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Hydraulic system for wireless control of high clearance inter-row weeding in organic-product

S. Suleiman[1,3,a], W.I. Wan Ishak[1,2], M.K. Muhamad Saufi[1,2] and M. Muhammad Razif[1,2]

[1]Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia; [2]Smart Farming Technology Research Center, Faculty of Engineering Universiti Putra Malaysia.; [3]Department of Agricultural and Bio-Environmental Engineering, Adamawa State Polytechnic, Yola

Abstract

Pedestrian tractor or Power tiller is an essential machine for horticulture in many parts of the world. They are mainly used for tilling, ploughing and ground preparation in small agricultural fields. Many custom designs of implement/machines are used on the pedestrian tractor such as seeders, cultivators/weeder and levelers. However, operating these machines is extremely tedious, fatiguing and time consuming. Thus, introducing automation on the high clearance pedestrian weeder can reduce fatigue associated to its operation. This article presents a high clearance inter-row weeder aimed at weeding at various stages of crop height, thus producing organic product. The system also enabled flexible power transmission and remote monitoring of the machine through the 12V solenoid operated valves.

Keywords: hydraulic-system, pedestrian-tractor, organic-product, weeding, cultivator, wireless control.

INTRODUCTION

The pedestrian tractor, also known as Power tiller is an essential machine especially for horticulture and small holder farmers. It is also known as hand tractor, walking tractor, pedestrian tractor or garden tractor. Power tillers are mainly used for tilling, ploughing and ground preparation on small agricultural farms. These equipment's are often used for breaking or working the soil in lawns, gardens, etc. (Hendrick and Gill, 1971). Nowadays, utilization of rotary tillers has increased in agricultural applications because of its simple structure and high efficiency for this type of tillage implements (Zareiforoush et al., 2010). Rotary tillers have become world famous for preparation of seedbed in fields. The rotary tiller is advantageous over the conventional implement (i.e. mouldboard plough and rake) due to the main effect of the direct application of power to the soil-engaging tool rotating around a horizontal-transverse axis. Two benefits of the direct application effect are: (i) rotary tiller achieves both ploughing and harrowing on the field, and (ii) the reduction in traction due to the ability of the soil-working blades to provide some forward thrust (Sirisak et al., 2008). Many custom designs of attached implement/machines are also made on the pedestrian tractor such as seeders, cultivator weeders and levellers.

Weed control in agriculture is an important constraint to increasing yields, especially in organic products (no synthetic pesticides, bioengineered genes (GMOs), petroleum-based fertilizers, and sewage sludge-based fertilizers). One of the major laborious and time consuming operations in organic crop cultivation is weeding**.** The concept of weed control is as old as agriculture itself. The global figure for crop yield loss is accepted as 40% of actual yield (Fletcher, 1983). The use of mechanical weeding cultivators is increasing among organic farmers due to health and environmental concern. However, controlling the power tiller while turning causes considerable fatigue to the operator.

An operator has to walk behind the machine for a distance of about 15 to 20 km, merely

[a] E-mail: slmnsamaila001@gmail.co

to rototill a hectare of land once (Sam and Kathirvel, 2008). However, research that examines the use of automation or wireless operation of pedestrian tractors are sparse (Piyathilaka and Munasinghe, 2010).This article describes the design requirement of a hydraulic operated cultivator weeder with 12V DC solenoid control to facilitate autonomous or remote control.

MATERIALS AND METHODS

Description Machine Components

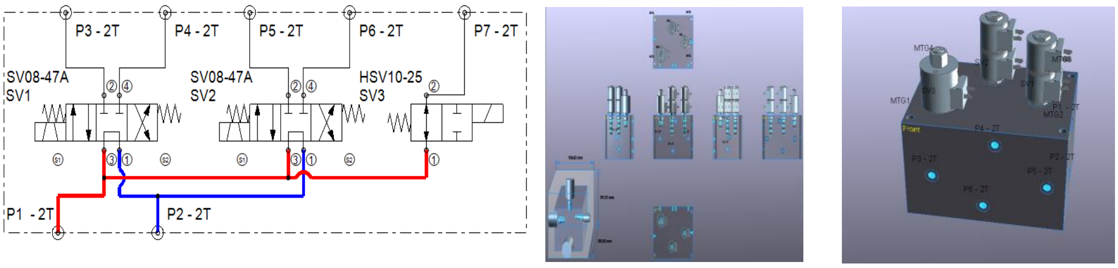
Kubota S25 12.5Hp Pedestrian tractor (figure 1a) was used as a prime mover for the development of the high clearance inter-row mechanical weeder (figure 1b). Diesel engines deliver roughly the same torque at high speed as they do at low speed, hence enough torque to drive a loaded hydraulic pump.

(a) (b)

Figure 1. Kubota S25 12.5Hp (a) and high clearance weeder (b).

Hydraulic Circuit design of the Cultivator-weeder

Fluid power is the transmission of forces and motions using a confined, pressurized fluid. The hydraulic circuit of the cultivator-weeder consists of a 6cc/rev hydraulic pump driven by the Kubota S25 gearbox output shaft at 1500rpm, to provide the needed flow of the hydraulic fluid. Two hydraulic cylinders to lift the weeding implement assembly in and out of work, and a 6cc/rev hydraulic motor to provide rotational power for the rotor assembly. Hydraulic flow controls to the actuators (motor and cylinders) are achieved through 12V DC solenoid electrically directional control valves. The hydraulic circuit was designed using the Hydra force i-Design 4.0 software. The manifold block hydraulic circuit of the cultivator is as shown in figure 2.



(a) (b) (c)

Figure 2. Hydraulic Manifold circuite. P1-2T: Pressure port, P2-2T:Return to tank, SV1 & SV2:3/4way solenoid valve, SV3:2/2way solenoid valve, P3-2T & P4-2T:Double acting cylinder 1 & 2 ports, P5-2T & P6-2T:Double acting cylinder 3 ports, P7-2T:Hydraulic motor port.

The 2D design of the manifold showing the details of the six sides is presented in figure 2(b) while the 3D block is presented in figure 2 (c). Cylinder CYL3 is used to engage and disengage the cluth, to start and stop the movement of the pedestrain tractor cultivator. The complete hydraulic system circuit diagram is shown in figure 3.

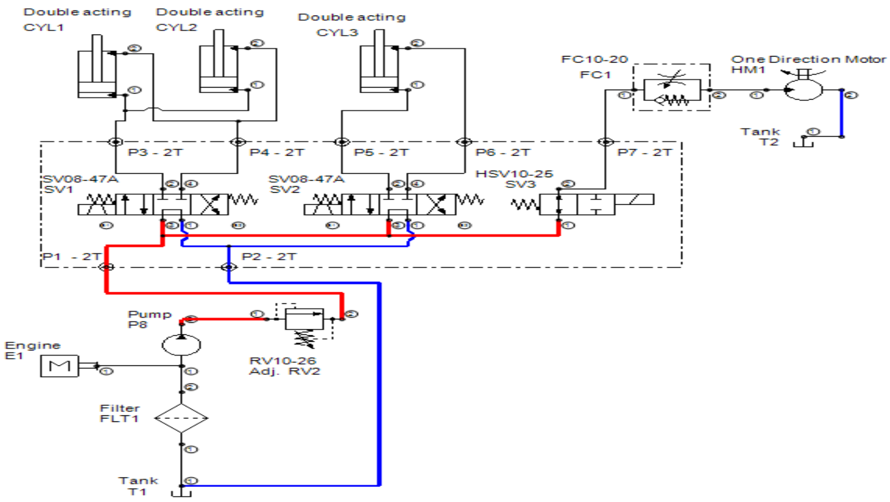


Figure 3. Hydraulic circuit diagram of Pedestrian tractor cultivator. T1 & T2: Tank, FLT1: Filter, P8: Hydraulic pump, RV10-26: Relief valve, CYL1, CYL2 & CYL3: Double acting cylinders, FC1: Flow control, HM1: Hydraulic motor.

Hydraulic System Assembly

The main components are the clutch actuation system figure 4(a). Implement depth control to lift the complete rotor assembly in and out of work was through two double acting cylinders in tandem as shown in figure 4(b). The rotary weeding units are operated by the

(a) (b) (c) (d)

Figure 4. Hydraulic actuators and control.

Wireless Control

A wireless android application (figure 5) was developed to control the system via Bluetooth signal within 100m range to actuate clutch, rotary unit and depth of cut of the weeding unit. A 2.4GHz wireless Radio Frequency video transmitter and 4.3 inch receiver was used to enable tele-operation of the machine.

VDU Android control

Figure 5. Wireless Android Control.

RESULTS AND DISCUSSION

Power requirement of the rotor unit assembly

The knowledge of the power requirement of the complete rotor assembly is essential to make an informed decision on the choice of appropriated actuator and the size of the prime mover. Thus, the power need of the rotor was calculated adopting the procedure reported in (Yatsuk et al., 1981) and (Olaoye et al., 2012) as described in equation (1). The soil shear resistance of high clearance vehicles as reported by (Abubakar et al., 2010) at 0-5cm depth to be 3.32KN/m^2 = 0.031Kgf/cm^2 was adopted. The effective width of cut is 100cn and average speed of 1.3m/s. Thus,

$$Pd = \frac{Sg\ X\ d\ X\ W\ X\ V}{75} = \frac{0.031\ X\ 5\ X\ 100\ X\ 1.3}{75} = 0.27Hp.\ \text{app } 0.3\text{Hp} \quad (1)$$

Where: Pd = Power required (Hp), Sg = Soil shear resistance (Kgf/cm^2) = 0.031Kgf/cm^2., d = Depth of cut = 5cm for weeding implements, W = Effective width of cut (cm) = 20cm x 5 units of rotors =100cm, V = Linear velocity of the weeding claw at point of contact with the soil = 1.3m/s (average working speed of the pedestrian tractor).

Hydraulic system analysis

Hydraulic Cylinder analysis

The hydraulic cylinder is a linear actuator using hydraulic fluid under pressure. In this design, the hydraulic cylinders are designed to lift the cultivator assembly and actuate the cultivator rotary shaft. The mass property of the rotor unit assembly to be lifted by the hydraulic cylinders was obtained through simulation using Autodesk Inventor 2013, to be 40138.95 grams (393.63 N). Thus, the force on each cylinder = 393.63 N/2 = 196.9 N = 44.26 Pounds. The stroke need of the cylinder is 18cm, thus the Bosch MP5 cylinder with bore of 25mm (0.98 inch), rod diameter of 18mm (0.71 inch) and weight of 1.13kg was adopted for this design. The hydraulic system is an open center system, thus:

$$\text{Pressure on the Piston end } (Pp) = \frac{Force\ (F)}{Piston\ Area\ (\frac{\pi d^2}{4})} = \frac{44.26\ (Pl)}{\frac{\pi (0.9)^2}{4}} = 58.70 \text{ Psi.} \quad (2)$$

$$\text{Pressure on the rod end } (Pr) = \frac{Force\ (F)}{\frac{\pi d^2}{4}(piston\ area) - \frac{\pi d^2}{4}(rod\ area)} = \frac{44.26\ (Pl)}{\frac{\pi (0.98)^2}{4} - \frac{\pi (0.71)^2}{4}} = 123.64 \text{ Psi} \quad (3)$$

The cylinder extension time = 3 seconds and the length of stroke = 18cm = 7.09 inch thus,

$$\text{Flow rate at the piston end of the cylinder } (\boldsymbol{Qp}) = \frac{Piston\ Area\left(\frac{\pi d^2}{4}\right) X\ Stroke\ length}{231\ X\ 60\ X\ Cylinder\ extension\ time}$$
$$= \frac{\pi (0.9)^2\ X\ 7.09}{231\ X\ 60\ X\ 3} = 1.29 \text{ X } 10^{-4}\text{gpm} = 1.29 \text{ x } 10^{-4}\text{gpm X two cylinders} = 2.57 \text{ x } 10^{-4}\text{gpm} \quad (4)$$

$$\text{Flow rate at the rod end of the cylinder } (Qr) = \frac{\frac{\pi d^2}{4}(piston\ area) - \frac{\pi d^2}{4}(rod\ area)}{231\ X\ 60\ X\ Cylinder\ extension\ time}$$
$$= \frac{\frac{\pi (0.98)^2}{4} - \frac{\pi (0.71)^2}{4}}{231\ X\ 60\ X\ 3} = 6.14 \text{ x } 10^{-4}\text{gpm x two cylinders} = 12.26 \text{ x } 10^{-4}\text{gpm} \quad (5)$$

Taking the maximum pressure and flow rate at the rod end of the cylinder, the maximum horse power inn at the rod end was obtained thus:

$$\text{Horse power inn cylinder } (Hpc) = Qr(gpm)\ X\ Pr(Psi)\ X\ 0.000583$$
$$= 12.26 \text{ x } 10^{-4} \text{ x } 123.64 = 0.15 \text{ x two cylinders} \quad (6)$$
$$= 0.30Hp$$

The total horse power (HP) on the hydraulic pump, are the power to lift the rotor unit assembly through the hydraulic cylinders and motor power to turn the rotary unit of the cultivator. These were both obtained as 0.3Hp in equation (1) & (6) respectively. Thus total hose power (HP) = horse power on the motor + horse power on cylinder = 0.3Hp + 0.3Hp = 0.6 Hp. Taking safety factor of 2.5 x 0.6Hp, total hose power (HP) = 1.5 approximate to 2Hp

Pump System Analysis

The Hydro-tek HGP-G204 series with Displacement = 04cc/rev, Volumetric efficiency = 93%, was selected to provide the required hydraulic flow.

$$\text{The actual pump flow rate } (Q_{act}) = \frac{D\ X\ N\ X\ V_{eff}}{231} = \frac{04\ X\ 1500\ X\ 0.93}{231} = 2.42\ \text{(gpm)}, \quad (7)$$

Where: D= Displacement = 04cc/rev; V_{eff} = Volumetric efficiency = 93%, N= Input speed (rpm).

Taking the maximum speed (N) of 1500 rpm from Kubota s125 Engine PTO shaft determined experimentally using digital a tachometer.
The actual Hose power in and out of the pump

$$\text{HPin} = \frac{QP}{1714} = \frac{8\ X\ 1200}{1714} = 5.60\text{Hp} \quad (8)$$

$$\text{HPout} = \frac{QP}{1714\ X\ Ep} = \frac{8\ X\ 1200}{1714\ X\ 85} \text{X}100 = 4.76\text{Hp} \quad (9)$$

Where: hp is horsepower, Q is flow in gpm, P is pressure in psi, and E_p is the pump's mechanical efficiency

$$\text{Horse power loss Hploss} = \text{Hpt} - \text{Hp} = 5.60 - 4.76 = 0.84\text{Hp} \quad (10)$$

$$\text{Overall system efficiency (\%)} = \frac{Hp\ out}{Hp\ in}\ X\ 100\ < 100\% = \frac{4.76}{5.60}\ X\ 100\ = 85\%$$

The expected motor flow rate Q = 6gpm, system pressure P = 1200 Psi, mechanical efficiency = 80%, input rpm to pump = 2400 rpm, motor displacement = 1.55cubic inches

$$\text{HPin} = \frac{QP}{1714} = \frac{6\ X\ 1200}{1714} = 4.20\text{Hp} \quad (11)$$

$$\text{HPout} = \frac{QP}{1714\ X\ Ep} = \frac{6\ X\ 1200}{1714\ X\ 80} \text{X}100 = 5.25\text{Hp} \quad (12)$$

Where: hp is horsepower, Q is flow in gpm, P is pressure in psi, and E_p is the mtor's mechanical efficiency.

$$\text{Horse power loss Hploss} = \text{Hpt} - \text{Hp} = 5.25 - 4.20 = 1.05\text{Hp} \quad (13)$$

CONCLUSIONS

The following conclusions can be drawn from the study:

– The hydraulic system on a high clearance inter-row weeer with an estimated power requirement of 2Hp was described.
– The hydraulic system were analysed for optimum performance and power selection. Actuators and solenoid operated control valves designed and described to facilitate wireless control and possible use for autonomous, tele-operated or wireless control on the pedestrian tractor, thus eliminating operator fatigue. The high ground clearance design will facilitate weeding at different stages of crop growth in organic agriculture.

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