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"SIM-LEI", the revolutionary efficient electric vehicle with in-wheel motors

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Abstract

SIM-Drive Corporation is a company that has spun off from Keio University in Japan.
The company's mission is to spread all the technologies that have been accumulated by Keio University for over 30 years on electric vehicles with "open source" method.

The electric vehicle named "SIM-LEI" is the 1st prototype from SIM-Drive's Advanced Development Project with multinational 34 participants including OEMs, tier1 suppliers, electrical manufactures and local governments.

In this paper, the technological highlights of "SIM-LEI" are described. Compared with the existing electric vehicles, "SIM-LEI" has more range (more than 250km on JC08mode with 24.9kWh battery), stronger acceleration (0 to 100km/h in 6sec) and larger cabin space. Those are mainly because this vehicle has adopted direct-drive outer rotor motors in four wheels, and a platform structure which contains all the components such as batteries, and inverters underneath the floor. Also, air drag and rolling drag are minimized by aero streaming body shape with drag coefficient (Cd) of 0.19 and by ultra low RRC tires.

Keywords: BEV (battery electric vehicle), efficiency, motor design, range, wheel hub motor

1 Introduction

1.1 Foreword

Although electric vehicles have a long history, they have never come into widespread use. This is attributable to their performance, which was formerly inferior to that of internal combustion engine vehicles. However, humankind has invented various technologies to dramatically improve their performance in its effort to resolve the oil crises as mentioned earlier. These technologies include lithium-ion batteries and highly-efficient electric motors with strong neodymium-iron magnets.[1]

SIM-Drive Corporation has utilized these core technologies to accumulate valuable high-performance electrical vehicle technologies. Our company was founded with the mission of rapidly pushing forward these technologies.

This is an open-source scheme. If desired, everyone can learn and work with the technologies, as well as to utilize them for the benefits of respective organizations.

To implement this, our company focuses on the Advanced Vehicle Development Projects, as our primary mission. The Advanced Vehicle Development Project I was started in January 2010. Total of 34 organizations, consisting of multinational 32 companies and 2 Japanese municipalities, participated in this project.

The purpose of our company is to allow people from participating organizations to observe the actual development process of electric vehicles, and take back the obtained experience to their organizations in order to promote the efficient transfer of technologies. This process includes all phases of production, including the vehicle concept creation, styling, design, experimental parts production, assembly, and testing, in which all participants can be involved.

1.2 Basic concept of the vehicle

The basic concept of SIM-Drive Advanced Vehicle Development Project No. 1 was to realize the advanced development model for electric vehicles that can stimulate the motivation of the automobile industry to utilize our electric vehicle technologies, with a view toward its mass production in around the year 2013.

More specifically, we aimed to develop electric vehicles that can surpass the same class of internal combustion engine vehicles in terms of acceleration, space, and comfort, and yet have a range per charge of 250 km. These were identified as the minimum requirements to realize commercialization.

The target users were set as motor vehicle enthusiasts in their fifties who will choose vehicles having adequate functions to enjoy a one-day short trip, for example, for playing golf with a group of four members. Therefore, the vehicle was required to be of a size that can accommodate four golf bags. The reason was that people of this age are economically advantaged and living a prosperous lifestyle, and they used to have a great longing for cars.

One reason for defining the target value of range per charge as 250 km is that the results of various questionnaires showed that 50% of consumers in Japan have an intention to buy electric vehicles if the range per charge is 250 km.

If enthusiastic users can buy new products, the initial market will be created. Once the market is established, technological development is gradually enhanced, thereby leading to the expansion of market. If this cycle is continued, it will ultimately be made possible to achieve a higher performance that can satisfy the demands of all people.

The primary technology employed for realizing the basic concept is our original outer rotor direct type in-wheel motor and component built-in frame.

The primary advantage of the outer rotor direct drive in wheel motor is extremely high efficiency as compared to the onboard type that is the basic drive system used for conventional electric vehicles. Further, this can increase the use efficiency of space. Also, the in-wheel motor can provide simpler structures and consequently facilitates the body design. In addition to these three major advantages, sophisticated vehicle control technique can be used to enable independent torque control of each wheel, and four-wheel drive vehicles can be easily developed. Because the heat release from the motor is easier, it is possible to expand the potential to use rare metal magnets without using dysprosium, which causes problems with resources.

Adoption of the component built-in frame can offer the following benefits. First, it can provide a larger interior space because major components are housed in a structure under the floor. Secondly, the vehicle weight can be reduced because the battery container is integrated with the frame structure. Thirdly, housing the heaviest motors under the floor allows for a lower centre of gravity.

The combination of the in-wheel motor and the component built-in frame makes it easier to develop four-wheel drive vehicles. This advantage can be used to deliver higher acceleration performance than in conventional internal combustion engine vehicles. In regard to space, major components can be housed in the space between the floorboard and wheels, which was not used in conventional vehicles, to offer a larger space above the floor.

With respect to comfort, the vehicle features less rolling during cornering and minimized nose dive during braking, resulting from higher controllability of the four-wheel drive system, ease of operation, and lower centre of gravity.

The second key technology employed in this Advanced Vehicle Development Project is the reduction of aerodynamic drag for extending the range per charge. Aerodynamic drag is an important factor while driving on highways. To minimize aerodynamic drag, it is required to reduce both the coefficient of drag (Cd) and the frontal projected area.

To reduce aerodynamic drag, persistent efforts have been made. Based on experiences, we aimed to achieve Cd=0.19 in this project.

As another new technique to minimize aerodynamic drag, the thickness of the doors were reduced and the moldings of a height of 10 cm and a width of 5 cm for protection against side impact were installed on the outer panels of the door to reduce the frontal projected area without decreasing the width of the passenger compartment.

This technology could be used to realize a structure with a reduced overall vehicle width, adequate strength against a side impact, and yet a smaller frontal projected area.

The third key technology is the selection of batteries and tires.
For the battery, lithium-ion battery with LTO anode was adopted in this project. This battery has great advantages in terms of power density, safety, and usable life. Of these characteristics, the magnitude of power density can guarantee excellent acceleration performance and increase the charging speed. In addition, this battery can increase the regeneration efficiency during deceleration. Especially, the increased regeneration efficiency contributes significantly to the improvement of the range per charge while driving in city traffic as represented by JC08 modes.

In regard to the selection of tires, we requested a tire manufacturer to develop tires with a low rolling friction coefficient with the aim of extending the range per charge. As a consequence, they have developed tires that can fully satisfy our requirements.

2 Technologies

2.1 Exterior/Interior Design

The concept of the exterior design is “The Proof of Concept”. It can also be referred to as the “body with ultra-low aerodynamic drag” because it was realized as one of the key strategies to attain the target of over the 250km range per charge. To minimize aerodynamic drag, a new approach was made to complete an aerodynamic profile, in addition to reducing the frontal projected area. The vehicle width was reduced to minimize the frontal projected area. The side impact beams usually located inside the door panel are installed outside the door in this model 1 to make the door thickness about 50 to 80 mm smaller, which helped reduce the frontal projected area, without compromising the interior space. In conventional passenger cars, overall approaches are made to improve aerodynamics with full attention to optimize various requirements such as the interior space, crosswind stability, and wind noise preventive measures, as well as to reduce the drag of coefficient (Cd value). In comparison, challenges were made with a focus on minimizing Cd value in this model 1. (The target Cd was set for 0.150 to 0.190, with respect to the Cd value of 0.250 to 0.350 for ordinary passenger cars.)

As the product of 3-stage wind tunnel testing(Fig. 1), the Cd value of 0.190 was achieved.

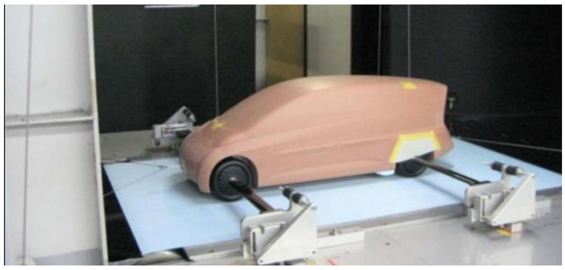


Figure1. Wind tunnel test

The concept of the interior design is “Iconic Design”, which refers to “visible technology”. This is the design that addresses the challenge to visualize the technical features of this vehicle employing the in-wheel motor structure in which the conventional engine or motor is not mounted under the hood and the component built-in frame (CBF) that houses all components under the floor.
When you open the door and sit on the front seat, the eye is immediately drawn to the impactful space that reflects the original concept called “Impact Space”. On the simple front fascia panel from which a massive dashboard and air-conditioning unit (HVAC) were eliminated, the panoramic display with a large 19-inch monitor is located and tightly secured by the trim extended forward from both doors. Four information display panels that tend to be inorganic and mechanical are surrounded by the full acrylic panel with finely wavy soft curves and surface, appealing to the emotional design that will be the new wave of an electric vehicle’s interior.

Figure2. Interior design of SIM-LEI

2.2 Body structure

While following the “component built-in frame” concept that was matured in “Eliica”[2][3] that was designed by a team at Keio University, the new steel monocoque body structure for next-generation electric vehicles was developed to realize high productivity, high quality, and low cost on a global scale, and yet also ensure great safety and stiffness.

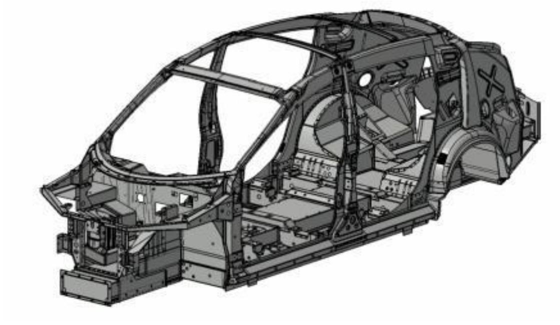


Figure3. Body structure of SIM-LEI

Especially, full-flat stepless floor for easy entry and exit was realized by battery/component built-in frame structure. The conceptual drawing is shown in Figure4.

With this structure, batteries housed inside the body can eliminate the sub-frame type, which are usually adopted by retrofitted battery housing structure in competitive electric vehicles, so that light weight, cost reduction, and high productivity are realized.

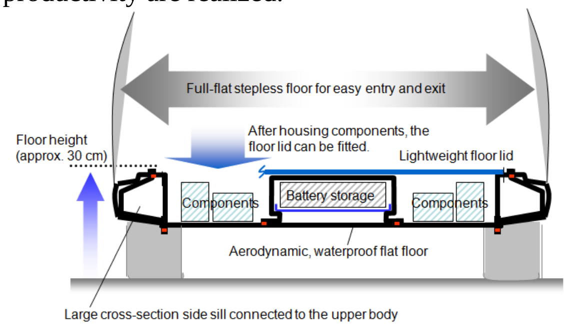


Figure4. Section Image of platform structure

2.3 Chassis

The chassis technology was developed and reviewed, with a primary focus on; In the outer rotor in-wheel motor vehicles, it is designed to resolve the problem with the layout arising from the motor width, track, BBF width, and tire size, and to realize the front suspension system fitted with the steering.

The multi-link suspension system developed for this model offers superiority in handling, tight turn capability, ride comfort, brake performance, and flexibility in styling. This suspension system made it possible to complete the layout of the front wheels containing the outer rotor in-wheel motors (Figure5).

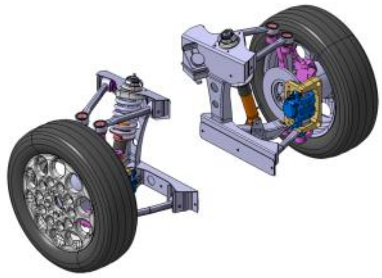


Figure5. Front suspension system

If the conventional McPherson strut or double wishbone type is adopted for the front suspension system, the kingpin axis inclines largely to the inside of wheel due to restriction of motor width. This increases the distance from the intersection point of the kingpin extension with the road surface to the centre of the wheel contact face (kingpin offset), which can degrade the straight line vehicle stability due to traction force, braking force, and road surface disturbance that exert on the wheel contact face.

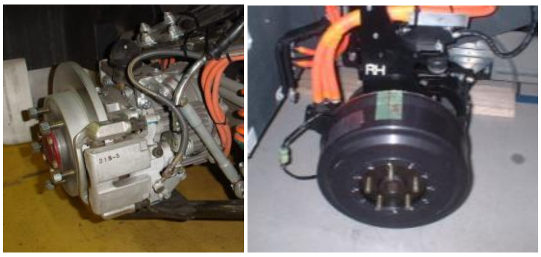
To resolve this problem, the multi-link suspension system that consists of two links for upper and lower arms was adopted to eliminate the kingpin offset and optimize the kingpin inclination. This could realize outstanding handling, stability, and ride comfort.

The kingpin axis in the multi-link system refers to a virtual axis formed by the intersection point of the two upper arm extensions and the intersection point of the two lower arm extensions. The support material strength of the kingpin axis is important in terms of handling stability.

2.4 Motors

This model is the four-wheel drive vehicle employing the direct drive outer rotor in-wheel motor technology capable of travelling at practical speeds. This was realized by the development of motor that can deliver high torque without using the reduction gear.

In-wheel motors can be driven either by a gear reduction as in Eliica[2][3] (Figure6) or using direct drive, which is the technology that has been newly developed for the last 5 years[4].



Gear reduction (Eliica, 2005)

Direct Drive (SIM-LEI, 2011)

Figure5. Two types of In-wheel motor

Because the gear reduction motor requires a high-speed low torque motor and a gearbox, friction, core and gear losses are higher. On the other hand, with a low-speed high torque motor to drive the wheel directly, a robust mechanical structure and much higher efficiency is obtained.

Table1. Motor Specification

Diameter	300mm
Poles	12
Teeth	18
Max Power	65kW
Rated Power	20kW
Max Torque	700Nm
Torque Constant	1.82Nm/Arms
Max Efficiency	96%
Weight	50kg

Due to the realization of this configuration, it could attain higher energy efficiency than conventional electric vehicles fitted with a gear reduction system. Furthermore, in terms of regeneration performance, high regenerative energy recovery could be realized because there is no energy loss caused by gears.

3 Performance

3.1 General specification

Utilizing newly developed technologies above, the advanced development model named “SIM-LEI” was completed in March 2011.(Figure6, Table2)

Figure6. SIM-LEI

Table2. Specification of SIM-LEI

Length	4787mm
Width (Overall)	1600mm
Width (w/o outer door impact beam)	1515mm
Height	1550mm
Wheel base	2950mm
Weight	1620kg
Min Turning radius tire	5.5m
Number of passengers	4

As mentioned above, the goal of this project is to develop an electric vehicle that can surpass the same class of ICEVs in terms of acceleration, space, and comfort, and yet have a range per charge of 250 km.

With the body structure named Component Built in Frame(CBF) and the long wheel base, SIM-LEI realized a full flat and larger cabin space than conventional ICEVs in C segment. Although width is much smaller than conventional cars, according to the result of questionnaire, most Japanese people did not find it insufficient, because the length of the cabin gave them enough space.

3.2 Acceleration

The result of the acceleration test is shown in Figure7.

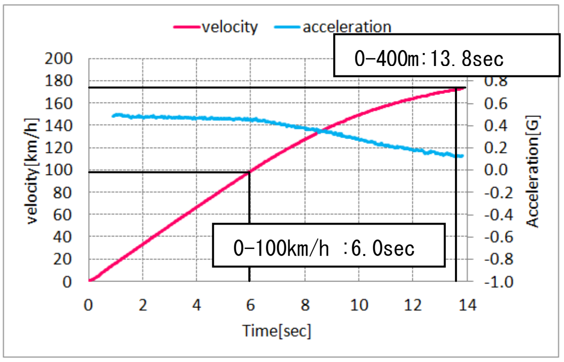


Figure7. Acceleration of SIM-LEI

Driven by four in wheel motors and high power battery, SIM-LEI realized the acceleration of 0-100km/h in 6.0sec and 0-400m in 13.8sec. Furthermore, passengers can enjoy strong and long-lasting acceleration (0.5G) from 0km/h to 100km/h. This character of acceleration can only be realized with direct drive in-wheel motors.

3.3 Efficiency

The result of electric energy consumption test is shown in Figure8 and 9.

Figure8. SIM-LEI on Chassis dynamo

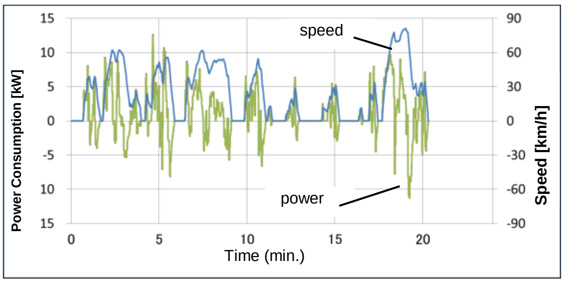


Figure9. Power consumption on JC08 mode

Whether or not negative values are obtained in the electric power shown in Figure9 depends on the electric power volume collected by the regeneration brake. The higher the negative value is, the better the efficiency of the regeneration is. As clearly shown, the negative values are extremely high, which indicates the collections by the regeneration were conducted sufficiently. This is the proof that the combination of direct drive in wheel motor and lithium ion battery with LTO anode gives an electric vehicle much more efficiency.

As a result, the electric energy consumption rate of SIM-LEI is 75Wh/km, so the autonomy would be 333km with 24.9kWh battery capacity.

4 Conclusion

The first Advanced Vehicle Development Project of SIM-Drive was conducted for a year from January 18, 2010 to March 31, 2011.

During the period, a series of processes was complete from the planning till the final stage to acquire a certification.

The result achieved was that the range is 333km by JC08 running mode, which was revolutionary for a practical electric vehicle. Furthermore, it has significant meaning in that it was proved by the battery capacity, 24.9kwh for this achievement.

This result was finally achieved after conducting the developments repetitively even though it was once said that the practical use of the electric vehicle was a dream.

As a matter of course, the developed one here is an advanced development model, and therefore, the arrangements are needed to proceed to mass production and commercialization.

Hereinafter, based on the results of the advanced development model, the productivity based on the reliability, durability, and safeness is required to testify for the commercialization. It is assumed that a high amount of cost will be incurred, but the directions on how we conduct them have been grasped.

The mission of SIM-Drive is to perform the activities toward the penetration of the electric vehicles along with the said direction in the future.

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