Characteristics of an Original Electric Vehicle with Three Wheels and One Wheel-in-motor

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Abstract

This paper shows an original-made electric vehicle (EV) and its characteristics. The EV, named NEV-III, has three wheels and one drive motor. There are two front wheels and one rear wheel in which a wheel-in-motor is mounted. The wheels are steered independently by each servo-steering system. Then the EV has several features and the special driving mode as well as the normal driving mode running like conventional cars. As the special driving mode, for example, the EV can move towards any directions horizontally, and pivot on the center of it. Some experimental and calculated data, especially rotary performances, show that NEV-III has excellent characteristics compared with conventional cars. Also, the EV can drive automatically without a driver. When the automatic drive carries out, an original-made position sensor detects the ideal trail. According to these data, it is proved that the concept of the EV is useful for unskillful drivers or drive at narrow space.

Keywords

electric vehicle, wheel-in-motor, quasi-current-source inverter, servo-steering system, driving mode, automatic drive

1. INTRODUCTION

In recent years, several kinds of electric vehicles (EV) have sold by some car-makers at reasonable prices. Promotion of EV would surely contribute to the environment of the earth and human's lifestyle. As a matter of fact, almost all the EVs are remodeled from conventional cars, therefore many inherent merits of EV don't utilize effectively.

On the other hand, there are some attractive EVs which have developed in Japan. For example, "IZA" by the group of Tokyo Electric Power Co. [Shimizu, 1992], "PIVOT" by Shikoku Research Institute Inc. [Nasu et al., 1996], and "Luciole" [Shimizu, 1999] or "Kaz" [Onishi et al., 2003] by the group on behalf of Mr. Shimizu, etc. They have obtained good reputations for their distinguished performances.

These EVs are driven by wheel-in-motors (between two and eight motors), then they can make the most of their merits as prospective vehicles. But, it is difficult to popularize these kinds of vehicles, because the wheel-in-motors used in these EVs are very expensive.

This paper describes an original-made EV which is named NEV-III, as shown in Fig.1. The EV has only one wheel-in-motor mounted in the rear wheel, and the three wheels are steered independently by using each servo-steering system. Therefore the EV has specific and interesting driving modes as well as the normal driving mode.

Also, there is one more feature of the EV, it can drive automatically without a driver, using an original-made position sensor and iron sheets that lead the ideal trails. Two types of running courses and two kinds of driving methods are examined.

2. BASIC STRUCTURE OF NEV-III

Figure 1 and Figure 2 show the basic structure of NEV-III. The EV has a unique shape and there are three wheels; two wheels put at both of front sides, and one wheel puts at the center of rear position. The steering angles of these three wheels are controlled independently by each servo-steering mechanism. All the wheels can turn in the range of ±120deg, therefore the EV achieves many kinds of movements .

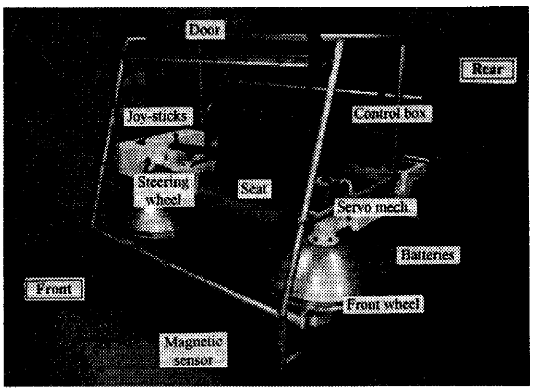


Fig. 1 Picture of NEV-III

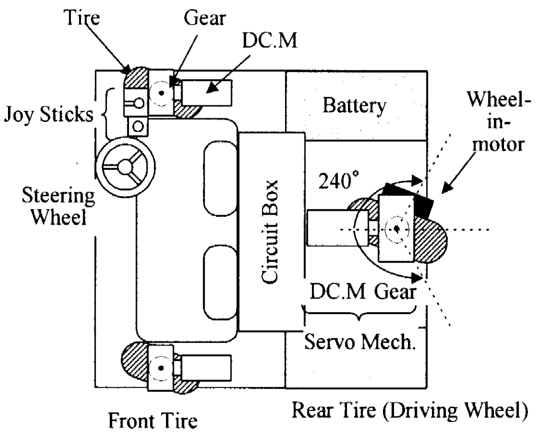


Fig. 2 Layout of main parts

The three wheels are laid out nearly equilateral triangle, i. e., the length between the front wheels' center is 1300mm, and between the front and the rear wheel's center is 1279mm.
For the sake of the drive of the EV, one wheel-in-motor is mounted in the rear wheel, as shown in Figure 3. Therefore, NEV-III can be called "Three Wheels and One Drive (3W-1D) Vehicle".

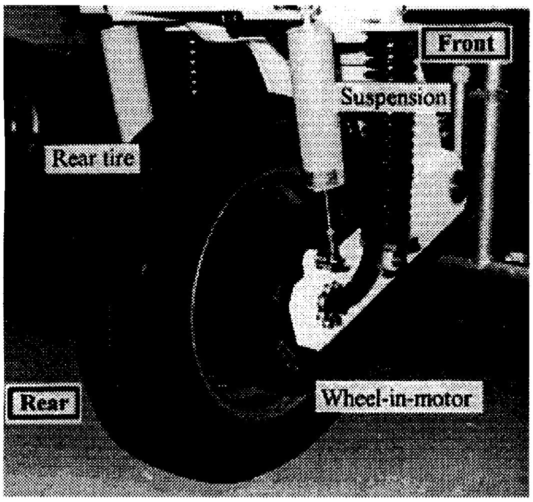


Fig. 3 Rear wheel

In order to determine a steering signal, there are three kinds of devices: a steering wheel for the normal driving mode, two joy-sticks for the special driving mode, a magnetic sensor for the automatic drive.
As the power supply, batteries are placed at the both sides of backward and lower position of the EV, because of weight balance and stability. The door opens upward in front of the seat, so the passengers get on and get off at the front of the EV.

3. SPECIFICATIONS OF NEV-III

Table 1 shows the specifications of NEV-III. There is a seat for two persons. The size of the EV is as follows:

Table 1 Specifications of NEV-III

Seating capacity		2 persons	
Size		1614 (L), 1560 (W), 1570 (H) mm	
Weight		440kg (including battery weight: 120kg)	
Drive	Circuit	Quasi-current-source inverter	
	Motor	Permanent magnet synchronous motor (Wheel-in-motor) 70V, 500rpm, 12poles Rated output: 2kW, Maximum output: 5kW	
Steering	Circuit	4-quadrant chopper	
	Motor	DC servo motor	
		Front	Rear
		110W, 3000rpm 75V/2A 8.5kg-cm	300W, 2500rpm 75V/5.2A 12kg-cm
Battery		DC 120V, 36Ah (Lead-acid battery)	
Maximum speed		40km/h (design value)	

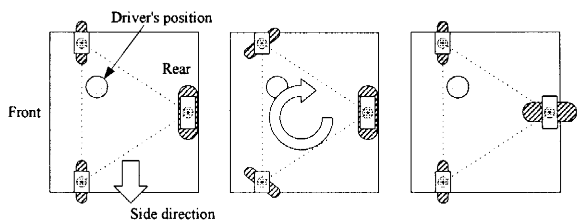
the length is about half of the Japanese standards of light-sized cars, and the width is almost the same of them. Like this, it is a compact shaped vehicle.
To reduce the weight, the framework of the body is made of aluminum pipes except the part of wheel suspensions. Thus, the total weight of the EV is about 440kg including 10 pieces of lead-acid batteries.
A quasi-current-source inverter is adopted for the drive of the wheel-in-motor. The motor is a permanent magnet (PM) synchronous motor of the outer rotor type with 12 poles, and the magnet is neodymium (Nd) series one. Rated output of the motor is 2kW, and the maximum output is about 5kW.
To control the three wheel angles, DC servo motors (front wheels: 110W, rear wheel: 300W) with mechanical gears (ratio: 1/100) are fixed on each top of the wheel.
The tires have following sizes: front tires are 8 inches in radius and the rear tire is 165/65R13. The lead-acid batteries (DC12V, 36Ah) are connected 10 pieces in series, the power supply voltage is DC120V. They can be charged directly from AC100V of the commercial power line. The maximum vehicle speed (design value) of the EV is 40km/h.

4. DRIVING MODE

NEV-III has following three driving modes.

(1) Normal driving mode
The EV runs, of course, like conventional cars, using a steering wheel.

(2) Special driving mode
The mode is peculiar to the EV, and Figure 4 illustrates these functions.



(a) Slide movement (b) Pivot movement (c) Braking

Fig. 4 Special driving mode

The EV moves towards any directions horizontally, e.g., lateral or oblique direction. (: Slide movement) The EV pivots on the center of it. (: Pivot movement)

Two joy-sticks, installed right-hand position of a driver, are chosen for these movements, respectively. Also, the EV has unique braking way. In this case, three tire angles are arranged as shown in Figure 4 (c).

(3) Automatic driving mode

Without a driver, the EV moves automatically. When the mode implements, an original-made magnetic sensor installed at the bottom of the chassis detects the ideal trail. As guide of the trail, some shapes of iron sheet putting on the ground are used.

In addition, some more drive functions could be expected by combination of these driving modes, especially at narrow space.

5. DRIVE OF THE WHEEL-IN-MOTOR

Figure 5 shows the drive and control system of the wheel-in-motor. The drive circuit of the motor is a quasi-current-source inverter, which is suitable for the drive of PM motors because of its good voltage waveform. The inverter comprises DC chopper and voltage source inverter. It has some advantages; the reactor of it can be much smaller than that of conventional current source inverter, IGBTs as switching devices don't need to have diodes in series. Therefore, the system can be designed compact and at low cost.

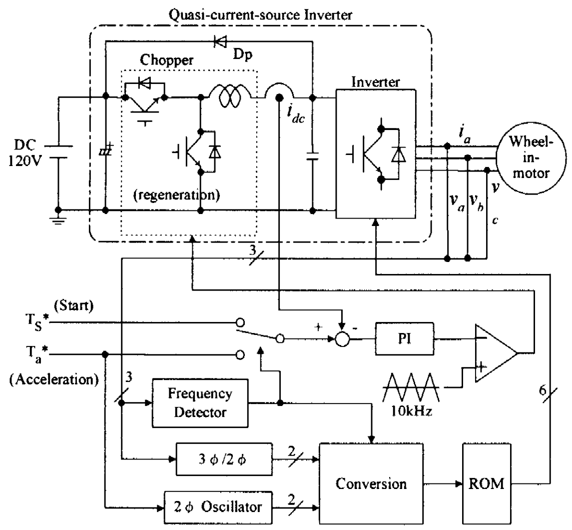


Fig. 5 Block diagram of motor drive

Since it is difficult to install some equipments in the wheel-in-motor, the sensorless drive system is adopted. The positions of magnetic poles of the motor are detected by the counter electromotive forces (EMF). But the EMF cannot be gained until the motor rotates.

When the motor stops or has very low speed condition, a starting torque signal *Ts** is applied, and the signal makes the chopper current constant. Also, the switching signals of the voltage source inverter are given by two phase oscillator.

As the motor speed increases, the torque signal is gradually changes from *Ts** to the acceleration signal *Ta**, then the switching pattern of the voltage source inverter is determined by using EMF. Thus the motor is pulled in synchronous drive.

By the way, when the brake signal is applied, power regeneration is carried out, namely the batteries are charged. If the acceleration and the brake signal are applied at once, the brake signal precedes the acceleration signal for safety.

6. SERVO-STEERING SYSTEM

As illustrated in Figure 6, the three wheels are steered independently by each servo-steering system. The system consists of a DC servo motor, a mechanical gear, a potentio-meter, and a chopper circuit driving the DC motor. Where θ_1, θ_2, and θ_3 mean the angles of the front left-side wheel, the front right-side wheel, and the rear wheel, respectively. The asterisk means the reference value given by a personal computer.

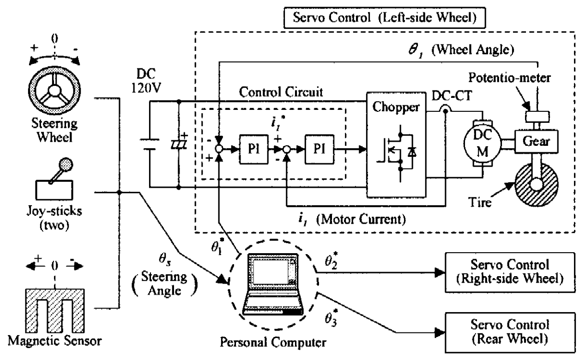


Fig. 6 Block diagram of servo steering

Depending on the steering angle θ_S, which is provided from the steering devices, the optimal wheel angles θ_1^*, θ_2^*, and θ_3^* are determined by ROM table in the computer. Then the commands of these angles apply to each servo control circuit.

The steering wheel is used for the normal driving mode, two joy-sticks are used for the special driving mode, and the magnetic sensor is used for the automatic driving mode. The joy-sticks are chosen owing to the slide movement or the pivot movement.

7. EXPERIMENTAL AND CALCULATED DATA

Figure 7 shows an experimental data of running test for the normal driving mode of NEV-III. The experiment was carried out on several conditions in series; acceleration, constant speed, re-acceleration and constant speed, free run, and deceleration. The EV can run like

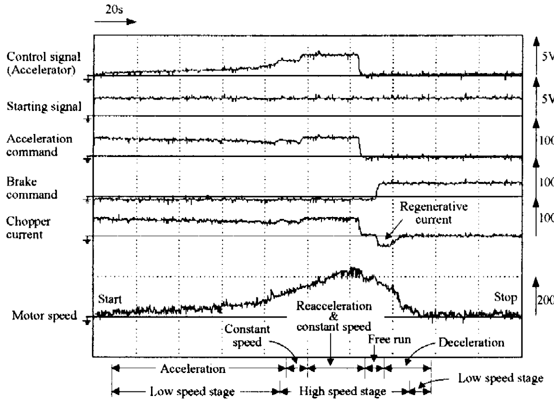


Fig. 7 Experimental data of running test

conventional cars in spite of rather low speed. In this case, the maximum vehicle speed was nearly 15km/h. The regenerative current is observed when the brake command is applied.

Using Ackermann Jeantaud theory for the dynamics of cars, the data of rotary radius vs. steering angle are calculated, as shown in Figure 8. Where the three types of driving methods are examined. The method 1 means the case of two front wheels' steering, and the method 2 means the case of only the rear wheel's steering. Also, the data of the pivot movement is shown in this figure. Because the vehicle speed is very low, the slip of the tires is negligible on these conditions.

According to Figure 8, it is known that the rotary radius of the EV is approximately half value compared to the conventional light-sized cars made in Japan. For 45deg of steering angle, these three data are verified by experiments, and they are in good agreement.

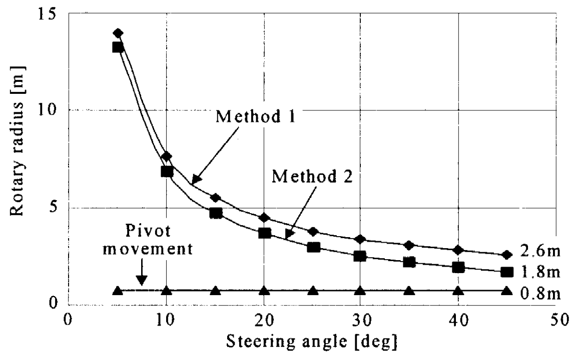
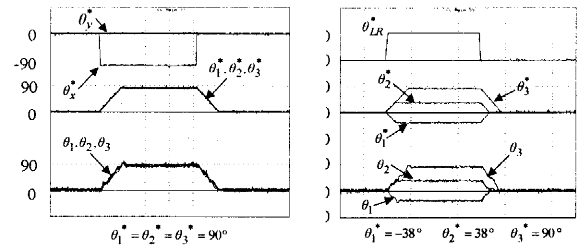


Fig. 8 Rotary radius vs. steering angle

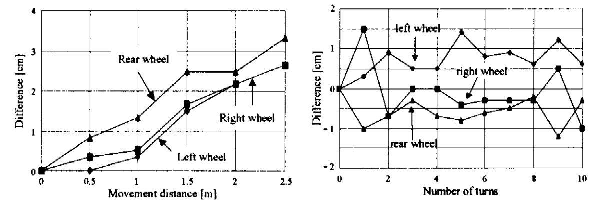
Figure 9 shows the experimental data of the special driving mode. Figure 9 (a) is the case of the slide movement towards lateral direction (90deg from the front), and (b) is for the pivot movement. It is proved that the wheel angles (θ_1, θ_2, and θ_3) respond to the command signals accurately. Owing to smooth movement, the angle signals shape ramp forms.

Figure 10 (a) and (b) demonstrate the deviation from



(a) Slide movement (b) Pivot movement

Fig. 9 Steering control of special driving mode

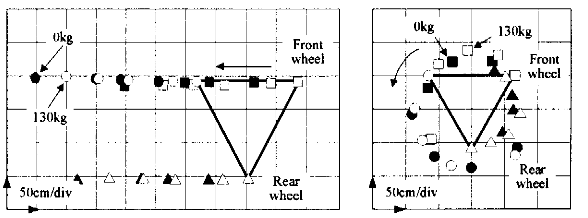


(a) Slide movement (b) Pivot movement

Fig. 10 Deviation of each tire at low speed

the ideal trail; (a) is for the slide movement (90deg from the front), and (b) is for the pivot movement. In the case of (a), the maximum value is within 4mm when the EV moves 2.5m. In the case of (b), the maximum value is 1.5cm though the EV pivots 10 times.

Figure 11 illustrates the tracks of the three tires, when the EV has a load (130kg weight) or not. Figure 11 (a) is for the slide movement, and (b) is for the pivot movement. Where the open symbols mean the condition for loading a weight, and the solid symbols mean no load condition, respectively. The maximum deviation from the ideal track is less than 10cm.



(a) Slide movement (b) Pivot movement

Fig. 11 Deviation of tires depending on load

These deviation shown in Figure 10 and Figure 11 easily can be improved much better, if a driver operate the steering devices adequately. As a consequence, the data show that there is no big problem for any conditions of the special movement.

8. AUTOMATIC DRIVE

NEV-III also has the automatic driving mode by using an original-made magnetic position sensor. The sensor was designed by analysis of finite element method (FEM). As shown in Figure 1, it is installed at the bot-

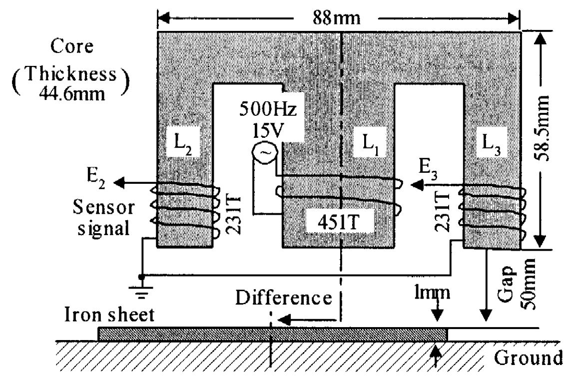


Fig. 12 Magnetic position sensor

tom and the center of the chassis. Figure 12 illustrates the shape of the sensor, where material of the core is silicon steel.

At the center leg of the core, the sensor is excited by AC15V/500Hz. The sensor signals are outputted from both sides of legs. Two detecting signals are compared each other and the difference voltage of them is amplified, then the voltage (i.e., position signal) inputs to the personal computer. As the trail guide, the iron sheet is put on the ground. The thickness of the sheet is 1mm and the width of it is 120mm.

Figure 13 and Figure 14 demonstrate the experimental traces for two kinds of control methods of the automatic driving mode. One is the method of only rear wheel's control (each Figure (a)), and the other is three wheels' control simultaneously (each Figure (b)).

Figure 13 shows the case of a quarter circle course, and Figure 14 shows the case of a S-line curve course. Both courses have 230cm radius of curvature.

To take an example in Figure 14 (b), maximum deviation of the rear tire from the ideal trail (i.e., center-line of the iron sheet) is 13cm, but the case of Figure 14 (a), it is 39cm. When comparing Figure 13 (a) and (b), a similar situation comes out. Consequently, these data show that the three-wheel control method is much better than the one-wheel control method.

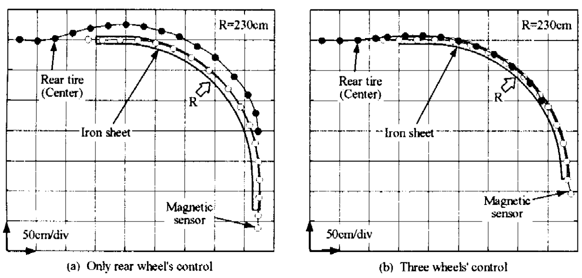


Fig. 13 Trace for 1/4 circle course

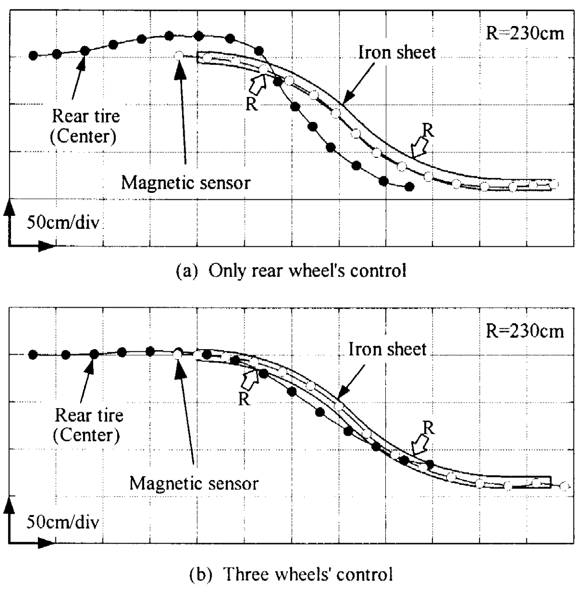


Fig. 14 Trace for S-line curve course

9. CONCLUSION

An original-made electric vehicle named NEV-III has three wheels and one drive motor, i.e., wheel-in-motor, installed in the rear wheel.

As the driving mode of the EV, there are three types as follows: the normal driving mode, the special driving mode, and the automatic driving mode.

The running characteristics of the normal driving mode are satisfied at speeds from zero to nearly 15km/h, and the regenerative braking is observed.

In the case of the special driving mode, some rotary characteristics of the EV have better results than that of conventional cars. The deviarions of all the tires from the ideal trail are small values when the EV performs the slide movement and the pivot movement, even if it is loaded heavy weight.

Moreover, regarding the automatic drive using an original-made magnetic sensor, satisfied performances are achieved.

In conclusion, the authors think that the EV and its technical concept is useful for unskillful drivers or drive at narrow space, and it would be able to contribute toward our lifestyle and traffic system in the future.

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