The Development of Chulalongkorn University's SAE Student Formula's Space Frame

Chartree Sithananun, Teekayu Limchamroon, Tanawat Limwathanagura, Thanyarat Singhanart

Abstract**—**The objective of this paper is to present the development of the frame of Chulalongkorn University team in TSAE Auto Challenge Student Formula and Student Formula SAE Competition of Japan. Chulalongkorn University's SAE team, has established since year 2003, joined many competitions since year 2006 and became the leading team in Thailand. Through these 5 years, space frame was the most selected and developed year by year through six frame designs. In this paper, the discussions on the conceptual design of these frames are introduced, focusing on the mass and torsional stiffness improvement. The torsional stiffness test was performed on the real used frames and the results are compared. It can be seen that the 2010-2011 frame is firstly designed based on the analysis and experiment that considered the required mass and torsional stiffness. From the torsional stiffness results, it can be concluded that the frames were developed including the decreasing of mass and the increasing torsional stiffness by applying many techniques.

Keywords**—**SAE Student Formula, Space Frame, Torsional Stiffness

I. Introduction

FRAME is one of the most important structures of the formula car that absorbs the load and provides the space for attaching other components to the car such as the suspension system and engine. The frame design, analysis, and testing [1], [2] is required in order to make the excellent frame.

In SAE formula racing there are two common types of the frame which are well known and being used; the space frame and the monocoque. The most popular among the two is the space frame due to its advantages in ease of the design and manufacturing and lastly the cost is lower when compared to the monocoque.

Faculty of Engineering, Chulalongkorn University, the oldest University and the oldest Engineering College in Thailand, was established the Automotive racing team named “MeCu” under Department of Mechanical Engineering since year 2003. At the beginning, MeCu joined the Fuel Efficiency Car Competition in 2005 by applying the basic engineering skills in designs and constructions. The designed car as shown in Fig. 1 was mainly proposed on the efficiency in fuel consumption but not the speed. To design the body of the car, the space frame was chosen. In this competition, our team earned a first prize among all participants. This was the beginning of the history of the space frame in our frame designs.

Fig. 1 MeCu’s fuel efficiency car

In 2006-2007, MeCu was firstly participated in the TSAE Auto Challenge Student Formula [3] (Auto Challenge competition) instead of the Fuel Efficiency Car Competition. The TSAE Auto Challenge is the Student Formula Competition of Thailand under Formula SAE International Rules organized by Society of Automotive Engineers Thailand. Our team, which was known as “Hot Rod racing”, was designed the racing car including body design, suspension design, and all other components. The space frame was introduced again in this competition and this will be the first frame we proposed in this paper. Up to now, our team was continuously participated in TSAE competition or since year2006-2007 to present.

Through these five years, the car is developed year by year including the design of space frame and monocoque. This frame’s development will be the useful knowledge for everyone who preferred to start the frame design. Therefore the objective of this paper is to present the development of the frames for Chulalongkorn University team under the Formula SAE International Rules and Regulations.

II. Formula SAE International Rules [4]

Mostly SAE International Rules are updating every year but main control target is to provide safety for the driver, for example, the main hoop is required to prevent severe injury during the rollover accident, the front part of the frame have to ensure the impact failure will not transfer the energy from the crash to the driver, etc.

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III. THE DEVELOPMENT OF SPACE FRAME FOR CHULALONGKORN UNIVERSITY TEAM

The five frames are developed and will be presented in this section.

A. The 2006-2007 Frame

The first frame is "Hot Rod racing" as shown in Fig. 2. At that time the space frame is designed base on the rules and regulations only. In the first design, there is no consideration of any other requirements such as mass or torsional stiffness.

Fig. 2 Hot rod racing student formula car

B. The 2007-2008 Frame (Schnell frame)

In next competition, our team known as "Schnell", the German language which means speed, designed the frame concentrated in reducing the overall mass of the car because the previous car's design was not considered much about the mass which affected the overall performance of the car. The 2007-2008 frame as shown in Fig. 3 and 4 was extremely changed to the use of Semi-Monocoque technique which resulted in large weight reduction when compare to the space frame. The word Semi-Monocoque means the frame is composed of monocoque part and space frame part. The Schnell frame is divided into three parts; (1) the front part with space frame technique, (2) the cockpit with the monocoque technique, and (3) the rear part with space frame technique. Schnell's frame achieved in the gradually reduce of the overall weight of the car and bring the team to the second price of the Auto Challenge competition.

The tremendous score from the conceptual design part was gained from frame with Semi-Monocoque technique. Although there was some problems about monocoque technique because of the limitation in our manufacturing experience of composite materials and the testing for torsional stiffness which is difference from the test for space frame. To obtaine the torsional stiffness, the CAE software such as CATIA was introduced to analyze the torsional stiffness of the frame.

Fig. 3 Schnell student formula car

Fig. 4 Schnell student formula frame

C. The 2008-2009 Frame (Schneller Frame)

In the 2009 Auto Challenge competition, Chulalongkorn University's team known as "Schnelller", means even more speed, are turning back to apply the space frame technique as shown in Fig. 5 and 6 with the main target of reducing the weight closed to the previous Semi-Monocoque frame. Schneller frame use same model at the rear as in Schnell frame but removed a lot of tubes and applied the rectangular mesh at rear resulting in the decrease of the stiffness of the car and leading to the failure of the frame during the race which cause the team went down to 21th place in the 2008-2009 Auto Challenge competition. Therefore, the improvement of torsional stiffness became significant for the next generation car such as to convert the major design from the rectangular mesh at the rear to the triangular mesh which will be discussed in next section.

Fig. 5 Schneller student formula car

Fig. 6 Schneller student formula frame

D. The 2009-2010 Frame (Rapidamente Frame)

Learning from the mistake in last competition, the Chulalongkorn university's team reform the members known as "Rapidamente" which also means speed, with the highly effort and strong willing to return to the top rank in the 2009-2010 Auto Challenge competition. The Rapidamente frame (Fig. 7 and 8) was modified from 2008-2009 frame using the rectangular mesh at the rear and the consideration of the torsional stiffness and the mass of the frame. Comparing with 2008-2009 frame, 2009-2010 frame's mass was decreased from 37kg to 31kg and the torsional stiffness was 1389Nm/deg which was higher than other cars in the 2010 Auto Challenge competition. Rapidamente team brought Chulalongkorn university's team returned to the winner position of the competition once again with a lot of awards and honors. During this year, Rapidamente team was challenged to participate in the Student Formula SAE Competition of Japan in year 2010 sponsered by TSAE.

Fig. 7 Rapidamente student formula car

Fig. 8 Rapidamente student formula frame

E. The 2010-2011 frame (Rapidamente91 frame)

In JSAE competition, Chulalongkorn University's team known as Rapidamente91 (Fig. 9 and 10), the design was created under the JSAE rules and regulations [4]. To avoid the violation of the rules, the frame was decided to use the over sizes tubes and became the heaviest and largest car in JSAE competition. Although it was claimed to be one of the best handling and best suspension system car when compared with other Chulalongkorn's formula cars in the last few years.

After the race in Japan before the 2010-2011 TSAE Auto Challenge Competition in Thailand, Rapidamente91 did a modification on the space frame. It is the same frame as Rapidamente91 frame used in JSAE competition, which the rectangular mesh at the rear is selected. Due to the over sizes tubes, the effort for reducing the overall weight is introduced in cutting some tubes from the Rapidamente91 frame as shown in Fig. 10 and 11. The modified space frame is shown in Fig. 12. With this frame, we got the 4th rank in Auto Challenge competition which considered being acceptable even thought the frame is over spec.

Fig. 9 Rapidamente91's SAE student formula car

Fig. 10 Rapidamente91's SAE student formula car

Fig. 11 Modified rapidamente91 student formula car (cut off members)

Fig. 12 Modified rapidamente91 student formula frame (cut off members)

F. The 2011-2012 Frame [5] (Rapidamente92 Frame)

The third generation of Rapiadamente, Rapidamente92 frame as shown in Fig. 13 and 14 was designed for 2011-2012 Auto Challenge competition. Base on the data collected from other team in previous competition, Rapidamente92 frame was designed by considering the mass less than 30kg and the torsional stiffness of the whole car more than 1200Nm/deg by using the space frame with improving many points of consideration which are (1) adding the cross bar under seat to increase the torsional stiffness (2) lowering the center of gravity of the car by using the curve floor and (3) using the triangular mesh at the rear. The finite element analysis for determining the torsional stiffness was performed and verified by comparing with the actual torsional stiffness test. The frame was constructed supported by Singha Cooperation Thailand as our main sponsor. As the results, the weight of the frame was 29.8kg after manufactured including all the weld spots and the torsional stiffness of the space frame was 870Nm/deg. The torsional stiffness of the frame is less than requirement of 1200Nm/deg which is the requirement of the whole car, therefore, the discussion on adding stress members [6] was introduced. Finally, the car can be considered to earn the torsional stiffness of more than 1200 Nm/deg.

Fig. 13 Rapidamente92 student formula car

Fig. 14 Rapidamente92 student formula frame

IV. Techniques for Improving Formula Frame

Torsional stiffness of the frame is the resistance of a frame to rotate under an applied torque which considered being maximum when making a turn. To improve torsional stiffness, many techniques can be applied as follows

A. Crossbars Technique

The cross bars under driver's seat was added to the Rapidamente92 frame as shown in Fig. 15. The experiment on comparing the torsional stiffness of the frame with and without extra crossbar member was studied [5]. The experimental results show that the torsional stiffness for Rapidamente92 frame was 10.4% increase by adding the extra crossbar member under the driver's seat. Therefore this technique provided the great increase in torsional stiffness of the frame.

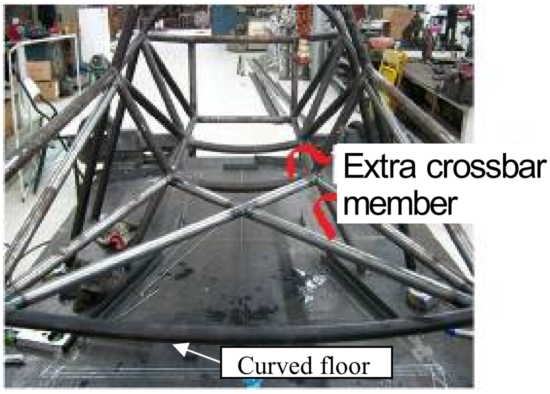


Fig. 15 Extra crossbar member

B. Stress Member Technique

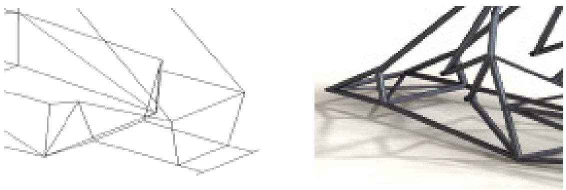
As mentioned before, if the engine block is added in the analysis [6], the torsional stiffness will increase. In fact, other components can also be considered such as anti-roll bar, cross damper, impact attenuator, etc. Therefore, the idea is to add the existed components as a stress member in the model (Fig. 17) which will results in the reduction of the frame's mass. Anyway, the effect of the load on that member has to be clearly identified.

C. Curved Floor Technique

The curved floor (Fig. 15) results in lowering the Center of gravity of the car or lowering the required torsional stiffness which give the prevention of the rollover of the car and also give the handling better when compare to the normal floor but it cannot be used together with cross bar technique.

D. Triangular Mesh VS Rectangular Mesh

The two type of mesh is shown in Fig. 16. The advantage of the rectangular mesh is to provide extra space for suspension system and lead to the ease of the suspension design. On the other hand, the triangular mesh has less space available for the suspension system. Anyway, the advantage of the triangular mesh is that it requires less member and short length when compare to the rectangular mesh resulting in the lighter weight and the short length of the car.



(a) Rectangular mesh (b) Triangular mesh

Fig. 16 Mesh at the rear

V. Finite Element Analysis

The model using CAD software such as CATIA or Solidworks is created and performed the finite element analysis. The frame model is fixed at one end when the torque is applied at the other end. The angle of twist is measured and the torsional stiffness can be calculated from $K = T/\theta$.

The example models for Hot Rod racing, Schneller, and Rapidamente92 car are shown in Fig. 17-19, respectively. From the analysis which will be focused on the Rapidamente series, the torsional stiffness is found to be 1390Nm/deg, 1250Nm/deg, 1120Nm/deg and 971Nm/deg for Rapidamente, Rapidamente91 in JSAE, Rapidamente91 in Auto Challenge and Rapidamente92, respectively.

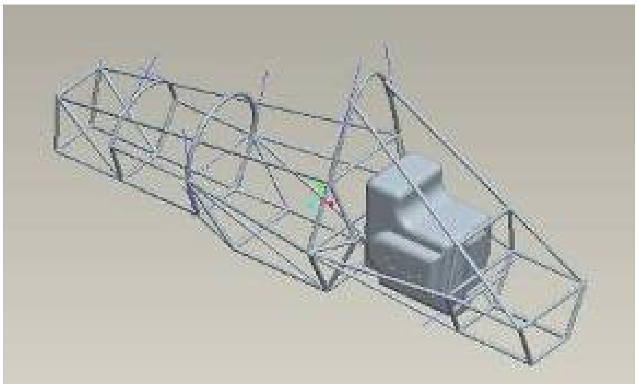


Fig. 17 Hot rod racing's CAD model

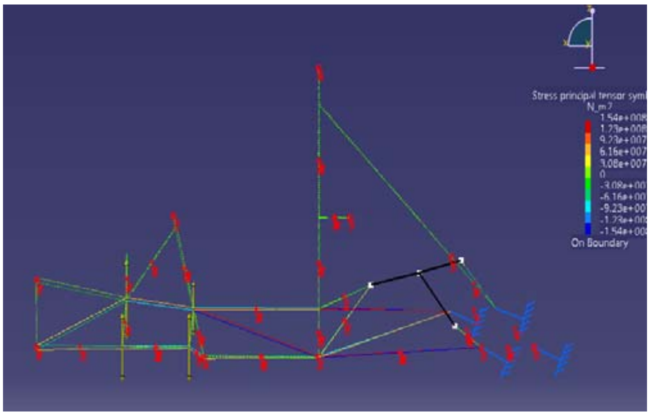


Fig. 18 Schneller frame (CATIA)

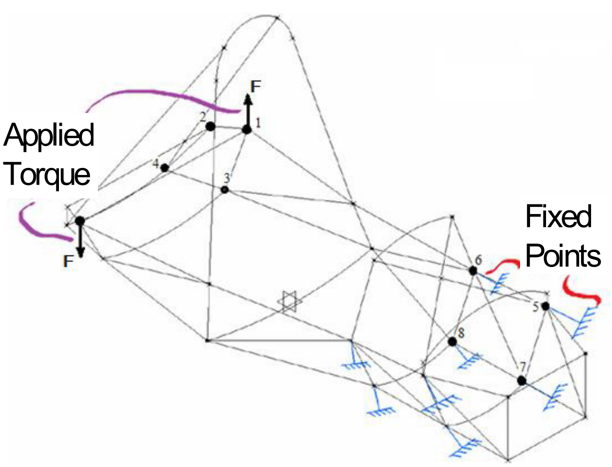


Fig. 19 Rapidamente92 (CATIA)

VI. Torsional Stiffness Test

The torsional test was performed on the real used frame to compare the torsional stiffness of the frames. The test rig is shown in Fig. 20. Noted that the frames were used in race and collected for many years, therefore the torsional stiffness may changed when compared to the original one and the frame in JSAE ad Rapidamente92 frames was not available, so the experimental results from past experiment were used. Anyway, this test on used frame will give the useful information about the improvement of the torsional stiffness of the frame. One more thing is that the Semi-Monocoque frame is not included in this test due to the lack of comparison.

The results of the torsional stiffness of Rapidamente, Rapidamente91 used in JSAE competition, Modified Rapiddamente91, and Rapidamente92 frames are shown in Table I.

Fig. 20 Rapidamente's torsional stiffness test rig

TABLE I
Torsional Stiffness

Frame	Torsional Stiffness (Nm/deg)	
	FEM analysis	Experiment
Rapidamente frame	1390	1470
Rapidamente91 frame in 2010 JSAE	1250	1090*
Modified Rapidamente91 frame in Auto Challenge	1120	993
Rapidamente92	971	870*

*from past experiments

VII. Discussions

The results show that the mass of the frame is improved from 37kg in year 2007-2008, and finally to 25.5kg in year 2011. However, the torsional stiffness is not considered in the first three years, therefore the discussing on torsional stiffness is neglected in that period. As the result, the discussion on torsional stiffness will be presented by using the frame since year 2010 by considering both mass and torsional stiffness. It can be seen from Fig. 21 and 22 that both stiffness/mass is improved and can be considered to be more effective frame. For next analysis, both mass and torsional stiffness should be the required conditions that have to be further improved.

m = 62kg
K = 993 Nm/deg
K/m = 15.9 m^2/s^2.deg

Fig. 21 Mass and torsional stiffness of modified rapidamente91

m = 29.8kg
K = 870Nm/deg
K/m = 29.2 m^2/s^2.deg

Fig. 22 Mass and torsional stiffness of rapidamente92

VIII. Conclusions

The frame for Chulalongkorn University team used in competitions is presented including the Hot Rod racing frame in year 2006, Schnell frame in year 2007-2008, Schneller frame in year 2008, Rapidamente and Rapidamente91 frame in year 2009-2010, and Rapidamente92 frame in year 2011. The frame is developed year by year with the improving weight and the torsional stiffness by applying several techniques. One more important thing is the development has to be made under the rules and regulations.

For the future design of Rapidamente's frame, the 2012-2013 frame is designed to use the same model as 2011 frame with minor change for example the space available for other parts and components such as suspension system. However, the improvement of finite element analysis and testing was required due to the great mistake in testing and the lack of the modification of the finite element model in the 2011-2012 frame.

For the long term plan, the development of the frame using Semi-Monocoque or the pure monocoque is our final target. As now our team also performs the parallel research and experiment on making the front part of car which is known as the impact attenuator by using composite material with the idea and concept of shell and sandwich structure technique together and conducting the experiment on the previous Schnell's Semi-Monocoque frame.

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