

DESIGN, CONSTRUCTION AND EVALUATION OF POTATO DIGGER WITH ROTARY BLADE

P. AZIZI¹, N. SAKENIAN DEHKORDI¹, R. FARHADI^{2*}

*E-mail: r.farhadi@urmia.ac.ir

Received January 3, 2014

ABSTRACT. Potato has an important role in human food. It was the sixth alimentary product in the world after sugar cane, maize, rice, wheat and milk in 2011 year. In addition, potato is the third product in Iran after wheat and sugar cane in 2011 year. Therefore, any attempt in the improvement of potato harvester will be valuable. In this study, a new semi-mounted one-row potato digger with rotary blade was designed and made in the workshop of Shahrekord University. It can be connected to rotary potato graders. Transmission system was mechanical from tractor (PTO) to blade by belt, pulley, gearbox, chain and sprocket. Blade diameter was 76 cm and the length was 10 cm which was assigned by the researchers. For separating of soil from potato, a helix containing bars with 2.6 cm distance and diameter of 9 mm was applied. Entered soil into set was calculated as 227 ton/h. Required power was got 5.5 horsepower. Computerized model of set was prepared in Mechanical Desktop Software and potato motion was studied in Visual Nastran Software. The device was tested at field with various advance speed, blade

angle and rotational speed. Results showed that advance speed of 1.5-3 km/h, rotational speed of 20-25 RPM and blade angle of 10-15° were proper for system. The average of damaged potatoes was 4%.

Key words: Rotary Potato Digger; Feed Rate; Helix; Potato Damages; Simulation.

INTRODUCTION

Potato is one of the main human alimentary resources. It was the sixth alimentary product in the world after sugar cane, maize, rice and paddy, wheat and milk (FAO, 2011) and the third product in Iran after wheat and sugar cane (Ministry of agriculture, 2011) There are problems regarding potato cultivation and storage in Iran. The collection of these problems cause the cut of product yield and rise of wastage value as the mean of

¹ Depart. of Mechanical Engineering in Biosystems, Faculty of Agriculture, Shahrekord University, Shahrekord, Iran

² Department of Mechanical Engineering in Biosystems, Faculty of Agriculture, Urmia University, Urmia, Iran

potato production is 24 tons/ha but this number amounts to 50 tons/ha at developed countries (Tarkesh, 2005). Head factors of low operation at harvest time and post harvest consists in disregard to finish physiologic maturity, unavailability of labor at harvest season, unsuitable methods of harvest, gradation, transport, packing and inaccessibility on proper technical storehouse (Modareserazavi, 1996). Potato wastage values during the investigation were 48% from harvest stage to consumption and wastages of harvest implements were declared 1.72% (Nasre Isfahani, 2003). Mechanical harvest of potato relative to manual harvest causes 65% frugality at harvest time and 45% at harvest costs (Muhhamad *et al.*, 2003).

These statistics show importance of activities in the field of potato diggers. Misener (1985) made a potato digger and evaluated it. Mean of hurt potato tubers by set was stated 3.2%. Sharma (1986) designed a one row mounted potato digger that the hurts of harvested potatoes were reported 4% and up to skin. Saqib and Wright (1986) studied a potato digger with oscillating blade. Generated clods with lower mean of geometric diameter were reported and volumetric density was decreased. Hyde (1986) compared performance and required power of potato digger with fixed and rotary blade. Tubers damages were about 3% at rotary state and blade cut was negligible. Kang and Halderson (1991) designed and tested a two row mounted potato

digger and reported that potato bruises were increased with addition of frequency and amplitude of vibration but it had not much effect on the remained potatoes in soil. In addition, amplitude had not much effect on traction but with increase of frequency traction was diminished. Vasta *et al.* (1993) made a potato digger with oscillatory sieves and studied effects of blade shape, advance seed and sieve vibration on potato digger operation. The best results were related to V shape blade with 99.23% intact potato and minimum cut damages of 0.65% and zero bruise. Kang *et al.* (2001) tested a single-row commercial potato digger by replacing the fixed blade with a vibrating blade. Yasin and others (2003) made a rotary potato digger at Research Center of Agricultural Engineering in Faisalabad, Pakistan. Intact harvested, cut and bruised potatoes were 99, 4 and 1%, respectively, at field test with moisture 10.3% and speed of 6 km/h. Singh (2006) developed and tested a tractor mounted, two-row multipurpose potato digger. Maximum exposure percentage of tubers was gotten 84.5% at 4.5 km/h and damages were 1.48%. Pasaman and Zakharchuk (2012) determined the parameters of a ploughshare-rotor potato digger.

Now there is a new potato digger and it's different parts, mechanism simulation, performance and efficiency should be studied. The aim of this study is to probe these factors.

DESIGN, CONSTRUCTION AND EVALUATION OF POTATO DIGGER WITH ROTARY BLADE

MATERIAL AND METHODS

Brief explanation of system performance

Set was designed into a semi-mounted state. *Fig. 1* shows various parts of set except power transmission system. The potato digger is connected by drawbar on tractors arms during work.

Blades cut potato row and soils and potatoes arrive to separating nets. At this part, soils are severed from potatoes. Set blade has rotation about central axle. This motion is provided by tractor PTO. Because of rotational motion and it's geometry, machine has capability to connect to rotary grader (Farhadi *et al.*, 2012).

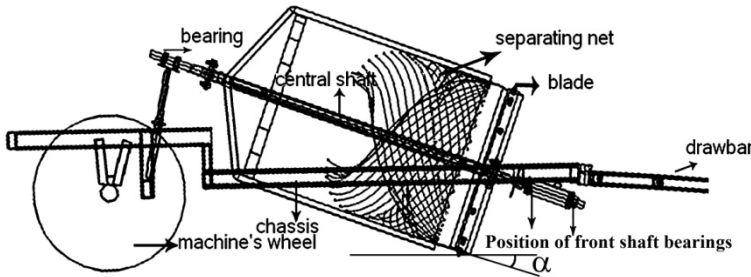


Figure 1 - Rotary potato digger

Blades

The blade is circular (*Fig. 2*) and formed from two parts of cutting and preserver. The cutting part contains crescent edges that slice soil hill. Preserver part contains steel belts with circular shape that their duty is blade keeping (the cutting blade connected to steel belts by bolt). Blade diameter (circle) $D=76$ cm and length $L=10$ cm was assigned.

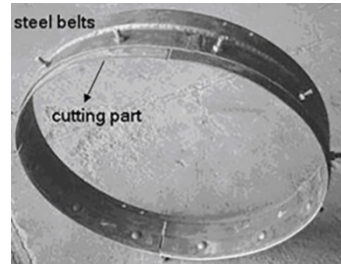


Figure 2 - Rotary potato digger blades

Required torque of blade is calculated as below:

$$T_t = T_C + T_{f_f} + T_{C_a} \Rightarrow T_t = F_c \times R + F_f \times R + F_{C_a} \times R$$

$$T_t = R(F_C + F_f + F_{C_a}) = R(A_c \times C + \mu N + A_{ca} \times C_a)$$

where: T_t : total torque (N.m); T_C : torque of cohesion force (N.m); T_{FF} : torque of frictional force (N.m); T_{ca} : torque of adhesion force (N.m); F_c : cohesion force (N); F_f : frictional force (N); F_{ca} : adhesion force (N); A_c : fracture area

(m^2); C : soil cohesion (N/ m^2); R : blade radius (m); μ : coefficient of friction between soil and metal; N : normal force (N).

N is computed as following:

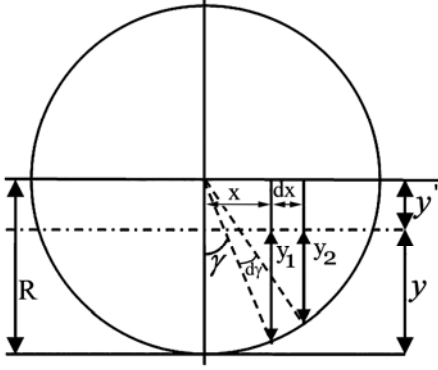


Figure 3 - Element for the calculation of surface reaction

According to Fig.3:

$$dA = \frac{1}{2}(y_1 + y_2)dx$$

y_1 : soil height at position of x ;

y_2 : soil height at position of $(x+dx)$

$$x = R \sin \gamma, \quad dx = R \cos \gamma \, d\gamma$$

$$y_1 = R \cos \gamma - y'$$

$$y_2 = R \cos(\gamma + d\gamma) - y'$$

$$y + y' = R$$

y' : free space between soil surface and blade center

γ : angle between radius passing from element and vertical axel of circle
 dA can be written as:

$$dA = \frac{1}{2} \left[(R \cos \gamma - y') + (R \cos(\gamma + d\gamma) - y') \right] R \cos \gamma \, d\gamma$$

By expanding $\cos(\gamma + d\gamma)$: $\cos(\gamma + d\gamma) = \cos \gamma \cos d\gamma - \sin \gamma \sin d\gamma$

$$dA = \frac{1}{2} \left(R \cos^2 \gamma \, d\gamma - 2y' \cos \gamma \, d\gamma + R \cos^2 \gamma \cos d\gamma \, d\gamma - R \sin \gamma \sin d\gamma \cos \gamma \, d\gamma \right) R$$

Whereas $d\gamma$ is very small:

$\sin d\gamma \rightarrow 0$, $\cos d\gamma \rightarrow 1$, hence

$$dA = R \left(R \cos^2 \gamma - y' \cos \gamma \right) d\gamma$$

Element volume is equal:

$$dV = dA \times l$$

l : blade length

Element weight is equal:

$$dW = \rho \times dV$$

ρ : soil specific weight (N/m^3)

Element of normal force is:

$$dN = \cos \alpha \cos \gamma \, dW$$

α : blade angle relative to movement direction (Fig.1)

Now we can write:

$$dN = (\cos \alpha \cos \gamma) \rho dV = \rho l \cos \alpha \cos \gamma \, dA$$

$$\int dN = \int \rho l \cos \alpha \cos \gamma \, dA = \rho l \cos \alpha \int \cos \gamma \, dA =$$

$$= \rho l \cos \alpha \int \cos \gamma \, R \left(R \cos^2 \gamma - y' \cos \gamma \right) d\gamma = \rho l R \cos \alpha \int \left(R \cos^3 \gamma - y' \cos^2 \gamma \right) d\gamma$$

Therefore, with $R = 38cm$ and $y' = 8cm$:

$$N = \rho l R \cos \alpha \left[R \left(\sin \gamma - \frac{1}{3} \sin^3 \gamma \right) - \frac{y'}{2} \left(\gamma + \frac{1}{2} \sin 2\gamma \right) \right] \Bigg|_0^{77.8^\circ}$$

Finally,

$$N = \rho l R \cos \alpha \left(0.2531R - 0.7822y' \right)$$

DESIGN, CONSTRUCTION AND EVALUATION OF POTATO DIGGER WITH ROTARY BLADE

This normal force was calculated for the half of blade.

Maximum torque was calculated as 0.8 kN.m.

Maximum draft force was calculated as 1.8 kN. For summarizing, the details of calculation were not presented.

Separating net

Cut soil after blade path arrives to separating net; at this part, soil should be separated from potato tubers. For separating net, diameter of bars was selected 9 mm and distances between them 2.6 cm. Proper plan for separating is usage of net with helix shape. Separating net is formed by sweeping semi- circle on helix path (Fig. 4).



Figure 4 - Semi- circle view and sweeping path

$$A_E = \iint dA = \int_{y=y'}^{y=r} \int_{x=-\sqrt{r^2-y^2}}^{x=\sqrt{r^2-y^2}} dy dx = \int_{y=y'}^{y=r} \left(\sqrt{r^2-y^2} + \sqrt{r^2-y^2} \right) dy = 2 \int_{y=y'}^{y=r} \sqrt{r^2-y^2} dy =$$

$$= \frac{\pi r^2}{2} - \left(y'x + r^2 \sin^{-1} \left(\frac{y'}{r} \right) \right)$$

With substitution of parameters

$$\begin{cases} x = r \sin \theta' \\ y' = r \cos \theta' \\ \sin^{-1} \left(\frac{y'}{r} \right) = \left(\frac{\pi}{2} - \theta' \right) \end{cases},$$

above relation is converted to below equation:

$$A_E = r^2 (\theta' - \sin \theta' \cos \theta'),$$

where: θ' : angle of filled product and soil into helix; y' : distance between product surface and helix center.

The volume of cut soil by blade is delivered momentarily to net. The net should have this transition capacity. Thus, helix volumetric capacity is computed.

Volumetric capacity of helix net

According to Fig. 5 if area of A_E is calculated, swept volume by this area can compute with having of net arc length (Fig. 6).

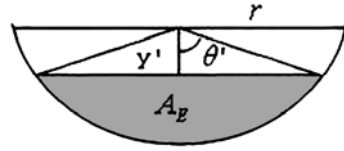


Figure 5 - Filled product and soil into helix

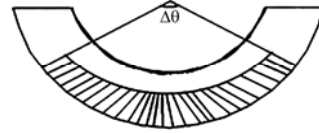


Figure 6 - Swept volume by A_E area

$$S = \int_{\theta_1}^{\theta_2} \sqrt{r^2 + \frac{k^2}{4\pi^2}} d\theta \Rightarrow S = \sqrt{r^2 + \frac{k^2}{4\pi^2}} (\theta_2 - \theta_1)$$

S: arc length

So swept volume is:

$$V = A_E S = r^2 (\theta' - \sin \theta' \cos \theta') \sqrt{r^2 + \frac{k^2}{4\pi^2}} (\Delta \theta),$$

where: r : Helix radius (m); θ' : angle of filled product into helix; θ : angle of product static surface; k : Helix pitch (m).

With allocation of advance speed 2.5 km/h,

$$r = 38 \text{ cm}, \theta' = 1.36 \text{ rad} = 77.8^\circ,$$

$$k = 80 \text{ cm}, \Delta\theta = 2\pi/3$$

transferable volume value by helix is $V = 0.139 \text{ m}^3$ and helix input volume rate is $\dot{V}_{in} = 0.057 (\text{m}^3/\text{s})$. Now with simple proportion can estimate required rotational speed:

$$\frac{\frac{2\pi}{\omega} \cdot 0.139 \text{ m}^3}{1 \text{ s} \cdot 0.057 \text{ m}^3} \Rightarrow \omega = 2.57 \left(\frac{\text{rad}}{\text{s}} \right) = 25 \text{ rpm}$$

A model was prepared at Mechanical Desktop software (Figs. 1 and 7) and potato motion on separating net was studied at visual Nastran software. The effects of advance speed of 0.42, 0.69 and 1.11 m/s and rotational speed of 15, 20 and 25 rpm and slopes of 10 and 15° were investigated on machine performance. It can be used as a pre-test of machine performance for main evaluation in field.

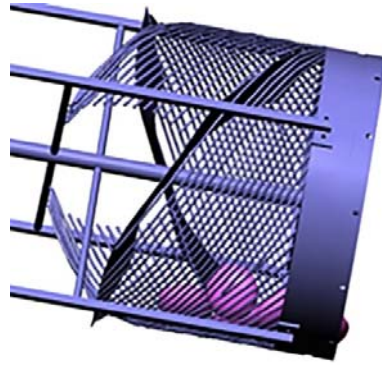


Figure 7 - Prepared model for potato motion study

Transmission system of rotational speed

Rotational motion transmission from tractor PTO to blade was performed by mechanical system. At this system according to Figs. 8 and 9 belt and pulley, gearbox, chain and sprocket were used. The chosen system was reducer.



Figure 8 - Set connection to tractor and it's situation at tractor behind

DESIGN, CONSTRUCTION AND EVALUATION OF POTATO DIGGER WITH ROTARY BLADE

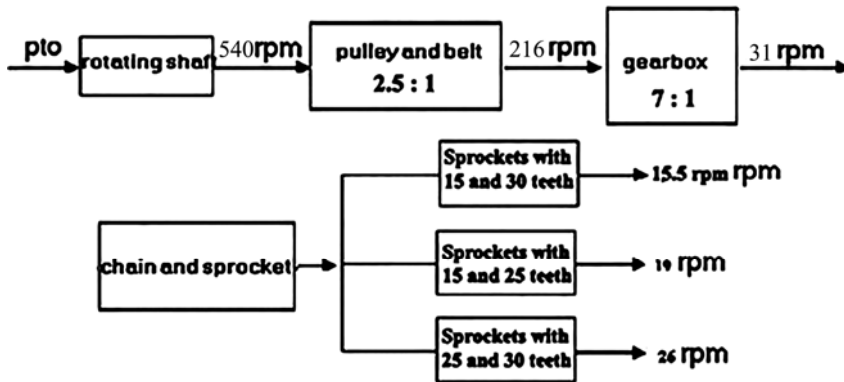


Figure 9 - Rotational motion transmission path to blade and speed reduction

RESULTS AND DISCUSSION

Two problems existed in machine evaluation:

- Cut soil by blade had slow movement rearward on separating net (it caused soil and tubers accumulation at front of the blade).
- The tendency of cut soil to go beside the blade and become remote from blade input opening.

Because of the foregoing problems, losses and product injuries was high. For correction of the first problem, several various types of plates (square, rectangle and crescent) were installed into the blade and tested. Crescent plate had better operation with inner helix shape. *Figs. 10 and 11* show their condition and installation situation.

A fixed plate was installed in opposite part and beside of the blade (with due attention to rotation direction) for the prevention of soil agglomeration at one side of the plate. Used plate is shown in *Fig. 11*.

Soil transition into separating system and product motion rearward noticeably became favorable. The Percentage of mechanical injuries rose by the impact of potatoes on plates but their values were low. The average of damaged potatoes was got 4%. Following limitations for set operation got at filed experiments. The blade slope cannot be more than 15° . More slopes than 15° cause soil and tubers accumulation at front of the blade. Pasaman and Zakharchuk (2012) reported optimal angle of blade 12° at machine speed of 0.4 m/s. Increasing machine speed and the ploughshare angle led to a dangerous accumulation of soil in front of the blade.

The problem of penetration in soil was observed at slopes less than 10° . Advance and rotational speed cannot be considered more than 4 km/h and 25 rpm. System required power was calculated as 5.5 hp and entered soil into set as 227 ton/h.

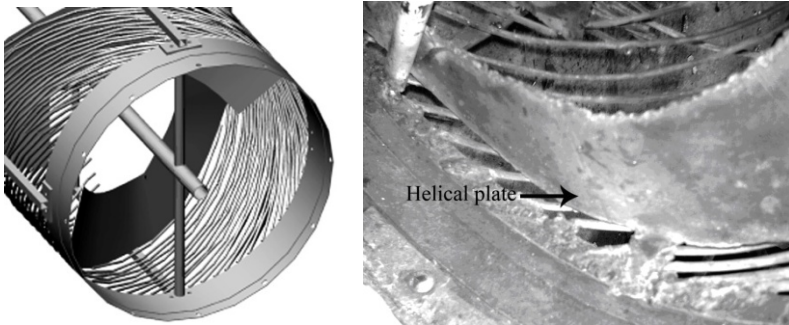


Figure 10 - Helical plates into the bale of potato digger

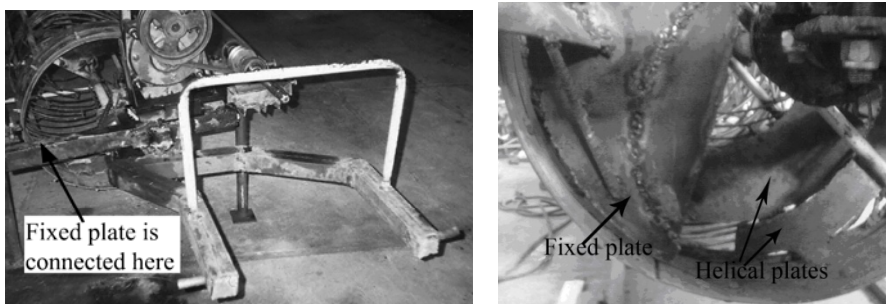


Figure 11 - Fixed plate at front and beside of the blade

CONCLUSIONS

Advance speed, rotational speed and blade slope is recommended as follows according to computer simulation studies and field results: 1) Advance speed was 1.5-3 km/h; 2) Rotational speed of blade was 20-25 rpm; 3) Blade slope was 10-15°.

The use of hydraulic driver for blade activation is suggested because mechanical parts of power transmission system are eliminated and it helps to cut weight and increase the machine effective capacity at different field conditions. Blade diameter should be increase to aid

product transition and to reduce damages caused by blade operation.

REFERENCES

- FAO, 2011 - Retrieved 12 29, 2013, from FAO: <http://faostat.fao.org/>.
- Farhadi R., Sakenian N., Azizi P., 2012 - Design and construction of rotary potato grader (Part I). Bulgarian Journal of Agricultural Science, 18 (2):304-314.
- Hyde G.M., 1986 - Solid and perforated rotary blade performance on a potato harvester. ASAE Paper No.86-1557.
- Kang W.S., J.L. Halderson J.L., 1991 - A vibratory, two-row, potato digger. Applied engineering in agriculture, 7(6): 683-687.
- Kang W.S., Rodriguez, Crow L.D., 2001 - Developing a small commercial

DESIGN, CONSTRUCTION AND EVALUATION OF POTATO DIGGER WITH ROTARY BLADE

- vibrating potato digger II. Effects of design parameters on draft, torque, and power. Transaction of the ASAE, 44(6):1391-1396.
- Ministry of Agriculture, 2011** - Retrieved 1229, 2013, from Ministry of Agriculture:
<http://dbagri.maj.ir/zrt/product.asp> (In Persian).
- Misener G.C., 1985.** A tractor - mounted digger for potatoes. AMA, 16(1):39-40.
- Modareserazavi M., 1996** - Losses in mechanized potato harvest. Part third, post-harvest, Sonbole magazine, 88(1):37-43 (In Persian).
- Muhammad Y., Mehmood A.M., Rehman R., 2003** - Design development and performance evaluation of rotary potato digger. AMA, 34(2): 43-46.
- Nasre Isfahani M., 2003** - Potato wastage in Freidan storehouse. Isfahan agricultural center research, Sapling and seed, 19 (2):191-208 (In Persian).
- Pasaman B., Zakharchuk V., 2012** - The determination of the parameters of a ploughshare-rotor potato digger. Econtechmod an International Quarterly Journal (2): 43-47.
- Saqib G.S., Wright M.E., 1986** - Vibratory digger for harvesting sweet potatoes in cloddy soils. J. Agr. Eng. Res., 34(1): 53-61.
- Sharma A.P., Verma S.R., Bansal A.S., 1986** - Design, development and field evaluation of oscillatory potato digger. AMA, 17(1): 60-62.
- Singh S., 2006** - Design, development and field testing of a multipurpose potato digger. Potato Journal, 33 (3-4): 134-138.
- Tarkesh S., 2005** - Potato operation comparison of American and European variety with use of molecular indicator of AFLP. M.Sc. Thesis, Iran, Shahrekord University, Agriculture Faculty (In Persian).
- Vasta D.K., Thakur T.C., Singh B., 1993** - Effect of speed and shape of shares on performance of oscillatory sieve potato digger. AMA 24(4):51-56.
- Yasin M., M.M. Ahmed, R. Rehman, 2003** - Design, Development and Performance Evaluation of Rotary Potato Digger. AMA, 34(2): 43-46.