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COMPUTER AIDED PROCESS OF DESIGNING THE MECHATRONIC SILESIAN GREENPOWER ELECTRIC CAR

Abstract: The aim of the article was to summarize some aspects of work performed during Silesian Greenpower Project, 2013 edition. The selected issues presented in the paper are: dataflow management, aerodynamics analysis, ergonomic position of a driver and motor control and drive circuitry.

1. Introduction

Silesian Greenpower Team is a combined strength and knowledge of 25 students from three faculties of the Silesian University of Technology – Mechanical Engineering, Automatic Control, Electronics & Computer Science and Power & Environmental Engineering. The main goal of Silesian Greenpower Project is to participate in Greenpower Corporate Challenge that is an annual electric vehicle race held on the prestigious circuits in Great Britain. Participation in the competition involves the design and construction of an electric car that is able to do the possibly largest number of laps on the track - during a limited time of 90 minutes. In order to equalize opportunities for individual teams, specific statutory limitations have been imposed. Participants are required to use cells and DC motor imposed by the organizer. This procedure has also resulted in increased level of competition and creativity of the participants in the process of construction. This article focuses only on several aspects which were performed during the designing process.

2. Dataflow management

Given the variety of issues and extended project team, it is essential to support the flow of information by implementing a computer system. Teamcenter Engineering – the Siemens software system – is applied in Silesian Greenpower project for this purpose.

During all stages of the product lifecycle, from the creation of the overall concept to project completion, cumulative data of various types - records, documents, models, detailed specifications and production schedules at the manufacturing stage - are gaining its volume.

What is the most problematic is the fact that on advanced stages the information is characterized by increasingly diverse recording format.

The basic function in Teamcenter environment is a possibility to create a virtual company using the Organization module. The application enables to define each team member as a unique user who is assigned to specific group and performs certain role (Fig.1.). Obviously one person can have more than one role in different groups.

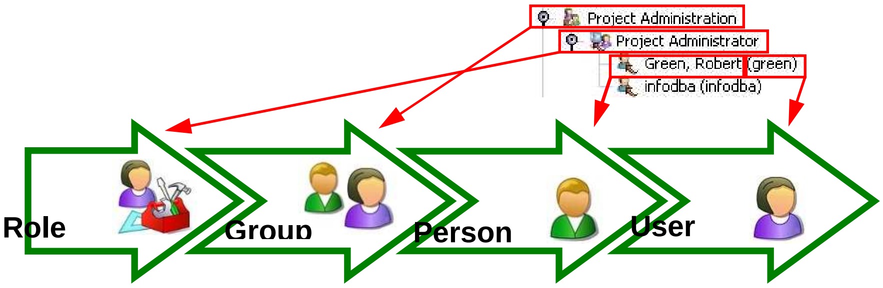


Fig. 1. Chart presenting an organization structure in Teamcenter 8 [5]

After creating whole structure by a DBA (Rich Client layer), every Project Administrator has privileges to start a new *Workflow Process* availing *Schedule Manager*. Both constructors and leaders are able to easily monitor progress from Thin Client layer, i.e. only by opening regular web browser where all tasks with their participation are shown. *Review Process* option is invaluable in supervising which stage of a task is completed, who is responsible for a delay and when it would be ready to transfer outside. [5]

Other modules used in the project are *Part Planner* and *Manufacturing Process Planner*. Solving a problem of data management is inevitable even in students' teams. There is also a need to organize information using a consistent interface and tools to assist during all activities related to product development.

3. Aerodynamics Analysis

Verification of vehicle aerodynamics was performed availing model of aerodynamic tunnel which is corresponding to the actual dimensions of the real tunnel – an exact projection of the air filling the real aerodynamic tunnel. In the analysis 3D tetrahedral FEM elements with given material properties of air were used to simplify the tunnel. Whereas body shell was modeled with 2D triangular FEM elements, whose function were to block the air flow [2]. Boundary conditions adopted for the study were the parameters of the air velocity at the inlet and outlet of the wind tunnel model. Therefore the front surface of the tunnel is set to imitate the movement of vehicle gaining 60 km/h. On the opposite side of the tunnel, boundary condition was implemented to simulate the free outlet of the air. The air flow direction took place in the vector of the x axis of the vehicle global coordinate system. This system was used in the automotive industry. The Studies were performed by adopting the air turbulent model, SST (Shear Stress Transport) which was associated with the corresponding value of the Reynolds number. Turbulent model was selected experimentally from all available turbulent models in the program, studying elementary shapes such as a cylinder or sphere and comparing them to actual results. During the project the following studies were performed:

- study of the SG 2012 car body with the wind blowing in the direction of main axis (x axis) of the vehicle
- study of the car body SG 2012 with the wind blowing at an angle α=15 ° to the direction of main axis (x axis) of the vehicle
- a study to prove the existence of a cross wind effect caused by the wind advancing at an angle α to the vehicle body.

However in the article .... The main criteria for the analysis was to obtain the drag force Fx and the resulting the drag coefficient Cx. Other important elements were the dispersion of air pressure and course of the stream. It allowed to determine the negative shape effects of aerodynamics and use this knowledge in designing a new car and adopt improvements to the existing vehicle [1].

Study results obtained on the dispersion of pressure on car's body is shown in figure (Fig.2) and table (Tab. 1.). On the figure high-pressure zones and underpressure zones were shown.

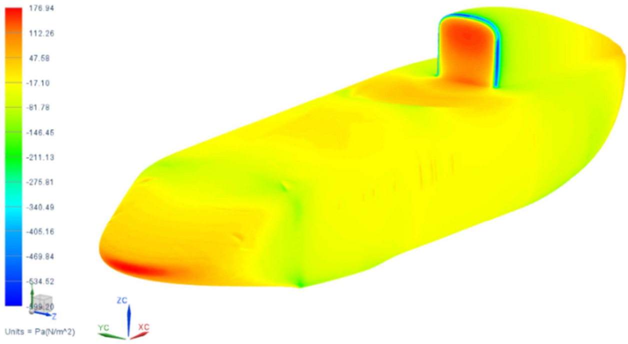
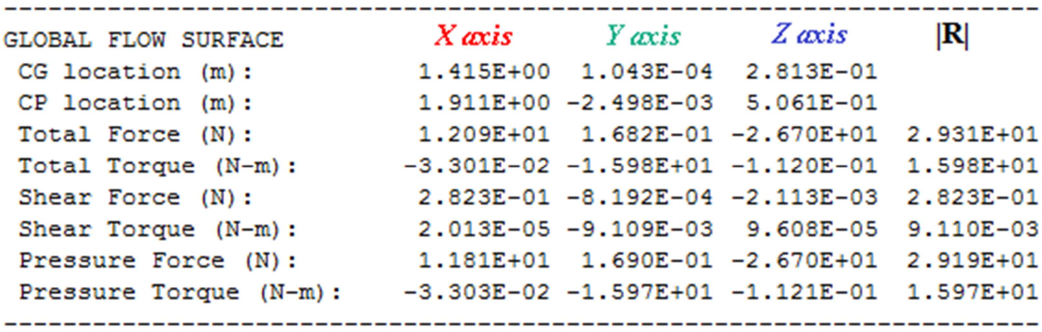


Fig. 2. Pressure dispersion on vehicle's body

Tab. 1. Results of aerodynamic calculations



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GLOBAL FLOW SURFACE            X axis      Y axis      Z axis      |R|
 CG location (m):            1.415E+00   1.043E-04   2.813E-01
 CP location (m):            1.911E+00  -2.498E-03   5.061E-01
 Total Force (N):            1.209E+01   1.682E-01  -2.670E+01   2.931E+01
 Total Torque (N-m):        -3.301E-02  -1.598E+01  -1.120E-01   1.598E+01
 Shear Force (N):            2.823E-01  -8.192E-04  -2.113E-03   2.823E-01
 Shear Torque (N-m):         2.013E-05  -9.109E-03   9.608E-05   9.110E-03
 Pressure Force (N):         1.181E+01   1.690E-01  -2.670E+01   2.919E+01
 Pressure Torque (N-m):     -3.303E-02  -1.597E+01  -1.121E-01   1.597E+01
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Awareness of pressure dispersion allowed to decide which vehicle parts should be improved. It also evaluated the speed of air streams around the car's body. For the highest pressure, speed of air streams were occurring near zero and for the lowest pressure areas where the phenomenon of overlapping air streams occurred, the speed was the highest. Knowing only the speed of streams, pressure of air could be found. It referred to Bernoulli's principle. The following figure (Fig.3) shows the course of air steams on the cross-plane hull of the vehicle [4].

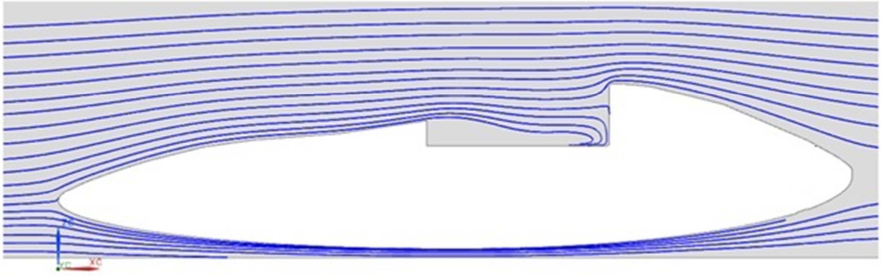

Fig. 3. Course of air streams on the cross-plane hull

It also includes areas where the stream is stopped, which results in the highest pressure. In the bottom part of a car, the phenomenon of the overlapping air streams is clearly visible. In the rear part of the vehicle streams of air which are detached from the surface of car can be noticed. This phenomenon is detrimental, since at this point, the air is disturbed and the underpressure zones are formed. This phenomenon has an impact on the overall results of the analysis, because of disturbances around body for small air speed, less than the speed of sound, propagated at the speed of sound and in the direction opposite to the direction of the incoming air [4].

4. Driver's ergonomic position

Essential part taken under consideration in designing process of the Silesian Greenpower car was the driver's ergonomic position. In the race car the driver should use free space inside the car optimally, with minimal outer dimensions of the car cabin and the whole car bodywork [3]. Because of the fact that the driver's comfort is less relevant, one of the assumptions is to accommodate the construction's dimensions for the person selected by the team.

There have been made detailed measurements of two candidates chosen by the team to be the driver – a man and a woman. The position of the driver was presented in the form of 3D visualization with the use of geometrical model of the Greenpower vehicle (Fig. 4.). The NX Human Modelling tool has been used. The tool generated a parameterized three-dimensional anthropometric model. The advantage of this tool is that it mirrors human form accurately. Model included all of the critical dimensions of the driver – including arm length, foot size, width of the shoulders and waist with driver's gender distinction.

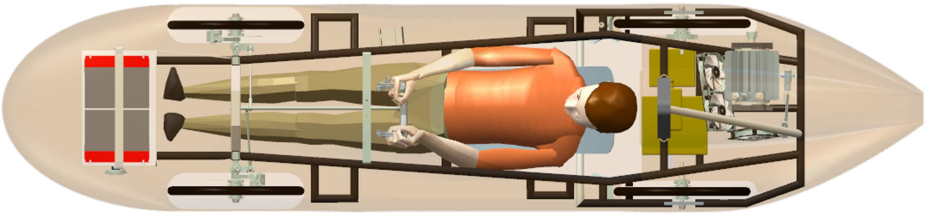

Fig. 4. Digital anthropometric model of a driver – woman, 1,57 m, 45 kg

In addition, the volume of the model also depends on the assumed mass and was taken to calculation of the actual dimensions of the driver. Measures were aimed primarily at:

- approximate evaluation of dimensions of the designed object and analysis of a free space between elements of the model
- verification of element collisions which occurred in the model
- designing technical device in respect of ergonomic
- verifing human limbs range
- simplified comfort angles analysis based on built–in algorithms and anthropometry researches.

The comparison of two drivers' anthropometric models has been conducted. According to the analysis, the optimal driver of the Silesian Greenpower car would be a woman weighing 50 kg and being 1,6 m tall.

5. Motor control and drive circuitry

Effective motor control allows to operate at high speeds and keep the motor safe (e.g. from overheating) at the same time. However, one may easily notice that the more complex and complicated the device is, the more effort has to be put in its design. There are of course many commercial solutions available, yet their limitations greatly reduce their usability in some situations.

The vehicle uses a battery-powered 240W (24V, 10A rated) brushed DC motor. As it was experimentally proven before, the motor is able to operate at ca. 30A continuous current and over 60A peak current as long as decent cooling is provided. For that reason, a specific controller was designed.

The controller itself is a non-standard application of a TL494 chip, which is an integrated PWM controller. Due to the fact, that the TL494 is normally not able to operate with 100% duty, additional negative power supply had to be used in order to pull the Dead Time Control pin low enough (ca. -100mV). The rest is a rather typical application of a constant current SMPS-like device with feedback taken from a hall effect current transducer instead of a shunt resistor. The differential amplifier and the TL431 provide both signal level adjustment for the transducer and the TL494's external frequency compensation. The whole controller operates at ca. 1kHz in order to keep switching losses at a small level. Additional feature of this controller is the presence of a "turbo" mode, which switches the reference voltage to transducer's full scale, thus providing a boost when needed.

The power output is a typical circuit (Fig. 5.): it contains a high-power MOSFET AUIRF3004WL (almost lossless: 1.4mOhm drain to source resistance) switch, a freewheeling diode (6 18TQ045PBF in parallel) and a high current gate driver. Additionally, it is possible to completely isolate the power module from the driving circuit using the optocoupler at input. In order to provide decent cooling, the transistor was soldered directly by its heatsink to a big polygon plane. Cables leading to the motor were also soldered directly to their specific planes on the PCB. The switch's gate is pulled low by a 4.7k resistor and secured by an 18V-rated transil diode. The switching power losses are approx. 20mW so it could be neglected [6].

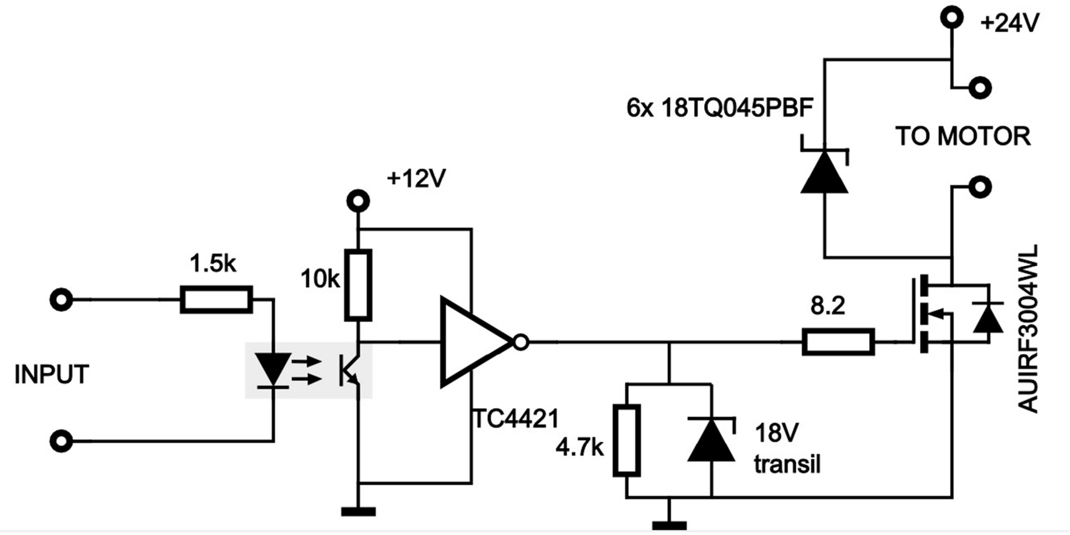

Fig. 5. Power circuit schematic

Summing up, the device was tested in both laboratory and field conditions and operates reliably. Features to be implemented are: the usage of DTC input as a throttle and the possibility of adjusting both standard and turbo mode currents “on the go”.

6. Conclusion

The entire process of analyses of the Silesian Greenpower mechatronic vehicle proved to be very helpful in the design of new construction. All advanced analyses that have been conducted during designing process indicated the direction of a structural modification of the vehicle. CFD aerodynamics verification method indicated a possible direction of future changes of the shape of the car’s. Research of driver’s anthropometric model enabled a rapid verification of a new vehicle’s concept at an early stage of designing and search through range of possible directions of changes. In future all of these activities will result in a building of a new Silesian Greenpower vehicle structure, better and more competitive than previous constructions.

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