EAEF Engineering in Agriculture, Environment and Food
published by AABEA
Research Paper

EAEF 6(4) : 160-164, 2013

Study on the Development of the Electric Tractor

－ Specifications and Traveling and Tilling Performance of a Prototype Electric Tractor －

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Abstract

To reduce the environmental impacts of agricultural production, an existing 10 kW-class internal combustion engine tractor was remodeled as an electric tractor with an AD motor. Remodeling the engine tractor to an electric tractor increased its overall weight. However, it had little damaging effect on the balance of the body. By using electric-only agricultural machinery, the energy consumption needed for traveling and tillage in the field can be reduced by approximately 70 %. Moreover, the electric tractor could operate continuously for one hour over a work area of approximately 1300 m^2 on a single charged battery. From the results of the CO_2 emissions estimated on the basis of the above result, it reduced by approximately 70 % rather than the engine tractor.

[Keywords] tractor, low-carbon society, carbon dioxide emissions reduction, electrification, power consumption

I Introduction

In 2004, as part of the global trend in recent years toward developing a low-carbon society, the United States EPA launched the “TIER 4” emissions standard in order to establish exhaust gas criteria for non-road diesel engines. Meanwhile, in April 2004, “2004/26/ES” was added to the set of European Union regulations on Stage IIIB and IV exhaust gas emissions. Both 2004/26/ES and TIER 4 set very strict values on the emission standards. At the same time, Japan introduced the Act on Regulation, Etc. of Emissions from Non-road Special Motor Vehicles as well as contributed to the introduction of low-carbon technologies that can minimize or even eliminate dependence on oil. As part of this effort, reduction in the environmental impact of agricultural production is required. Under the Japanese law, new emission standards are being phased in from 2011 for non-road special motor vehicles that use diesel engines, including agricultural machinery; clean energy use has thus become an agricultural industry mandate. Among the various types of mobile agricultural machinery, the agricultural tractor is one of the most prolific consumers of fuel (MAFF, 2008; NAME, 2009); as a result, the tractor has become an obvious target for electrification research.

In the previous research, electric tractors with DC motors were assessed, with the body of research including the analysis of the relationship between the drawbar pull performance and energy consumption, as well as the battery layout configurations (Arjharn *et al*., 2001a; 2001b). In this study, an electric tractor with an AC motor is proposed and assessed in terms of its torque characteristics, torque variation control, the number of motor rotation, and water resistance.

A prototype electric tractor with a motorized system consisting of a motor, controller, and battery, replacing an internal combustion engine was used to perform actual work in the field under a variety of terrain and operating conditions. This study focuses on the driving performance of the tractor during crop cultivation, rather than on the drawbar pull performance. Basic data on power consumption and other factors were collected, and the motor capacity needed for the practical use of was analyzed.

Finally, the practical aspects of the electric system performance, such as the attainable continuous work time and area using a single charged battery, were assessed.

II Materials and Methods

1. Prototype tractor specifications

We have carried out this study as a basic assessment to determine future directions in the development and use of electric tractors. For the experiments, a commercially available, 10-kW-class, 4-wheel-drive tractor with a relatively simple power transmission and small engine-exhaust levels was remodeled and used. Retaining the power transmission unit, we replaced the two-cylinder diesel engine with a three-phase, 10-kW AC motor. Power from the electric motor

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was used, via a reduction gear, to drive the rotary tiller and the front and rear wheels.

Table 1 Specifications of the prototype tractor

Style		ISEKI Piccoro	
Model		TC13 (T0614)	
Drive system		4 wheel drive	
Size	Length (mm)	1905	
	Width (mm)	915	
	Height (mm)	1760	
	Minimum ground clearance (mm)	265	
Traveling section	Shift transmission	6 speeds forward 2 speeds back	
	Travelling speed (km/h) Forward	0.72 - 11.98	
	Travelling speed (km/h) Back	0.90, 5.47	
Minimum turning diameter (m)		1.5	
		Engine	Motor
Type		Water cooled 4 cycle twin cylinder diesel	Three phase AC motor (Ohsei, GLMI10A1)
Weight (kg)		470	553
Rated power (kW [PS]/rpm) (kW)		9.6[13.0]/2700	10
Controller		-	Input DC 100V Output 3φ200A (Ohsei, GL CI6008A2)
Battery		-	Lithium battery 99V (3.3V×30) (Sky Energy, SE100AHA)

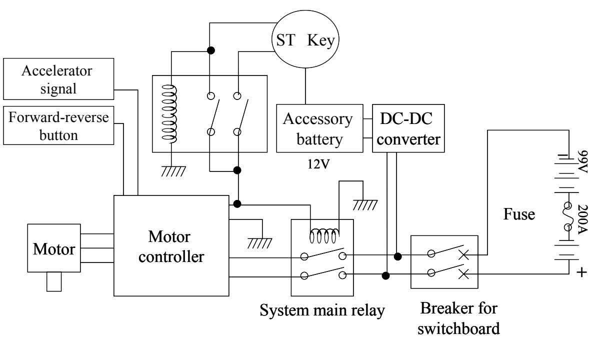

Fig. 1 Schematic diagram of the electric tractor

Table 1 lists the major specifications of the tractor before and after remodeling. Fig. 1 shows a diagram of the electric system of the prototype electric tractor. Fig. 2 shows a photograph of the prototype electric tractor, which has been equipped with a battery (30 cells of 3.3 V each, totaling 99 V), a controller, a motor, and a 12 V accessory battery, which is charged from the main battery via a DC-DC converter. The converter output varies on the basis of the state of charge of the accessory battery, with a maximum output of 8.5 A.

Fig. 2 Photograph of the electric tractor

2. Measurement of weight and the center of gravity

The weight of the tractor before and after remodeling was measured using a weight measuring device (INTERCOMP, SW777PRO). By placing the load meter of the measuring device under each tire, the center of gravity before and after remodeling was also calculated. Each load meter was able to measure up to 750 kg; thus, a total weight of 3,000 kg could be measured.

3. Measurement of energy consumption during travel and tilling

This experiment was carried out in two different fields in Ehime Prefecture: in the paddy fields of Tobe town, Iyo-gun, and in the upland field of the experimental farm of the faculty of agriculture, Ehime University. The upland soil used for the test was derived from a residual called decomposed granite soil, which, according to the International Soil Texture Classification Standards (JSAM, 1996; FUJIWARA *et al*., 1999), is equivalent to sandy soil. Although an attempt was made to measure its hardness using a cone penetration test machine, the soil was too soft to measure. The moisture content of the upland soil was 14 %, while its liquid limit (LL) was 51.0 % and its plastic limit (PL) was 36.3 %. The paddy field soil had a cone penetration resistance value of 0.45 MPa with a moisture content of 20.3 %. The LL was 46.4 %, and the PL was 33.2 %.

The motor had a rotation speed of approximately 2650 rpm with a rotational power take-off (PTO) speed of approximately 465 rpm; the running speed and the tillage depth were set as shown in Table 2. Under each of the