

Manufacturing and Control of an Electric Power Tiller

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Abstract

As agricultural machines, many tractors using mainly diesel or turbo engines have been used. Such tractors are compact and highly efficient. However, they cause noise and air pollution. From the viewpoint of ecological environment and avoiding global warming, tractors not using such engines are required to be developed. So far we have conducted to produce electric vehicles including electric motor-cycle. In this report, we explain the technology of electric tillers for agricultural industries.

The electric tiller we aim is compact, considering use for garden work. The weight is less than 25 kg, and the size is within 1,100 mm x 600 mm x 1,000 mm. The weight of 25 kg was selected because of being able to carry by hands. The motor used is the one for small-sized electric vehicle. In the project, design, manufacturing, stress analysis, producing electric circuit and control unit, and experiment have been conducted. The design using 3D-CAD and manufacturing was successfully conducted. In regard to control, feedback control remains to study in the future, although the control using potentiometer and H8 microprocessor worked. The other remained research item is to make the tiller to be lighter so that elderly people can use.

Keywords

electric tiller, 3D-CAD, control, engineering education

1. INTRODUCTION

In Japan, the work force in agricultural industries gradually decrease year by year, and elderly people more than 60 years old among the work force is now 65 % [Data of Ministry of Agriculture, Forestry and Fisheries 2003]. Besides, ecological and global warming consideration is required for agricultural industries as well. From the above mentioned viewpoint, we started to study electric tillers.

The Kochi University of Technology was opened in April, 1997, and has been trying to develop the following new engineering educational curricula. These are first year seminars using real products [Sakamoto et al., 1999], experimental courses using vehicles [Sakamoto, 2001], computer assisted English education [Greene, 1999; Hunter, 1999] and so on. Among them, the author thinks that the design education is of great importance, as Fargason [Fargason, 1995] mentioned that design is engineering synthesis. In the previous paper [Sakamoto et al., 2003], two extracurricular (out of class and no credit) activities [Sakamoto, 2001; Sakamoto et al., 2001], were reported. As for design education, 3D-CAD lecture has been considered, and design of manual winch was selected because the text [Technical Education Committee, 1991] teaches how to calculate, and is thought to give an appropriate time to draw. Along with such design practices, an electric tiller was selected to be a

project since it can be a good target to study.

As agricultural machines, many tractors using mainly diesel or turbo engines have been used. Such tractors are compact and highly efficient. However, they cause noise and air pollution. From the viewpoint of ecological environmental and avoiding global warming, tractors not using such engines are required to be developed. So far we have conducted to produce the electric vehicle [Sakamoto et al., 2004] including electric motor-cycle [Sakamoto, 2004]. In this report, we explain the technology of electric tillers for agricultural industries. As well as the design and manufacturing for the electric tiller, the analysis and control aspect is considered to be of great importance.

In the following, as a design and manufacturing practice, the project of an electric tiller is reported.

2. 3D-CAD DESIGN AND MANUFACTURING OF ELECTRIC TILLER

In our laboratory of the mechanical engineering department, basic and advanced design education has been conducted. Figure 1 shows the examples [Sakamoto et al., 2004; Sakamoto, 2004] of practice conducted in 2003-2004. The reason to select an electric tiller for the project in 2004 is as follows. In 1970, the work force of agricultural industries in Japan was 10,300,000, and the number decreased to 3,900,000 in 2000. In the past 30 years, people is 1/3 as is shown in Figure 2. The rate of elderly people more than 60 years old increased from 26 % in 1970 to 65 % in 2000 as is shown in Figure 3.

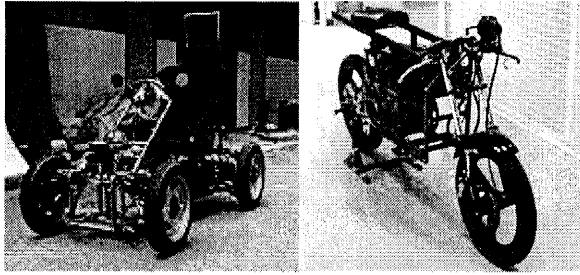


Fig. 1 Small-sized electric vehicle and electric motor-cycle

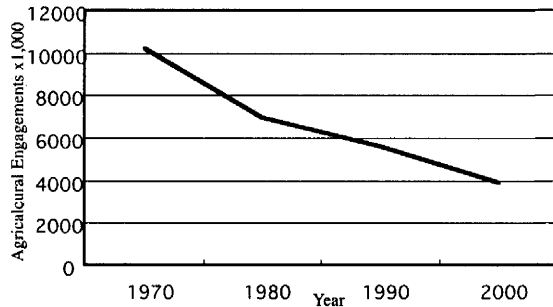


Fig. 2 Work force in agricultural industries

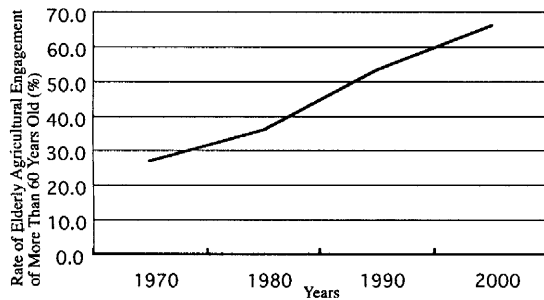


Fig. 3 Elderly work force rate more than 60 years old in agricultural industries

2.1 Specification of electric tiller

The conventional tiller of 60 cc engine displacement was considered to determine the electric tiller, which is used for gardening and the same size. The tiller is light-weight and easy treatment. Table 1 shows the specification of the aimed tiller.

Table 1 Specification of planned tiller comparing to the existing

Items, Tiller	Length (mm)	Width (mm)	Height (mm)	Power (W)	Weight (kg)
Planned	1,100	600	1,000	400	25
Commercial	1,115	585	975	1kW	27

The motor and batteries for electric vehicles are used for the planned electric tiller. Figure 4 shows the motor and batteries, and Table 2 shows the specification.

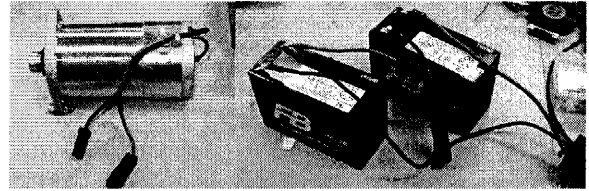


Fig. 4 Motor and batteries for electric tiller

Table 2 Motor and battery

Motor	Power	Voltage	Torque	Weight
	400 W	24 V	1.4 N · m	4.4 kg
Battery	Voltage		Ampere · Hour	Weight
	12 V		7.2 Ah	2.5 kg

2.2 Design and analysis of electric tiller

The frame design was conducted by using 3D-CAD software. Solid designer was used for the rough design, and ProEngineer for the detail design. The planned tiller is not the one which moves forward by driving wheels. Instead, it moves forward during tilling. The design was conducted taking into consideration of easy dissembling and not using many welding parts. The design idea of repairing and maintenance was based on the experience in electric vehicles [Sakamoto et al., 2004; Sakamoto, 2004].

The main frame material was decided to be 3.2 mm thickness SS400 plate. The natural frequency which relates to the rotational speed was considered for determining the design. Figure 5 shows the designed 3D-CAD frame, and Figure 6 shows the 3D-CAD for the assembly.

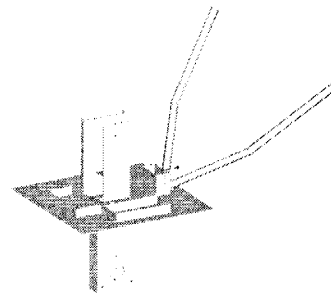


Fig. 5 3D-CAD for the frame

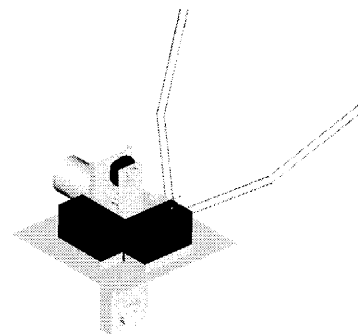


Fig. 6 3D-CAD for the assembly

After the design was made, the stress analysis by using ProMechanica which is a part of ProEngineer was performed. The model is the one shown in Figure 5, and the analytical condition is as follows. The loading condition is to load the weight of carrying motor and batteries to the place of the rotary attachment. The support location for analysis is the one of handle by hands. The maximum stress was found at the location at the attachment of handles from the stress analysis. The stress analysis result is shown in Figure 7. The result is 218 MPa as the maximum stress, and the safety factor for SS400 material is 1.32 for tensile strength, 1.08 for yield strength, and 2.22 for fatigue strength. The fatigue safety factor was calculated, assuming that the dynamic vibration is ± 0.3 g. Since the factor for yielding is higher than 1.0 and less marginal, in order to obtain the more safety, the design was reconsidered. The maximum stress of 123 MPa was found. The safety factors for tensile, yield, and fatigue are 3.25, 1.91, and 3.27. Naturally, the more safety factor is desired. However, the light-weight is of importance. The design was fixed, and Figure 6 is 3D-CAD for the final design assembly.

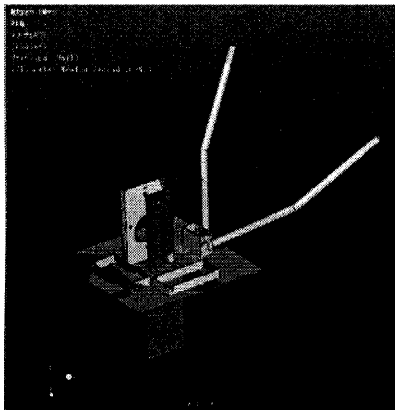


Fig. 7 Result of stress analysis

2.3 Manufacturing of electric tiller

The manufacturing of the designed electric tiller was conducted. We asked bending and drilling work to the manufacturer near the university. Small size drilling,

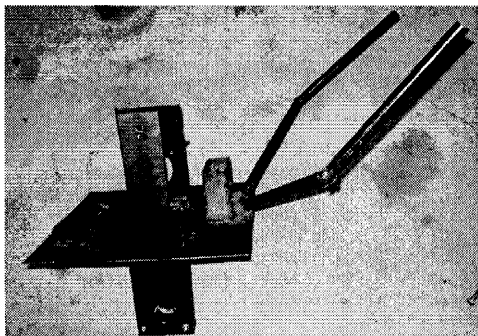


Fig. 8 Fabricated frame for electric tiller

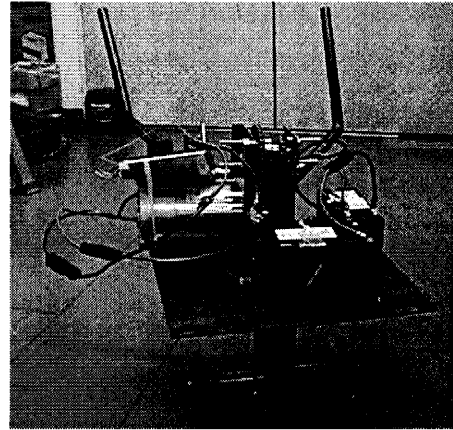


Fig. 9 Assembled electric tiller

welding, and assembly were conducted by us. Figure 8 shows the tiller frame for our project, and weighs 10 kg. Figure 9 shows the assembled tiller. We were able to comparably easily assemble, because we considered to decrease the welding parts.

3. CONTROL OF ELECTRIC TILLER

3.1 Control without feedback using potentiometer

In order to control the electric tiller, a speed controller for the motor used was used. Positive-opposite control is performed by a switch. The speed is controlled by the controller, whose input voltage is 0-5 V analog value. The output to the motor is produced by PWM (Pulse Width Modulation) control from the speed controller, using a microprocessor. The potentiometer is the one for the motor and speed controller. The voltage of the potentiometer is 0-5 V, and the voltage that the speed controller recognizes is 0-2 V. When the potentiometer resistor is 2 k Ω , the speed controller input is 5V, and the rotation is the maximum. Figure 10 shows the experimental equipment.

In the case of using the potentiometer, we need to operate the potentiometer. The operation needs when the rotation decreases due to the resistance from soil. How-



Fig. 10 Experimental equipment for control using potentiometer

ever, such operation during tilling may cause unstable balance in working operation, be upset, and be caught by the tiller. It has a possibility of danger.

3.2 Control without feedback using H8 microprocessor

In the next step, the speed control using H8 microprocessor was considered. In replace of the potentiometer for speed control, the microprocessor was used. The microprocessor used in this study is H8/3048, and Figure 11 shows the board, and Figure 12 is the schematic figure of the board circuit. The D/A converter can change the control speed such as fast and slow ones by changing a switch. Figure 13 shows the control unit using switches. When No.1 switch is on, D/A board provides 5V to the speed controller, and when No.2 switch is on, it provides 4V. This method helps not to use the potentiometer.

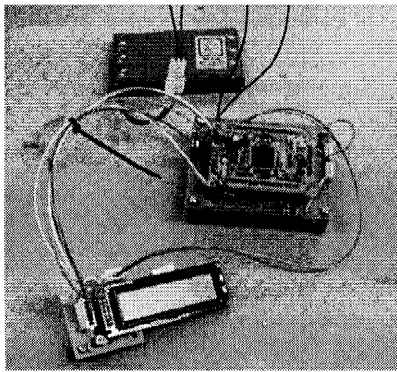


Fig. 11 H8 microprocessor board

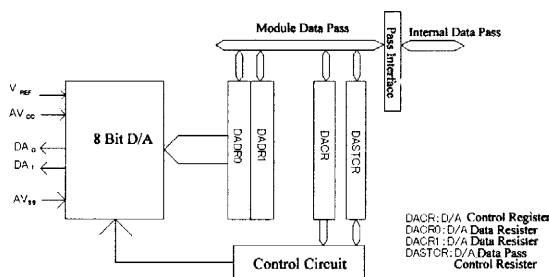


Fig. 12 H8 microprocessor D/A board

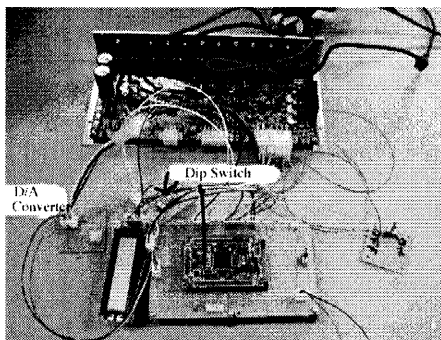


Fig. 13 Control unit using switches

3.3 Control with feedback using microprocessor

The control using the potentiometer may cause for the tiller to fall, and the tiller operation may have a danger. When using H8 microprocessor, the motor output can not be changed due to soil resistance when the motor rotation changes, which enables to be safe.

Therefore, we started to study the feedback control using both of H8 microprocessor and rotary encoder. H8 microprocessor and encoder monitor the motor rotation, and the motor output is changed depending on the motor rotational variation. The rotary encoder is the incremental and open collector output type. In this study, the experiment that can show the motor rotation was conducted. The experiment was performed by using a coupling between DC motor and rotary encoder. Figure 14 shows the rotary encoder attachment and control unit. Since the specification of the motor rotation is 6,400 rpm for 1.5 V, the rotation is decreased to 103 rpm for 3 V by using the gear ratio of 126:1. DC motor driver IC of TA 8429H is used for the control of DC motor. The control is PWM, and when H8 microprocessor board output is converted to D/A from PWM, the same program can be used for the tiller.

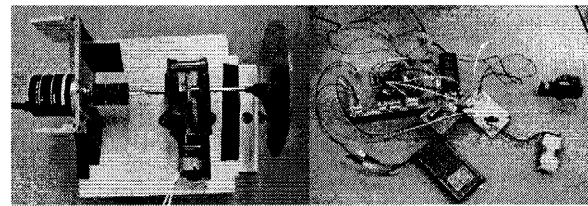


Fig. 14 Rotary encoder attachment and control unit

4. EXPERIMENT

4.1 Field experiment using potentiometer without control

The experiment by the potentiometer without control was conducted. The location for the experiment is an ordinary garden, which is for planting vegetables. The nail of the tiller is a hatchet. Since the field is rather soft due to frequent use, the tilling work was not so tough. However, digging depth was about 50 mm. Figure 15 shows the photograph of operation.



Fig. 15 Operational experiment in field

4.2 Experiment using microprocessor

The experiment to confirm the control operation was conducted. Using a tester, the output from the microprocessor was confirmed. The output of 5 V is expected from the D/A output terminal of the microprocessor. The motor rotation can be controlled by connecting the D/A output to speed controller. Figure 16 shows the apparatus for measuring D/A converted output. The figure shows the almost exact value of 5 V. Since the D/A output value of 5 V is confirmed, the H8 microprocessor board was connected to the speed controller, and the experiment for operation was conducted. The measurement of motor rotation was also tried by using the value of the rotary encoder from H8 microprocessor board. The rotational frequency from the encoder was displayed in the tester. Figure 16 shows the motor control by the microprocessor and the display of motor frequency.

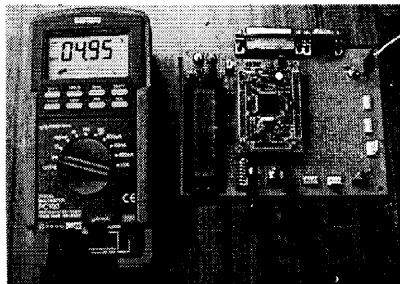


Fig. 16 D/A output experiment

5. DISCUSSION AND CONCLUSION

According to the literature, the tilling power needed to dig 50 mm depth is 1,500 W. In this study, 400 W power for the manufactured tiller enabled to dig to the depth. The reason why the power required to dig 50 mm depth was small for the developed tiller is considered due to soft soil in the ground for the experiment location. We need to study in different locations of various soil.

As for the control experiment using the microprocessor, the experiment was successful, and is considered to be safer than using the potentiometer. However, the dip switches used are small and are hard to handle the controller.

As for the designed and manufactured electric tiller in this study, the power is enough and the operation is easy, if normal adults operate. However, it might be hard for elderly people to operate due to the heavy weight. It is required to develop more light-weight and greater tiller capability.

The following results conclude,

- (1) The developed tiller is successful from the viewpoints of design and manufacturing, since it satisfies the

aimed specification.

- (2) The control of the tiller was considered. The methods are the control without and with feedback. The feedback control using the microprocessor needs to study more, since the field experiment using the feedback control was not able to be conducted due to time shortness.
- (3) In the future program, the feedback control and modification of the tiller for elderly people to easily handle are desired.

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