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Investigation of Energy Efficient Power Coupling Steering System for Dual Motors Drive High Speed Tracked Vehicle

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Abstract

This paper presents an energy efficient power coupling steering system for dual motors drive high speed tracked vehicle. The system consists of a new type of center steering motor, two electromagnetic（EM） clutches, two planetary gear couplers, and two propulsion motors. The motor torque and power required by dynamic steering with different steering radiuses for dual motors drive high speed tracked vehicle were investigated. A motor-speed-based control strategy of dynamic steering is designed to achieve vehicle lateral stability enhancement. The model of the proposed control strategy in RecuDyn and Matlab/Simulink is given. The simulation results of dynamic steering with 0.5B and 2B radius show that understeer in small radius steering can be significantly improved.

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Keywords:Tracked vehicle; Dual motors drive; Dynamic steering; Power coupling; Speed control

1. Introduction

Energy saving in vehicles is becoming more important [1,2]. Electric tracked vehicle is one of the main trends of the future tracked vehicle and developed to solve problems of energy crisis and air pollution [3].

Nomenclature	
2METV	dual motor drive electric tracked vehicle
2MIETV	dual motor independent drive electric tracked vehicle
ECDS	electronic controlled differential steering

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It is necessary to have higher manoeuvrability and off-road capability for high-speed tracked vehicles [4].The power of outer side motor required for the high-speed steering for 2MIETV is more than 2.5 times that of engine in internal combustion engine vehicle, which results in large size and power of motor and inverter. Especially, more power of outer side motor is required for dynamic steering. So an energy efficient power coupling steering system is proposed for the 2METV dynamic steering in the paper.

2. Mathematical Model for Dynamic Steering

The electric drive system configuration of 2MIETV is shown in Figure 1, which is widely used in the 2METV. The torque and power required by dual motors with different steering operation are calculated according to the vehicle parameters as shown in table 1. The tractive force F_1 , F_2, the output torque T_1, T_2 and the desired rotation speed n_1^* , n_2^* can be expressed as follows:

■ Table 1. Vehicle parameters

Parameters	Value
Vehicle tread, B(m)	1.3
Wheel, 2n	10
Ground contact length, L(m)	1.7
Rolling resistance coefficient, f	0.04
Transmission efficiency, η	0.9
Drive ratio, ig	7
Mass of vehicle, m(kg)	2000
Mass gain coefficient, δ	1.5
Moment of inertia, J(kg/m2)	3000

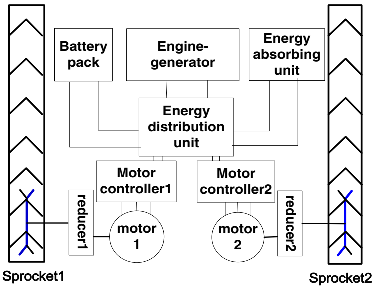


Fig.1. Electric drive system configuration of 2MIETV

2.1.Center steering

$$T_1 = T_2 = (0.5fm\mathbf{g} + \frac{\mu m\mathbf{g}L}{4B} + \frac{J}{B}\frac{d\omega}{dt})\ r_z/i_g\eta \le F_z r_z/i_g\eta \tag{1}$$

$$n_1^* = n_2^* = \frac{1000 i_g}{120\pi r_z}\cdot 3.6\cdot\omega^*\cdot\frac{B}{2} = n_0 \tag{2}$$

2.2.Small radius steering

$$\begin{cases} T_1 = F_1 r_z / i_g\eta = [0.5fm\mathbf{g} + \dfrac{\mu m\mathbf{g}L}{4B} + \left(\dfrac{J}{B} - 0.5\delta Rm\right)\dfrac{d\omega}{dt}] r_z / i_g\eta \le F_z r_z / i_g\eta \\ T_2 = F_2 r_z / i_g\eta = [0.5fm\mathbf{g} + \dfrac{\mu m\mathbf{g}L}{4B} + \left(\dfrac{J}{B} + 0.5\delta Rm\right)\dfrac{d\omega}{dt}] r_z / i_g\eta \le F_z r_z / i_g\eta \end{cases} \tag{3}$$

$$\begin{aligned} n_1^* &= \frac{1000 i_g}{120\pi r_z} * \frac{v_{des}}{R_{des}} * \left(\frac{B}{2} - R_{des}\right) \\ n_2^* &= \frac{1000 i_g}{120\pi r_z} * \frac{v_{des}}{R_{des}} * \left(\frac{B}{2} + R_{des}\right) \end{aligned} \tag{4}$$

2.3.0.5B Steering

$$\begin{cases} T_1 = F_1 r_z / i_g \eta = [\dfrac{\mu m \mathrm{g} L}{4B} + \left(\dfrac{J}{B} \text{-} \delta R m\right)\dfrac{d\omega}{dt}] r_z / i_g \eta \le F_z r_z / i_g \eta \\ T_2 = F_2 r_z / i_g \eta = [\dfrac{\mu m \mathrm{g} L}{4B} + 0.5 f m \mathrm{g} + \dfrac{J}{B}\dfrac{d\omega}{dt}] r_z / i_g \eta \le F_z r_z / i_g \eta \end{cases} \tag{5}$$

$$\begin{cases} n_1^* = 0 \\ n_2^* = \dfrac{1000 i_{\mathrm{g}}}{120 \pi r_{\mathrm{z}}} * \dfrac{v_{des}}{R_{des}} * \left(R_{des} + \dfrac{B}{2}\right) \end{cases} \tag{6}$$

2.4.Brake steering

$$\begin{cases} T_1 = F_1 r_z / i_g \eta = [\dfrac{\mu m \mathrm{g} L}{4B} \text{-} 0.5 f m \mathrm{g} + \left(\dfrac{J}{B} - 0.5 \delta R m\right)\dfrac{d\omega}{dt}] r_z / i_g \eta \le F_z r_z / i_g \eta \\ T_2 = F_2 r_z / i_g \eta = [\dfrac{\mu m \mathrm{g} L}{4B} + 0.5 f m \mathrm{g} + \left(\dfrac{J}{B} + 0.5 \delta R m\right)\dfrac{d\omega}{dt}] r_z / i_g \eta \le F_z r_z / i_g \eta \end{cases} \tag{7}$$

The steering angular speed of tracked vehicle is generally π/4/s~5π/12/s. If the acceleration time from 0 to 5π/12/s is assumed to be 1s, Table 2 shows steering power and torque required by dual motors during dynamic steering with 0, 0.2*B*, 0.5*B* and stationary steering with 0, 0.2*B*, 0.5*B*, 2*B*, 5*B*, 10*B*.

Table 2. Dynamic & Stationary steering torque and power required by two motors

	R	T_{in} (Nm)	T_{out} (Nm)	P_1 (kW)	P_2 (kW)	n_1 (r/min)	n_2 (r/min)
■ Dynamic	0	246	246	9.8	9.8	379	379
	0.2B	228	252.6	5.4	14	227.5	530.8
	0.5B	163.6	233.3	0	18.5	0	758.3
■ Stationary	0	174	174	6.9	6.9	379	379
	0.2B	169	169	4	9.4	227.5	530.8
	0.5B	152.6	161.9	0	12.9	0	758.3
	2B	-116	134	-13.8	26	1137.5	1895.8
	5B	-82	100	-29	43	3412.5	4170.8
	10B	-53	72	-40	60	7204.1	7962.5

The parameters of the motor was determined by straight running dynamic characteristics: P_e=20kW, P_e is the rated power; P_{max}=40kW, P_{max} is peak power; T_e=75 N·m , T_e is the rated power; T_{max}=150 N·m, T_{max} is the peak torque; n_e=3000rpm, n_e is the rated speed; and n_m=9000rpm, n_m is the peak speed. However table 2 shows that the required maximum torque for each propulsion motor during dynamic steering and the required maximum power for each propulsion motor during stationary steering exceed the maximum torque and maximum power of the motor designed for straight running.

3. Power Coupling Steering Drive System Design

3.1. Power Coupling Steering Drive System

A power coupling steering drive system composed of a new type of center steering motor, two electromagnetic clutches, two planetary gear couplers, and two propulsion motors is designed and shown in Figure 2. There are two steering modes used in 2MIETV. The ECDS mode is adopted when the steering torque and power required for the outer motor is smaller than the maximum torque and power of single propulsion motor, otherwise, the dual motors coupling drive steering (2MCDS) is activated.

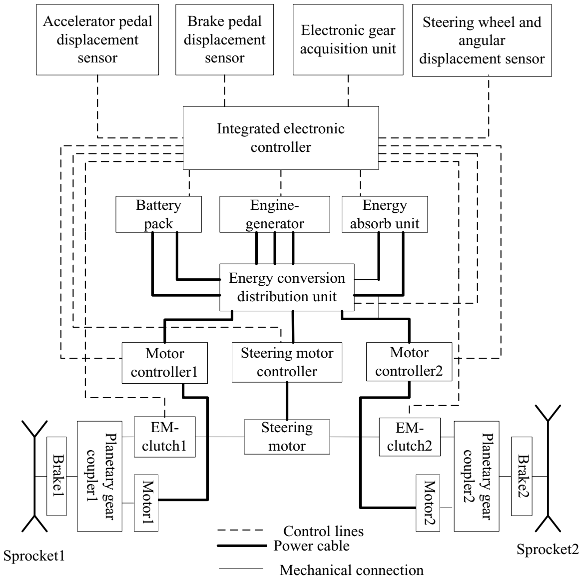


Fig.2. Power coupling steering drive system configuration

3.2 .Planetary Gear Coupling Structure Design

The dual motor power coupling steering system is designed as Fig.3. When the 2MCDS is activated, the gear&EM-clutch is controlled to be combined, and the torque generated by both the steering motor and the propulsion motor is coupled through the outer planetary gear coupler to drive the outer sprocket. When the power required exceeds the maximum power of the motor, the reducer&EM-clutch is controlled to be combined, and the power generated by both the steering motor and the propulsion motor is coupled. The power and rotation speed relationship in the planetary gear can be expressed as

$$\begin{aligned} &P_c = T_c n_c = T_r n_r + T_s n_s = P_r + P_s \\ &n_s = i_p n_c + (1 - i_p) n_r \\ &T_s : T_r : T_c = 1 : i_p - 1 : i_p \end{aligned} \tag{8}$$

Where P, T, n is the power, torque and rotation speed of the sun gear with subscript s, and that of ring gear with subscript r, planet carrier with subscript c. i_p is the transmission ratio of planetray gear. The simulation platform is modeled in software ProE and imported into software Recurdyn®. The simulation and experimental platform of 2 METV are shown as Figure.4.

4. Control Strategy of Dynamic Steering

A motor-speed-based close-loop control strategy of dynamic steering is presented in Figure 5. The desired wheel speeds of inner and outer side motors are calculated according to the target vehicle speed and steering radius by the mathematics model of the vehicle. Two slip ratio fuzzy controllers are used to produce the adjusting torques acting on two-side motors to work under the best slip ratio condition and achieve better speed following and steering radius following in real time.

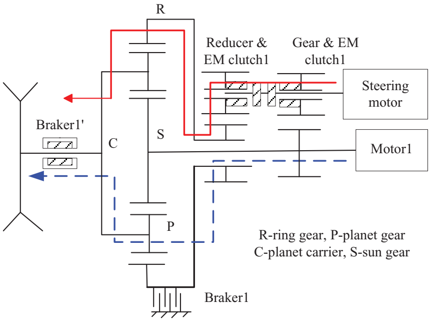


Fig.3. Dual motor power coupling steering schematic

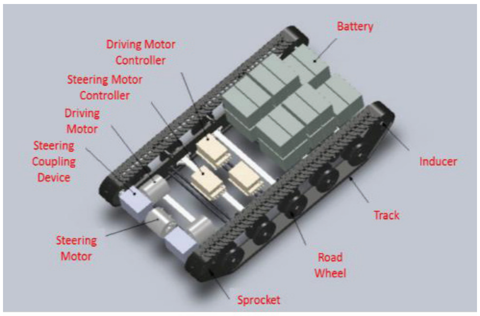


Fig.4. 2METV platform in Recurdyn

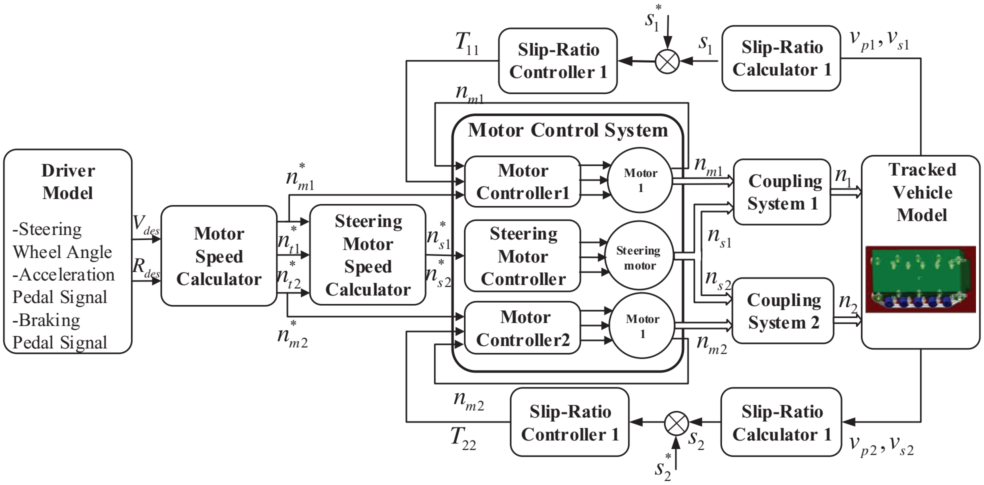


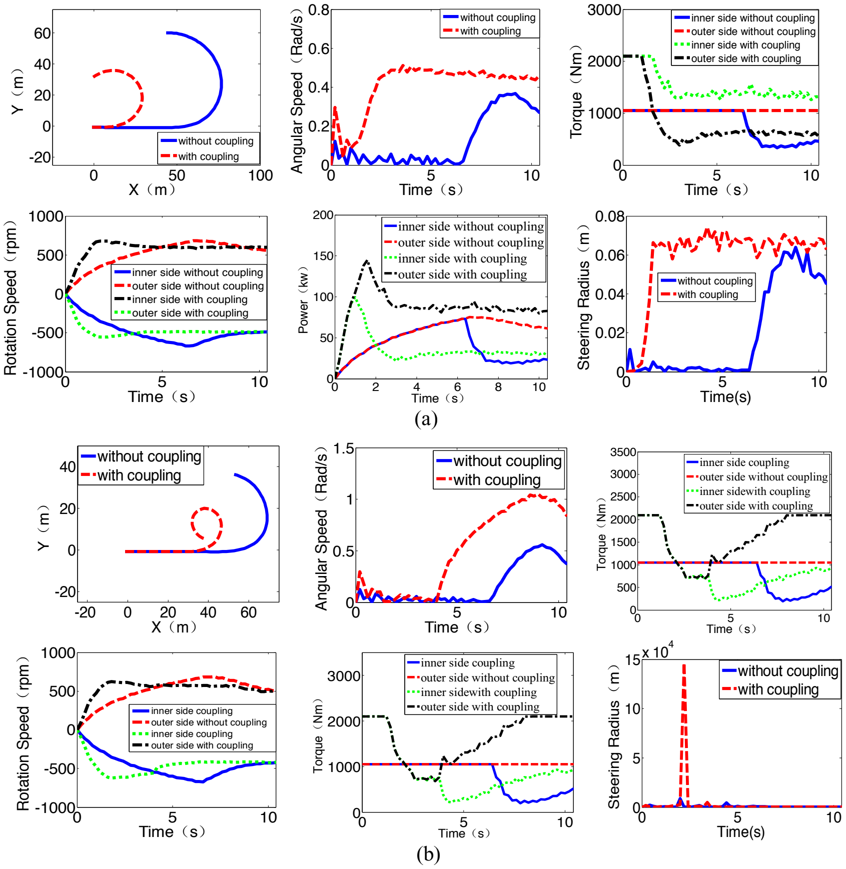
Fig.5. A motor-speed-based close-loop control strategy of dynamic steering

5. Modeling and simulation results

The 2MIETV model and ground model are developed in Recurdyn®. Driver model, motor speed calculator, steering motor speed calculator and motor control system model are developed in Simulink. The simulation results of 2MIETV with power coupling steering system in 0.5B and 2B dynamic steering manoeuvres on the hard pavement are shown in Fig.6. From Fig.6, it can be seen that the tractive torque and power of each sprocket with coupling device are much larger than that without coupling one.

6 Conclusions

An energy efficient power coupling steering system for 2METV is designed to increase the torque and power required for above two steering issues. The total power of two propulsion motors in 2MIETV using this system can decrease by 25%. A motor-speed-based close-loop control strategy of dynamic steering for 2METV is designed to achieve better trajectory following and vehicle speed following to improve the understeer in small radius steering due to smaller torque and power of each sprocket.



(a)

(b)

Fig.6. Simulation results (a) 0.5B, (b) 2B

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Biography

Li Zhai, she received the Ph.D. in 2004 and is an associate professor at the national engineering laboratory for electric vehicle, beijing institute of technology, since 2009. From 2013-2014, she was a visitor scholar at university of missouri-rolla, USA. Her research interests include the integration control of multi-motor drive EVs.