

Development of an Automatic Charger for ICVS City Pal

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ABSTRACT

An inductive charger and automatic connecting unit have been developed to charge the two-seater electric vehicle “ICVS-City Pal”. Inductive charge coupling is accomplished in just one action, that is, by placing a convex cylinder shaped inductive charge coupler into a concave shaped inlet. The automatic connecting unit employs a multi-joint robot arm structure to smoothly connect the unit to the City Pal regardless of slight variations in stopping position.

1. Introduction

Tests of the futuristic Honda ICVS⁽¹⁾ joint utilization-type regional transportation system began in October 1998 at the “Twin Ring Motegi” speedway located in the town of Motegi in Tochigi prefecture. During the course of that tests, the City Pal, a two-passenger electric vehicle, was driven with the aim of becoming a next-generation commuter vehicle.

This City Pal allows automatic parking and pickup before leasing and after return within an unmanned driving area⁽²⁾. In addition, as the battery capacity of the City Pal decreases, it automatically moves to a stopping position for charging to be charged by an automatic charging unit. These units are installed and operated at two locations, the south gate port within the Twin Ring Motegi speedway and in front of the Hotel Twin Ring. Fig.1 illustrates the inductive charger and automatic connecting unit.



Fig.1 Inductive charger and automatic connecting unit

This paper provides an explanation of the overall configuration of the automatic charging system, the structure and functions of the inductive charger and automatic connecting unit, and the operating sequence. This paper also clarifies the performance of the inductive charger and automatic connecting unit.

2. Automatic Charging Technology

2.1. Automatic Charging of the City Pal

The automatic charging technology for the City Pal was designed to attain a high charging rate and to operate unmanned. Described next are the automatic charger and connecting system for the automatic charging unit.

2.2. Automatic Connecting

In order to charge an electric vehicle (EV), it is necessary to connect the charging port (charging inlet) of the EV with the charge coupler on the charger.

Automatic charging requires the charging inlet and charge coupler to be moved automatically within the connectable range.

The City Pal can move to a stopping position within an unmanned port automatically and achieve consistent stopping position accuracy. In addition, the charge coupler can move within a three-dimensional envelope defined by a robot arm. After the City Pal has stopped, the charge coupler moves to a position close to the charging inlet and is then connected, after which charging of the City Pal begins.

2.3. Structure and Characteristics of the Automatic Charging Unit

2.3.1. Arrangement of Charging Inlet and Automatic Charging Unit

- Although conventional automatic charging frequently involves connecting beneath the floor,⁽³⁾ the City Pal has

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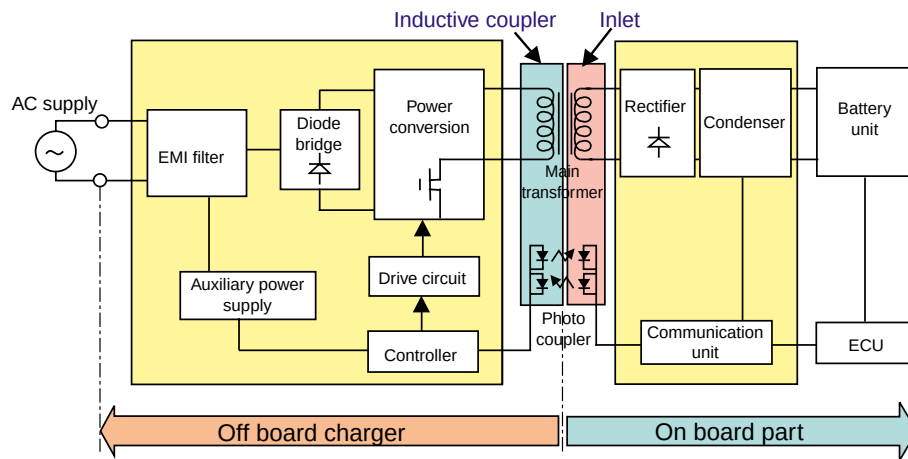


Fig.2 Inductive charging structure

a charging inlet on the side of the vehicle, thereby facilitating manual charging as well.

- The automatic charging unit can be installed above the road, enabling construction costs to be reduced by eliminating the need for embedding work.
- Since arranging the charging inlet on the side of the vehicle instead of underneath the floor results in less risk of contamination by rain and mud, the performance is stable and reliability is high.

2.3.2. Structure of the Automatic Connecting Unit

- The automatic connecting unit comprises a biaxial horizontal multi-joint mechanism, a vertical movement mechanism and a balancer mechanism (see Fig.7), thus eliminating the need for a position holding force. This structure enables the unit to follow changes in a vehicle's stopping position and maintain the connection during charging. Further, the automatic connecting unit can be easily disconnected during a power outage, malfunction and so forth.
- Connection can be performed with the driving force of a small servo motor.
- The latching mechanism on the charge coupler conserves energy, even when charging for several hours, because no energy is required to maintain the holding position.

2.3.3. Horizontal Multi-joint Structure

- Two axes of movement are provided for the horizontal multiple joints of the robot arm to enable the charge coupler to move freely within the horizontal plane, making it possible to set a wide operating range for connection.
- The joints in the robot arm allow it to be folded into a compact shape when stowed, enabling the automatic charging unit to be installed in parking lots where there is little free space.
- The charging cable runs along the robot arm, so the problem of cable slack does not occur.

2.3.4. Inductive Charging System

The charger employs an inductive charging system. As shown in Fig.2, this inductive charging system uses

electromagnetic induction to transfer electrical power through a magnetic coupling between a primary coil at the end of the charging cable and a secondary coil in the charging inlet.⁽⁴⁾ Since there is no direct connection of electrical contacts with this system, the charge coupler and charging inlet can be easily connected and made waterproof for outdoor use.

3. Automatic Charging Unit for the City Pal

3.1. Installation Sites

As shown in Fig.3, inductive chargers and automatic connecting units were installed at the South Gate of the Twin Ring Motegi speedway and in front of the Hotel Twin Ring. Automatic parking at return and delivery to the collection point as well as platooning⁽²⁾ of the City Pal mainly took place at the South Gate, with automatic charging was also provided there. Views of the installation sites are shown in Figs.4 and 5.

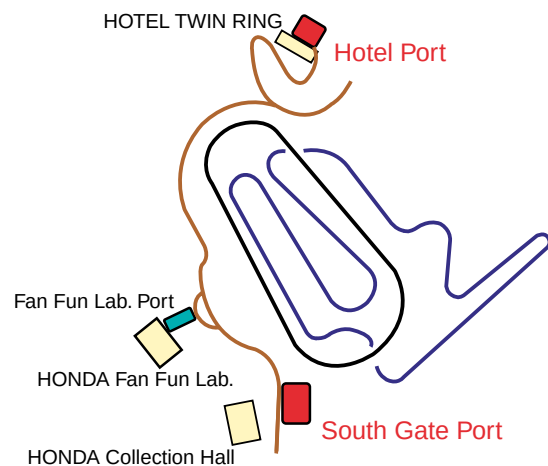


Fig.3 Automatic charger installation locations



Fig.4 South Gate Port



Fig.5 Hotel Port

3.2. Design Concept

The ICVS design concept is based on a circle. Since the ICVS project involves numerous sectors throughout the company, an overall design was employed that strongly reflects the design image of each sector. The inductive charger and automatic connecting unit also incorporate this design concept of a circle.

The housing of the arm covers the complex moving joints and cable. Although the cable is completely covered, there is sufficient free space for its movement within the housing.

In order to foster a sense of integration with the connecting unit and other ICVS, the automatic charger was designed while taking into consideration the height of the connecting unit in the standby condition. The shape is based on a circle motif, and a gray housing makes the exterior of both the automatic charger and connecting unit appear smaller. The result emphasizes that the two machines are part of a single system. Fig.6 shows image sketches of the automatic charger before development.

During the course of this development, studies were



Fig.6 Sketched image of automatic charger

conducted on the component shapes and internal arrangement of the automatic charging unit based on these image sketches. The inductive charger made it possible to save space when arranging the internal components. The automatic connecting unit was given a long vertical shape for stacking the internal components that closely matches the sketched image.

3.3. System Configuration

A block diagram of the ICVS automatic charging system is shown in Fig.7.

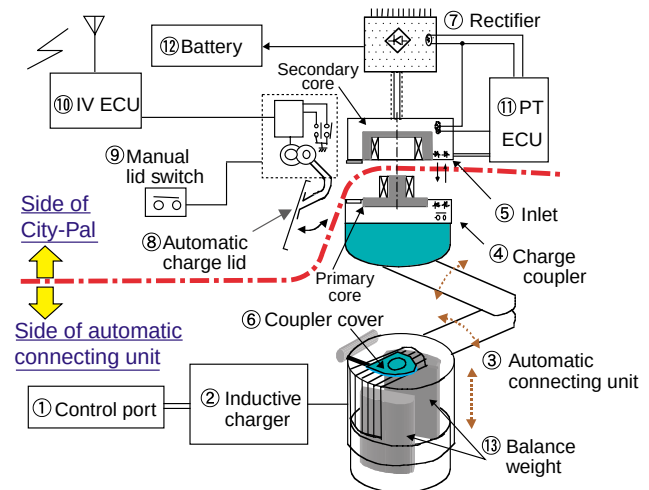


Fig.7 Automatic charging system structure

3.4. System Components

A description of the system components and their functions follows.

(1) Port Controller

The port controller controls the opening and closing of the lid, the starting of the connection and the interruption of charging, and it sends out status request commands when a vehicle is being automatically charged at the port.

(2) Inductive Automatic Charger

The inductive automatic charger is connected to the port controller by an RS422A line resistant to external interference, and performs charging according to charging commands from the port controller. The power circuit converts AC 200 V to 100 kHz high-frequency power to generate an output of 6 kW. This charger contains controllers for charging and for the connecting unit.

(3) Connecting Unit

The connecting unit is a horizontal biaxial and vertical uniaxial horizontal multi-joint robot with a charge coupler mounted on the end of the robot arm. This unit has an ultrasonic sensor for detecting the presence of a vehicle and measuring the relative distance, and a balance weight for maintaining position when the servo is off.

(4) Charge coupler⁽⁴⁾

As shown in Fig.8, the charge coupler has a primary coil around the outside of a cylindrical ferrite core. An infrared photoelectric sensor for detecting the location of the charging inlet on the side of the vehicle, and a light-receiving element for two-way optical communication

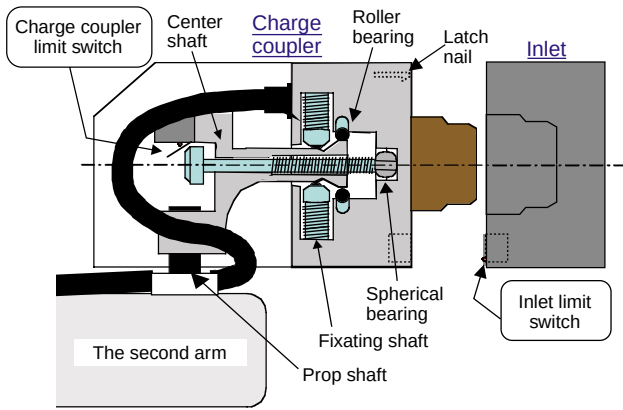


Fig.8 Set of charging coupler and inlet

between the charger and vehicle are mounted on the surface of the charge coupler. The charge coupler contains a small motorized fan that provides forced air cooling from the charge coupler to the charging inlet. A microswitch for detecting connection with the charging inlet is installed on the rear end of the charge coupler support shaft. The periphery of the charge coupler is provided with a latch to prevent disconnection by external factors during charging.

(5) Charging Inlet

The charging inlet has a secondary coil around the inside of the core. During connection, the overlapping coil arrangement results in a large coupling coefficient between the primary and secondary sides. The power transfer efficiency is 99.6%. A reflecting plate for the infrared photoelectric sensor, a light-receiving element for optical communication, and a microswitch to detect the connected condition are installed on the surface of the charging inlet.

(6) Coupler Cover

This covers the charge coupler when not connected to protect it from the effects of water and dust. During the connecting operation, the cover is open and closed by the coupler cover drive motor that operates through a crossed helical gearbox. It also has a retracting function.

(7) Rectifier

The rectifier rectifies the high-frequency power supplied through the charge coupler and charging inlet, and converts it to direct current power for charging the battery.

(8) Motorized Charging Lid

The lid protects against the ingress of rain and mud, damage caused by flying stones and tampering. This lid is motorized, and is automatically opened and closed according to a command from the IV ECU in coordination with the start and end of charging.

(9) Manual Lid Switch

The lid can be opened and closed during manual charging by the manual lid switch located in the floor of the trunk.

(10) IV ECU (Intelligent Vehicle ECU)

This controls all of the vehicle operation systems, including automatic charging. It also controls motorized lid opening and closing commands as well as charging request commands sent to the port controller.

(11) PT ECU (Power Train ECU)

This performs overall control of the EV drive system and battery management. When the residual battery charge

becomes low, a command prompting charging is sent to the port controller through the IV ECU. In addition, this also checks the temperature of the charge coupler and rectifier to monitor any abnormalities.

(12) Batteries⁽⁵⁾

Twenty-four 50 Ah Ni-MH batteries are used to generate a total voltage of DC 288 V. The total battery weight is 250 kg.

(13) Balance Weight

The weight of the arm and charge coupler are balanced by two equal weights installed inside the connecting unit to enable a small servo motor to be used.

3.5. Operating Sequence of the Automatic Connecting Unit

A detailed description of the operating sequence of the connecting unit during automatic charging is provided next.

3.5.1. Measurement of the Relative Distance

- The charging lid opens in response to a charge request from the port controller.
- The automatic connecting unit rises from the standby position (see Fig.9) to the operation reference position.
- The relative distance between the vehicle and the connecting unit is then measured at that position by an ultrasonic sensor.



Fig.9 Stand-by posture

3.5.2. Opening Operation of the Coupler Cover

- The coupler cover that protects the charge coupler during standby opens automatically.
- The coupler cover can be retracted by a crossed helical gear, and it is housed in the upper portion of the connecting unit.

3.5.3. Search Operation for the Charge Coupler

- The charge coupler moves to the charging inlet search starting position according to the measured relative distance between the vehicle and the connecting unit.
- The charge coupler begins a search sweep at the rate of 200 mm/s in front and behind the vehicle while maintaining a fixed distance between itself and the vehicle so as not to interfere with the charging lid (see Fig.10). The approximate location of the charging inlet reflecting plate is detected by an infrared photoelectric sensor installed on the front of the charge coupler.
- The charge coupler then moves to a position roughly corresponding to the location of the reflecting plate while maintaining a fixed distance from the vehicle.
- A precision search sweep is then performed at the rate of 20 mm/s to determine the planar coordinates of the reflecting plate.



Fig.10 Search action

3.5.4. Connecting Operation

- After the charge coupler position has been corrected by the amount of offset from the center line between the location of the reflecting plate and the charging inlet, it approaches the charging inlet at the rate of 100 mm/s.
- The charge coupler slows down to a speed of 20 mm/s about 50 mm in front of the position where it connects with the charging inlet, after which the charge coupler and charging inlet are connected.
- This action activates the connecting switch on the charging inlet to inform the vehicle that connection has been completed.

3.5.5. Swinging of the Charge Coupler and Completion of Connection

- When the charge coupler is pushed in towards the charging inlet by the servo motor (see Fig.11), the bearing of the charge coupler is disengaged from the fixing shaft to enable the charge coupler, which had previously been fixed on the arm, to move freely.
- The freed charge coupler is then connected at the correct angle to the vehicle and securely locked to the charging inlet.
- At the same time, the center shaft that has been pushed in by the charge coupler depresses the charge coupler limit switch, and the resulting signal interrupts movement of the charge coupler while simultaneously freeing up the servo.
- The charge coupler is finally stabilized by the resistance of the robot arm while inserted into the charging inlet. This completes the connecting operation and charging then starts.



Fig.11 Connecting action

4. Performance of the Automatic Charging Device

4.1. Inductive Charger

Fig.12 shows the charging output characteristics of the inductive charger.

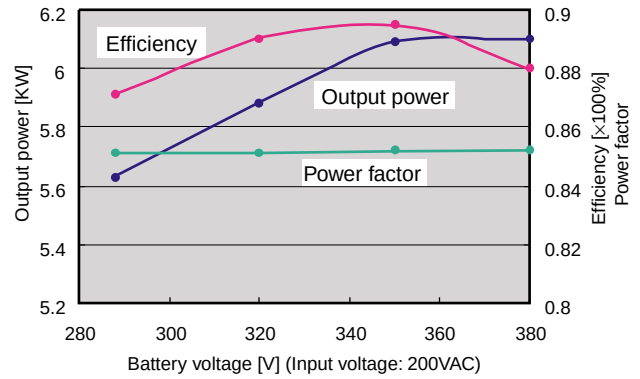


Fig.12 Characteristics of inductive charger for City Pal

A charging output of 6 kW is achieved with a battery voltage of DC 335 V or higher. As a result of this high output, the capacity of the City Pal Ni-MH batteries can be charged from 20% to 100% in roughly 2 hours. A high vehicle operating efficiency can be achieved as a result of this short charging time. The charging efficiency is 87% or better over nearly the entire range of the battery working voltage, which is higher than the figure for conventional on-board chargers.

On the other hand, the power factor is of the order of 0.85, which is somewhat lower than the figure for conventional chargers. This has resulted from the priority placed on minimizing the size of the charger, but can be improved by adding a power factor improvement circuit in the future.

4.2. Automatic Connecting Unit

Charging by the automatic charging device can be performed when the charging inlet installed inside the motorized lid of a City Pal parked at the automatic charging port is within range of the defined three-dimensional stop position. The conventions front and rear of the vehicle, left and right, up and down, and the pitch, yaw and roll angles are defined as shown in Fig.13.

The allowable ranges for the relative position and connection angle between the charge coupler and charging inlet within which automatic connection is possible are shown in Table 1 and Fig.14. The actual measured values are also shown. This device has been demonstrated to have a level of performance that is more than adequate for practical use based on the allowable ranges and measured values.

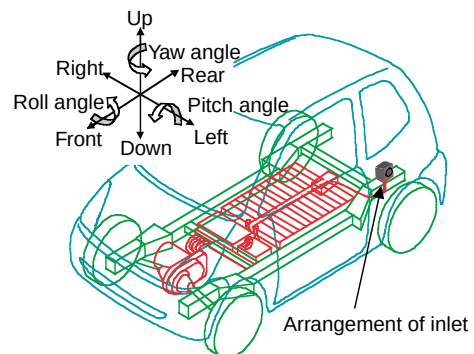
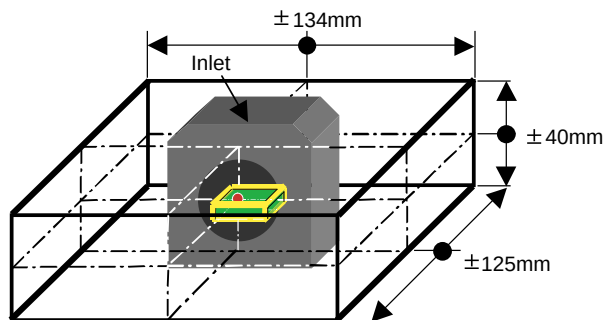


Fig.13 Definitions of directions and angles

Table 1 Test data of automatic connecting unit

Items		Connectable range of automatic connect unit itself	Automatic stoppable range of City-Pal
Difference of relative position	Front-rear	$\pm 134\text{mm}$	+7 mm -20
	Left-right	$\pm 125\text{mm}$	+5 mm -37
	Up-down	$\pm 40\text{mm}$	+4 mm -2
Difference of connected angle	Roll angle	$\pm 5^\circ$	+0.5° -2.5°
	Pitch angle	$\pm 5^\circ$	+0.5° -1.5°
	Yaw angle	$\pm 5^\circ$	+0.16°



Black frame: Connectable range of automatic connecting unit itself
 Yellow frame: Automatic stoppable range of City-Pal
 Red point: Ideal center point of connect

Fig.14 Test results for connectable range

5. Conclusion

An automatic charging system was developed that uses an inductive charger and automatic connecting unit. The following results were achieved through this development.

- The use of an inductive charging system enabled a cylindrical shape to be adopted for the charge coupler and charging inlet. This allows connection to be achieved in a single operation to provide contact between the charge coupler and charging inlet.
- The use of a horizontal biaxial and vertical uniaxial horizontal multi-joint robot arm for the automatic connecting unit allows connection to be made regardless of slight variations in stopping positions of the City Pal without causing practical problems.

These achievements have made it possible to minimize the charging time for the City Pal, maximize operating efficiency and allow unmanned operation.

6. Prospects

When considering the ideal form of automatic charging in the future, there are still many problems that must be overcome to adapt the method to manual operation for home use due to the allowable range of stopping position.

When considering the development of electric vehicles in the near future, it is predicted that the charging equipment will use a higher power level and be larger in size to provide high-speed charging of vehicles with a greater travel range,

and there will likely be a need for automatic charging based on these requirements. It will be necessary to conduct more studies on practical automatic charging systems that are compatible with manual operation.

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