Development of Tracked Combat Hybrid-Electric Vehicle

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***Abstract*—Electric power needs are significantly increasing and the vehicular power management system becomes more and more important for combat vehicles. Hybrid electric vehicle technologies are advancing in civilian sectors and military ground vehicles obtain following advantages by implementing hybrid electric drive systems: improvement of acceleration and fuel economy, silent mobility and silent watch capabilities and enhancement of on-board electric power generation. However, to the best of authors' knowledge, there has been no deployed hybrid military vehicles so far and the availability of hardware related papers is limited in spite of these advantages. This paper shows a system design and details of mobility testing of a Tracked Combat Hybrid Electric Vehicle (T-HEV) for the first time. Basic mobility performances for ground combat vehicles such as acceleration, top speed, gradeability and pivot turn capabilities are evaluated and advantages of a hybrid electric system are discussed. Finally, it was revealed that a series hybrid electrical drive system was applicable to combat type vehicles.**

Keywords—Hybrid Electric Vehicle, Tracked Combat Vehicle, Acceleration, Top speed, Gradeability, Pivot turn

I. INTRODUCTION

Electric power needs are significantly increasing and the vehicular power management system becomes more and more important for combat vehicles. Although hybrid electric vehicle technologies are advancing in civilian sectors, the idea of combat vehicles with electric drive systems has also a long history. For example, the Saint-Chamond tank was built in between 1916 and 1918 in France and deployed in the First World War. Germany built and deployed Ferdinand (Elephant) tank in the Second World War [1]. The U.S. also developed T-23 tank with an electric drive in 1943 and evaluated its performance [2]. However, these pioneering vehicles were driven by DC motors and no traction batteries were employed due to the immaturity of relevant technologies and these programs were eventually abandoned [1,2].

Around 2000s, with the progress in HEV technologies in civilian sectors, the research and development of military HEVs became active again and several countries began HEV development programs such as Future Combat Systems (FCS) and Joint Light Tactical Vehicle (JLTV) in the U.S., Future Rapid Effects System (FRES) in the U.K., and Spliterskyddad EnhetsPlatform (SEP) in Sweden [3-5]. In these programs, both hybrid electric wheeled and tracked vehicles were studied and it was revealed that military ground vehicles obtain following advantages by implementing hybrid electric drive systems: improvement of mobility and fuel economy, silent mobility and silent watch capabilities and enhancement of on-board electric power generation [3,4,6]. However, to the best of authors' knowledge, there has been no deployed hybrid military vehicles so far and the availability of hardware related papers is limited in spite of these advantages [7-10]. In addition, the evaluation of basic mobility requirements for ground combat vehicles such as acceleration, top speed, gradeability and pivot turn capabilities were overlooked even in these hardware related papers.

This paper presents a system design and details of mobility testing of a Tracked Combat Hybrid Electric Vehicle (T-HEV) recently developed by Acquisition, Technology, and Logistics Agency, Ministry of Defense of Japan (ATLA-MOD) for the first time. Mobility performances concerning acceleration, top speed, gradeability and pivot turn capabilities are evaluated on concrete roads and advantages of the hybrid electric system for combat vehicles are discussed.

II. OVERVIEW OF T-HEV

A. System design of T-HEV

Hybrid electric drive system is generally classified as series and parallel types depending on the connection of each component [4,5]. In a series hybrid system, two electrical power sources provide energy to an electrical component that propels a vehicle and there is no mechanical connection between an engine and driven wheels or sprockets. Thus, an internal combustion engine (ICE) can be operated at its optimal range and the better fuel economy can be achieved. In addition, electric motors have an ideal torque-speed profile for the traction of combat vehicles, i.e., high torque at the acceleration, climbing and turning and a wide range of high power. For these reasons, the series hybrid system was employed for the T-HEV development and Fig. 1 shows the structure of the component arrangement of T-HEV. As the primary power source, the mechanical power of the ICE is converted into the electrical power by a permanent magnet synchronous generator, which produces three phase AC power. Then, this AC power is converted into DC power by a converter and provided to DC power bus (600 Volt). As the secondary power source, lithium-ion battery directly provides DC power to DC power bus. DC powers by these two sources are combined and provided to inverters and after the conversion into AC power, this AC

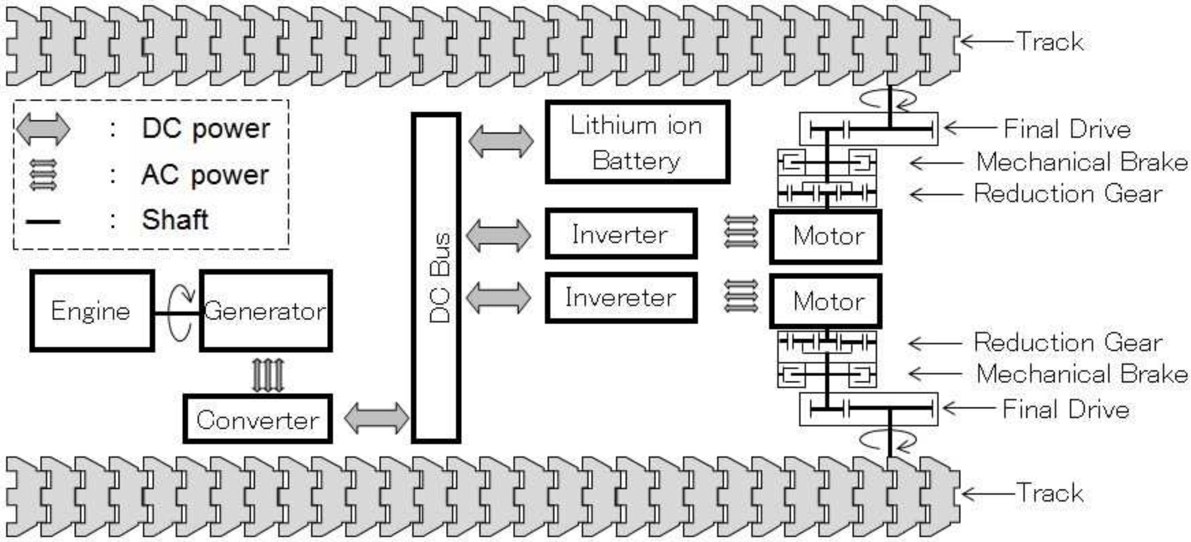

Fig.1. Structure of component arrangement of T-HEV

power drives permanent magnet synchronous motors for propulsion. These motors are independent each other and can drive each track individually with reduction gears and final drives. In general, it is necessary for tracked vehicles to give a velocity difference between right and left tracks to make a turn and conventional tracked vehicles provide this difference by mechanical transmissions. However, when T-HEV makes a turn, the inner side motor works as a generator by the running resistance from the ground and this generated power is provided to the outer side motor for a velocity difference. Moreover, although conventional tracked vehicles have only mechanical brakes, T-HEV has both mechanical and electrical brakes and electrical brakes regenerate electrical power by using motors as generators when stopping and this regenerative braking enhances the energy efficiency of the vehicle system.

B. Specifications of T-HEV

Fig. 2 shows the outside appearance and main components of T-HEV. Electric motors are placed at the front side of the vehicle to provide a cabin space at the rear side of the vehicle, which is typical for Armored Personal Carriers (APCs) and the lithium ion battery is placed beside the cabin with deliberated safety measures. Major specifications of T-HEV are presented in Table I.

TABLE I. MAJOR SPECIFICATIONS

Item	Specification
Dimension (Length x Width x Height)	5.7 x 2.8 x 2.2 (m)
Weight	13 (metric ton)
Engine	In-line 6 cylinder diesel engine Max. power: 168 (kW)
Generator	Permanent Magnet Synchronous type Max. power: 168 (kW), Max. rotation speed: 2200 (/min), Max. torque: 968 (Nm)
Electric Motor	Permanent Magnet Synchronous type Max. power: 250 (kW), Max. rotation speed: 5000 (/min), Max. torque: 2034 (Nm)
Battery	Lithium ion Battery Max. power: 185 (kW), Capacity: 32.6 (kWh)

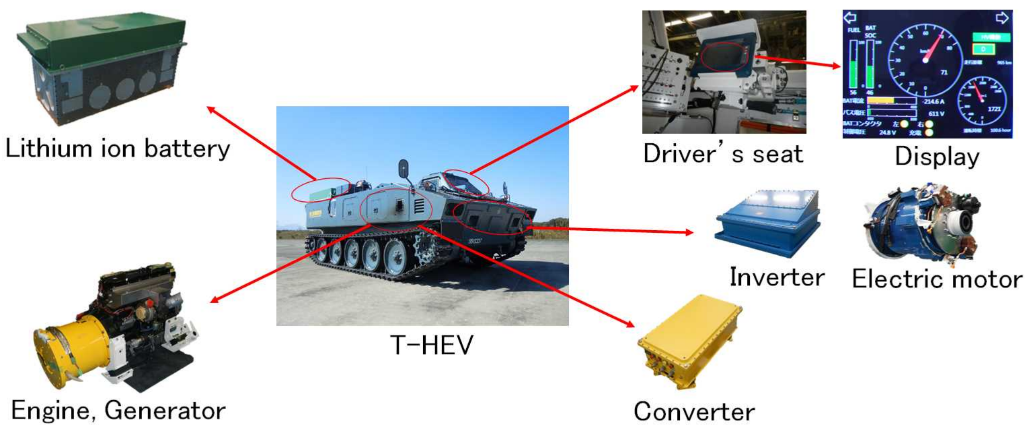

Fig. 2. Outside appearance and main components of T-HEV

III. RESULTS AND DISCUSSION

A. Acceleration and top speed performances

Fig. 3 shows the results of acceleration and top speed performances on the level road. T-HEV accelerates from 0 to 56 kilometer per hour (35 mile per hour) in about 15 seconds and this is 12 seconds faster than that of the U.S. Army's M113A3 APC [9]. In addition, the top speed is about 73 kilometer per hour and this is 10 percent faster than that of the M113A3 [9]. Since T-HEV is driven by electric motors, the acceleration is much smoother and it is more powerful than conventional vehicles with mechanical drivetrains and this is one of the advantages of the series hybrid system. Furthermore, T-HEV achieved about 40 percent improvement of the fuel economy performance compared with the conventional APC and this is another merit of the hybrid system.

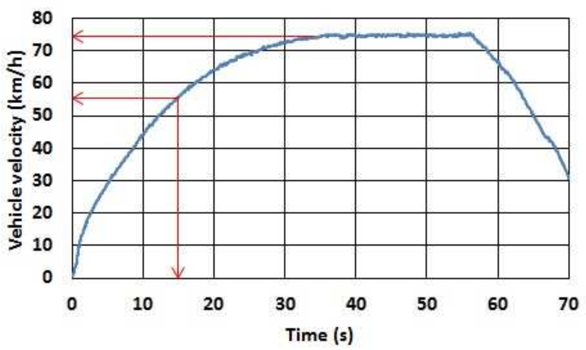

Fig. 3. Profile of vehicle velocity at acceleration and top speed tests

B. Gradeability performance

Fig. 4 shows results of the velocity and the body pitch angle during the gradeability test on the 60 percent slope. It is verified that T-HEV stably climbs the 60 percent slope even at the low speed (around 5 kilometer per hour) owing to the characteristic of the motor, i.e., large torque at low speed although the body pitch angle exceeds 60 percent (31 degree) on the 60 percent slope because of the deflection of suspensions. Also, since there are angle changes at the approach and the exit of the 60 percent slope of the test facility in this test, the pitch angle of the vehicle varies before and after the 60 percent slope.

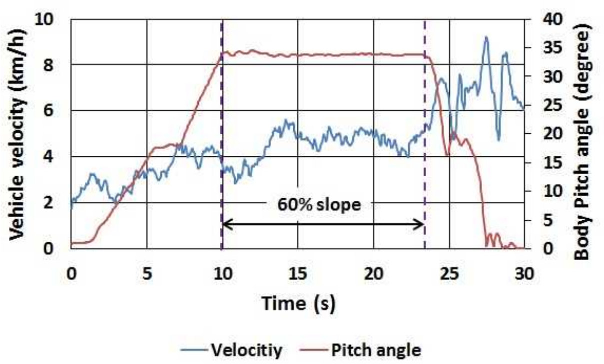

Fig. 4. Profiles of vehicle velocity and pitch angle at gradeability test

C. Pivot turn performance

Fig. 5 shows results of the motor speed and the accelerator ratio during the clockwise pivot turn, where 100 percent of the accelerator ratio denotes the full-throttle condition. The sign of the rotation speed of motors represents the direction of the rotation and the positive sign means the forward direction and the negative sign denotes the backward one, respectively. With the increase of the accelerator ratio, rotation speeds of right and left motors increase to drive each track to opposite directions for the pivot turn. It is proved that T-HEV can make a pivot turn with mechanically decoupled motors when rotation speeds and the torque of right and left motors are properly controlled.

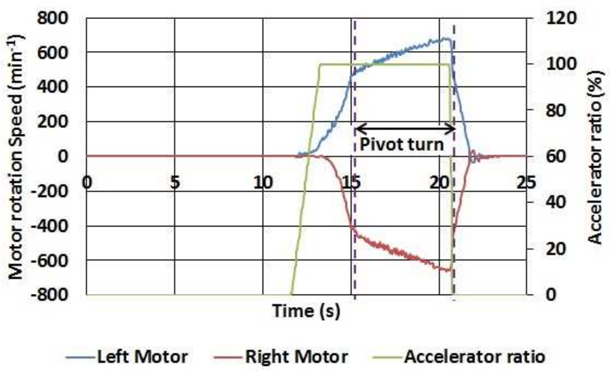

Fig. 5. Profiles of motor speed and accelerator ratio at pivot turn test

IV. CONCLUSION

In order to meet electric power needs for combat vehicles, T-HEV, a tracked combat hybrid electric vehicle, was developed and basic mobility performances were evaluated. By conducting several on-road tests, it was revealed that the series hybrid electric drive system was effective and applicable to combat type vehicles.

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