Report of Student Formula Project

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Abstract

In 2013, Tohoku University took part in Student Formula Japan for the first time and entered the electric car class, which is established this year. Our team finished in the fourth among eight teams participated in the electric car class, but was not able to pass the technical inspection to proceed to the dynamic events. This report reflected our results and indicated the improvements to pass the technical inspection and achieve better results next year. The most important point for the improvement was the low tolerance design of the front part of the car. In the next year, we will decide the specification of the suspension and steering system at first and then design the frame.

Tohoku University Formula Team

1. Introduction

Recently, the number of students is decreasing because of the falling birthrate. Moreover, young people are shying away from scientific fields drastically. Those trends might lead to the Japanese automobile industry losing its international competitive power and losing talented engineers in the future.

In the USA, it was noted that excellent engineers cannot be nurtured only in classrooms. Actually since 1981, SAE International has held Formula SAE as a practical student education program to provide opportunities for students to create objects[1)]. In this competition, students manage a team on their own to plan, design, produce and test a formula car. While creating their cars, students acquire widely diverse practical knowledge that is not limited to machinery and electronics. They also strive to increase performance, reduce costs, and improve their vehicle marketability. Leadership and teamwork among members is fostered with a strong sense of camaraderie. Therefore, this competition sharpens students' ability to identify and resolve problems on their own. They experience the magnificence and fun of manufacturing. Results show that a basis for nurturing human resources has been established through cooperation of industry, academia, and governmental offices.

In Japan, however, the curricula of engineering universities is currently lacking in practical, design/drawing elements, and other skills, thereby engineering a shortage of opportunities for object creation. Although solar car conventions and robot contests have been established as nationwide contests for object creation in Japan, no design contest has given full play to the special technologies obtained by students aiming at being active in automotive fields.

Under these circumstances, JSAE chose to hold the Student Formula Japan[2)]. Students can create an object independently, which enables them to deepen their understanding of technology, cultivate their practical abilities, and strive enthusiastically to achieve higher levels of accomplishment. The competition intends to aim at nurturing engineers who are rich in originality through an environment of object creation, in which they can learn the essence of object creation and the processes this entails, as well as experiencing team activities, and the difficulty, interest, and enjoyment of object creation.

In 2013, Tohoku University took part in Student Formula Japan for the first time. It entered the electric car class that was established. Our team did relatively well in the static events, but could not pass the technical inspection and fail to proceed to the dynamic events. This report reflected the results of our team and indicated the improvements to pass the technical inspection and get better results next year. First, all events of the competition and their outline are shown. Second, the details of our car are described. Third, our results are showed. Forth, we reflect the static events to get better result next year. Fifth, we indicate the improvements to pass the technical inspection. Finally, we summarize this report.

2. Summary of Competition

This competition emphasizes not only the running performance, but also the car concept and design, as well as costs and other vehicle aspects. The competition has three categories of evaluation: technical inspection, static events, and dynamic events.

Table 1 Outline of competition

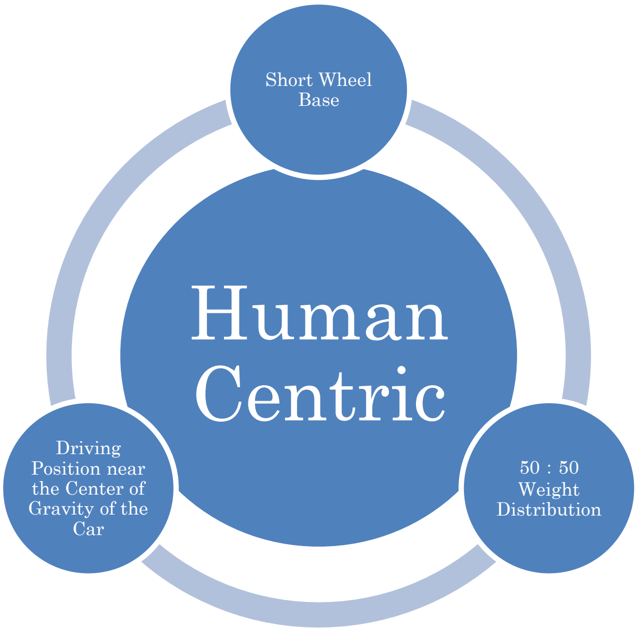
Events		Contents
Vehicle Examinations	Technical Inspections	Vehicle safety and conformance to design requirements as stipulated inthe rules
	Tilt	Checking that no fuel leakage occurs when the vehicle is tilted at 45 degrees, and no rollover occurs at 60 degrees.
	Noise	An exhaust noise of110 dB or less under prescribed conditions - ICV teams only
	Brake	Four-wheel locking
	Rain test	Checking an insulation state when water is sprayed at the car any possible direction for 120 seconds - Electric teams only
Static Events	Cost	The validity/competitiveness of cost calculation are examined. (100P)
	Design	Appropriateness, the reformation, the processability, and the repair, etc. of the design are examined. (150P)
	Presentation	The presentation technology for the manufacturing sales is examined. (75P)
Dynamic Events	Acceleration	The acceleration performance from 0 to 75m . (75P)
	Skid-pad	The vehicle's cornering performance is evaluated in steady state turns over a figure-of-eight course.(50P)
	Autocross	Vehicles are driven over an approximately 900 m course comprised of a combination of straights, turns, and slaloms. (150P)
	Endurance	Vehicles are driven over an approximately 20 km course comprised of a combination of straights, turns, and slaloms.(300P)
	Fuel efficiency	Fuel efficiency is evaluated in terms of the amount of fuel consumed in the endurance .(100P)

3. Description of our car: TF13

3.1. Concept

Figure 1 shows the concept our car. We aimed to achieving high performance in high score event such as autocross and endurance, then we set the concept of our car TF13 to human-centric. In other words, it is an easy-to-use tool of human beings.

Our concept also means to maximize the merits of electrification. The merits are as follows. First, because the battery can be placed near the center, good weight balance and mass concentration will be gained. Second, the electric motor requires no large space and the driving position can be put close to the center of gravity. Thereby, the design can realize unity of the car and driver. However, rival cars use a frame designed for an internal combustion car, so they cannot take full advantage of electric car capabilities. Therefore, we design a car tailored for the electric powertrain, which makes the most of electrification.



- Short Wheel Base

  We designed our car extremely compact. It is important for student formula car to be easy to grasp the size of the car because this competition's course has a lot of tight corner.

- 50:50 Weight Distribution

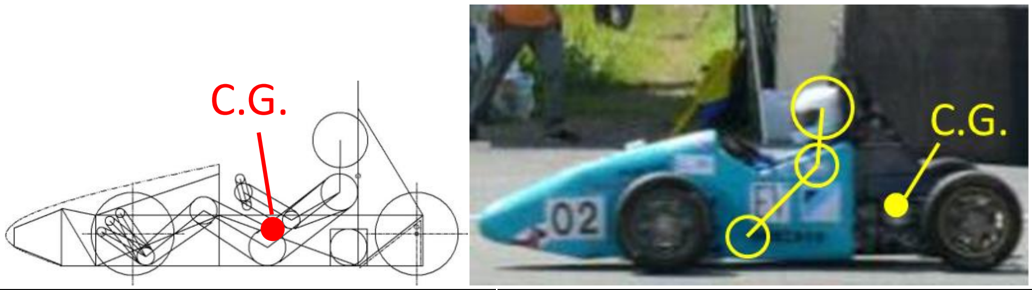
  Ideal 50:50 weight distributions can easily be achieved by using battery as a balancer. By this approach, we aimed to have high driving ability.

- Driving Position near the Center of Gravity of the Car

  It is easy to feel driving's sense by locating the center of gravity to driver's waist.

Fig. 1 The concept of our car

Comparison of TF13 with the competitor is presented in Figure 2. The important features of TF13 are its short wheelbase, short overhang, good weight balance, mass concentration, and the appropriate driving position. They will lead the car to have quick and neutral handling and good performance in the autocross and endurance event will be expected. Based on the concept 'human-centric' by these approaches leads to achieve a car that is friendly for any drivers.



Frame	Steel	Frame	Steel
Body-work	GFRP	Body-work	CFRP
Overall Length	2450 mm	Overall Length	2815 mm
Wheelbase	1530 mm	Wheelbase	1600 mm
Track	Front 1175 mm	Track	Front: 1150 mm
	Rear : 1175 mm		Rear : 1150 mm
Height	1050 mm	Height	1074 mm
Ground Clearance	37.5 mm	Ground Clearance	36 mm
Wheel	13 inch	Wheel	13 inch
Weight	270 kg	Weight	270 kg
Weight Dist.	50 : 50	Weight Dist.	30 : 70
Rated Power	12 kW	Rated Power	15 kW
Max. Power	30 kW	Max. Power	37 kW
Battery	Li-ion, 5.9 kWh, 84 V	Battery	Li-ion, 380 V
Suspension	Front: Pushrod	Suspension	Front: Pushrod
	Rear : Pushrod		Rear : Pullrod

Fig. 2 Comparison of TF13 with the competitor.

3.2. Frame

The points on the designing chassis are manufacturability and human-centricity. Manufacturability is the most important point for the team which participates in the competition for the first time, as we are. To design a chassis that is easy to manufacture, we took the following approaches. First, we used steel pipes as the main structure. Unlike carbon fiber monocoque, steel spaceframe is inexpensive and workable. Furthermore, the steel spaceframe is repairable if the chassis get broken. These characteristics are suitable for fresh team like ours. Second, we designed the chassis to have as few welded points as possible. For example, the lowest frame of both the right and left side of the car are made of continuous pipes. It contributes to reduction of cost and improvement of accuracy. Human-centricity is our strongest theme. Our ways to realize human-centricity are as follows. First, we made driver’s view wider by devising shape of front hoop and main hoop so that drivers can easily confirms the location of pylons. Second, the frame is designed inserting truss structure appropriately in the frame structure so that the toe variation is less than 0.001 degree on 1 G turn. Cornering force is generated by slip angles of tires and 1 degree rudder variation generates 1000 N cornering force. The toe decrease results from centrifugal force; it will cause understeering if the lateral body stiffness is insufficient. Therefore, to realize pure handling, we think much of lateral body stiffness[3]. Figure 3 presents results of displacement analysis of 1 G turn using software: (SolidWorks 2010). From the displacement of each section, it is recognized that the toe variation is less than 0.001 deg on a 1 G turn. Figure 4 shows the front, rear and lateral view of the frame, and Figure 5 shows the actual pictures of the frame.

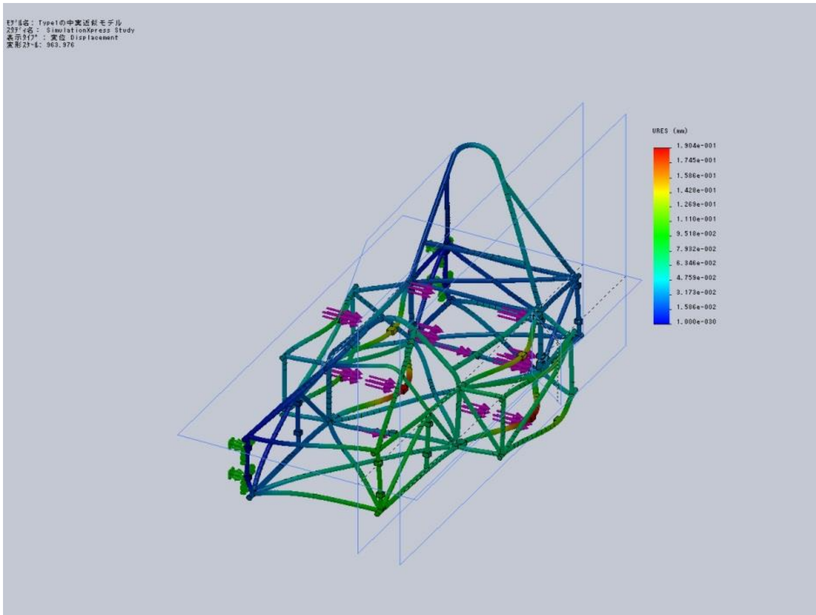
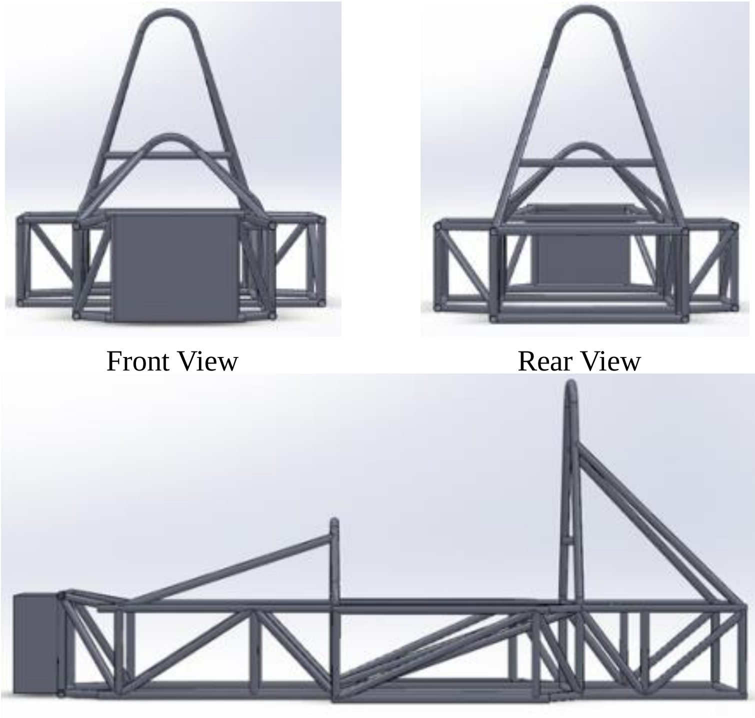


Fig. 3 Result of displacement analysis of the frame



Lateral View

Fig. 4 Front, rear and lateral view of the frame

Fig. 5 Actual pictures of frame

3.3. Suspension

For suspension design, we used double wishbone system that has low camber change for front and rear side. This enables the drivers to have good control of the car. For tires to have optimum grip even in any position, we focused on minimizing camber change in negative direction with bound and rebound[4)]. In the geometry design, we made the program that calculate the camber angle change by Microsoft Office Excel going back to basic behavior analysis of four-bar linkage we have ever learned in Mechanism class in the university. Figure 6 shows the result of calculation of camber angle change with bound and rebound. As a result, we succeed in achieving the geometry whose camber angle change is lower than 0.1 ° for stroke ± 35 mm. We also aimed to make parts as few as possible to reduce the cost and make the production process easier. Moreover, by making the process of dismantling and set up easy, we able to make time took for test run’s preparations shorter.

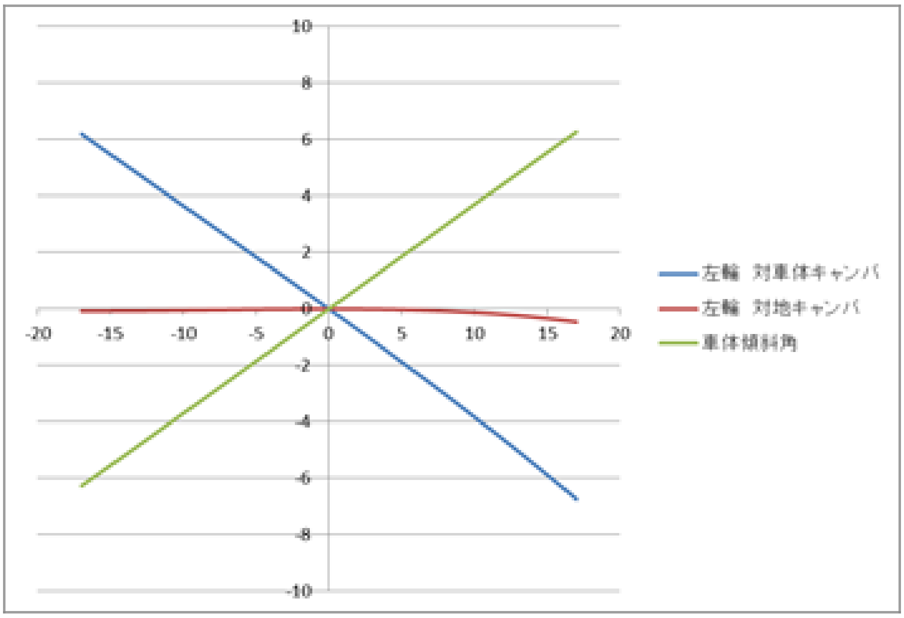


Fig. 6 Result of calculation of camber angle change with bound and rebound

3.4. Drive train

3.4.1. Drive train

As the chassis, the points on the designing drive train are manufacturability and human-centricity. Sufficient reduction is necessary for powerful acceleration, but we want to avoid having manufacturing and setting of the reducer complex, and what is more, we need to avoid the troubles and convection loss. Therefore, the simple reducer with chain drive is adopted. We achieved reduction ratio of 4.94 by combination of a 1-speed gearbox that has reduction ratio of 2.6 and a final drive that has 1.9. Because generation of sufficient torque in a wide range of revolutions is one merit of the electric motor, we abolished the transmission to realize easy driving.

Figure 7 shows the actual picture of gearbox. For the gear box, we used KHK Helical Gears. Main reason for this selection was that KHK Helical Gear has high reliability, contact ratio and surface’s strength compared to normal spur gear. We calculated the strength and designed light gearbox using the SolidWorks. The design condition is that the distortions will not exceed 0.15mm which is the back rush of the gears. As a result, we completed a gearbox made of A7075.

We chose chain drive system as a final drive because this is simpler and lighter than shaft drive system. Moreover, this system is flexible to torsion of car body and difference which would occur between driven-drive units. Furthermore, this type of system is easy to change the reduction ratio. We chose RK Non Seal Chain for chain due to high reliability and driving efficiency. As a result of squeezing the rear side of the frame to reduce overhang's weight, driven sprocket project out from rear part of the car. This problem is solved by designing jacking point to double as a bumper.

We used mechanical type LSD from F.C.C. as a differential considering availability and reliability. By using mechanical type LSD, no loss in driving force will occur even when inner wheel floats during turning at a corner. This feature helps in driving and leads to time improvement in the course where a lot of corners exist. By locating the differential at the center of the track, shaft length is designed to be symmetric to prevent torque steering.

Fig. 7 Actual picture of gearbox

3.4.2. Motor

The motor is chosen in reference to the power of the competitors with lightness and smallness paramount in thinking to reduce mass and inertia moment of the car and develop human-centricity. Figure 8 shows the drawing of the electric motor which we chose, and figure 9 shows the output characteristic of the motor. Consequently, a motor with specifications of 5000rpm, output 12kw, maximum output 30kw was selected based on revolution number at maximum speed of 97km/h and acceleration performance to be competitive in endurance event.

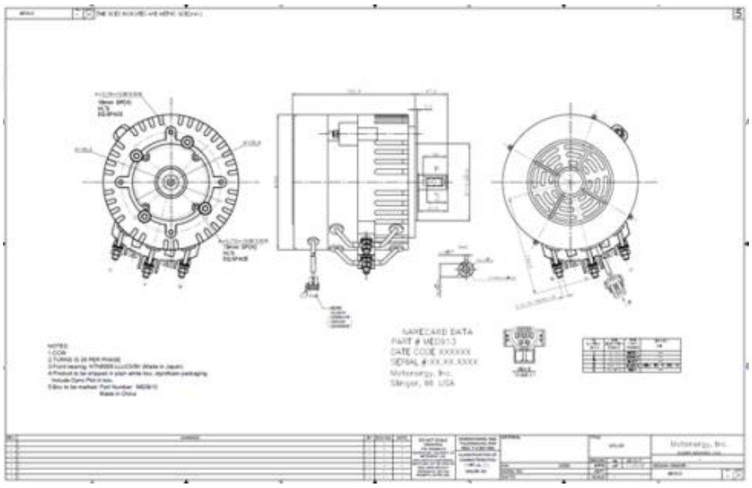


Fig. 8 Drawing of the electric motor

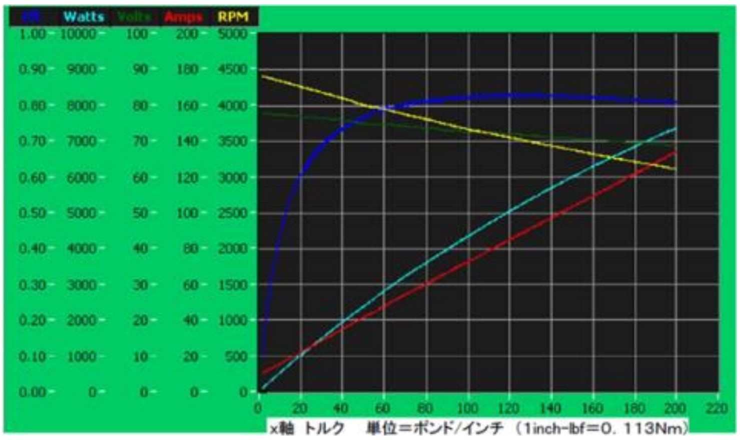


Fig. 9 Output Characteristic of the Motor

3.4.3. Battery

The battery specification is decided based on the running data of the competitors as well as the motor. On validation of selection of the battery and the motor, the performance curves are used. The maximum power of the battery and the running resistance on each running velocity is depicted in Figure 10. The intersections of the graph indicate the maximum velocity on 3C continuous discharge, which is ensured by the manufacturer. From Figure 10, it turns out that our car can do 106 km/h at maximum. Figure 11 is the travel performance curve. The driving force of the motor and the running resistance on each running velocity are shown. The driving force is calculated based on the rated output, the rated revolution and the maximum revolution. The intersections of the graph show the maximum velocity. From this figure, we infer that our car can do 90 km/h at minimum. For these discussions, it is considered that the performances of our motor and battery are not insufficient for the autocross or endurance course.

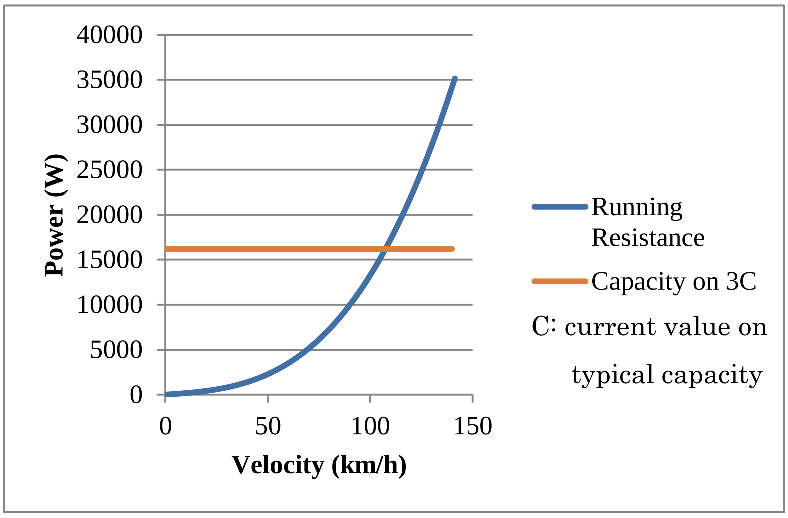


Fig. 10 Battery performance and the running resistance

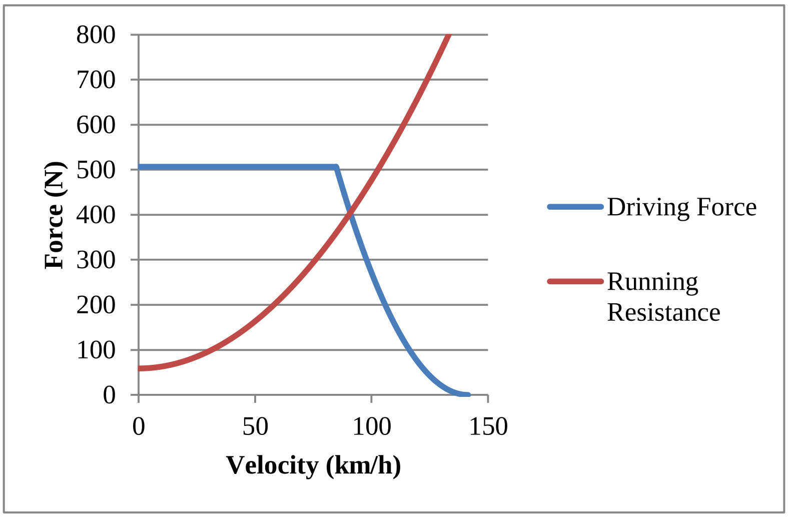


Fig. 11 Travel performance curve

3.5. Pictures of our complete car

Figure 12 is the pictures of our complete car. Almost all parts are handmade.

Fig. 12 Picture of our complete car

4. Results

- **Overall Standing (EV):** **4th** **(from 8 teams)**
  Overall Standing (All): **69th** **(from 78 teams)**

- **Results**

Event	Points	Time	Ranking (EV)	Ranking (Overall)
Cost	4.12		1st / 8 teams	61st / 78 teams
Presentation	52.50		1st / 8 teams	13th / 78 teams
Design	25.00		3rd / 8 teams	67th / 78 teams
Acceleration	0 (DNA)	0.00 (DNF)	—	—
Skid-Pad	0 (DNA)	0.00 (DNF)	—	—
Autocross	0 (DNA)	0.00 (DNF)	—	—
Endurance	0 (DNA)	0.00 (DNF)	—	—
Electricity Usage	0 (DNA)		—	—

5. Details of Static Events

5.1. Presentation Event

The objective of the presentation event is to evaluate the ability to develop and deliver a comprehensive business case. The business case has to convince the executives of a manufacturing corporation that the design best meets the demands of the market. Concretely, imaginary situation of how to sell the car for 1000 unit per year was given.

During the presentation event, presenter will be asked questions from 4 officials and the questions do not informed in advance, so we prepared for this event steadily from last year so that we can answer the questions clearly and confidently. In the presentation event, 3 members played the roles of the presenter, technical representative and marketing leader. All members were nervous during the event, but the presentation was coolly done and questions were answered competently. In one question, because of our mistake in understanding the rule, our opinion differed with the officials. Fortunately, in the end, the officials agreed with our team.

Overall comment from the officials was that our team made the best use of EV characteristics, which was a great evaluation to our team. Although this was our 1st year participating in this competition, we managed to get ranking 13 from all participating teams. From this, we hope to achieve high marks for the presentation event and hope this event can be our strong point in the future.

Fig. 13 Slides for presentation event

5.2. Design Event

In the design event, we got 25 points from full points of 150. We ranked 67 in overall ranking. This failure to achieve high points can be concluded into 2 things.

Firstly, completion of car was drastically delayed. The design was completed after the submission of design report, and there were many differences between content of the design report and the actual car. That resulted in the reduction of significant points.

Next, the preparation for this event was not properly done because the production of the car took very much time. The design event is based on the report submitted beforehand and the questions and answers (Q&A) during the event. Q&A was held depending on the parts, but as the leaders of the parts had been too busy, they could not answer the questions from officials smoothly and affected the points gained in this event.

From the result, we clearly learned the problems regarding this event and hope to use this experience to achieve better points next year.

Fig. 14 Picture during design event

5.3. Cost Event

The cost event is to teach the participants how to correctly calculate the cost of the car produced by the team. This event evaluates the marketing and production potential of the car. Not only materials costs, but also labors costs are included in cost report. The organizer provides a standard cost list for materials and labors. Student formula team submits the cost report that thick as a dictionary beforehand. During the cost event, mainly things that insufficient in submitted cost report are pointed out.

Our team's cost report lacked design drawing. The definition of the cost report is that even a 3rd person can make the same car by just referring to it. Our team's design drawing only included complete design drawing and lacked manufacturing process drawing. Looking at established teams, we understood that to make a good race car, there definitely are a good design drawing and good cost report. We swore to ourselves to make a much better cost report in the coming years based on the things learnt during the event.

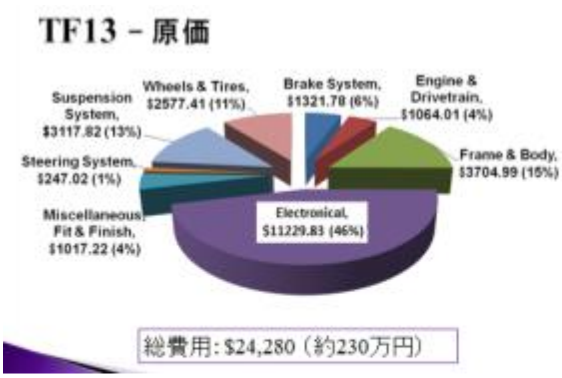


Fig. 15 Picture during cost event

Fig. 16 Cost of TF-13 based from cost report

6. Points of Improvement in Technical Inspection

In Student Formula Japan, the car which has not passed technical inspection cannot proceed to the dynamic events considering driver's safety. We failed to pass the technical inspection and proceed to the dynamic events. After the competition, we held a meeting to review about the reason of the failure and how to improve for the coming competition next year.

Fig. 17 Technical Inspection

6.1. Mechanical

About 15 points were pointed out in mechanical inspection.

The points are listed below. The left side is the topic/problem and the right side is the reason or how to improve.

① Center nut for tire hub: Lock nut and split pin should be used, double nut is prohibited.

② Not enough clearance around front tire: Tire and frame surrounding battery are remarkably close. Reason will be explained later.

③ Height of upper Side Impact Structural member from ground exceeds upper limit which is defined in rule: Results of trying to secure height of car and suspension's stroke.

④ No [I] marks and torque control at bolt and nut in suspension system: Have no time enough to think about required torque.

⑤ No stopper mechanism at rack and pinion in steering: Knuckle arm and frame are in contact.

⑥ Handle jut out from front roll hoop: Failure in arrangement of steering shaft.

⑦ Some bolts and nuts without securing strength are used in suspension and steering system: Failed to notice the importance of strengthened screw.

⑧ Interference of seat belt and seat: Solved by expanding hole in the seat for seat belt to pass through without contact.

⑨ No protections for steering shaft: Installed afterwards.

⑩ Roll Bar Pad was not fixed enough: Fixed it properly afterwards.

⑪ Template for ensuring whether driver's foot space is enough or not could not get in: Most critical problem. Details will be explained later.

⑫ Gearbox and driven sprocket are misaligned: Due to leaning the motor during installation.

⑬ Rigidity for brake pedal is not enough and direction of return spring was opposite: Due to lack of space in driver foot area. Misunderstood of regulation.

⑭ Interference of brake caliper and inner wall of wheel: Lack of measurements in brake caliper and assembly in wheel.

⑮ Too small steering gear ratio: Failure in arrangement of rack and pinion. Details will be explained later.

Among all the points, fatal problems were ②, ③, ⑤, ⑪ and ⑮. These are due to problem in frame structure. These problems happened because we did not know what parts should be prioritized in component layout phase and the selection of those parts was extremely late. Lateness in selection of battery and parts related to steering and suspension system is the main reason for this year's results. In details, those parts/problems are rack and pinion for steering, tire size, wheel, brake caliper, brake disk, brake master cylinder, driving position and main battery.

Due to above reason, frame structure was decided before the layout of steering and suspension system that controls the car's behavior and we began the production right after. Moreover, we designed such a compact frame although this was our 1st year, so the problems such as the important components decided later were too big to be installed in proper position occurred. For example, steering rack and pedal was too big and cannot be installed properly. Looking at other teams, rack and pinion is placed nearby the center axis of front tire to achieve ideal steering geometry and maneuverability. By this, Ackerman geometry can be implemented and big rudder angle can be gained easily. In most cases, this position is below the driver's knee. Moreover, to secure rigidity between pedal system and surrounding equipment, pedal and mount was designed to be big. These conditions demand big front section of the car.

However, we designed the front section to be too compact. Thus, when arranging rack and pinion around front tire, space in below driver's kneel became insufficient and breaking the regulation. In the end, rack and pinion was placed rearward from front tire. This cleared the regulation, but in exchange, steering ability was remarkably lost. In addition, small pedal unit became necessary and resulted in lack of strength and was pointed out by officials.

Other than that, due to lack of production precision of suspension arm's installation parts in frame side, we installed many adjustment systems. This installation backfire us afterwards. The arms are swept back because the bearings are protruding to compensate for the errors in installation parts for arm. That leads to the difference of approximately 20 mm in wheelbase length between right and left, and this is the main reason of ②.

Our car was supposed to equip with order made lithium ion battery, but due to certain reasons, it was changed to ready-made lead battery. That leaded to not only electrical but also mechanical troubles. The dimensions of the battery were different from the initial design, and we needed to alter some parts of the frame. We had to continue designing the battery container until just before we have left Sendai, and we continued altering the battery container at the competition's venue.

Based on the reflects and review of the result of this year, what to do for technical inspection for next year and in the future are as stated below;

① Early decision and confirmation of main component.
② Arrangements of components are main priority in designing frame. Frame's design will adjust to those arrangements.
③ Overall design of the frame will be based on measurement of every part. And the design should have additional margin for flexibility. (Especially front section)
④ Failure and remake always happen, thus early production and improvement is important.
⑤ Main components in this year's car will be reused as possible, and improve skills to make original parts.

6.2. Electrical

Problems occurred during competition and things pointed out by officials during electrical inspection are listed below;

① Not enough cover for high voltage system.
② Many wiring problems.
③ Failure of compact motherboards system's
④ Insufficient illumination of brake lamp: Our lamp was not enough. Using LED that can be seen from far away even in bright day.

Electrical system that needs immediate improvement is ②③. Both are due to the lack of test and maintenance.

Firstly, we only have 3 people in-charge for electrical system though our car is EV. That clearly was not enough. Electrical system itself was not so complex, but wiring error occurred frequently. To reduce mistakes during hard works, all wire should be tagged well.

Moreover, several compact motherboards for control system were made but they failed to operate properly till the competition. As a countermeasure to this problem, it is important to tag wire for easy identification of the cause of the failure and to put the motherboard in a dust-free/protection case after motherboards were made. After that, we should cover the motherboards with corrugate tube as soon as possible.

Other than that, one of the reasons of failure was no operation test conducted before the competition including main battery. Because the troubles in Electrical/Control system are not visible, it takes time to operate normally even though the system seemed to be made perfectly. Points of improvements also include the fact that our members, including me, were not aware of these problems and continued our activities.

Fig. 18 Picture during driver egress test

7. Conclusions

In 2013, Tohoku University took part in Student Formula Japan for the first time and entered the electric car class, which is established this year. Our team finished in the fourth among eight teams participated in the electric car class, but was not able to pass the technical inspection to proceed to the dynamic events.

Based on the reflects and review of the result of this year, what to do for technical inspection for next year and in the future are as stated below;

① Early decision and confirmation of main component.

② Arrangements of components are main priority in designing frame. Frame's design will adjust to those arrangements.

③ Overall design of the frame will be based on measurement of every part. And the design should have additional margin for flexibility. (Especially front section)

④ Failure and remake always happen, thus early production and improvement is important.

⑤ Main components in this year's car will be reused as possible, and improve skills to make original parts.

For the electrical system, we need the following improvements.

① It is important to tag wire for easy identification of the cause of the failure.

② The motherboard should be placed in a dust-free/protection case.

③ Operation test should be conducted in the early stage.

References

1) Formula SAE [Internet]. c2013. SAE International; [updated 2012 Dec 3; cited 2013 Feb 3]. Available from: http://students.sae.org/competitions/formulaseries/

2) Student Formula SAE Competition of Japan [Internet]. c2013. JSAE; [updated 2012 Dec 20; cited 2013 Feb 3]. Available from: http://www.jsae.or.jp/formula/jp/

3) JSAE; Motor Car Development/Fabrication Guide For Students and Junior engineers (Japanese); JSAE; 2008

4) S. Royce, M, Royce, W. Kimberley and R. Brawn; Learn & Compete A primer for Formula SAE; Racecar Graphic Limited; 2012