Designing and Manufacturing of a Hand-made Electric Motorcycle

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Abstract
In the department of Intelligent Mechanical Systems Engineering, Kochi University of Technology, the synthesis lecture has been being carried out in 3rd and 4th year grades of the undergraduate program. One project of the synthesis lecture in our laboratory is design and manufacture of a hand-made electric motorcycle. In this report, the student activity of design and manufacture for a hand-made electric motorcycle is described. In the past, the electric motorcycles by other educational organizations had been produced by replacement of gasoline-engine to electric motor and batteries as the other parts are those of purchased motorcycle. In our project, the design and manufacture for a whole motorcycle was conducted by a student himself. As well as the design, the analysis and manufacturing aspect is considered to be of great importance for mechanical engineers. As a capstone learning course in the 4th year, the student in our laboratory tried to design and manufacture of a hand -made electric motorcycle. These designing and manufacturing results are reported.

Keywords
electric motorcycle, 3D-CAD, engineering education

1. INTRODUCTION
The Kochi University of Technology was opened in April, 1997. The university has been trying to develop new engineering educational curricula such as first year seminars using real products [Sakamoto et al., 1999], experimental courses using vehicles [Sakamoto, 2001], computer assisted English education[Greene, 1999; Hunter, 1999], and so on. Among them, the author thinks that the design education is of great importance, as Fargason [Fargason, 1995] mentioned that design is an engineering synthesis. In the previous paper [Sakamoto et al., 2003], two extracurricular (out of class and no credit) activities [Sakamoto, 2001; Sakamoto et al., 2001] were reported.

The synthesis education like design was performed after the 3rd year grade, and the experiences gained by extracurricular and in class activities helped in their education. As for design education, 3D-CAD lecture has been considered, and a design of manual winch was selected because the text [Technical Education Committee, 1991] teaches how to calculate and is thought to give an appropriate time to draw. As for 3D-CAD software, three kinds are applied, ProEngineer, Solid Edge, and Solid Designer. Along with the design practices, an electric motorcycle was selected to be a project since it can be a good target to start. As well as the design, the analysis and manufacturing aspect is considered to be of great importance for mechanical engineers. In the past, the students designed, and the manufacture was conducted by a neighboring company because of the technology and tools. As a capstone learning course in the 4th year, a student in our laboratory tried to design and manufacture of a hand -made electric motorcycle, using a welding equipment.

In the following, the designing and manufacturing practice for an electric motorcycle is reported.

2. 3D-CAD DESIGN EDUCATION
In our laboratory of the mechanical engineering department, basic and advanced design education has been conducted. Figures 1-4 show the examples of practices conducted in 1997-2004.

3D-CAD design education and practice conducted in the past in our laboratory are considered to bring a practical knowledge for design and manufacture of electric vehicles [Sakamoto, 2004] such as electric motorcycle.

As the course and practice summary, the followings are concluded.

(1) As a design exercise, the design of electric vehicles is proposed, and the design course and practice was performed in our laboratory.

Fig. 1 A CG of three-wheels electric vehicle in 1997

(2) The 3D-CAD parts and assembly design in the past were successful.
(3) However, the manufacturing exercise using welding has not been conducted so far. For the next project, manufacturing using welding is to be included.

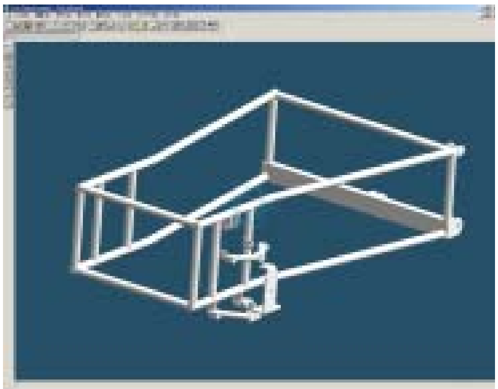

Fig. 2 A 3D-CAD view of the electric vehicle frame in 1999

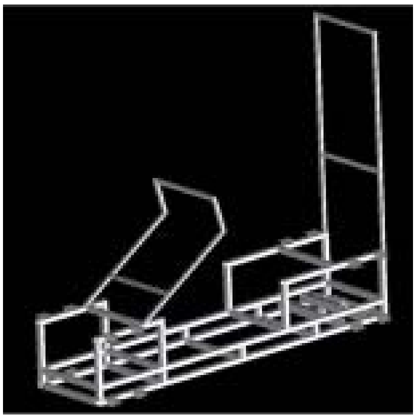

Fig. 3 A 3D-CAD of electric vehicle frame in 2003

Fig. 4 A 3D-CAD of electric vehicle in 2004

3. DESIGN AND STRESS ANALYSIS OF HAND-MADE ELCECTRIC MOTORCYCLE

3.1 Engineering aspects to be considered

An electric motorcycle has been studied as a capstone project of a 4th grade undergraduate. In this chapter, a brief explanation of the design and manufacture is given. The size of the motorcycle is decided in the same manner of the electric automobile [Sakamoto, 2004]. The electric motorcycle has to be transported, when batteries are gone or an emergency accident happens. The idea is the same as the electric automobile [Sakamoto, 2004], and small-sized trucks are possible to carry. Therefore, the size should be within 1,900 mm length and 1,200 mm width. The size was decided to be similar to a gasoline-powered bicycle. 3D-CAD using ProEngineer is studied for the planned motorcycle.
After the design is finished, the motorcycle is to be manufactured. The welding equipment is ready to use this time in our laboratory. The motorcycle is produced mainly by welding. The maximum speed aimed is 25 km/h. Table 1 shows the main specification of the electric motorcycle.

Table 1 The specification of designed motorcycle

Category	Items	Value
Dimension	Length	1,470 mm
	Width	575 mm
	Height	900 mm
Motor	Type	DDW-4060-D
	Axle Output	600 W
	Torque	30 Nm
	RPM	200 rpm
	Weight	12 kg
Battery	Type	BP35
	Capacity	16V-33Ah
	Weight	6.48 kg
	Numbers	4
Others	Tire Size (Front)	80/90-16 *
	Tire Size (Rear)	80/90-17 *
	Max. Speed	23 km/h
	Distance	20 km
	Total Weight	70 kg

* Japanese Standards

3.2 Suspension, motor, battery, and gear ratio

The role of suspension is to support the weight of the motorcycle, to absorb the shock energy, and to maintain the vehicle posture stable. The front suspension applied is stereo-scopic one, which is the main front suspension used for most motorcycles. This suspension enables cushion stroke to be long enough in the fork space, and consists of a coil spring and an oil damper in the cylinder. The rear suspension is the swing-arm type linked one. The reason for selection is to maintain the motorcycle stable and easy driving by locating the weight center in the middle. At the same time, the swing stroke

should be minimum at the bottom location, and the mechanism can be simple.
The motor for the motorcycle is selected to be an in-wheel motor DDW-4060 type D manufactured by Honda Co. The motor is brush -less one, and the voltage is 48 V. The disadvantage of the motor is the heavy weight. A battery used is lithium-iron. Figure 5 shows the motor and battery.

Fig. 5 In-wheel motor and lithium-iron battery used

The aimed maximum running speed is 25 km/h (6.9 m/s), and the value was determined from the experience of the previous rally [Sakamoto, 2004] using the same motor and with the speed limitation of gasoline-powered bike. The gear ratio is 1:0.872, which was decided from the sprocket gear number of 41 and the tire size of 90/90-17 (Domestic standard) at the rotational speed of 200 rpm.

3.3 Frame configuration

The frame is a double-deck one to maintain the enough space to install four batteries inside. This frame configuration aims to obtain the enough strength. So, the size is determined to be 1,200mm in length, 250mm in width, and 700 mm in height.
For the frame configuration, the design was conducted by using a ProEngineeer. The design of light-weight and easy maintenance is the target. The material used is rectangular pipes, because they are stronger than round pipes when the motorcycle subjects to bending due to cornering. In this research, the rectangular pipes of 40 x 20 mm and 25 x 12 mm and the square pipes of 19 x 19 mm and 25 x 25 mm are used. The material is SS 400.
Figure 6 shows the main frame designed, in which the strength for bending and the space for the motor and batteries were taken into consideration. Figure 7 shows the rear frame, which needs the strength against stresses at the swing-arm attachment portion. By designing the triangular form, the light-weight and sufficient strength were confirmed. Figure 8 shows the motor mount, whose pipes used are 16 x 16 mm square ones. The assembly of the parts were designed and shown in Figure 9.

Fig. 6 The main frame

Fig. 7 The rear frame

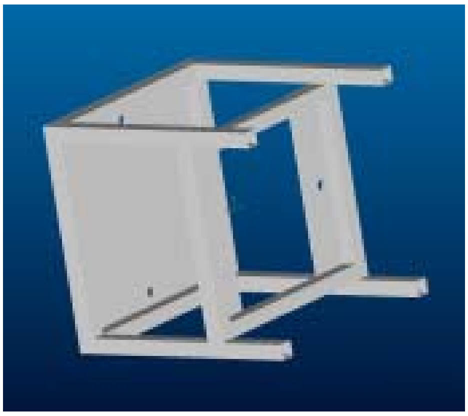

Fig. 8 The motor mount

Fig. 9 The assembly model of the motorcycle

3.4 Stress analysis

To confirm the strength of the designed motorcycle frame, the stress analysis using ProMechanica was performed. In prior to the analysis of the designed frame, a simple calculation was conducted, using a cantilever model of 100 mm x 100 mm cross-section and 1,000 mm length with the force of 50 N at the tip. The calculation by hand is 0.3 MPa and the result by FEM is 0.29 MPa. This result is considered to be enough to perform the FEM stress analysis for the motorcycle model.

The conditions for the analysis are as follows,

(1) Weight: Person of 80kg, Battery of 6.48 kg/one, Motor of 12 kg

(2) Fixed portions: 2 portions of the front frame steering head and the rear front swing-arm attachment.

(3) Material of SS400: Tensile strength of 400 MPa, yield strength of 230 MPa, and fatigue strength of 180 MPa

The result is shown in Figure 10. The maximum stress origination is 166.7 MPa at the main frame. The safety factors are 2.4 for tensile strength, 1.4 for yield strength, and 3.6 for fatigue strength. The safety factor for yield strength may not be enough. However, by conducting the experiments, the modification will be considered.

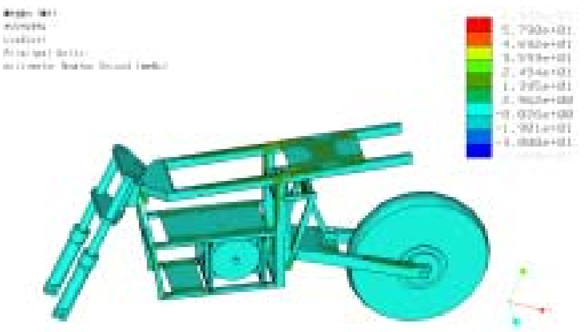

Fig. 10 A result of FEM stress analysis

4. MANUFACTURING AND THE PERFORMANCE OF HAND-MADE ELCECTRIC MOTORCYCLE

4.1 Manufacture

In the research on electric vehicles [Sakamoto, 2004], the welding was conducted by a neighboring manufacturer, because the laboratory had not possess the welding equipment. At the present, the welding equipment was purchased. In the case of the arc welding for a pipe whose thickness is less than 1.6 mm, the welding may cause a hole due to high temperature rise. In our laboratory, semi-automatic welding which may be able to weld without troubles is not available. Therefore, in this case, brazing for pipes of thickness less 1.6 mm is applied, and pipes of more than 2.0 mm thickness is welded by arc welding.

Even though the melting point for brazing is low, distortion might occur. Actually, the local distortion happened. However, the design was conducted in a manner not to have such distortion. Figure 11 shows the constructed frame. After finishing the construction, front-arm, swing-arm, batteries, and motor are assembled in the frame. Figure 12 shows the manufactured motorcycle.

Fig. 11 The welded frame

Fig. 12 The fabricated motorcycle

4.2 Running experiment

After the design and manufacture was completed, the running experiment had been conducted. The location is in the university, and the road loop around 1 story building is 300 m length. Number of running cycles are 40, and the total distance of running is 12,000 m. The items measured are the maximum speed obtained, voltage reduction change according to the running, and the temperature of the batteries during the continuous running. One lithium-iron battery contains four cells. One cell is used as BMU (battery module unit), by which the voltage is controlled to be constant. The speed control is conducted by a potentiometer shown in Figure 13. Figures 14 and 15 show the voltage reduction for one battery, the one of total four batteries, and the temperature rise during the continuous running experiment. The maximum velocity obtained was 23 km/h (6.4 m/s). The value is considered to be fairly good from the planned maximum velocity of 25 km/h (6.9 m/s), considering the friction between tire and road. The speed of 25 km/

Fig. 13 The potentiometer for speed control

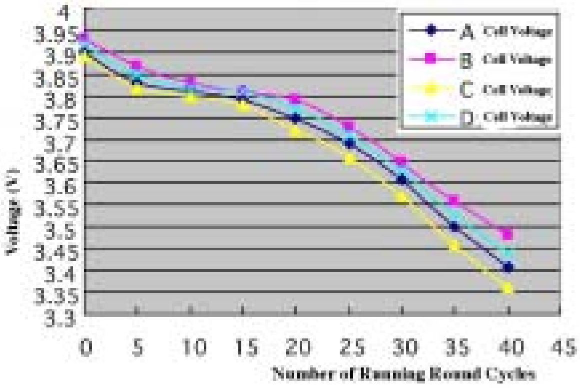

Fig. 14 Experimental variation of the No. 2 battery voltage vs. running cycle

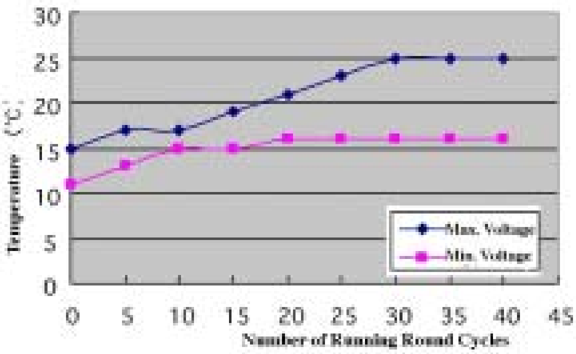

Fig. 15 The temperature change during running cycles

h is almost same as our estimation.

As for the voltage of the batteries, the minimum voltage should be more than 32.4 V, and the obtained minimum voltage during the running test was 42.6 V. The total running capacity is estimated to be 20 km. As Figure 15 shows, the temperature of the batteries measured was 25 ℃, and the permissible temperature of the batteries is 65 ℃. In the range of the experiment, the battery was able to be used without troubles.

5. DISSCUSION AND CONCLUSION

As an undergraduate capstone project of design and manufacture, a 4th year grade student in our laboratory challenged a hand-made electric motorcycle, and some same grade students supported the project.

5.1 Design and manufacturing education

Students learned how to design using 3D-CAD software, mainly ProEngineer and Solid Designer. The course in the past includes how to assemble, and they were able to make 3D-CAD even in a form of assembly. Solid form like a ProEngineer or a Solid Designer enables students to perform the stress analysis using solid forms. In the project, there introduced 3D-CAD and stress as well as the manufacturing practice of a hand-made electric motorcycle. The manufacturing was conducted by welding, which is the first experience in our laboratory.

5.2 Design and manufacture project of electric motorcycle

One of the students in our laboratory, Mr Taku Fukui who went abroad for study at the present, selected the capstone project for his graduation theme in 2003. The project is a hand-made electric motorcycle. The work included 3D-CAD, stress analysis, and manufacture. The manufacturing was conducted by himself by using the welding equipment. Since the category of the vehicle is in gasoline-powered bicycles, the maximum velocity should be below 30 km/h. The aimed maximum velocity was 25 km/h determined from the capacity of the motor, and the actual maximum velocity obtained was 23 km/h. The project contains 3D-CAD and manufacture, and is thought to be a good example for engineering education.

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