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A power estimator for an integrated active-passive tillage machine using the laws of classical mechanics

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ABSTRACT

The integration of an active and a passive tillage tool results in several benefits. In this study, power requirement of an integrated active-passive tillage machine was investigated using a theoretical procedure. To achieve this goal, two of the models developed previously regarding the power needs of a rotary tiller and a subsoiler were modified and combined to result in an integrated estimator for prediction of the power requirements of the combined machine. Verification of the integrated estimator was carried out by comparing the estimator outputs with experimental results obtained by other researchers. According to the results of the study, the error percentage of the estimator in predicting draft force, rotational power, drawbar power, and negative draft of an integrated active-passive tillage machine in comparison with the experimental data of Weise (1993) were 16%, 47%, 6%, and 3%, respectively. Moreover, similar proportions of rotational power to total power as well as similar volumetric energy consumptions were obtained from the estimator developed herein and the experimental study of Chamen et al. (1979). Furthermore, there were promising correlations between estimated torques in this study and the study of Anpat and Raheman (2017), as well as between estimated draft forces and powers in this study and the study of Shinners et al. (1993). Finally, considering the correlations between the data obtained herein and the study of Manian and Kathirvel (2001), the estimator developed in this study predicted the values of draft force, draft power, total power and required torque of the machine fairly well. However, it overestimated the value of draft force, especially when forward speed of the machine was low. To sum up, the majority of the estimator outputs were aligned with the results obtained by other researchers.

1. Introduction

A single tillage machine can be categorized either as an active machine or as a passive implement. While the required rotational power of an active tillage machine (a driven implement) is obtained through the tractor power take off (PTO) shaft; a passive tillage machine (a drawn implement) requires only drawbar power of tractor to be operated (Srivastava et al., 2006).

Consider an active tillage machine having blades that rotate in vertical plane clock-wisely while its power source (i.e. tractor) is moving straight forward to the right. The interaction between the rotating blades and soil makes the soil to be loosened greatly, but at the same time this operation generates negative draft force and the machine tends to reduce its working depth. On the other hand, if a passive tillage machine having blades with an acute rake angle is considered, the interaction between the blades and soil, tends to deepen the working depth of the machine and to increase the implement draft force (McKyes, 1985; Godwin and O'Dogherty, 2007). Therefore, in order to reduce the draft force requirement of a tillage implement, the idea of combining an active and a passive tillage machine to form an integrated active-passive tillage implement seems promising. Because in this combination the negative draft force of the active implement supplies a portion of the draft force needs of the passive machine and the operation of the passive implement stabilizes the working depth of the active one without adding additional depth stabilizing ballast (Anpat and Raheman, 2017).

During the last three decades, researchers have tried to study different aspects of this type of tillage machine. These aspects include the effects of the integrated machine on the properties of the tilled soil and the harvested crop yield (Chamen et al., 1979; Weise, 1993), as well as calculation of power requirements for the operation of the combined implement (Chamen et al., 1979; Shinners et al., 1993; Weise, 1993; Manian and Kathirvel, 2001; Anpat and Raheman, 2017). Almost all of the studies carried out with the aim of estimating power requirements of the active-passive tillage machine have been followed an experimental procedure. An exception in this regard is the work performed by Russian scientists (Bernacki et al., 1972) who developed a number of theoretical formulas for calculating required power of it.

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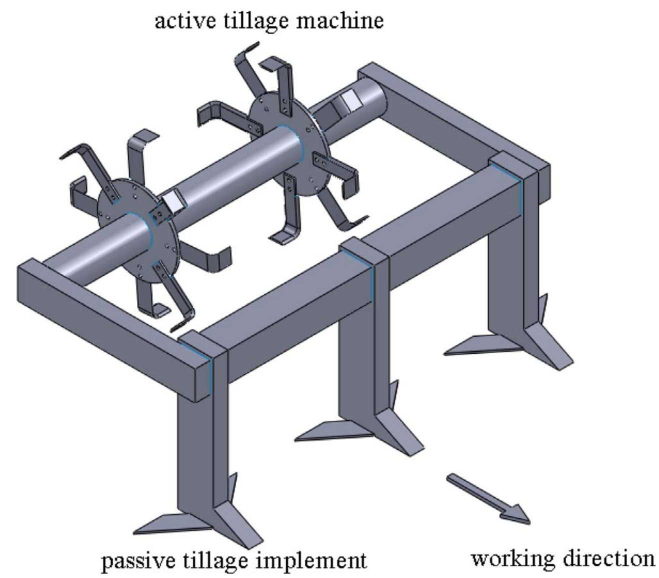

Fig. 1. Schematic diagram of an active-passive tillage machine.

Therefore, in this study a power estimator for an active-passive tillage implement has been developed by modifying and combining the two other theoretical models presented by Ahmadi (Ahmadi, 2016, 2017). One of the aforementioned theoretical models is developed to calculate the required rotational power of a rotary tiller (an active tillage tool), and the other is created to estimate the drawbar power needs of a winged subsoiler (a passive tillage machine).

2. Materials and methods

2.1. Essential components of the power estimator developed in this study

The machine considered as an active-passive tillage implement is composed of a rotary tiller and a subsoiler (Fig. 1); therefore, its power estimator is developed by modifying and combining the power calculators of a rotary tiller (Ahmadi, 2017) and a subsoiler (Ahmadi, 2016).

Each of the primary power calculators receives the soil, machine, and working state parameters as its inputs and results in the required power of the corresponding machine as an output. The soil parameters include cohesion (c), internal friction angle (φ), and bulk density (ρ). The machine parameters include rotor radius (R), blade length (BL) and width (BW), number of blades per flange (Nb), number of flanges (Nf), and angle of soil-metal friction (δ) for the rotary tiller; and width of the subsoiler wing (W), width (b) and thickness (t) of the shank (it is supposed that the subsoiler share width is also equal to *b*, as depicted in Fig. 1), number of the shanks (N), surface area of the wing (An), and angle of soil-metal friction (δ) for the winged subsoiler. The working state parameters include forward velocity (v), angular velocity (ω), and working depth (d) for the rotary tiller; and forward speed (v), soil vertical upheaving (Δh), disturbed soil overlap percentage of the adjacent shanks (OP), and working depth (h) for the winged subsoiler. To automate performing necessary calculations, all of the mathematical formulas were entered into an Excel spreadsheet (Excel, Microsoft Corporation, Redmond, Wash.); therefore, users should only enter the values of input parameters into the spreadsheet in order to obtain the estimator outputs.

2.2. Modifications required for the integrated estimator

It is necessary to modify the final estimator in order to involve the negative draft force developed by the action of rotating blades. Furthermore, because the blades of the second machine of an active-passive implement must affect the soil that is tilled before by the blades of the first machine, the values of the soil parameters (i.e. *c*, *φ*, and ρ) of the second machine must be different from the first one.

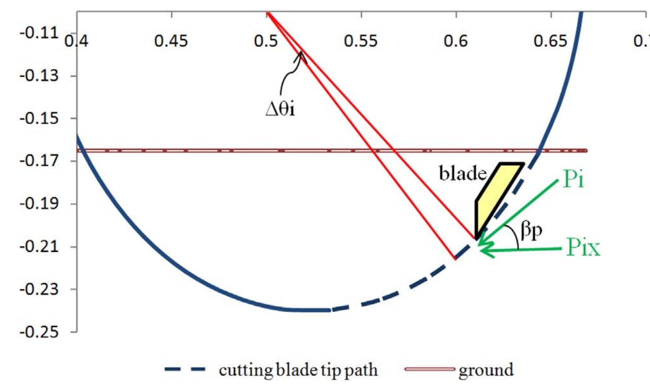

Fig. 2. Details of parameters used to calculate rotary tiller negative draft force.

According to the method presented by Ahmadi (2017), the letter *P* has been selected to name the force exerted by a blade of a rotary tiller to the cut soil. This force has a significant effect on the amount of torque needed to operate a rotary tiller. However, the value of this force varies with the angular position of the blade. According to the Newton's third law of motion, if the average value of the horizontal component of *P* is calculated, the negative draft developed by that blade will be available. Therefore, the rotary tiller negative draft force was estimated using the procedure outlined below (refer to Fig. 2 for visual definition of parameters):

- Dividing the time span from the instant when the rotating blade meets the soil to the instant when it reaches to the deepest point of its path into ten equally sized segments, and calculating the corresponding length of soil that is cut during each of the time segments using the procedure given by Ahmadi (2017).
- Calculating the force P_i needed to cut the i-th segment of soil as suggested by Ahmadi (2017).
- Calculating the horizontal component of P_i i.e. P_{ix} by multiplying P_i by $\cos(\beta_P)$ (β_P is obtained following the procedure given by Ahmadi (2017)).
- Multiplying P_{ix} by the central angle devoted to the i-th segment of the cut soil ($\Delta\theta_i$, rad).
- Calculating $S_i = \sum_{i=1}^{10} P_{ix}\Delta\theta_i$.
- Calculating the average negative draft force developed by a blade using the formula $\overline{P_{ix}} = \frac{S_i}{2\pi}$.
- Obtaining the negative draft force of the machine using the multiplication of $\overline{P_{ix}}$ by the number of the rotary tiller blades.

Automated calculation of this procedure using the Microsoft Excel software, led to the first modification of the active-passive estimator utilized in this study.

To achieve the second modification of the active-passive estimator, the results of the study carried out by Schjonning and Rasmussen (2000) was considered. They compared the soil strength as well as soil pore characteristics for direct drilled and moldboard plowed soils. The soils studied consisted of a coarse sandy soil, a sandy loam and a silty loam soil. They measured shear strength of soil in the field with a vane shear tester. Furthermore, separate soil samples were used for measuring soil bulk density and soil pore characteristics as well as for estimating soil cohesion and internal friction by a shear annulus method in a lab. Based on the results obtained in the study of Schjonning and Rasmussen, three conversion coefficients were defined for relating cohesion, internal friction, and bulk density of the plowed soil to the corresponding parameters of the direct drilled soil. Therefore, these conversion coefficients (Table 1) were used to change the soil strength and bulk density parameters of the untilled soil (used for