# Eco Car Challenge using Small Electric Car
# (1st, Characteristics of Handmade Motor for adapting to Car)

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***Abstract***

Electric car is considered as one of Eco (Ecological and Economical) friendly vehicles. Nowadays many solar generation facilities are set in local area because of cost benefit. Electricity is obviously clean energy and also more familiar for us in automotive area. World Econo Move which is Competition of electric eco car was held 4 times (2007, 2008, 2010 and 2011) in Thailand and Econo Move in Thailand 2013 was held in last year. However motor characteristic and car performance was not adapted well in many cases. As the result, running distance per regulated time was not satisfactory. The main reasons are that there is no appropriate motor which can be available for eco car and less accumulated knowledge for eco car making. This study purposes to achieve the best matching of the characteristic of DC motor to small electric car to get highly efficient eco car. 1st report shows the construction of handmade DC motor assembled by ourselves, test equipment used to evaluate the performance of the motor and the test result of the characteristic of the motor with varying wire diameter of the coil and number of wire turn as parameter. This study will be progress to make a small eco car which considers light weight design using steel and carbon materials in next step.

***Keywords**:* small electric car, brushless DC motor, characteristic of DC motor.

## 1. Introduction

Various approaches are attempted to prevent the global warming. Electric energy is regarded as clean and cost acceptable energy. In the automotive area, electric car production is rapidly proceeded and advanced systems like PHV

(Plugin hybrid vehicle)or small EV (Electric vehicle)with energy regeneration system are proposed for convenient car life by automotive makers. Electric car is coming more familiar steadily.

From several years ago, small handmade electric car by students is used to educational training material in school and college in Thailand. World Econno Move and Econo Move in Thailand, which are competition of small single-seated electric eco car, contributed obviously to their training activities. Lesser knowledge of optimization of a motor and body and matching of gear ratio connecting the motor to the wheel were seriously recognized through experiences of their competitions. In their competition, many teams used motors from electric bicycles or motorcycles without performance expression and heavy bodies without deep consideration of reducing energy consumption. Therefore it was thought to be meaningful to try to best matching with a motor which is well known performance characteristic and a small car which is designed for lightweight.

This study purposes to try to get the long running distance within regulated 2 hours using high efficiency motor and small lightweight car.

This report as part 1 describes the characteristics of the tested handmade motor which are output power, torque and efficiency and suggestsavailable motor characteristic for eco car. Test was conducted under 24V condition using 2 batteries of rated 12V. Main parameter is the number of wire turn and the wire diameter of coil. Coil temperature was monitored to observe heat loss in the motor.

## 2. Experimental Apparatus

### 2.1 Outline of experimental apparatus

Figure 1 shows the experimental apparatus system. Test motor and torque meter are connected by hard rubber coupling after adjusting same shaft height. Test motor is controlled by the controller with the sensor attached to the motor.

Input power is supplied by two batteries of rated 12V connected in series, which is always charged by battery charger during the test. Voltage and current meters are used for evaluating the input power.

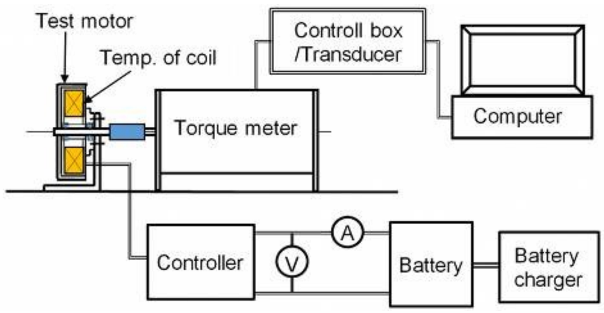



Fig. 1 Experimental apparatus system

Torque meter system is comprised from torque meter, transducer and computer, which is Model MDSKSRS056-33 made by Lenze Co., in Germany (Max. torque of 4.2N·m and Max. speed of 4000rpm).

Coil temperature was measured by Laser pyrometer (Model FT3700, HIOKI Co.)

### 2.2. Test motor

Brushless DC motor of the outer/rotor type (KtM/G-1 type, MITSUBA Co.) was used for the test. This motor is not assembled yet when purchase it. It is designed as handmade motor kit for educational use. In other word, user is able to change wire diameter of coil and number of wire turn winding into coil. This 3 phase brushless DC motor is rectified by MOSFET installed in the controller. Rated output power is 60W at 24V in assembled condition with the wire diameter of 1.0mm and the number of wire turn of 20. Maximum efficiency is 89%. Maximum speed is less than 1000rpm. However those characteristics are obtained with well assembled motor. So it is necessary to confirm the characteristics of the motor whether it is achieved by different users under the different condition. Outside view of the assembled motor is shown in Fig.2.

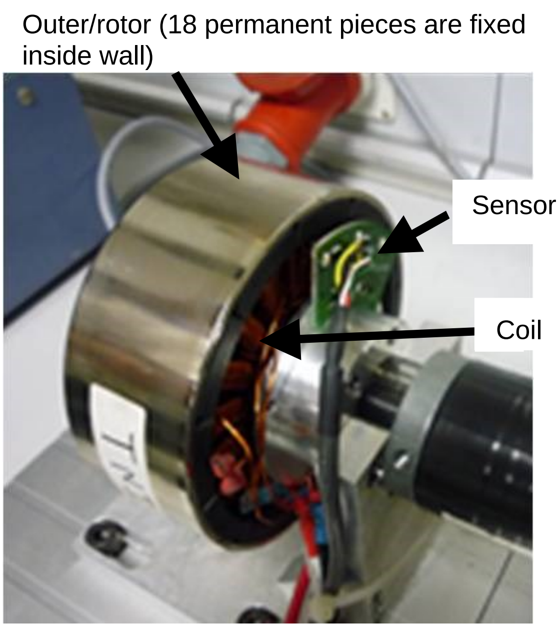



Fig. 2 Outside view of the motor

The motor is consisted from the stator with Coil in inner hub side and outer/rotor with 18 permanent pieces fixed on inside wall of rotor. Coil has 18 poles with winding wire as shown in Fig.3. Outer/rotor is connected to shaft.

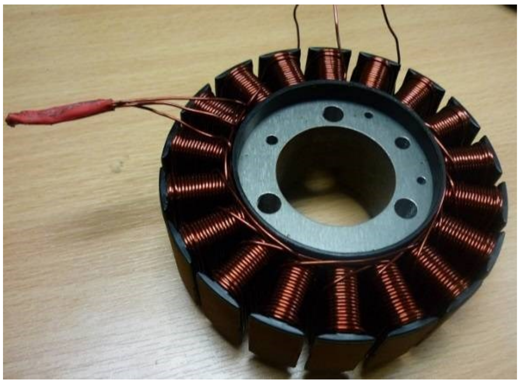


Fig. 3 Configuration of coil

### 3. Test Procedure

At the first, the motor starts on running with minimum controller volume under no load condition. After a few minute, it is accelerated to full speed by increasing controller volume and loaded to the set speed by computer input. Test was conducted with varying setting speed in decreasing by 100rpm.

Input energy of the motor is calculated with the current and the voltage measured by multi-meters attached between battery and controller of the motor by Eq. (1). Output power is calculated by torque and speed indicated on computer by Eq. (2).

$$\mathrm{Pin} = \mathrm{V} \times \mathrm{I} \tag{1}$$

Pin: Input power (W)

V: Voltage (V)

I: Current (A)

$$\mathrm{Pout} = 2 \times 3.14 \times \mathrm{N} \times \mathrm{T}/60 \qquad (2)$$

Pout: Output power (W)

N: Rotation speed (rpm)

T: Torque (N・m)

Efficiency of the motor is calculated by Eq. (3).

$$\mathrm{Eff} = \mathrm{Pout}/\mathrm{Pin} \times 100 \qquad (3)$$

Eff: Efficiency (%)

Number of wire turn was changed to 12, 16, 20 and 24 as test parameter. Wire diameter of 0.6, 0.8, 1.0 and 1.2mm was used for the test parameter.

Supplied voltage was varied from 24.5 to 28V according to the test condition. Tests were conducted under the room temperature of around 20℃.

### 4. Test Result

#### 4.1 Effect of wire turn winding into coil

When the wire turn is changed to 12, 16, 20 and 24 in the wire diameter of ϕ1.0, rotation speed and torque to the current are shown in Figs. 4 and 5. Rotation speed was decreased parallel according to the increase of wire turn. Torque was increased linearly with the increase of current and increased with the increase of wire turn. Those characteristics are remarkable point on the designing of eco car.

Selection of the rotation speed and torque is depending on the weight and speed of the car. It is reminded that higher rotation speed causes higher loss.

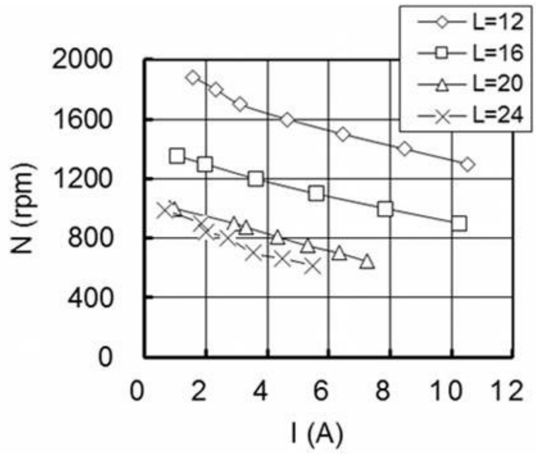



Fig.4 N-I (D=ϕ1.0)

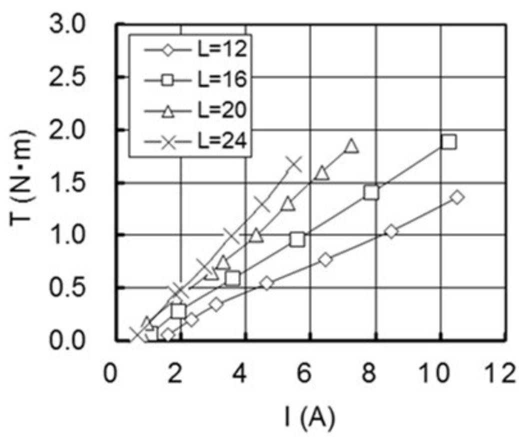



Fig.5 T-I (D=ϕ1.0)

Also in low torque selection like L=12, higher current is necessary to get the same torque.

Figures 6 and 7 are output power and efficiency. Smaller turn like L=12 can get larger output power as shown in Fig. 6, but efficiency decreases in the small current area as shown in Fig.7 because of higher loss in the high rotation speed. From Fig. 6, in the case of L=16, 20 and 24, Pout is 70W at 3A, 100W at 5A. Those output power level is suitable for the small eco car. In

L=12 and 16,higher efficiency is extended to larger current side. The maximum efficiency of 84% was obtained in L=20 (at 3A) and 24 (at 2A). In L=12 and 16, maximum efficiency was 74% at 4A and 79% at 3A respectively.

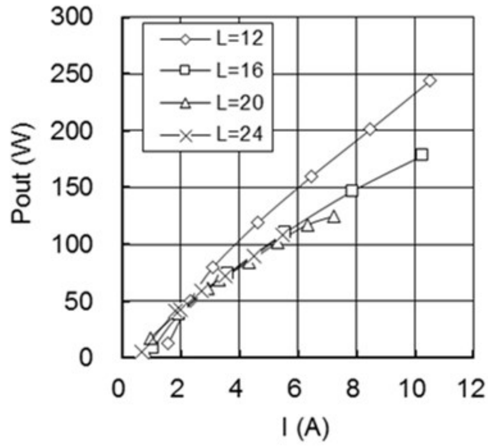



Fig.6 Pout-I (D=ϕ1.0)

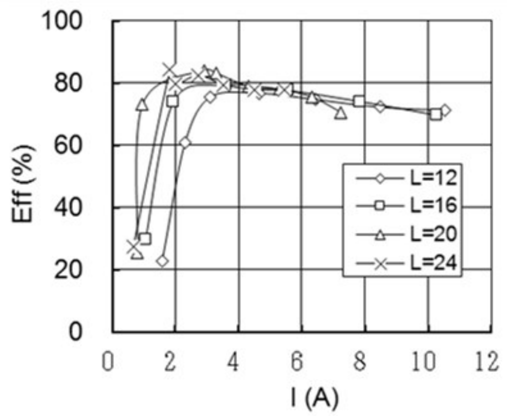



Fig.7 Eff-I (D=ϕ1.0)

When the required torque for eco car is higher, the wire turn should be selected to larger turn. If the matching of motor and car is carried out in the high rotation speed condition, the wire turn should be selected the smaller turn. From the above data, it will be suggested that L=16 has the most acceptable characteristic for eco car in case of the required power is about 150W.

**4.2 Effect of wire diameter**

When the wire diameter changed from 0.6mm to 1.2mm with the same wire turn of L=16, rotation speed and torque are shown in Figs. 8 and 9. From Fig.8, when the diameter is changed to large one at the same current, the rotation speed is increased.

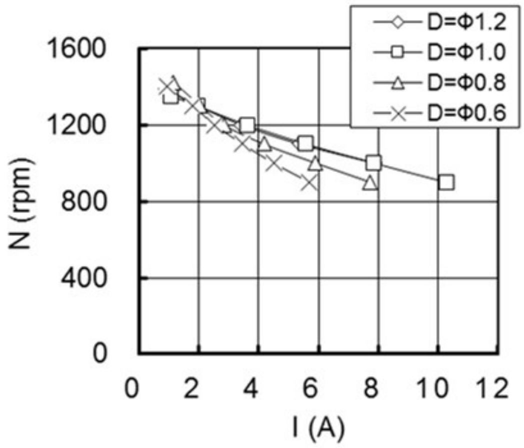



Fig.8 N-I (L=16)

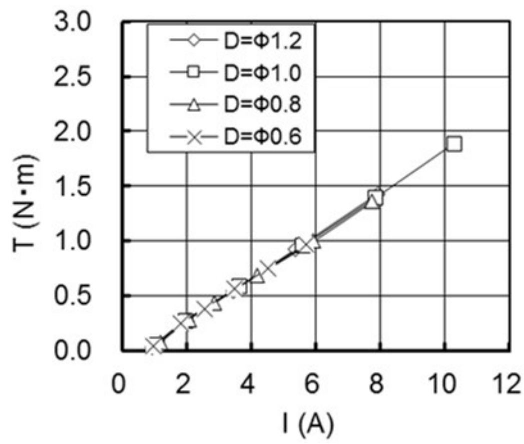



Fig.9 T-I (L=16)

Torque is almost same at the same current on each wire diameter. The torque factor which is defined as torque divided by ampere is 0.17 to 0.18 in each diameter.

Figures 10 and 11 are output power and efficiency. In the case of D=ϕ1.0 and ϕ1.2, lager output power and higher efficiency were obtained in comparison with other two cases. Therefore the candidate for the winding conditions of the coil are D=ϕ1.0 and ϕ1.2 with the wire turn of L=16.

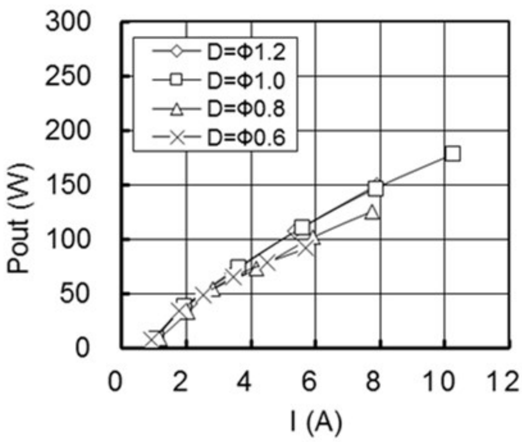
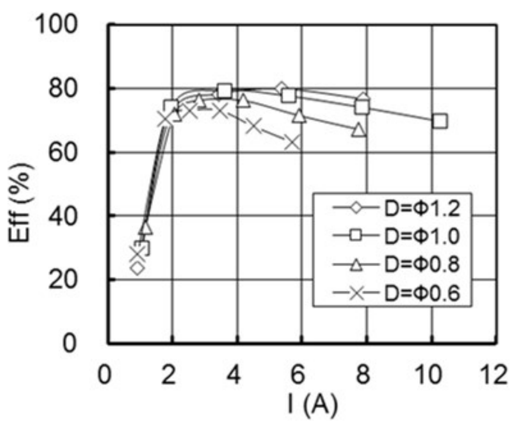



Fig.10 Pout-I (L=16)

Fig.11 Eff-I (L=16)



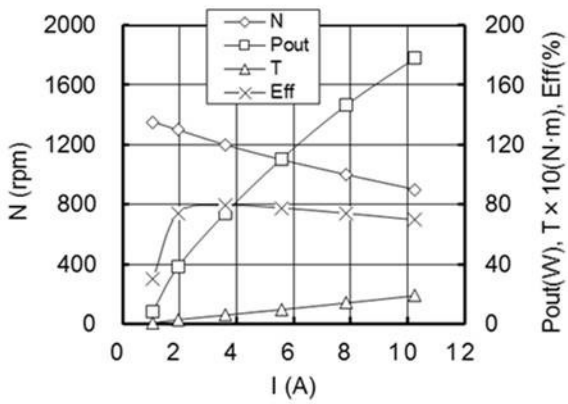




Fig.12 Characteristics of the tested motor (D= ϕ1.0, L=16)

The characteristics of these two conditions are summarized in Figs 12 and 13 respectively. Main difference of them is that the higher efficiency in the case of D=ϕ1.2 is expanding to larger current comparing with the case of D=ϕ1.0. The reason is that the higher efficiency in D=ϕ1.2 is caused by lower wire loss than that of D=ϕ1.0.It is recognized obviously by the coil temperature.

At the current of 6A, the measured temperature of coil in 4 wire diameters were 43.7℃ (ϕ0.6), 30.0℃ (ϕ0.8), 29.9℃ (ϕ1.0) and 29℃ (ϕ1.2) respectively. As the wire diameter was lager, the coil temperature was lowered. It will be suggested that the wire diameter of ϕ1.2 are recommended for eco car. In D=ϕ1.2, the output power is 150W at 8A and the maximum efficiency is 80% at 5.4A and the high efficiency is maintained comparatively wide range of the current.

## 5. Adaptation of Tested Motor to Small Car

The required power of a small car running on a flat road is calculated by Eq. (4). Rolling resistance (Rr) and aerodynamic resistance (Ra) in Eq. (4) are shown in Eqs. (5) and (6).

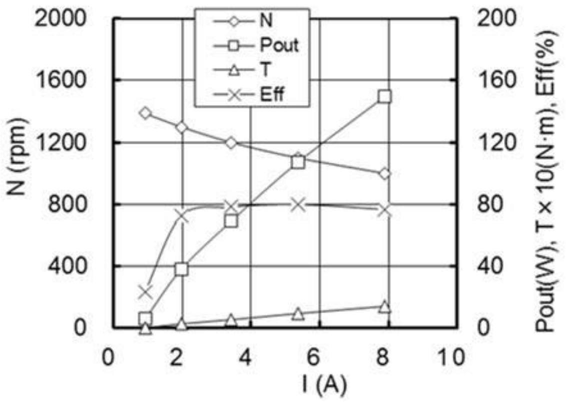



Fig.13 Characteristics of the tested motor (D= ϕ1.2, L=16)

$$P=(Rr + Ra)\times v\times(1000/3600) \tag{4}$$

P: Driving power (W)

Rr: Rolling resistance (N)

Ra: Aerodynamic resistance (N)

v: Vehicle speed (km/h)

$$Rr = \eta r \times W \times 9.8 \tag{5}$$

ηr: Coefficient of rolling resistance

W: Total vehicle weight (kg)

9.8: Gravity ($m/s^2$)

$$Ra = 1/2 \times Cd \times \rho \times A \times v \tag{6}$$

Cd: Coefficient of aerodynamic resistance ($N\cdot s^2/(kg\cdot m)$)

ρ: Air density ($kg/m^3$)

A: Cross sectional area from front view ($m^2$)

Supposing the eco car in a race, it is challenged that the car runs as long distance as possible within the regulated time or low energy consumption at the restricted distance. Therefore low powered car for saving energy is necessary when it runs at the same speed. In order to estimate the required power, the followed condition in Table 1 is used.

Table 1 Used condition

| | |
|---|---|
| ηr | 0.08 |
| A | $0.5m^2$ |
| Cd | 0.011 (with caul) |
| | 0.5 (without caul) |
| ρ | 1.2 $kg/m^3$ (at 20°C) |
| W | 70 kg (Car 20kg, driver 50kg) |
| | 80 kg (Car 30kg, driver 50kg) |
| | 90 kg (Car 40kg, driver 50kg) |

Effect of the caul (Cover above a driver to reduce aerodynamic resistance) is shown in Fig.14. It is clear that the caul is available to extremely reduce the required power. Figure 15 is the effect of vehicle weight on the required power. It is shown that light weight is effective means to reduce the required power. For the reason, composite material is considered to reduce vehicle weight. When eco car runs on 40 to 50 km/h in speed, the required power is 100W to 160W. This power range is sufficiently covered by tested motor as shown in Fig.13. Matching the characteristics of the tested motor with gear ratio to be optimized to eco car will be significant subject. It will be proceeded in the next step.

## 6. Conclusion

It is concluded in this experimental study that the characteristics of the brushless DC motor with the wire diameter of 1.2mm and the number of wire turn of 16 is the most candidate for the small sized eco car. The high efficiency of 80% in the wide current region and the output power of 100160W which meet to the required power for eco car was obtained.

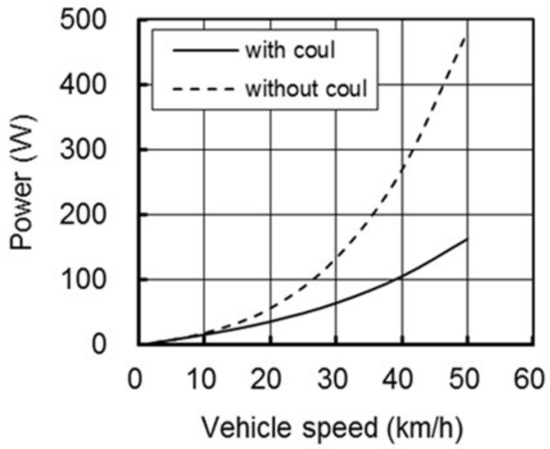



Fig. 14 Required power (with/without caul)

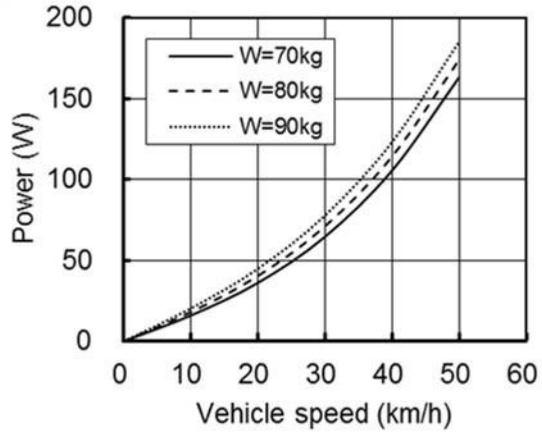



Fig. 15 Effect of vehicle weight on required power

## 7. Acknowledgement

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## 8. Reference

[1] http://www.mitsuba.co.jp/scr/about-scrproject/