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Assessment of Kinematic Design Parameters of Vibrating Potato Diggers

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Introduction

Non-vibrating tools used in root crop harvesting must have considerable power to provide the traction required to pull them through the soil. 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 the soil, and improving the separation efficiency of the potatoes from soil. Producing small clod sizes can reduce harvesting losses, which in turn improves the potato recovery rate and reduces the damage rate. The reduction in clod size may be controlled by one or more factors including vibratory amplitude, cam shaft speed, forward velocity, soil strength, digging depth, and direction of vibration.

Several researchers have attempted to relate the effects of a vibrating tool on the soil to an index of operating variables. One of these forms used by Brixius and Weber (1975) was the ratio $\lambda = A\omega/Vt$ (please see LIST OF SYMBOLS), of the maximum velocity of blade vibration to the forward velocity of the machine. Using this parameter, Butson and MacIntyre (1981) reported no draft reduction when λ was less than 1, but draft reduction greater than 50 percent when λ was greater than 1. However, the use of λ did not fully explain the performance of a vibrating potato digger tested by Kang and Halderson (1991a). They observed some limitations in the blade performance with low levels of amplitude. Tractor traction was insufficient for $\lambda = 0.969$, a suitable value as indicated by

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several researchers. For this value of λ, the blade was operated at the lowest amplitude (4 mm), the lowest cam shaft speed (9.1 Hz) and a forward velocity of 0.85 km/h. It appeared there were no clear effects of vibration on the material flow and tuber separation. Also, they observed that six treatment combinations with $\lambda < 1$ (0.583 through 0.952) had good material flow and good separation of potatoes. In the same study, they used a parameter, $\rho = A\omega^2 / Vt$ to reflect the effects of blade acceleration and forward velocity. The results of three of the amplitude and cam shaft speed combinations could not be explained by using ρ, and six combinations could not be explained using λ. Also, ρ had a wider range of values for the range of variables tested and therefore reflected the effects of vibration more accurately than did λ. It should be noted that ρ is not dimensionless.

In another study, Kang and Wright (1996) used a parameter $K = A\omega^2 / g$. K is the ratio of vibratory acceleration to gravitational acceleration. They concluded that K was found to evaluate the performance of a vibrating digger blade as well or better than the two previously used indices, λ and ρ. The data taken in the tests of three similar models of a vibrating digger blade, each tested at different times and places showed strong indications that the parameter K was the most consistent indicator of performance. However, the parameter K does not reflect the effect of forward velocity on the flow of soil over the blade of the vibrating blade. That is, the slower the digger travels when operated at a given K value, the less draft that is required and the smoother the soil flow.

The objective of this study was to develop a vibratory tillage parameter and to compare it to existing λ , ρ, and K.

2. Materials and Methods

Two single-row (Model I and II) and one double-row (Model III) digger blade were constructed. The two single-row machines were attached to a two-wheeled, hand-steered tractor equipped with a 7.35kW engine and the double-row digger was mounted on a four-wheeled tractor of approximately 60kW. The machines had similar pairs of four-bar linkages. Eccentric cams on each side of each row were inputs to generate vibration. The frame constitutes a four-bar linkage which was kinematically analyzed using a vector loop equation and complex numbers. This analysis revealed that the total acceleration of the blade was always proportional to the product of the amplitude and the square of the frequency. From this analysis the parameter K was developed.

The combinations of levels used in each individual test are given in Table 1. The rear portion of the blade consisted of round rods with spaces between them. When the blade was operating optimally, most soil was discharged through the rods and the potatoes fell off the rear edge almost completely separated from the soil.

During the tests it was noted that the response of the vibrating blade to its operating conditions fell into one of three rather distinct categories: (1) complete success : soil and potatoes flowed evenly over the blade and the potatoes were separated from the soil and left in a layer on top of the row, (2) partial success : the soil and the potatoes flowed evenly over the blade but the potatoes remained mixed with soil. And (3) complete failure : the potatoes and soil were pushed aside rather than flowing over the blade (bulldozing) and/or the prime mover could not produce enough traction for forward movement. These three categories were somewhat qualitative but distinguishable enough to use as dependent variables to characterize each test. The last category, complete failure, was more obvious than partial success.

3. A new design parameter for vibratory digger blades

Soil clods on a vibrating blade are lifted upward by vibration and returned to the blade by gravity. The time required to return to the blade depends on the initial velocity, Vo, added to the clods by the vibration of the blade. The longer the period the blade is unloaded the farther apart and the fewer the loads on the blade before the soil exits the blade. A time ratio, $Rt = 2(Vo/g)/(60/N)$, was defined as the ratio of the time for the clods to leave the blade and return to the period of digger vibration. It also seems reasonable that the velocity ratio λ multiplied by Rt would make a good estimating parameter for including the effect of forward velocity. However, it was shown that the existing acceleration ratio K is equal to πRt. So, $T = \pi\lambda Rt$, was defined as a new parameter $T = \lambda K$ which includes the effect of the forward velocity and the acceleration of blade related to gravity. All of these variables are important. Increasing blade acceleration increases the energy added to the soil and should result in smaller clod sizes. On the other hand increasing forward velocity relative to blade speed should increase clod size. The partial loss of generality of each of the prescribed existing parameters, λ, ρ, and K could be supplemented by this new parameter T because it reflects all the variables related.

Table 1 shows the four parameters, T, λ, ρ, and K, arranged in descending order, (includes previous work by Kang and Wright, 1996). In that work they claimed that K greater than or equal to 2.0 should be used as a design and performance parameter of vibrating potato diggers. $T = 1.97$ is considered a marginal value for good material flow over the bottom plate (Table 1). Parameter T evaluated the performance of the blades better than previous parameters λ and ρ. While all the combinations with $K < 2.00$ were indications of failure, two combinations with $T < 1.97$ were completely successful. However, the overall T distributions of treatment combinations of failures and partial successes were more compressed than any of the other parameters.

4. Conclusions

A parameter T the product of the ratio of maximum blade velocity to forward velocity multiplied by the ratio of the acceleration of a vibrating digger blade to gravitational acceleration was found to be useful in evaluating the performance of vibrating digger blades. T was better than two previously used indices: λ, and ρ. Though the parameter T was not quite as effective as the existing parameter K, it has the advantage of including all the variables for vibratory potato digger operations: amplitude, cam shaft speed, and forward velocity. It also includes gravitational acceleration and other derived physical quantities such as vibratory speed and vibratory acceleration. The higher the value of T the better the blade performance. $T = 2.0$ is recommended as minimum for vibrating digger design. Larger values of T should be used for more conservative designs.

List of Symbols

$\lambda = A\omega / Vt$, the ratio of maximum velocity of the digger blade to the forward velocity of the digger.

$\rho = A\omega^2 / Vt$, the ratio of the maximum acceleration of the digger blade to the forward velocity of the digger, s^{-1}.

$K = A\omega^2 / g$, the ratio of the maximum acceleration of the digger blade to gravity.

N = rpm of cam shaft driving the vibrating blade.

Rt = time ratio for clods to leave a digger blade and return to the period of vibration.

$T = \lambda K$, parameter including both the effects of velocity and acceleration.

A = Zero-to-peak amplitude of vibration, m.

ω = Angular velocity of the tool, rad/s.

$Vo = A\omega$, initial velocity of clods being lifted by a vibrating blade.

Vt = forward velocity of the tractor, m/s.

g = gravitational constant, m/s^{-2}.

5. References

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Table 1. Test results and parameters for the improved vibrating digger blade by Kang and Wright (1996).

Amp mm	Cam rpm	Veloci. km/h	T	Test No.⇒	λ	Test No.⇒	ρ	Test No⇒	K	Test No. ⇒
12	1227	1.7	81.23	1	4.02	5	419.53	1	20.19	1
12	1039	1.7	65.94	2	3.27	1	332.29	6	20.19	4
9	1227	1.7	45.69	3	3.02	14	314.65	3	15.15	3
12	1227	3.3	44.01	4	2.91	6	300.82	2	15.15	9
16	580	0.9	41.88	5	2.89	11	244.40	5	14.48	2
6	1092	0.9	40.60	6	2.80	24	225.61	7	14.48	8
9	1039	1.7	30.03	7	2.76	2	221.53	17	10.86	7
12	1039	3.3	26.60	8	2.45	3	216.12	4	10.86	15
9	1227	3.3	22.57	9	2.24	16	212.37	13	10.10	12
12	794	1.7	21.90	10	2.17	20	209.76	12	10.10	23
16	580	1.2	17.87	11	2.11	10	196.62	16	8.46	10
6	1227	1.7	17.78	12	2.10	32	183.30	14	8.46	22
6	1092	1.3	16.58	13	2.07	7	175.72	11	8.00	6
12	580	0.9	16.12	14	2.02	28	175.68	10	8.00	13

9	1039	3.3	16.09	15	2.01	27**	162.09	9	8.00	21
6	840	0.9	14.03	16	1.94	17	154.97	8	7.24	19
4	1092	0.9	13.45	17	1.86	13	150.41	19	7.24	30**
9	794	1.7	10.67	18	1.68	4	141.58	26	6.34	18
6	1039	1.7	10.35	19	1.63	12	133.23	21	6.34	29
12	580	1.2	9.54	20	1.58	18	131.79	20	6.02	5
6	1092	2.1	9.10	21	1.51	37	131.76	18	6.02	11
12	794	3.3	7.95	22	1.49	31	131.08	31	5.33	17
6	1227	3.3	7.75	23	1.45	39	125.66	25	5.33	26
16	404	0.9	7.71	24	1.45	33**	122.20	27**	5.33	36**
6	840	1.3	6.76	25	1.43	25	118.73	24	4.73	16
4	1092	1.3	6.74	26	1.42	8	116.22	15	4.73	25
8	580	0.9	6.63	27**	1.40	41*	108.06	23	4.73	35
16	404	1.2	6.24	28	1.38	19	90.50	22	4.52	14
9	794	3.3	5.70	29	1.26	9	89.05	32	4.52	20
6	1039	3.3	5.23	30**	1.24	26	88.82	36**	4.23	33
4	840	0.9	4.93	31	1.17	21	87.86	33**	4.23	40**
12	404	0.9	3.43	32	1.09	22	87.84	33	3.15	31
6	794	1.7	3.37	33	1.07	15	85.37	28	3.15	38
8	580	1.2	3.33	33**	1.06	33	83.77	38	3.15	42**
6	840	2.1	3.03	35	1.01	45*	83.07	39	3.01	27**
4	1092	2.1	3.03	36**	1.01	44*	78.83	35	3.01	33**
12	404	1.2	2.83	37	0.97	46*	77.48	30**	2.92	24
4	840	1.3	2.79	38	0.95	38	67.87	29	2.92	28
6	546	0.9	2.04	39	0.93	43	64.03	37	2.19	32
6	794	3.3	1.97	40**	0.90	35	61.10	44*	2.19	37
8	404	0.9	1.68	41*	0.84	23	59.37	41*	2.00	39
4	840	2.1	1.63	42**	0.82	29	55.38	46*	2.00	43
6	546	1.3	1.55	43	0.78	36**	53.09	43	2.00	47
4	580	0.9	1.09	44*	0.72	48*	52.56	42**	1.51	44*
8	404	1.2	1.07	45*	0.71	30**	45.25	40**	1.51	48*
4	546	0.9	1.03	46*	0.70	51*	43.93	48*	1.46	41*
6	546	2.1	0.91	47	0.62	49*	42.68	45*	1.46	45*
4	580	1.2	0.80	48*	0.60	42**	35.39	49*	1.33	46*
4	546	1.3	0.78	49*	0.58	47	33.31	47	1.33	49*
4	546	2.1	0.73	50*	0.54	40**	29.68	51*	1.33	50*
4	404	0.9	0.37	51*	0.50	52*	22.20	50*	0.73	51*
4	404	1.2	0.28	52*	0.39	50*	21.34	52*	0.73	52*

Note:* : failure, bulldozing

**: partial success, good soil flow, but unsatisfactory soil/potato separation

⇒: arranged in descending order of T by treatment combination, and the test numbers apply to the other parameters λ, ρ,and K.