstly, the 3D models of parts and components were constructed with feature-based modeling approaches; then, Virtual Assembly Technology (VAT) was employed for assembling HRP; finally, Interference Check Technique (ICT) was used for verification of the 3D HRP model (Fig. 1). Detailed geometrical data of HRP are available in Ref. (Zhu et al., 2016a,b). The practical dimensions of HRP include 2.8 m length, 2.35 m width and 1.2 m height (Zhu et al., 2008).

2.2. Kinematic and kinetic analysis

A three-dimensional model of reversing mechanism of HRP is illustrated in Fig. 2 (A). Fig. 2 (B) shows its simplified kinematic diagram. This diagram consists of the main components of the mechanism, e.g. Basic Beam 1, Reversing Rod (RR) 2 and Hydraulic Cylinder 3. The detailed information on HC is presented as follows:

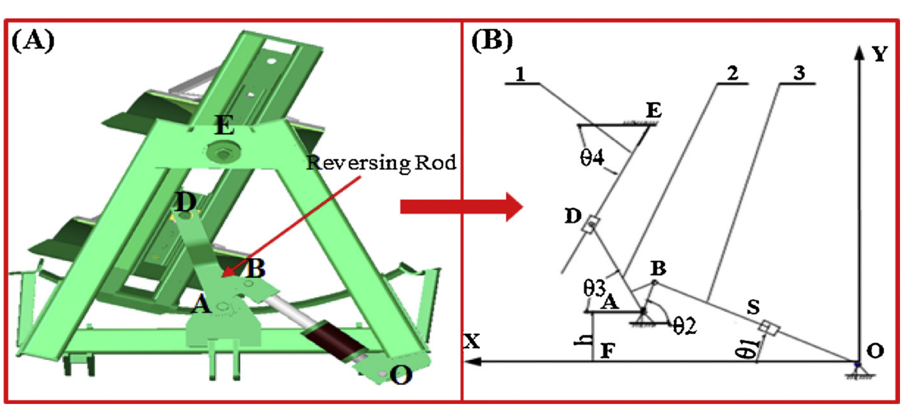

Fig. 2. (A) 3D model and (B) 2D diagram of Reversing mechanism of HRP: "A, E, O" are the fixed pivots of the reversing mechanism,"B"is the hinge joining HC and RR, "D"is the BB and RR, "S"is the lengths of OB, and"h" is the vertical distances between pivots A and O.