[1.]Ferenc GÁSPÁR, [2.]Constantin COŢA, [2.]Petru CÂRDEI,
[1.]Lucian Viorel FECHETE-TUTUNARU

STARTING TRACTION EFFORT EVALUATION FOR A SIMPLE TILLAGE TOOL

[1.] Technical University of Cluj-Napoca, Automotive Engineering and Transport Department, ROMANIA
[2.] National Institute of Research - Development for Machines and Installations Designed to Agriculture and Food Industry – INMA, Bucharest, ROMANIA

Abstract: The paper presents an experimental study on the evaluation of the maximum draft force in the transient operation from standstill to constant working speed of a tillage tool with simple geometry. Experiment was performed in laboratory conditions in a soil-bin with washed and sorted quartz sand (0.3 mm grain diameter) a test environment without structure and cohesion. The measurements were made at a depth of 0.15, 0.20 and 0.25 meters at three rake angles of 25, 35 and 50 degrees and a constant velocity of 0.67 m/s. Results show that the starting force is 26-58% higher compared to the average drag force.
Keywords: starting force, tillage tool, draft force, soil-bin

1. INTRODUCTION

During the design process of tillage implements, accurate prediction of forces acting on tools is an important phase (Manuwa, 2009, Moeenifar et all, 2014, Ani Ozoenema et all, 2018). For that, several approaches are used, for example tillage tools are calculated for assigned tool design parameters and operational conditions considering soil engineering properties as constants (Godwin, 2007, Godwin and O'Dogherty, 2007, Gheres, 2014, Ibrahmi et all, 2015). A different approach is based on numerical methods as i.e. finite element method or discrete element method. Beside classical design approach, another one takes into consideration the integration of reliability analysis into the design and optimization process of tillage tools implements. As presented in (Abo Al-Kheer et all, 2011, Kharmanda et all, 2014) randomness of tillage forces is accounted for, respectively a reliability-based design approach based on uncertainty analysis of basic random variables and the failure probability of tillage machines. Taking into consideration the elements of systemic analysis method presented in (Fechete et all, 2017), the present paper proposes to determine for a tillage tool implement, with a simple geometry, the variability of the draft force, respectively the traction effort during the starting phase. The starting phase, as a transient working regime, will be considered from standstill until constant imposed velocity is reached.

Figure1 - Soil bin assembly

2. MATERIAL AND METHOD

A simple tillage tool model (a tine) was used in this experimental study. The tool is made from polypropylene PP-C, a material used for its favorable mechanical properties and easy machining. Between the mechanical properties of this material can be enumerated: tensile strength 32MPa, flexural strength 41MPa, and density 900 kg/m^3. The model used was beveled on the cutting edge at an angle of 45 degrees and has dimensions of 100x100x10 mm.

Experiments were conducted in controlled conditions in a soil-bin at Automotive and Transportation Department, Technical University of Cluj-Napoca, Romania.

Testing equipment consist in an indoor soil-bin in which the tools can be moved on a circular trajectory with a diameter between 1700-2000 mm at a 900 mm maximum depth. Tool speed is assured by an electric motor (3.2kW, 720rpm) and a dual transmission system consisting in a gear reducer and belt driven transmission and a variable speed controller (Unidrive M200, 15kW). The equipment is completed with a DAQ system (HBM Spider 8) and different force transducers for measuring draft force. An overview of the soil-bin is presented in Figure 1. The tool mounting frame Figure 2, allow the possibility of measuring draft force and offers several possibilities for adjusting angular and vertical position of the tool.

Figure 2 - Tool frame assembly

To reduce the influence of different physical parameters of agricultural soil, washed and sorted quartz sand was used. Sand particles diameter is between 0-0.3 mm which correspond to fine and medium sand according to ISO 14688. This way, the selected soil corresponds to a friction medium without cohesion and without structure. Soil penetration resistance (cone index) was measured and the results are presented in Table 1.

Table 1. Soil penetration resistance of the selected soil

Depth [mm]	50	100	150	200	250
Average resistance [N]	102.4	191.0	258.0	322.2	333.0
Dispersion	8.2%	19.4%	15.1%	17.9%	12.9%
Cone parameters	Cone no. 4; cone base diameter – 25.33 mm; base cone area – 500 mm^2				
Soil resistance [N/cm^2]	20.48	38.20	51.60	64.44	66.60

Variation of draft force of the tool from standstill to imposed speed inside the soil bin was measured and recorded with the DAQ system at a rate of 50 measurements/sec. Experimental trials were carried out nine times at three depths (0.15, 0.20 and 0.25 m) and at three different rake angles (25, 35 and 50 deg.) resulting 9x9 measurement data sets. An example of measurement data set for the draft force variation during starting phase is presented in Figure 3.

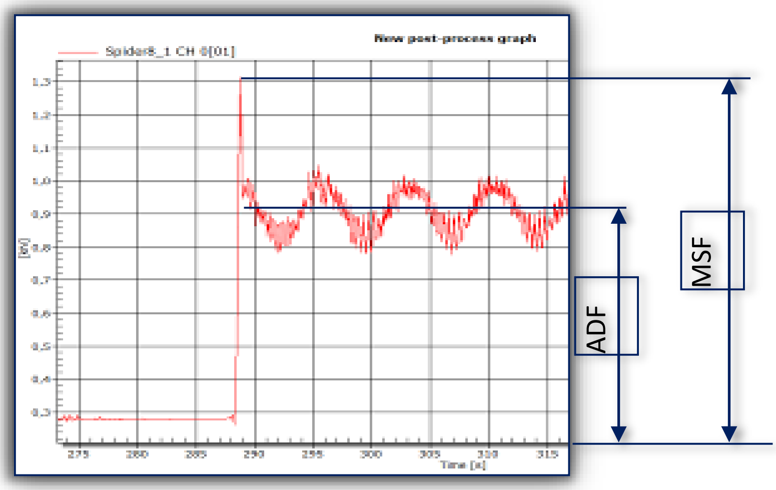

Figure 3 – Catman Easy print screen of recoded data during the starting phase.
ADF – Average Draft Force, MSF – Maximum Starting Force.

3. RESULTS

The results obtained consists in mean values of draft force ($ADF_{avg.}$) during constant working speed, the maximum ($MSF_{max.}$) and mean ($MSF_{avg.}$) values of starting force. All the other data are calculated according to the formulas presented in Table 2. The relative difference (6) is calculated to show the magnitude of *maximum maximorum* starting force relative to average draft force. Also, the average relative difference (9) is calculated to show the magnitude of the mean starting force of all nine replications relative to average draft force.

Table 2. Statistical data of the experimental measurements

Rake angle [deg.]	Tool depth [m]	$ADF_{avg.}$ [N]	$MSF_{max.}$ [N]	Diff. [N]	Rel. diff. [%]	$MSF_{avg.}$ [N]	$Diff._{avg.}$ [N]	Rel. $diff._{avg.}$ [%]
(1)	(2)	(3)	(4)	(5)=(4)-(3)	(6)=(5)/(3)*100	(7)	(8)=(7)-(3)	(9)=(8)/(3)*100
25	0,15	96,09	153,00	56,91	59,23	128,96	32,87	34,20
	0,2	202,81	255,60	52,79	26,03	239,49	36,68	18,08
	0,25	329,14	470,20	141,06	42,86	426,42	97,28	29,55
35	0,15	167,70	241,90	74,20	44,25	219,87	52,17	31,11
	0,2	314,22	415,60	101,38	32,26	394,17	79,94	25,44
	0,25	490,66	714,10	223,44	45,54	647,29	156,63	31,92
50	0,15	288,97	433,80	144,83	50,12	387,83	98,87	34,21
	0,2	526,70	828,40	301,70	57,28	732,42	205,72	39,06
	0,25	791,34	1001,60*	210,26*	26,57*	982,10*	190,76*	24,11*

* The values are corrupted due to limited working range of force transducer.

The results show an increase of the maximum starting force between 26 – 59% relative to average draft force. For a different perspective the average of maximum starting forces shows an increase between 18-39% related to average draft force. This increase of the draft force can be attributed to the soil acceleration components. Considering mechanical - electrical analogies, the average draft force can be associated with nominal current and starting force with inrush current. As can be seen in figure 4, an increase of working depth or rake angle will lead to a proportional increase of the starting force.

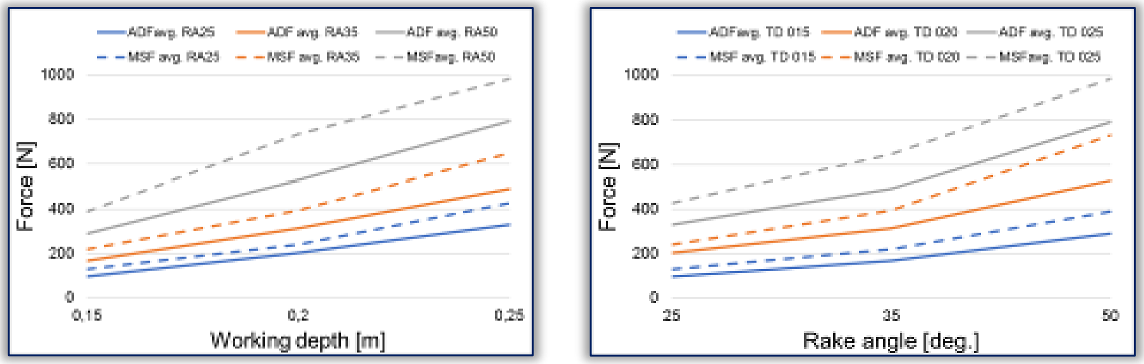

Figure 4 – Variation of draft force and starting force with working depth and rake angle of the tool.

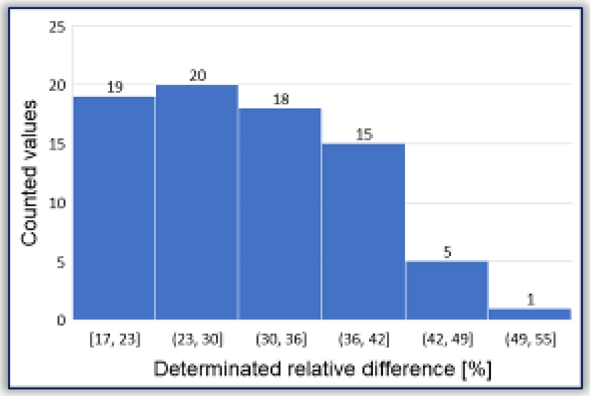

Figure 5 - Distribution histogram of differences between MSF and ADF.

When designing tillage implements to ensure its necessary resistance a safety factor (1.3 - 4.0) is usually used due to uncertainties that may occur in the strength of a part and the uncertainties that may occur related to loads acting on the tool (Ogbeche and Idowu, 2016). Related to relative difference (6) calculated in table 2 the results suggest that the safety factor should be at least 1.6 for the considered experiment. When related to average relative difference (9), calculated in table 2 and considering distribution histogram of differences (Figure 5) the safety factor may take lower values.

Due to uncertainties that may occur in real field conditions, a minimum safety factor used should be at least 1.6 for sandy soils. For harder soils the safety factor should be higher and to establish that, more experimental studies need to be carried out.

4. CONCLUSIONS

The traction effort, on simple tillage tool, during the starting phase was evaluated in an indoor controlled conditions soil-bin experiment. During the transient phase until constant working speed an increase of the draft force with 26-59% was recorded. Based on the results obtained a safety factor of minimum 1.6 should be used for tillage tool design. The information obtained in this experiment can improve the optimization process related to tillage tool design based on systemic analysis procedures.

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