Design and Control of a Motor-assisted Tricycle

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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. Projects of the synthesis lecture in our laboratory so far have been design and manufacturing of hand-made electric vehicle, motorcycle, and tiller. In this report, the student activity of design and manufacturing for a hand-made motor-assisted tricycle is described. In the past, the four-wheels electric vehicle was produced for the elder drivers. However, the four-wheels vehicle cannot be used in pavements and roads for bicycle or tricycle. In the country-side in local areas in Japan, which is apart from main roadways, a tremendous roads are narrow. Therefore, there is not distinct boarder for roadways and pavements in such areas. From such a viewpoint, the tricycle vehicle was planned for the people who need to use in the country-side. The vehicle was designed for especially elderly drivers by using a motor-assisted tricycle. In our project, the design and manufacturing of a motor-assisted tricycle was conducted. Receiving a development proposal from the Kochi University of Technology for a motor-assisted tricycle, Daioh Machinery Co.,Ltd. designed and manufactured a hand-made motor-assisted tricycle. The Kochi University of Technology assisted Daioh Machinery Co.,Ltd., and three students in the fourth year grade joined the team under the guidance of Daioh Machinery Co.,Ltd. and the university.

Keywords

electric vehicle, tricycle, 3D-CAD, stress analysis

1. INTRODUCTION

The Kochi University of Technology was opened in April, 1997. Since then, engineering educational curricula using electric vehicles have been studied. They are small-sized electric vehicles [Sakamoto et al, 2001; Sakamoto and Amimoto, 2004], electric motorcycle [Sakamoto, 2004], and electric power tiller [Sakamoto, 2005 to be published]. The other curricula are English assisted lectures [Greene, 1999; Hunter, 1999] and 3D-CAD for manual winch [Technical Education Committee, 1991]. The small-sized electric vehicle was tried to develop, taking into consideration of gentle to elderly drivers. The reason is that our area is country-side and local one, and the ratio of elderly people is around 20%. As for the transportation circumstance, there are two aspects. One is the ratio of elderly drivers, and the other is the issue of global warming. Fatal transportation accidents in Japan have increased, and the rate of elderly drivers fatal accidents is 40.4 % among the total in 2003. In the past 10 years, the accidents by the first person concerned (the one using vehicles of motorbike or more powered one) increased 2.8 times. In the country-side, the elderly drivers need to use such vehicles because the public transportation system is not well developed in such areas. The other issue of global warming is a big one for the world. We have conducted to study electric vehicles for the future use from such a consideration. Our viewpoint is to spread out the electric vehicles in the country-side and local use for especially elderly people.

In order to develop the vehicle which takes into consideration of use by elderly drivers and global warming, we started the project. The basis is the electric vehicles we have studied in the past. However, we needed to survey the required specification for use by elderly drivers and for use of vehicles in permitted pavements or roads for bicycles. The final specification decided is a motor-assisted tricycle, which can run by a motor only in the speed range of less than 6 km/h (1.7 m/s) and by motor-assisted in the range of 6 km/h (1.7 m/s)-25 km/h (6.9 m/s). The project consists of surveying the traffic regulations, 3D-CAD design, stress analysis of designed frame, and control.

In the following, the design and manufacturing practice for an electric tricycle is reported.

2. SPECIFICATION OF MOTOR-ASSISTED TRICYCLE

In the Society of Electric Vehicle in Japan (SEV), there is a committee called as AREEV (http://www.areev.org) [Uchida, 2004]. The committee developed the four-wheels electric vehicle shown in Figure 1. The vehicle received a good reputation, and many academic schools purchased it as an educational tool. However, we thought that it might be hard to drive because of the low seat location and the pedal action at such a location. From the above mentioned viewpoint, we modified the vehicle as is shown in Figure 2. The seat location was changed to the height of around 1,000 mm from around 400 mm. The wheel base width of 830 mm was modified to 560 mm, because of the capability to run on pavements if the regulation is permitted. However, after the search of traffic regulations, we noticed the four wheels vehicle can not run on pavements or roads for bicycles.

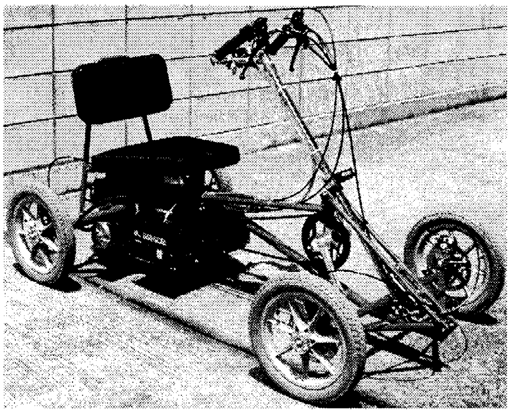

Fig. 1 Four-wheels electric vehicle by SEV (Courtesy of SEV)

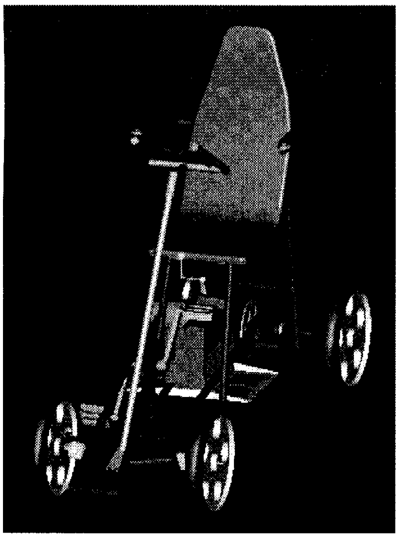

Fig. 2 3D-CAD of modified four-wheels electric vehicle

2.1 Target of motor-assisted tricycle

After the survey of the traffic regulations and discussion in the laboratory, we decided the target for development as follows.

The vehicle is a motor-assisted three-wheels one (tricycle), and it runs by a motor only mode at a low speed below 6 km/h (1.7 m/s) and by a motor-assisted mode at a higher speed from 6 km/h to 25 km/h (6.9 m/s). The reason for the idea is in the followings.

(1) The vehicle aimed is the motor-assisted tricycle. The bicycle with motive power can not be registered as a light weight bicycle, and not be able to run on the pavements whatever the traffic sign on pavements shows. For a bicycle, the sign, if there is a sign beside the pavement, permits for it to run.

(2) The motive power light-weight vehicle like bicycle or even a mini-car are not permitted to run on the roads for bicycles. In the case that batteries are gone, the vehicle needs to put the light on.

(3) The traffic law in Japan describes that light-weight vehicles like bicycles have to run on pavements for bicycles and roadway as is described in Item 17 of Chapter 1. Running on roadway by bicycles is dangerous, unless the roadway is wide enough. Normal roadways in country-side and local areas are narrow, and running on roadway by bicycles is not fit in such areas.

(4) The same law prohibits for vehicles of not 2 or 3 wheels to run on roadways. Therefore, the aimed vehicle needs to be 2 and 3 wheels one, if we design the vehicle to be able to run on pavements with the permission sign for bicycle use or pavements for bicycles.

(5) For elderly people to use vehicles, we need to consider the one without licenses, and the one to run at a low speed.

2.2 Design concept and rough design

The vehicle specification was studied by the following existing vehicles.

(1) Motor-driven senior wheelchair by Suzuki

(2) Motor-assisted bicycle Assista-series by Bridgestone

(3) Motor-assisted bicycle VIVI series by National Bicycle

(4) Three-wheels tricycle Trike by Avantec

We started to consider Trike during the middle of studying the specification for our vehicle because we noticed at that time that the aimed vehicle is similar to Trike. The Trike at the beginning was a tricycle without motor-assistance. When our specification was established and we started to design and manufacture our vehicle, the motor-assisted Trike was put in the market.

The specification for our motor-assisted three-wheels tricycle is as follows. The dimension was decided in a manner that conventional bicycles are to be within 1,900mm length x 600mm width, and wheelchairs are to be within 1,200mm length x 600mm width x 1,090mm height. The motor unit, battery, and battery charger were purchased from a trading company in Kochi. The condition for purchasing is that they should be used for the

Table 1 Specification for motor-assisted tricycle for development

Item		Value or Content
Dimension (Length x Width x Height)		1,160x560x1,000 mm
Weight		20 kg
Motor Unit (By National Bicycle)		VIVI unit
Battery (By National Bicycle-Ni-Hydrogen)		VIVI unit
Battery Charger (By National Bicycle)		VIVI unit
Tire (Front 2 wheels, Rear 1 wheel) Normal Type		16x1.5, 18x1.75
Driving Method		Chain type
Brake Method		Manual
Steering Method		Front wheel by hands
Control Method	Assisted Running	Pedal force proportional
	Wheel Chair	Electric switching
Maximum Speed	Assisted Running	24 km/h
	Wheelchair (Forward)	2-6 km/h
	Wheelchair(Backward)	2 km/h
Slope Angle		10 °
Continuous Running for Wheelchair Mode		15 km/h
Driver' Maximum Body Weight		100 kg

purpose of our project development. The specification is shown in Table 1

Figure 3 shows the rough design of the tricycle based on the design concept. (1) is the side frame having a camber angle for both sides. (2) is the steering part. (3) is the pedal location which is not under the seat. (4) is the location for battery. (5) shows the adjustment for seat height and location so that a driver can smoothly drive. (6) shows the device for hopefully adjusting the angle. Figure 4 shows the 3D-CAD based on the rough design for the motor-assisted tricycle to be developed.

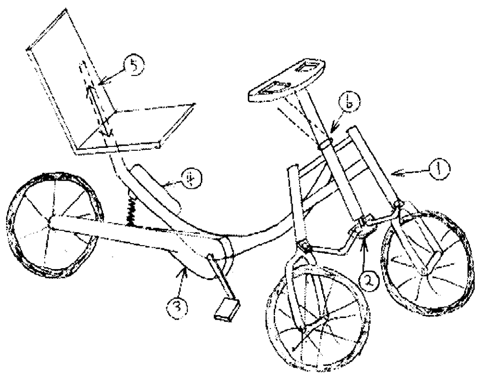

Fig. 3 Rough design of motor-assisted tricycle

Fig. 4 3D-CAD of version 1 motor-assisted tricycle

3. DESIGN AND STRESS ANASYSIS OF MOTOR-ASSISTED TRICYCLE

3.1 Detail design

Based on the specification and the rough drawing, the 3D-CAD was made. Figure 4 shows the first version of 3D-CAD. By drawing the 3D-CAD, the dimension and configuration was cleared. The rear frame configuration and the location of battery needed to be changed. The seat was to be reconsidered because the vehicle size is outside the limitation. The handle angle, (6), adjustment was found not to be necessary because the vehicle size is smaller than expected. Figure 5 is the second version of 3D-CAD after the above modification was taken into consideration. The design and manufacture was conducted by Daioh Machinery Co.,Ltd., and the Kochi University of Technology assisted the design work. The parts designed are about 40, excluding the ones from outside.

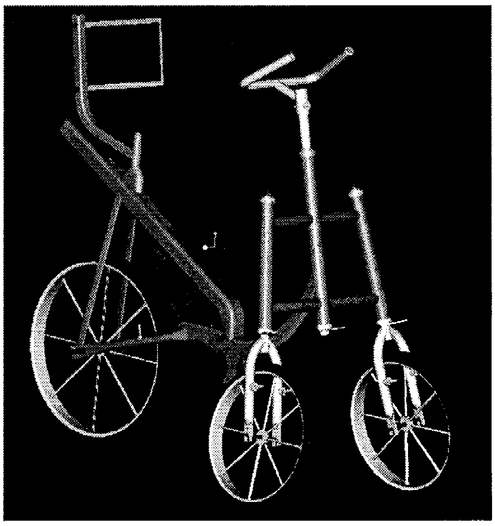

Fig. 5 3D-CAD of version 2 motor-assisted tricycle

After the design work was finished, Daioh Machinery Co. estimated the manufacturing cost, and requested to both team of Daioh and KUT the cost reduction. The ideas we applied were to use the standardized aluminum rectangular or round pipes, to reduce machined parts by applying bending or squeezing, to apply bolted parts instead of welding, and so on. We also modified the rear configuration, frame for supporting the motor unit, frame thickness, and so on. As was mentioned, we noticed that Avantec Co. in Chiba, Japan produces the tricycle without motor-assistance when we were almost finalizing the design work. Due to the complicated design of

the front portion of the tricycle we aimed, we decided to apply the front portion of Trike because of time shortness for development. Avanec Co. permitted for us to use the portion, since our vehicle is in the development stage. We need to consider the way to produce the portion in the future. However, we might continue to purchase the portion by discussing with Avantec Co.
The next step before manufacturing is the stress analysis of the frame, and if no need to modify is admitted we proceed the manufacture. The stress analysis was conducted for the main rear frame since the front frame is to be purchased from Avantec Co.

3.2 Stress Analysis

To confirm the strength of the designed motor-assisted tricycle front frame, the stress analysis using ProMechanica was performed. The analysis was performed under the condition in Figure 6 as follows. The fixed points are A and B. The loading conditions are 800 N at C as personal weight, 10 N at D as battery weight, and 60 N at E as motor weight.

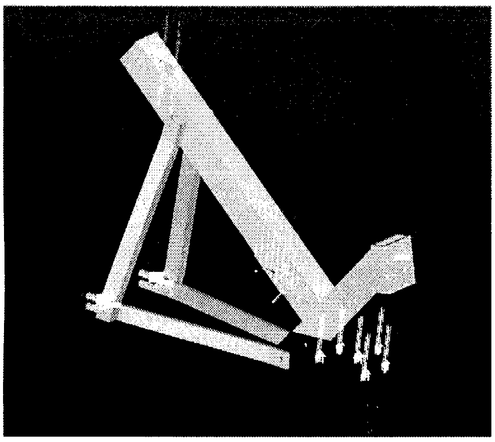

Fig. 6 FEM stress analysis model

Fig. 7 Results of FEM analysis

The maximum stress originates at the fixed position for the rear wheel support. The value is 35.2 MPa, and the safety factors are 3.5 for tensile strength, 2.7 for yield strength, and 4.4 for fatigue strength. The material properties of the used material A6063 are the tensile strength of 185, the yield strength of 145 MPa, and the fatigue strength of 70 MPa. The stress concentration factor was assumed to be 3.5, and the dynamic stress amplitude to be ± 0.3 g.

4. MANUFACTURE AND CONTROL OF MOTOR-ASSISTED TRICYCLE

4.1 Manufacture

The final design was decided. Since the front portion of the vehicle is going to be purchased from Avantec Co., the 3D-CAD was completed for the rear portion. Supposing the rear potion is the one by 3D-CAD, the whole assembly as an image is described as 3D-CAD assembly shown in Figure 8. We put a different backrest for the seat. The total parts designed are 23. Figure 9 shows the fabricated tricycle.

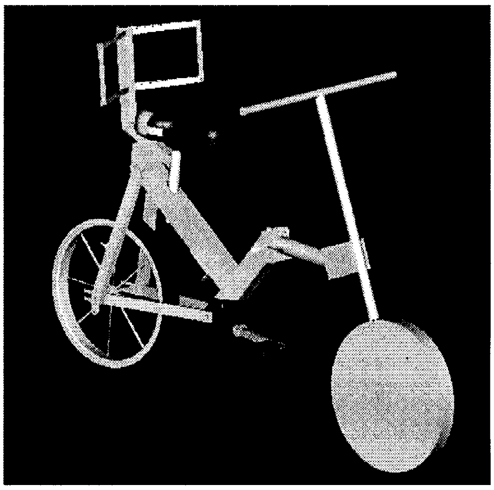

Fig. 8 Whole assembly image with assumed front portion

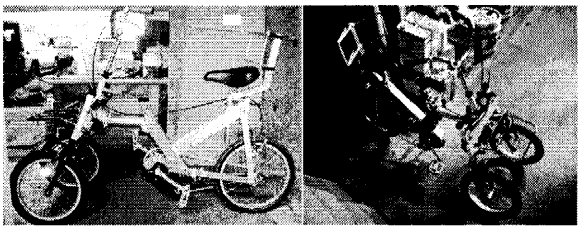

Fig. 9 Manufactured motor-assisted tricycle

4.2 Control for motor-only drive

In order to secure the function of the motor-assisted tricycle, motor-only drive under 6 m/h and motor-assisted drive in the range of 6-25 km/h, we need to add the control function for motor-only drive. The motor-assisted drive is given by the motor unit purchased from a trading company in Kochi. Therefore, we needed to consider a special control device for the motor-only drive. We also need to consider the explicit switching device for changing the function from and to the motor-only drive to and from the motor-assisted drive. This is the request from the police station when we asked a possibility to realize the motor-assisted tricycle. The vehicle should be able to run at a low speed less than 6 km/h by motor-only driving on pavements.

According to the specification of the catalog received from the manufacturer, the motor characteristics are as follows. They are the motor of DC brushless, power of 240 W, motor-assisted drive control of pedal force proportional method, battery of lithium-ion or lithium-hydrogen with 24-26 V and 2.8-3.6 A. The motor unit consists of torque sensor, microprocessor, and DC brushless motor.

In order to add the function of motor-only drive to the motor for the motor-assisted tricycle, we decided to use a wire for signal in the torque sensor. We firstly need to switch from the function of motor-assisted drive to motor-only drive. We add a button besides a switch to start because we need to avoid for the vehicle to run immediately after switching. Using a wire of torque sensor signal, we made a H8 microprocessor (AKI-H8/3048F) circuit. Since this circuit is only used for the experiment of motor-only drive, the circuit is hand-made one.

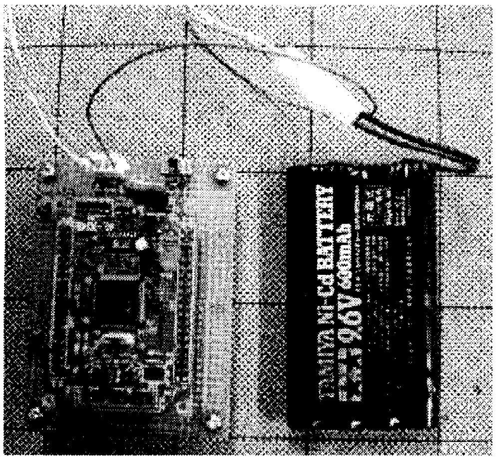

Fig. 10 Experimental set-up

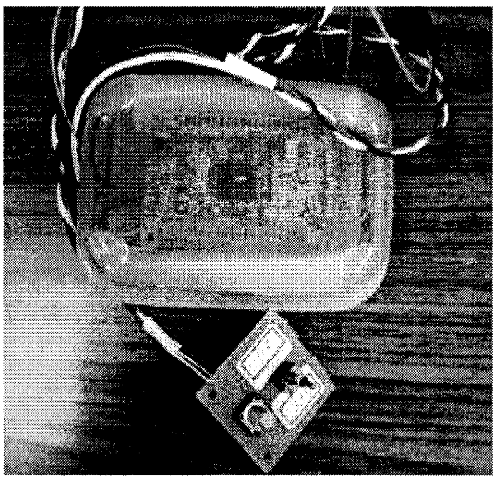

Fig. 11 Circuit for motor-only drive

The circuit contains a LED for displaying power-on, a switch changing of motor-only and motor-assist drive, a button for the motor-only drive start, and a control circuit. Figure 10 shows the circuit and a battery of 9.6 V and 600 mA for H8 microprocessor. After the experiment conducted to the circuit action confirmation, we added a relay for the control by H8 processor. The final circuit manufactured is shown in Figure 11.

The program for motor-only drive consists of those for LED-on, drive start when a button on, motor-only running, and speed control. The speed is controlled by changing the current flow interval. We confirmed the function in the circuit, and found that the circuit for motor-only drive works without troubles. The circuit is attached to the purchased motor unit. Although the motor-only drive worked, the start acceleration was faster than expected, and as a result the speed was higher than 6 km/h. It remains to be modified, since it affects the safety as a vehicle for elderly drivers.

5. DISSCUSION

5.1 Design and manufacturing education

The students who jointed the team under the guidance of Daioh Machinery Co.,Ltd. and the university faculty were able to learn how to design using 3D-CAD software, mainly by 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 ProEngineer or Solid Designer enables students to perform the stress analysis using solid forms. In the project, there introduced 3D-CAD and stress analysis.

5.2 Subjects remained and future work

The project was performed, and many subjects to be solved remained.

(1) Stability of the vehicle

When the front side arms for both sides are fixed in order not to move individually, the vehicle is unstable. We think that the reason is lack of the camber angle against the desirable caster angle. This should be studied more and be solved.

(2) Frame configuration

The height of the main rear frame seat was higher than expected due to decrease of the bending work from consideration of manufacturing cost reduction. The circle mark in Figure 12 is an idea to make the frame low position.

(3) Vehicle size

The vehicle length is a little longer than the specification limitation. The tire size and a space between rear tire and frame are to be considered.

(4) Manufacturing cost

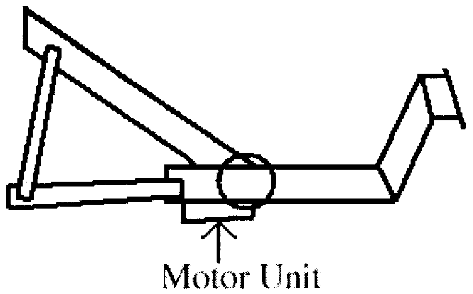

Fig. 12 Idea for modified main rear frame

The issue of the cost is to be considered.

(5) Control for motor-only driving
From the running experiment using the completed control circuit, there remain the issues to be solved. One is the more rapid acceleration by the start button than expected, and the other is that the maximum speed exceeds the limitation of 6 km/h. Such a control result may make feel uncomfortable for especially elderly drivers. The modification of assistance ratio to lower one is a possible option. Such a control modification can be conducted by a small change in the circuit.

6. CONCLUDING REMARKS

The project concludes the followings.

(1) The specification for the motor-assisted tricycle was surveyed by collecting traffic regulations and discussion with related people including Police Stations nearby.

(2) The vehicle of motor-assisted tricycle was designed, stress analyzed, and manufactured. The control circuit for controlling motor-only drive under 6 km/h was designed, fabricated, and experimented.

(3) Some issues remain for realization of the planned motor-assisted tricycle. Those issues are safety, frame configuration, cost, and control for motor-only driving. The future work for realization of the vehicle is desired.

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References

Greene, D., "LATCH: a syllabus design for EFL instruction in CALL" in Computer Assisted Language Learning, *Lisse, The Netherlands*, 11, 4, 381-96.

Homepage of Electric Vehicle Society Japan.

Hunter, L., "Text nouveau: visible structure in text presentation" in Computer Assisted Language Learning, *Lisse, The Netherlands*, 11, 4, 363-79.

Sakamoto, H., and K. Amimoto, Education of Design and Manufacture Using Hand-made Small-sized Electric Vehicles, *Journal of Asian Electric Vehicles*, Vol.2, No.1, 565-570, 2004.

Sakamoto H., and T. Tsuneishi, Manufacturing and Control of an Electric Power Tilter, *Journal of Asia Electric Vehicles*, Vol.3, No. 1, to be piblished.

Sakamoto H., Designing and Manufacturing of a Hand-made Electric Motorcycle, *Journal of Asia Electric Vehicles*, Vol.2, No.2, 645-650, 2004.

Sakamoto, H., T. Uchino, T. Kaino, T. Sawada, and M. Yokoyama, Capstone Design and Manufacture of Hand-Made Small-Sized Electric Vehicle, *ASME IDECE*, DETC2001/IED-21220, 2001.

Technical Education Committee, Design of Manual Winch, *Power Co.*,1991. (in Japanese)

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