# Development of Electric Vehicles in Nagaoka University of Technology

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***Abstract*** **This paper describes four types of electric vehicles (EV) which have been developed in Nagaoka University of Technology. These EVs are named NEV-I, II, III, and NEV-4. NEV-I and NEV-II are converted from commercial cars, driven by a DC motor or an induction motor, respectively. NEV-III is an original EV with in-wheel motor drive, which has innovative structure and some unique driving modes as well as automatic drive. NEV-4 has been improved to achieve high performances of running stabilization. These four EVs possess proper features, and they have been investigated for each appropriate viewpoint. According to calculated and experimental results, it is verified that these EVs have their own essential performances.**

***Keywords*** *electric vehicle, DC motor, induction motor, in-wheel motor, chopper, inverter, steer-by-wire, special driving mode, automatic drive, running stabilization, yaw-moment, cornering stiffness*

## I. INTRODUCTION

In these days, topics of EVs (i. e., battery cars) as well as hybrid cars, fuel-cell cars, and some kinds of eco-friendly cars have been increased amazingly. Different styles of EVs have been produced in Japan. Also, there are many discussions on drive motor, control system, battery, and etc. Even though, the specialties of most EVs are not utilized very well. [1]- [3]

The authors have developed four types of EVs called NEV to improve their performances and challenge to new technologies since 1996. The name of NEV is derived from Nagaoka and Electric Vehicle. The study started with converted EVs, i.e., NEV-I and NEV-II. Following them, NEV-III was designed and produced as a new-type EV. Lately, NEV-4 becomes a main subject, and its running stabilization control systems have been examined.

In this paper, the points of the features of these EVs and their particular characteristics are introduced, and the performances of them are investigated.

## II. FEATURES AND PERFORMANCES OF THE ELECTRIC VEHICLES

### A. *NEV-I (Converted EV)* [4], [5]

NEV-I is the first EV developed in Nagaoka Univ. of Tech., which was made in 1996. This EV was converted from a commercial car with gasoline engine (550cc). Fig. 1 and Table 1 show a picture and main specifications of NEV-I. For the drive motor, a DC motor was adopted, because it was thought that DC motor drive by a chopper circuit was easy to produce an EV as the first step. Indeed, a commercial car was converted to the EV in three months.

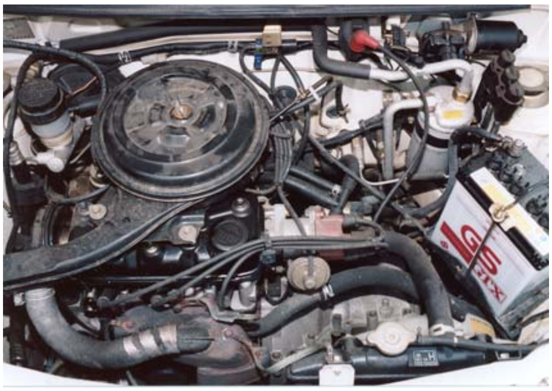

Fig. 1 NEV-I

Table 1 Specifications ( NEV-I )

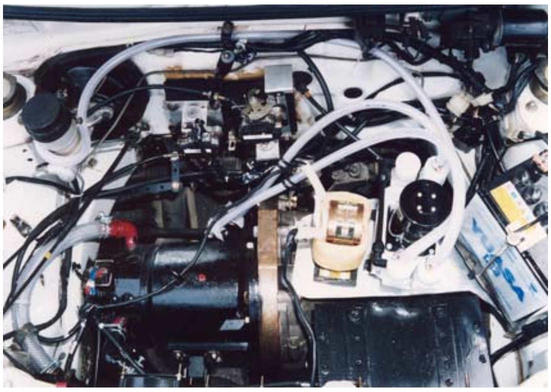
| | |
|---|---|
| Seating capacity | 2 |
| Size | 3195 (L), 1395 (W) 1335 (H) mm |
| Motor | DC motor (rating: 3.5kW) |
| Drive system | Chopper circuit |
| Battery | 120V (Lead-acid) |
| Maximum speed | 60km/h |

As shown in Table 1, the seating capacity was changed to two persons from four because of setting batteries in the rear seat position. Fig. 2 (a) and (b) show the engine room (before and after remodeling). Battery arrangement and the layout of main components are shown in Fig. 3 and Fig. 4, respectively.

Fig. 5 shows the drive system using a chopper circuit. It has the motoring and the regeneration modes, then regenerative current charges batteries when the EV brakes. In case the acceleration and the brake signal are both given, the brake precedes. Fig. 6 shows running data of the EV. Transmission was shifted from the 1st to the 4th, finally braking. The vehicle speed reached about 50 km/h, and regeneration was observed when the brake operated.



(a) Before remodeling



(b) After remodeling

Fig. 2 Engine room ( NEV-I )


Fig. 3 Battery arrangement ( NEV-I )

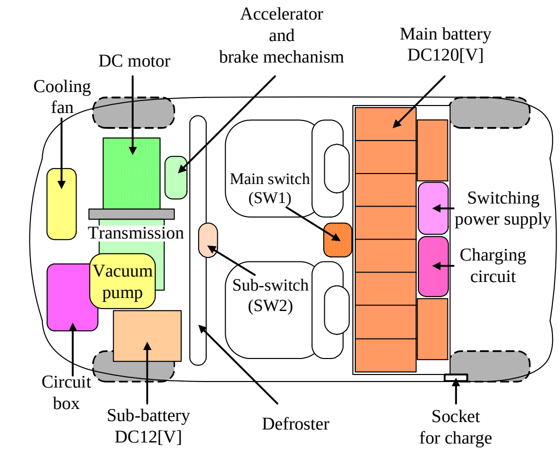



Fig. 4 Layout of main components ( NEV-I )

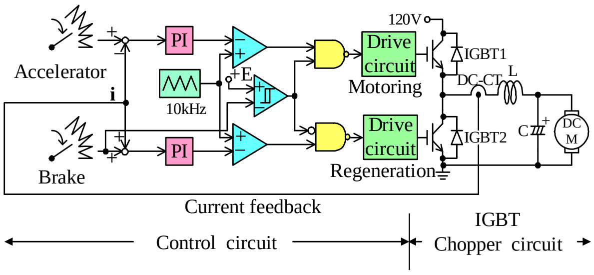



Fig. 5 Motor drive system ( NEV-I )

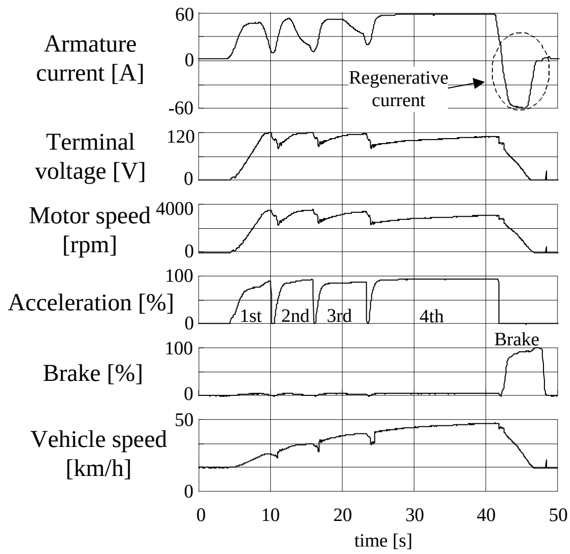



Fig. 6 Running characteristics ( NEV-I )

*B. NEV-II (Converted EV)* [6]

NEV-II was produced in 1997 followed by NEV-I to make a comparison between DC motor and AC motor drive systems. Therefore, the structures of these two EVs including the layout of main components are almost the same, as known from Fig. 7 and Fig. 8. The original car of NEV-II is selected the same type of NEV-I. But, as shown in Table 2, the motor adopted in NEV-II is an induction motor, which is altered from a commercial motor (rating: 3.7kW) to increase the rating output (4.5kW). The motor drive system is made up of a PWM inverter with quick-response and high-efficiency control which called direct torque control (DTC) method. [7]


Fig. 7 NEV-II

Table 2 Specifications ( NEV-II )

| | |
|---|---|
| Seating capacity | 2 |
| Size | 3195 (L), 1395 (W) 1335 (H) mm |
| Motor | Induction motor (rating: 4.5kW) |
| Drive system | PWM inverter with DTC |
| Battery | 240V (Lead-acid) Maintenance free battery |
| Maximum speed | 90km/h |

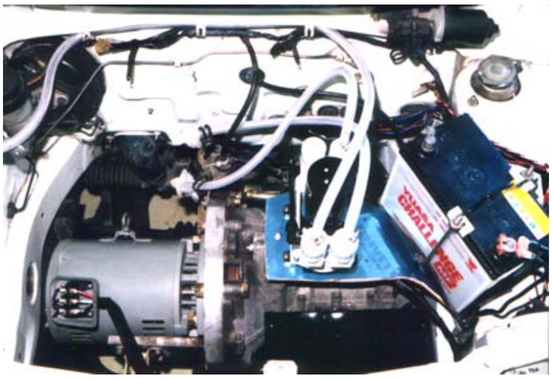


Fig. 8 Engine room ( NEV-II)

The drive system is illustrated in Fig. 9. DTC method has equivalent characteristics of field-oriented control, but it doesn't need a position sensor attached on a motor. Then the system can be composed easily and at low cost.

Field-weakening control is applied to the motor to increase its speed. As a result, the vehicle speed reached about 90km/h, as shown in Fig. 10. Besides, Fig. 11 shows actual brake function. The vehicle speed decreases quickly from 0 to around 5 seconds. It means regeneration of the motor assists the mechanical brake. The effect corresponds to the regenerative current shown in Fig. 10.

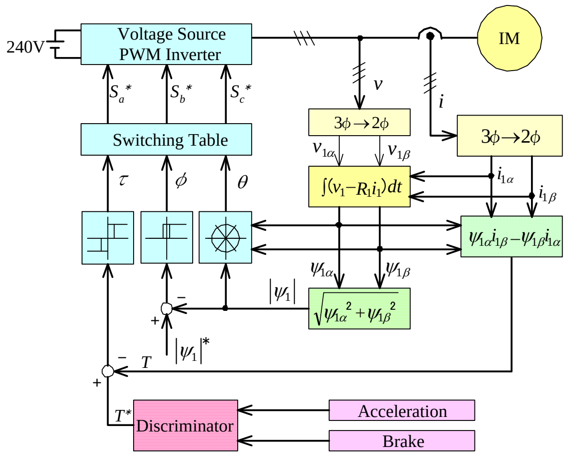



Fig. 9 Motor drive system ( NEV-II )

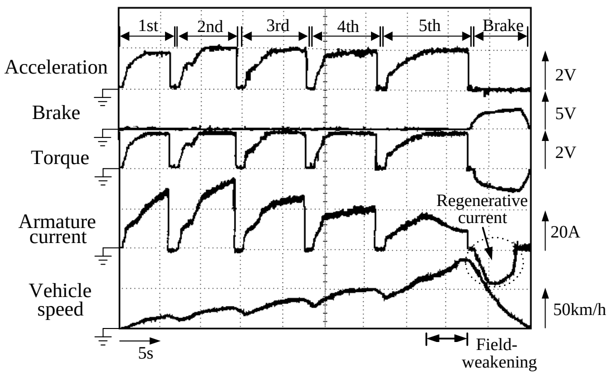



Fig. 10 Running characteristics ( NEV-II )

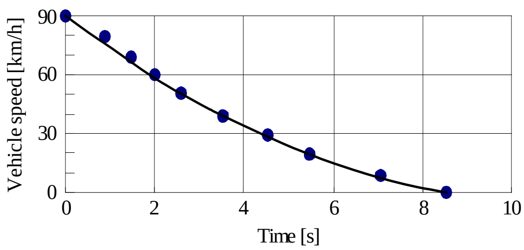



Fig. 11 Experiment of brake function ( NEV-II )

## *C. NEV-III (Original EV)* [8], [9]

NEV-III is an original EV, and it has many unique features. The prototype of the EV was made in 1997. Fig. 12 and Table 3 indicate the basic character of the EV; three wheels arranged like a triangle shape, drive by an in-wheel motor (PM motor) installed in the rear wheel, etc.

One of the merits of NEV-III is to have special driving modes, as illustrated in Fig. 13 (a), (b) and (c). The modes are slide move, pivot, and brake arranged the direction angles of three wheels. These modes can be also utilized when automatic drive is carried out without a driver.

Fig. 14 shows the servo steering system of NEV-III. There are three kinds of steering devices, as shown in Fig. 12, too. A steering wheel is used for normal driving mode which is the same style drive of conventional cars. Two joy sticks are the devices for special driving modes. Moreover, a magnetic sensor is used for automatic drive. Each servo steering system controls the direction angles of the three wheels independently, using steer-by-wire. The angles are detected by potentio-meters all the time, and compared with the signal given by one of the steering devices. Then the wheels are turned toward proper directions by DC servo motors.

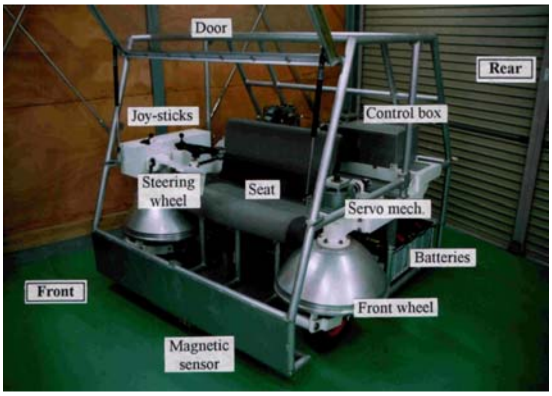



Fig. 12 NEV-III

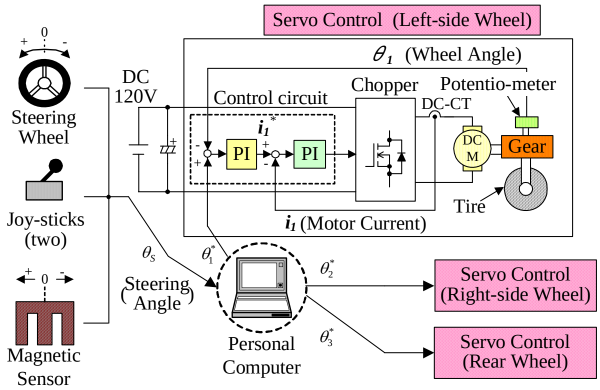
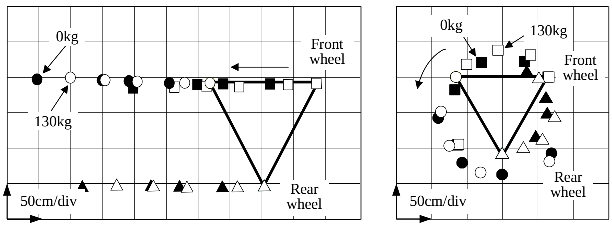



Fig. 14 Servo steering system ( NEV-III )

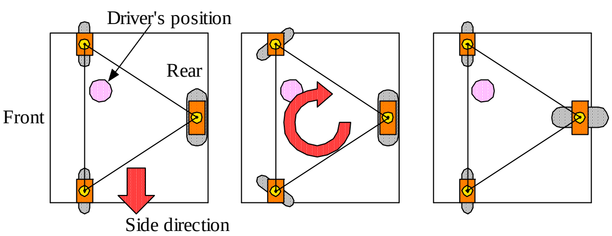
Table 3 Specifications ( NEV-III )

| | | | |
|---|---|---|---|
| Seating capacity | | 2 | |
| Size | | 1614 (L), 1560 (W) 1570 (H) mm | |
| Drive | Circuit | Quasi-current-source inverter | |
| | Motor | In-wheel motor (rating: 2kW) | |
| Steering | Circuit | 4-quadrant chopper | |
| | Motor | DC servo motor | |
| | | Front; 110W | Rear; 300W |
| Battery | | 120V (Lead-acid) | |
| Maximum speed | | 40km/h (design value) | |




(a) Slide move (b) pivot

Fig. 15 Experiment of special driving modes ( NEV-III )




(a) Slide move (b) Pivot (c) Brake

Fig. 13 Special driving modes ( NEV-III )

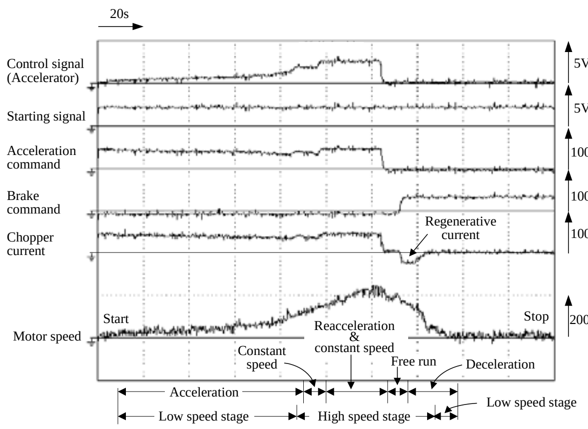
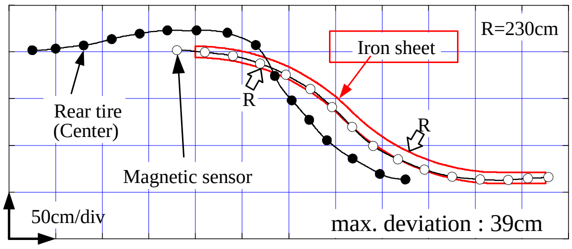
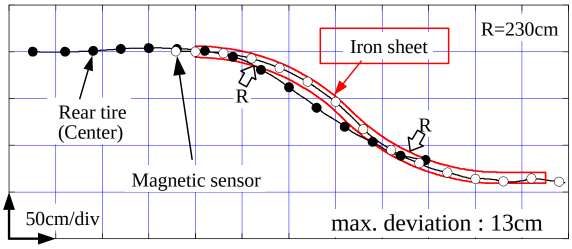



Fig. 16 Running characteristics ( NEV-III )




(a) Only rear wheel control




(b) Three-wheel control

Fig. 17 Experiment of automatic drive ( NEV-III )

The automatic drive is possible by employing an original magnetic sensor. As the running course, thin iron sheet (thickness: 1mm, width: 120mm) is put on the ground. The magnetic sensor designed and made originally is attached on the bottom of the chassis at front side of NEV-III, and it detects the course.

Fig. 15, 16, and 17 show typical experimental results of NEV-III. Firstly, examples of special driving modes comparing between the two different load conditions (0kg and 130kg) are shown in Fig.15 (a) and (b). The maximum deviation from the ideal trace was less than 10cm when 130kg weight was loaded. It is probably no problem for real drive.

Secondly, running characteristics for normal driving mode are shown in Fig. 16. The experiment carried out on several conditions continuously; acceleration, constant speed, re-acceleration and constant speed, free run, deceleration, and stop. The maximum vehicle speed reached at 15km/h in this experiment.

Thirdly, Fig. 17 (a) and (b) show the results of automatic drive. Two ways were examined, one is only rear wheel control, and the other is three-wheel control simultaneously. The maximum deviation of the rear tire from the ideal trace was 39mm and 13mm, respectively. It is clear that the latter is superior to the former. In this figure, the trace line of the magnetic sensor means the front-side center of the EV.

When one of the three steering devices gives the directional reference, NEV-III moves properly for any driving modes. According to these experimental results, it is known that the EV is appropriate to drive in small place, also it can contribute to unskilled driver. In addition, concept of the technological design of NEV-III will be able to utilize for future vehicles.

### *D. NEV-4 (Improved EV)* [10]

This is an EV with two in-wheel motors in rear wheels originally, as shown in Fig. 18 and Table 4. NEV-4 has been improved to achieve high performances since 2002. As the first strep, running stabilization control for yaw motion has been studied.

Fig. 19 and Fig. 20 show the novel direct yaw-moment control (DYC) systems. In addition, new anti-slip control is utilized as inner-loop system to control longitudinal motion. First, a simple DYC system with yaw-moment observer (YMO), as outer-loop lateral controller, is shown in Fig.19. This observer can nominalize the yawing dynamics by compensating the unknown nonlinear lateral force and yaw-moment as lumped disturbance.

On the other hand, an advanced DYC is proposed with road condition estimation, as shown in Fig. 20. In this scheme, an immeasurable parameter known as cornering stiffness is estimated from the detected yaw-rate, steering angle, wheel speed, and yaw-moment observer output in real-time.

Fig. 21 (a) and (b) show the experimental results of stabilization control on dry and snowy terrain conditions. The proposed adaptive control was compared with the robust control based on YMO when the sinusoidal steering reference was provided. The experimental results show that the yaw-rate error ( $\gamma_{error}$ ) is well attenuated by these control systems. The technologies applied to NEV-4 are very important components for safe drive, especially on snowy or iced road.

Fig. 18 NEV-4

Table 4 Specifications ( NEV-4 )

| | |
|---|---|
| Seating capacity | 1 |
| Size | 2365 (L), 955 (W)<br>1600 (H) mm |
| Motor | Two in-wheel motors<br>(max.: each 2.0kW) |
| Drive system | PWM inverter<br>with stabilization control |
| Battery | 72V (Lead-acid) |
| Maximum speed | 50km/h |

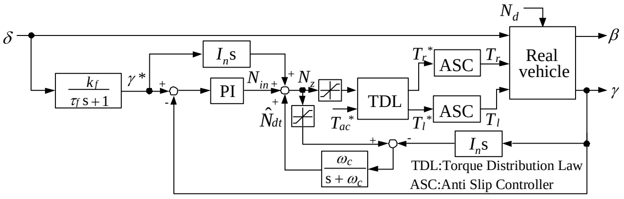



Fig. 19 DYC based on yaw moment observer ( NEV-4 )

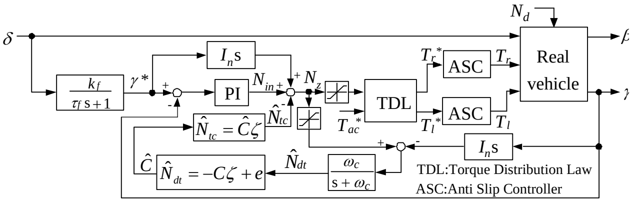
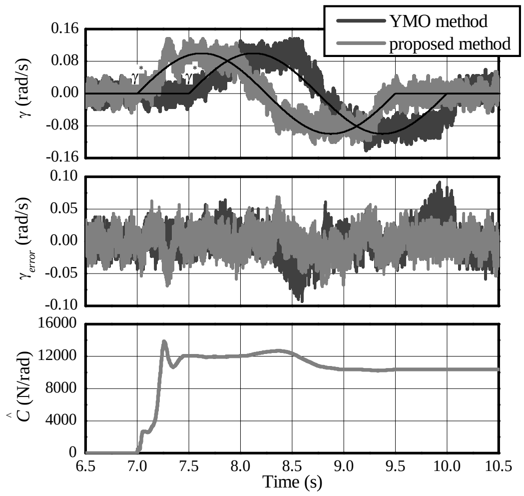
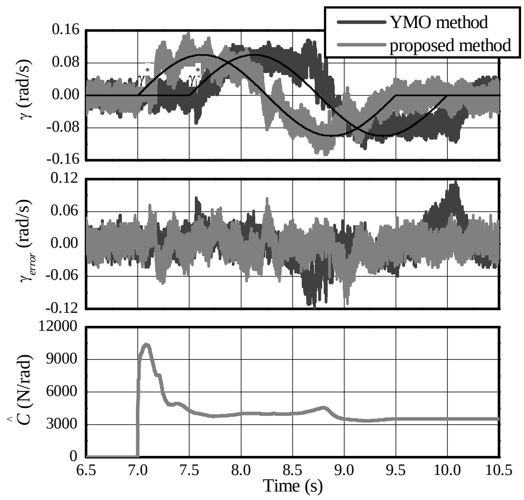



Fig. 20 Proposed DYC with cornering stiffness estimation ( NEV-4 )




(a) Dry terrain




(b) Snowy terrain

Fig. 21 Experiment of stabilization control ( NEV-4 )

# III. CONCLUSIONS

The different types of EVs developed in Nagaoka Univ. of Tech. have each meaningful feature. NEV-I has the simplest drive system among the four, and this EV has passed the automobile safety inspection of Japanese Standards since 1997 until now. NEV-II has higher maximum speed than that of NEV-I, because it is driven by the induction motor with field-weakening control. NEV-III is using steer-by-wire control for three wheels, therefore it has peculiar performances. NEV-4 is going on study; the novel direct yaw-moment control systems have accomplished already, and next challenge is examined.

Small EVs, exampled in this paper, are expected for new transport, e.g., commuter car, second car, delivery service car, vehicle for elderly people, etc. We hope that the new technologies applying to these four NEVs would contribute to the design of future vehicles.

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