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DESIGN AND PERFORMANCE PARAMETERS OF VIBRATING POTATO DIGGERS

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ABSTRACT

The performances of three same type of vibrating potato diggers were estimated by observing the potato separation and material flow on the bottom plate. Four-bar machanisms were adopted for three diggers and pairs of eccentric cams on both sides of driving shaft were used as driving link of the diggers. Each machine was tested with different amplitudes, frequencies, and travel speeds.

Blade performances were observed in three categories; Impossible forward travel, acceptable operation, and unsatisfactory potato digging, but good material flow.

Three parameters were used to set marginal values that enable the machines operate for potato digging, and the parameters were compared to select best one. Three parameters are λ, ρ, and K. λ is the ratio of vibrating speed to travel speed, ρ is the ratio of blade acceleration to travel speed, and K is the ratio of blade acceleration to gravitational acceleration.

K value of 2 or more is suggested to be used as design and evaluation criterion of the vibrating digger.

Keywords : potato digger, tuber separation, digger performance agricultural mechanization.

INTRODUCTION

Moldboard plows, subsoilers and other non-vibrating tillage tools used in root-crop harvesting require large tractors to produce the traction require to pull them through the soil. Vibrating potato digger blades have been shown to reduce draft, sometimes dramatically - 70 percent in one reported test. Additionally, the average clod size is reduced considerably making soil-tuber separation easier. Large amounts of soil must be handled on potato diggers to expose the tubers and, if it is not conditioned sufficiently, as much as 25 percent of the edible roots may be unrecovered.

The use of vibrating blades for harvesting potatoes has been proposed by many researchers with the objectives of reducing potato damage and losses, reducing the power required to pull the harvester through soil, and improving the separation efficiency of potatoes from soil. Harvesting losses can be reduced by producing small clod sizes which in turn improves the potato recovery rate. The reduction in clod size may be controlled by one or more factors including vibratory frequency, amplitude, forward speed, soil strength, digging depth, and direction of vibration.

The literature by Dubrovskii (1968) revealed that the specifics of vibratory tillage are rather complicated. The total effects include: (1) the geometry of the soil-working tools, (2) the mode of vibration and (3) the soil conditions. To develop significant tillage tool design information it appears that each principal geometry must be investigated sepatately. The simplest form, and the most useable one, for digging root crops, is the inclined plane (Gill and Vanden Berg, 1968).

Brixius and Weber (1975) used a parameter $\lambda = A\omega / V_t$ to explain soil failure, where V_t was the forward speed of the tractor in m/s, ω was the angular velocity of the tool in rad/s, and A was the zero-to-peak amplitude of vibration in the horizontal direction in m/s.

Saqib, et al. (1982) reported that the vibrating blade reduced clod size as frequency and amplitude increased and travel speed of the tractor was decreased. The frequency and travel speed effects were significant only in compacted soil. These results are contradicted by observations of Johnson (1974) who reported that the flow of material over the blade and the soil-potato separation was best at the highest amlitude used for a potato digger blade with fore and aft motion. Tomkins and Bledsoe (1979) reported similar results.

Kang, et al. (1989) reported that maximum tuber damage was 3.3 percent when the blade was operated with 16mm of amplitude, 9.67 Hz, and 1.21 km/h of travel speed. They also observed that, without vibration, soil accumulated on the blade and prevented forward travel because of wheel slippage. The operating efficiency of the blade with 16mm amplitude and 9.7Hz at a travel speed of 0.87 km/h was the best combination tested. However, more potatoes were damaged by the greater vibration and the tractor operator experienced undesirable vibrations.

In an another work by Kang and Halderson (1991), they used a new parameter $\rho = A\omega^2/V$, where A is amplitude (m), ω is frequency (rad/s), and V (m/s) is travel speed of the tractor. Of 18 treatment combinations, there were three amplitude and frequency combinations which could not be explained the performance of the vibrating digger by using ρ, while there were six combinations using λ. Also, ρ showing a wider range of its values, reflects the effects of vibration more than λ. They suggested that ρ be used rather than λ to evaluate the performance of vibratory diggers.

The objective of this study was to introduce a new parameter K, a ratio of vibratory acceleration to gravitational acceleration, and discuss the effects of it and the other two parameters on the performance of three vibratory potato diggers.

MATERIALS AND METHODS

Two single (model I and II) and one two-row (model III) digger blade were constructed using same kinematic model shown in Fig. 1. Two single-row machines were attached to a two -wheeled, hand-steered tractor equipped with a 7.35kw engine and the two-row digger was attached to a four-wheeled tractor. Digger model I and model II were built and tested in 1987 (Kang and et al., 1989) and in 1989(Kang and Halderson, 1991), respectively, and model III was constructed and tested in 1990 (Kang and Halderson, 1991). The machines were composed of one or two identical pairs of four-bar linkages. They have two or four eccentric cams used as input links to generate vibration. Each linkage was fixed on both sides of frame of the machine. A bottom plate was attached to each linkage to travel through the soil. The digger blade, $EBCDO_4$, in Fig. 1, is oscillated by the cam and travel through the soil while breaking up the soil.

The amplitudes, frequencies, and travel speeds were set different. The levels of them were shown in Table 1. In general, levels of model III were higher than those of model I and II.

Power to operate the blade was obtained directly from the power take-off of the tractor through chain drive (model I), V-belt drive (model II), and U-joint and gear box (model III), to the cam shaft of the machine.

Acceleration of each model was analyzed by use of complex numbers.

RESULTS AND DISCUSSION

Observed blade performances of model I through III are shown in Table 2, 3, and 4 in terms of actual machine travel and smoothness of material flow for each combination of amplitude, frequency, and travel speed. Parameters λ (used by Brixius and Weber, 1975; Butson and MacIntyre, 1981), ρ (used by Kang and Halderson, 1991) and K defined as the product of amplitude, in m, and square of frequency, in rad/s, devided by gravitational acceleration, in m/s^2, are also shown in three Tables.

In general, digger blade performance was better in separating tubers with high amplitude vibration than with low.

Some limitations in the blade performance were observed with low levels of amplitude(Table 2 and 3). Tractor traction was insufficient when the blade was operated with the lowest amplitude and lowest frequency(LLX). Though λ for the treatment combinations of MLH, MLL, and LHL(Table 2) were greater than 1 and LLL(Table 3) was very close to 1-which was estimated to be a suitable value by several researchers-they appeared that there were no clear effects of vibration on the material flow and tuber separation. Another limitations were observed with the treatment combinations MHH and MHL(Table 2) and LHH and LMH(Table 3). In these four operations, material on the blade flowed well over the bottom plate and the machine would continue to move through the soil, but soil-tuber separation was so poor that most of the potatoes were not exposed on the soil surface.

All the operations observed showed good material flow(LMH, LLH) or good tuber separation for machine model III (Table 4).

As for the model I and model II, some operations with λ values less than 1 appeared to have good effects on the soil-tuber separation.

It was concluded that the ratio λ, in this study, was not a good parameter to eatimate the performance of the vibrating potato digger blade. The parameter λ to evaluate blade performance does not correlate the treatment results. In many cases, the blade with higher λ values worked better. However, this was not always true when some of the λ values less than 1 were compared.

Acceleration of the bottom plate of the digger blade might be a good parameter to estimate the performance, but it continuously varies along the bottom plate and with time. It was also analyzed that acceleration of each digger blade was proportional to the amplitude and to the square of frequency. Accordingly, a parameter, ρ, was introduced and defined as explained earlier.

It is clear that in model I ρ is good parameter because all treatment combinations with higher ρ values of 64.0 for treatment HLH performed better than those of lower ρ values (Table 2). However, there are three treatment combinations (LMH, HLM, and HLH) with lower ρ values and better performance than 78.8 for treatment HMH in machine model II (Table 3). In model II, there were six treatment combinations that could not be explained by using λ, however three of them could be accounted for when ρ was used as an estimating parameter.

But in machine model III (Table 4) all treatment combinations with ρ value of 45.0 or higher showed good material flow or soil-tuber separation. It was considered that ρ was a better parameter than λ.

A new parameter reflecting the effects of acceleration of the blade on the tuber separation, K, was introduced and defined as $K=A\omega^2/g$, where A is amplitude (m), ω is frequency (rad/s), and g is gravitational acceleration (m/s^2) (Table 2, 3, and 4).

K value of 2.93 or higher operations showed better tuber separation and material flow than the lower K value operations for model I (Table2), and 2.00 for model II (Table 3). All the performances with K values of 4.22 or higher were observed to be acceptable or showed good material flow for model III (Table 4). There were no limitations to evaluate the performance of three models of potato digger blade by using the new parameter K. It would be better to use K greater than 2 than to use λ or ρ to evaluate tuber separation. Further studies are suggested to prove the usefulness of K.

CONCLUSIONS

Acceleration of the vibrating blade showed that the total acceleration was proportional to the amplitude and to the square of frequency. A parameter K (a ratio of acceleration of the vibrating blade to the gravitational acceleration) was introduced and found to evaluate the performance of the blade better than an existing parameter λ or ρ. It is recommended that a K value of 2 or more be used for future vibrating blade design.

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Table 1. Amplitudes, frequencies, and travel speeds of three models of digger blade.

Variables	Levels		
	Model I	Model II	Model III
Amplitude (mm)	4 8 12 16	4 6	6 9 12
Frequency (Hz)	6.7 9.7	9.1 14 0 18.2	13.2 17.3
Travel speed (km/h)	0.9 1.2	0.9 1.3 2.1	1.7 3.3

Table 2. Observed results of vibrating digger blade, 1989, and parameters λ, ρ, and K of machine model I.

Treatment*	Results**	λ	Treatment*	Results**	ρ	Treatment*	Results**	κ
S H L	O	4.02	S H L	O	244.0	S H H	O	6.02
H H L	O	3.01	H H L	O	183.0	S H L	O	6.02
S H H	O	2.89	S H H	O	175.7	H H H	O	4.12
S L L	O	2.80	H H H	O	131.8	H H L	O	4.12
H H H	O	2.17	M H L	△	122.0	M H H	△	3.01
H L L	O	2.10	S L L	O	118.5	M H L	△	3.01
S L H	O	2.02	H L L	O	88.9	S L L	O	2.93
M H L	△	2.01	M H H	△	87.8	S L H	O	2.93
H L H	O	1.51	S L H	O	85.4	H L H	O	2.19
M H H	△	1.45	H L H	O	64.0	H L L	O	2.19
M L L	X	1.40	L H L	X	61.0	L H H	X	1.51
M L H	X	1.01	M L L	X	59.2	L H L	X	1.51
L H L	X	1.00	L H H	X	43.9	M L L	X	1.46
L H H	X	0.72	M L H	X	42.7	M L H	X	1.46
L L L	X	0.70	L L L	X	29.6	L L L	X	0.73
L L M	X	0.50	L L M	X	21.3	L L M	X	0.73

Note: * : Amplitude, frequency, and travel speed

Amplitude:	Frequency:	Speed:
S : 16 mm	H : 580.2 rpm	H : 1.21 km/h
H : 12	L : 404.4 rpm	L : 0.87
M : 8		
L : 4		

** : Results

X : Impossible forward travel
△ : Unsatisfactory potato digging, but good material flow
O : Acceptable operation

Table 3. Observed results of vibrating digger blade, 1991, and parameters λ, ρ, and κ of machine model II.

Treatment*	Results**	λ	Treatment*	Results**	ρ	Treatment*	Results**	κ
H H L	O	2.91	H H L	O	332.2	H H H	O	8.00
H M L	O	2.24	L H L	O	221.5	H H M	O	8.00
L H L	O	1.94	H H M	O	212.2	H H L	O	8.00
H H M	O	1.86	H M L	O	196.6	L H M	O	5.33
L M L	O	1.49	L H M	O	141.6	L H L	O	5.33
H L L	O	1.45	H H H	O	133.2	L H H	△	5.33
H M M	O	1.43	L M L	O	131.1	H M L	O	4.73
L H M	O	1.24	H M M	O	125.7	H M M	O	4.73
H H H	O	1.17	L H H	△	88.8	H M H	O	4.73
L L L	X	0.97	L M M	O	83.8	L M M	O	3.15
L M M	O	0.95	H L L	O	83.1	L M H	△	3.15
H L M	O	0.93	H M H	O	78.8	L M L	O	3.15
H M H	O	0.90	L L L	X	55.4	H L L	O	2.00
L H H	△	0.78	H L M	O	53.1	H L H	O	2.00
L L M	X	0.62	L M H	△	52.6	H L M	O	2.00
L M H	△	0.60	L L M	X	35.4	L L M	X	1.33
H L H	O	0.58	H L H	O	33.3	L L L	X	1.33
L L H	X	0.39	L L H	X	22.2	L L H	X	1.33

Note: * : Amplitude, frequency, and travel speed

Amplitude:	Frequency:	Speed:
H : 6 mm	H : 1091.96 rpm	H : 2.12 km/h
L : 4	M : 839.96	L : 1.33
	L : 546.04	L : 0.85

** : Results

X : Impossible forward travel
△ : Unsatisfactory potato digging, but good material flow
O : Acceptable operation

Table 4. Observed results of vibrating digger blade, 1991, and parameters λ, ρ, and K of machine model III.

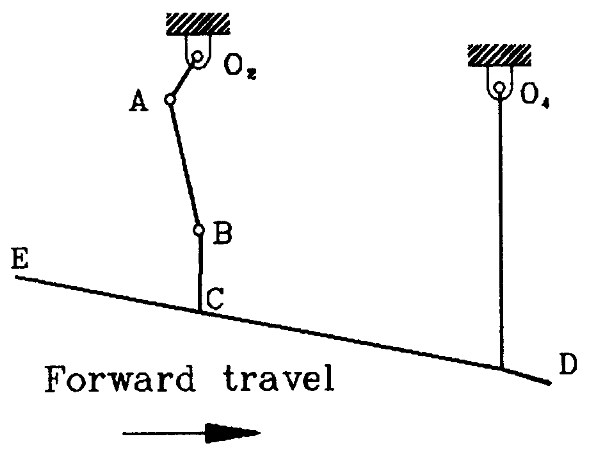
Treatment*	Results**	λ	Treatment*	Results**	ρ	Treatment*	Results**	κ
H H L	O	3.28	H H L	O	421.5	H H H	O	20.20
H M L	O	2.78	M H L	O	316.1	H H L	O	20.20
M H L	O	2.46	H M L	O	300.5	M H H	O	15.15
H L L	O	2.12	M M L	O	226.6	M H L	O	15.15
M M L	O	2.08	H H H	O	215.3	H M L	O	14.48
H H H	O	1.67	L H L	O	210.7	H M H	O	14.48
L H L	O	1.64	H L L	O	176.3	M M H	O	10.86
M L L	O	1.59	M H H	O	161.5	M M L	O	10.86
H M H	O	1.42	H M H	O	153.5	L H H	O	10.10
L M L	O	1.39	L M L	O	151.1	L H L	O	10.10
M H H	O	1.26	M L L	O	132.2	H L L	O	8.44
H L H	O	1.08	M M H	O	115.8	H L H	O	8.44
L L L	O	1.06	L H H	O	107.6	L M H	△	7.24
M M H	O	1.06	H L H	O	90.0	L M L	O	7.24
L H H	O	0.84	L L L	O	88.1	M L H	O	6.33
M L H	O	0.81	L M H	△	77.2	M L L	O	6.33
L M H	△	0.71	M L H	O	67.5	L L H	△	4.22
L L H	△	0.54	L L H	△	45.0	L L L	O	4.22

Note: * : Amplitude, frequency, and travel speed

Amplitude:	Frequency:	Speed:
H : 12 mm	H : 1227 rpm	H : 3.3 km/h
M : 9	M : 1039 rpm	L : 1.7
L : 6	L : 794 rpm	

** : Results

X : Impossible forward travel
△ : Unsatisfactory potato digging, but good material flow
O : Acceptable operation



Location	Dimension (mm)		
	Model I	Model II	Model III
O_2 − O_4 (Frame)	403	311	660
O_2 −A (Cam)	4, 8, 12, 16	4, 6	6, 9, 12
A−B (Con−rod)	245	187	216
B−C	339	188	354
C−D	555	310	834
O_4 −D	475	381	560
C−E	220	140	370

Fig. 1. Kinematic representation and dimensions of three models of vibrating potato digger. B−C−E−D−O_4 (digger blade)