Apéndice A

Data sheets

A.1. Fuel cell

2.1 Technical Specifications

Table 1: FCPM Technical Specifications

PROPERTY	UNIT	VALUE
PRODUCT INFORMATION		
Model Number		HyPM HD 8-200-01
Part Number		1028699
PHYSICAL		
Overall Dimensions (L x W x H)[1]	mm	853 x 417 x 251
Mass (overall)[2]	kg	60
With Covers, ex. Coolant Pump and DI Polisher	kg	52
Without Covers, Coolant Pump or DI Polisher	kg	45
Volume	L	89
PERFORMANCE		
Net Rated Electrical Power	kW	8
Operating Current Range	A	0 – 170
Operating Voltage Range	V	47 – 76
Peak Efficiency[3]	%	52
Time from Off to Idle[4]	s	≤ 30
Time from Idle to 8 kW	s	≤ 12
FUEL SYSTEM REQUIREMENTS		
Gaseous Hydrogen (dry)[5]	%	≥ 99.99
CO	ppm	< 0.2
Sulfur (total, ex. H_2S, COS)	ppb	< 4
Total Hydrocarbons	ppm	< 2
Supply Pressure[6]	kPa	600–700
Hydrogen Temperature	°C	2–35
Stack Operating Pressure	kPa	< 120
Consumption[7]	slpm	< 120
Fuel Storage Medium		Customer-provided

Table 1: FCPM Technical Specifications

PROPERTY	UNIT	VALUE
AIR DELIVERY SYSTEM		
Flow Rate	slpm	< 850
Air Filtration (included)		Chemical and Particulate Filter
Composition		Ambient Air
Sulfur	ppb	< 4
OPERATING ENVIRONMENT		
Storage Air Temperature	°C	2 – 40
Operating Air Temperature	°C	2 – 35
Orientation	°	Nominal Horizontal
EMISSIONS		
Max. Pressure Drop of Customer Exhaust System	kPa	4
Water Collected:[8]		
Anode	mL/min	< 40
Cathode	mL/min	< 10
Noise[9]	dBA	< 75
COOLING SYSTEM REQUIREMENTS		
Heat Rejection	kW	< 10
FCPM Coolant Outlet Operating Temperature	°C	65
Coolant Type		De-ionized Water (DI H_2O)
Resistivity	kΩ·cm	> 200
Coolant Flow Rate	slpm	35
Max. Pressure Drop of Customer Coolant System[10]	kPa	40 kPa
ELECTRICAL INPUT		
Signal Voltage	VDC	12 to13.8
Start-up	-	12–13 VDC, 300 W < 30 s
Diagnostic State	-	12–13 VDC, 300 W < 6 min

Table 1: FCPM Technical Specifications

PROPERTY
MAIN SAFETIES
Cathode Exhaust High Temperature
Coolant High Temperature
Coolant Low Flow Rate
Fuel Cell Stack Low Voltage
Fuel Low Pressure
Stack High Pressure
COMMUNICATION INTERFACES
CAN Bus v2.0A (standard 11 bit)
Baud Rate 250 kbit/s
Discrete Signals

1. All dimensions are ± 3 mm. Dimensions of external water pump: ø 95 mm x 250 mm L; Dimensions of external DI polisher: ø 60 mm x 148 mm L.
2. Wet mass basis. Overall mass includes covers, external coolant pump and DI polisher.
3. Operating at 60 A (lower heating value of hydrogen: 25 °C, 101.3 kPa), excludes radiator fan power.
4. “Off” means that the FCPM is not operating in any way; when off, the FCPM does not require 12 VDC start-up or signal power.
5. Hydrogen supplied should conform to the *Hydrogen Fuel Quality Specification Guideline*, published in SAE J2719, November 2005.
6. All reported pressures are absolute pressures
7. Fuel consumption at 0°C, 101.3 kPa, 170 A, and ambient operating temperature of 21°C.
8. 21 °C ambient temperature, 101.3 kPa, normal operation.
9. At 170 A, measured at a 1 m distance from the module.
10. At 35 slpm of coolant flow.

2.2 FCPM Dimensions, Components and Interfaces

The following subsections present the FCPM dimensions. Important FCPM components and interfaces are labelled in the accompanying drawings.

A.2. Super Capacitors

p	**Series: MC Power** **Round, Terminal Type**	Ultra low internal resistance Highest power performance available Lowest RC time constant

› Features:

- » 2.7 Volt Operating Voltage
- » Ultra low internal resistance
- » Over 1 million duty cycles
- » Highest power performance available
- » Lowest RC time constant
- » Threaded terminal or weldable post versions

› Applications:

- » Hybrid drive trains
- » Automotive subsystems
- » Transportation
- » Rail system power

› Overview:

The Power-type ultracapacitor product line gives customers in the automotive and transportation sector a much wider range of choices to meet their energy storage and power delivery requirements.

The cells are specifically engineered for hybrid vehicle drive trains, automotive subsystems and other heavy duty applications that require the lowest equivalent series resistance (ESR) and highest efficiency available.

In addition to meeting or exceeding demanding automotive and transportation application requirements for both watt-hours of energy storage and watts of power delivery per kilogram, all of these products will perform reliably for more than one million discharge-recharge cycles.

The proprietary architecture and material science on which BOOSTCAP® products are based enable continued leadership in controlling costs, flexibility in product offerings and allow application specific performance tailoring. The cells operate at 2.7 volts, enabling them to store more energy and deliver more power per unit volume than any other commercially available ultracapacitor products.

› MC Power Series Specifications:

Item	Performance	
Operating Temperature Range	-40 °C to +65 °C	
Storage Temperature Range	-40 °C to +70 °C	
Rated Voltage	2.7 V DC	
Capacitance Tolerance	+20% / -5%	
Resistance Tolerance	Max.	
Temperature Characteristics	Capacitance Change	Within ± 5% of initial measured value at 25 °C (at -40 °C)
	Internal Resistance	Within 150% of initial measured value at 25 °C (at -40 °C)
Endurance	After 1500 hours application of rated voltage at 65 °C	
	Capacitance Change	Within 20% of initial specified value
	Internal Resistance	Within 60% of initial specified value
Shelf Life	After 1500 hours storage at 65 °C without load shall meet specification for endurance	
Life Test	After 10 years at rated voltage and 25 °C	
	Capacitance Change	Within 30% of initial specified value
	Internal Resistance	Within 150% of initial specified value
Cycle Test	Capacitors cycled between specified voltage and half rated voltage under constant current at 25 °C (1 million)	
	Capacitance Change	Within 30% of initial specified value
	Internal Resistance	Within 150% of initial specified value

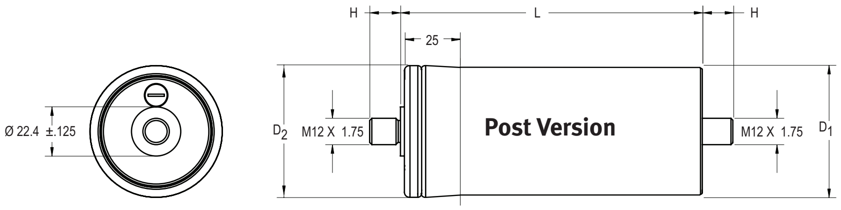
› MC Power Product Specifications:

Part Number	Capacitance (F)	ESR, DC (mohm)	ESR, 1khz (mohm)	Ic (mA)
BCAP0650 P270	650	0.80	0.60	1.5
BCAP1200 P270	1200	0.58	0.44	2.7
BCAP1500 P270	1500	0.47	0.35	3.0
BCAP2000 P270	2000	0.35	0.26	4.2
BCAP3000 P270	3000	0.29	0.24	5.2

› MC Power Product Properties:

Maxwell Part No.	Rth (C/W)	Isc (A)	Emax (Wh/kg)	Pmax (W/kg)	Pd (W/kg)
BCAP0650 P270	6.5	3500	3.29	15,100	5,400
BCAP1200 P270	5.3	3750	4.05	13,800	5,000
BCAP1500 P270	4.5	3900	4.75	16,200	5,800
BCAP2000 P270	3.8	4300	5.06	17,500	6,200
BCAP3000 P270	3.2	4800	5.52	13,800	5,400

› Dimensions:



Part Number	Vol (l)	Mass (kg)	Size (mm)			
			L	H (±0.5mm)	D_1 (±0.2mm)	D_2 (±0.7mm)
BCAP0650 P270 T04	0.211	0.20	51.5 ±0.5	14.0	60.4	61.3
BCAP1200 P270 T04	0.294	0.30	74.0 ±0.3	14.0	60.4	61.3
BCAP1500 P270 T04	0.325	0.32	85.0 ±0.3	14.0	60.4	61.3
BCAP2000 P270 T04	0.373	0.40	102.0 ±0.3	14.0	60.4	61.3
BCAP3000 P270 T04	0.475	0.55	138.0 ±0.3	14.0	60.4	61.3

Product dimensions and specifications may change without notice. Please contact Maxwell Technologies directly for any technical specifications critical to application.

› Mounting Recommendations:

Do not reverse polarity.
Maximum torque for M12 screw terminals are 10Nm.
Cells are designed to be connected into series or parallel strings.
Clean terminals before mounting.

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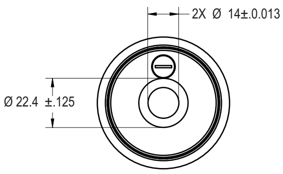
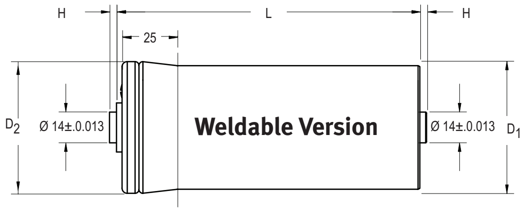
› Dimensions:





Part Number	Vol (l)	Mass (kg)	Size (mm)			
			L	H (±0.125mm)	D_1 (±0.2mm)	D_2 (±0.7mm)
BCAP0650 P270 T05	0.150	0.20	51.5 ±0.5	3.18	60.4	61.3
BCAP1200 P270 T05	0.233	0.30	74.0 ±0.3	3.18	60.4	61.3
BCAP1500 P270 T05	0.264	0.32	85.0 ±0.3	3.18	60.4	61.3
BCAP2000 P270 T05	0.312	0.40	102.0 ±0.3	3.18	60.4	61.3
BCAP3000 P270 T05	0.414	0.55	138.0 ±0.3	3.18	60.4	61.3

Product dimensions and specifications may change without notice. Please contact Maxwell Technologies directly for any technical specifications critical to application.

› Markings:

Capacitors are marked with the following information - Rated capacitance and rated voltage as well as energy/power type indication in the product naming. Serial number, name of manufacturer, positive and negative terminal, warning marking.

› Additional Technical Information:

Capacitance and ESR, DC measured per document 1007239

I_c= Leakage current after 72 hours, 25˚C   Isc = short circuit current (maximum peak current)

R_{th} = Thermal resistance

$$E_{max} = \frac{\frac{1}{2} CV^2}{3600 \text{ x } mass} \qquad P_{max} = \frac{\frac{V^2}{4R\,(1khz)}}{mass} \qquad P_d = \frac{\frac{0.12V^2}{R\,(DC)}}{mass}$$

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A.3. Step Up

5.20 Electrical Specifications (Control).

Input resistances.

Terminal 1 and 4 are common (control plug).

Terminal 2, VREF+: 10k ohm to common with terminal 3 tied to common. 20k ohm with respect to terminal 3.
Terminal 3, VREF-: 20k ohm to common.
Terminal 6, VFB+: 50k ohm to common with terminal 5 tied to common. 100k ohm with respect to terminal 6.
Terminal 5, VFB-: 60k ohm to common.
Terminal 7, DISABLE+: 2.2k ohm pull up to +5V or +12V, depending on selector on board.
Terminal 8, DISABLE-: 2.2k ohm pull up to +5V or +12V, depending on selector on board.

Switching Frequency:	31,250Hz, crystal controlled
Gain Range, velocity mode:	.86V to 10V for max output voltage.
Gain Range, current mode:	.86V to 10V for max current.
Offset:	Adjustable to zero with ZERO Pot.
Drift:	.1%/Deg C, max
VFB Input voltage range:	plus or minus max bus voltage.
VREF input voltage range:	-10 to +10 volts
STATUS:	NC Contact, 100 V DC, 10 Watt reed relay

5.30 Electrical Specifications (Power).

Input Voltage, DC: See Product bulletin.
(http://zahninc.com/httpzahninc.comssloose.html)

Output Voltage: 0 to the .94*DC Bus voltage - 2 volts

Continuous Output Current: See Product bulletin.
(http://zahninc.com/httpzahninc.comssloose.html)

5.40 Operational Modes.

1. Voltage Loop, without IR Compensation.
2. Voltage Loop, with IR Compensation.
3. Current Loop.

5.50 Status

The Status of the **CH unit** is conveyed by a normally closed contact available at terminals 11 and 12 of the control plug. The Status is also referred to as fault and "AOK". The red LED turns on and the contacts are opened if:

1. There is no power to the unit.
2. The internal power supplies have failed.
3. The **CH unit** is in thermal limiting.

A.4. Motors

PERM MOTOR

Technical Specs
PMG 132

Voltage	24 V	36 V	48 V	60 V	72 V
Operation mode	S 1	S 1	S 1	S 1	S 1
Current	110 A	110 A	110 A	110 A	110 A
Power	2,5 kW	3,5 kW	4,74 kW	5,97 kW	7,22 kW
rpm	1080 min-1	1700 min-1	2300 min-1	2870 min-1	3480 min-1
torque	20 Nm				
inertia	0,025 kgm²				
inductance	0,019 mH				
resistance	16 mOhm				
protection	IP 20				
weight	11 kg				
Short time operation	200 A	S2 10 min			
peak torque	38 Nm				

TECHNICAL DESCRIPTION
PMG MOTOR SCOPE

Subject motor is a high poled, permanently excited direct-current disc motor.

To create the main field, high powered rare earth permanent magnets are used , which are attached to the flanges on the right and left hand side of the motor.

The armature is constructed as a disc and consists of Cu-profile-lamellas at the end of which in its centre a disc commutator is connected. Between the windings are tapered core sheet layers, which are made out of christal core sheet material. The torque transmission from the rotor to the shaft is handled by a special modelling compound connecting the rotor with the shaft.
On the exterior circumference of the winding ends, soldering connectors are mounted, which simultaneously serve for self-ventilation.

The power transmission occurs through tapered carbon graphite brushes, which are adjusted to the commututator form and are carried by a special brush holder design. The brush holder serves simultaneously as the connecting element to the power supply and has in its interior area a bore hole to incorporate the B-side ball bearing. The drive sided ball bearing is fitted in the mounted flange on the opposite side.

The magnetic flux created in the permanent magnets runs axially through the sheet layers placed between the armature conductors. Through this design air gaps are reduced to a mechanically minimum; the magnetic losses are minimal. Furthermore, the thickness of the disc is independent of the air gap - hence an extremely high Cu-profile can therefor be used, so that the current density is controllable in the armature conductors

ADVANTAGES

The described motor construction yields a very small power to weight ratio, which is about 1/3rd of that of a traditional direct-current-motor. The compact construction allows small exterior measurements, i.e. less space requirements. an additional advantage is the high efficiency degree (around 90 %) covering a broad range of operational conditions.

Application of the motor as a generator results in the same determining features. The motor can therefore be used in a traction application as electric brake, resp. be used for energy-recovery.

COSTS

The low power to weight ratio and the fully integrated commutator result in cost advantages comparing most favourable with a traditional direct-current-motor.

AREAS OF APPLICATION

Basically all battery powered drives, e.g. electric vehicles of all types, ventilators, boat drives, wind generators, lawn mowers, go-karts, golf cars, forklifts etc.

Appendix B

Formula Zero Championship

B.1. Introduction

Nowadays new energy sources for the transport sector are raising. The main motivation for this change is the exhaustion of the global petrol storage during the next decades. Also the Territorial distribution of the petrol is not homogeneous. So there are countries with big petrol storage that sell it to the countries with less storage or no storage. That situation causes a big energetical and economical dependence for the countries without petrol resources. So one of the objectives of the new energy sources is to reduce the energetically independence of each country. As an ideal, each country had to produce store and use it´s own energy.

Another factor that forces this change is the emissions caused by the actual energy society. Almost all the energy used in transport came from petrol. So there is a huge carbon dioxide emissions to the atmosphere. That emissions are causing the worldwide known green house effect, witch is the most important factor in the climate change global problem. Therefore another big objective of a new transport energy source should be the reduction in the carbon dioxide emissions.

On the other hand the efficiencies of the petrol engines are really low . Most of the primary energy is wasted in the engines and turbines exhaust. So another objective for a new energy should increase the devices efficiency, use less energy for the same results.

Attending to this criterias the optimal energy sources for the coming energy revolution are the renewable energies.

But then, how to use renewable energies in mobile applications and transport became as a problem. Most of the known renewable energy sources are stationary (wind, solar, ...). Another problem is, how to store the energy. Most of the renewable energy sources are random (Energy is not produced necessarily when the it is needed) so is necessary to store these energy to be used when needed.

Here is where hydrogen appear as a posible solution for energy supply in mobile application. Because hydrogen can be produced from renewable energy sources, can also be stored and used when and where is needed.

So the advantages of hydrogen energy technology are:

- Hydrogen can be stored in big scale
- It can be used in mobile applications
- Device efficiencies are high
- Renewable stationary energies can be used for mobile applications
- The efficiency of the electrical network can be increased by storing residual energy
- It is a clean carbon free technology

The present problems to implement hydrogen technology are:

- The necessity of a new energy production and distribution network

- The actual price of the equipments
- The necessity of develop, production and commercialization of new devices

The first necessity for the progress of the hydrogen society is the promotion of the technology, so the companies can get interest to invest in. Then the technology have to be tested and improved until a commercial reliable product would be feasible.

The competition is a good way to improve, accelerate the implementation and show new technologies.

Formula Zero is a international motor sport hydrogen competition that promotes hydrogen technology all around the world. At the same time all the teams develop new designs for its cars, helping to go forward with the technology. [14, 15]

B.2. The race

Formula Zero organization aim to organize four events during the 2009/10 FIA [?]Formula Zero Cup.Each event will consist of at least one Sprint Race and one main Race.The results of both Sprint and Main races will count towards the cup rankings.

- There will be separate qualifying sessions to determine the initial ranking for the Sprint and Main races. In each session, all participating teams make one run. Teams are ranked for the race based on time (fastest to complete the entire run ranked first), distance completed (if the vehicle does not complete the run), and fastest time recorded in practice (if the vehicle does not start the run).
- Sprint and main Races will both be held in a single elimination tournament format consisting of multiple rounds.
- Sprint race is a single lap race
- Main race is a several laps race (the number of laps depends on the circuit place)
- Teams will be allocated one hydrogen cylinder to complete the three heats of the Sprint Race. Teams will be allocated one hydrogen cylinder for each heat of the main Race.
- Charging the Energy Storage System ESS (see technical rules section B.3) from an external power source is prohibited between rounds. Once the vehicle begins the Qualifying Round, no energy source other than on-board hydrogen and recovered kinetic energy may be used to charge the ESS.
- If two or more teams complete their run within the same time according to the official timing equipment, the fastest lap time recorded by each team during the practice session(s) for the event will be used to rank the teams.
- Teams that are unable to start their run will be ranked after teams that do start their run. If two or more teams are unable to start their run, the fastest lap time recorded by each team during the practice session(s) for the event will be used to rank the teams.
- Cup points will be awarded to all teams entered in the 2009/10 FIA Formula Zero Cup after each race. Points will be awarded based on the official race results according to the following schedule:

Table B.1: Races puntuations

-

B.3. The technical rules

In a motor sport competition every team have to follow rules in order to ensure a fair competition. In the Formula Zero championship, there are many rules, for the different aspects of the race but here the most relevant technical ones are marked:

- Vehicle General characteristics: Fuel-cell powered hybrid electric drive train, single seater, no roof, no suspension, Four wheels, Steering ensured by at least two wheels, propelled by at least two wheels.
- The maximum weight is 275kg without driver and the minimum 150Kg. If the driver weights less than 75kg, ballast must be added to the vehicle to rise 75Kg.
- Dimensions(Maximum): length 230cm, Width 150cm, Height 75cm, Wheelbase 110cm min 160 cm max, ground clearance 35mm min

FUEL CELL

- Vehicles must be powered by one hydrogenics HyPM HD 8 Fuel Cell Power Module (section C.2)
- Modifications to the fuel cell components that reside inside the fuel cell enclosure are prohibited
- Components supplying anything other than air at ambient pressure to the air intake(cathode) are prohibited.
- Exhaust water must be collected in a container on-board the vehicle.

ENERGY STORAGE

- The collection of all components witch store energy recoverable to participate in the propulsion of the vehicle, except for the hydrogen cylinder provided by the organizer, is considered The Energy Storage System(ESS)
- The maximum usable energy storage capacity of the ESS is 250.00 Joules.(Capacitors)

PROPULSION AND MOTORS

- Only electric motors may be used.
- Propulsion of the vehicle must be made trough the wheels
- The vehicle must be fitted with a reverse mode.

BRAKES

- A Hydraulic braking system (the primary braking system) operated by pedal is mandatory.
- The primary braking system must be a dual-circuit system, With a front and a rear circuit.
- Any kinetic energy recovery system may not be activated by any means other the brake and/or the accelerator pedal

ELECTRICAL EQUIPMENT

- The fuel cell have to be started without connecting an external energy source
- Batteries or capacitors not included in EES must be fused to limit power output to 600W
- Battery types other than those listed below are prohibited: Nickel-iron, Nickel-Zinc, Nickel-Metal -Hydride, Lithium-Ion and Lithium-Metal-polymer
- Capacitors others than the following types are prohibited: Glycol Ether, Lactone, Amide, Aliphatic carboxylic acids, Ammonia based, Polypropylene film.

- Electrical potential of more than 120V DC or 71V AC RMS referred to system ground is prohibited
- Electrical potential of more than 50V between system ground and the chassis or body of the vehicle is prohibited.

HYDROGEN FEED SYSTEM

- The hydrogen feed system must be routed such that accumulation of hydrogen in enclosed or semi-enclosed areas is minimized in the event of a leak.
- Hydrogen cylinders other than those supplied by the organizers are prohibited. Those are 200 bar pressurized deposit.
- The manual shut-off valve must be accessible by the driver while seated in the cockpit

The complete rules can be check in [?] or in the appendix.

B.4. Our team

The ´´Foundation Hidrogeno Aragón"[?] located in Huesca promotes set up a Formula Zero team. The University of Zaragoza join this project as well. For the development of the technical parts of the go-kart another companies have joined to the team:

- Team Elias: Is a Small Size Enterprise (SME) motor sport racing team that design and build the chassis and body work of the car.[?]
- CIRCE: Is a Investigation center specialized in energy energetically consumption and production. They design the power electronic circuit.[?]
- Inicom: Is a company specialized in measurements and computer programing. They measure all the system status and store the information. They also implement some microprocesing control of the system.[?]
- Eupla: It is a part of the University of Zaragoza. They make the telemetry of the fuel cell data.[?]

´´Fundacion Hidrogeno Aragon" leads and coordinates the project and designs the hydrogen and energy management system.

Appendix C

Car configuration

C.1. General energy configuration

The objective of the system is to help the pilot to drive the car as fast as possible along the circuit. So the system have to transmit as much energy as possible to the wheels, when the pilot push the accelerator.

Different connections of the components and transformers was considered. Finally the configuration show in the Figure:C.1 was chosen taking into account the better control of the capacitor and the commercial availability of the components.

The energy is obtained from hydrogen in a low temperature Polymer Electrolyte Membrane (PEM) fuel cell that supplies DC electrical energy. This energy is adapted in voltage by a DC/DC converter to the super capacitor voltage. Finally that energy is used in the motors that drives the rear wheels. The function of the super capacitor is to supply the motor peak demand , when these demand is greater than the Fuel Cell production.

Figure C.1: System General sketch

Using the dispensable devices the capacitor can be also connected directly to the Fuel Cell terminals. This case will be studied in the simulations.

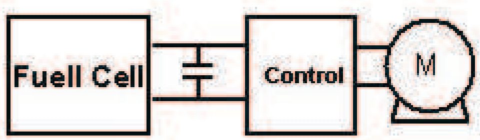


Figure C.2: Capacitor directly connected to the Fuel Cell terminals

The idea behind controlling the capacitor voltage, is to get the capacitor supply more energy. A capacitor current depends on the voltage variations. If the voltage goes down the capacitor supplies current trying the voltage not to fall, if the voltage goes up the capacitor get current from the system and store the energy. So the capacitor voltage have to decrease when some energy from the capacitor is needed and increase when some energy is been stored in it. Controlling that voltage the power generated by the system can be controlled.

C.2. Fuel Cell

The Fuel Cell used in the system is a HyPM HD 8 from Hydrogenics manufacturer. There is not possibility of using another one because of the race rules.(sectionB.3)

It is a low temperature Polymer Electrolyte Membrane Fuel cell with a power of 8.5kW. This power is supplied between 49 and 79 Volts DC.

It is also forbidden to open the fuel cell. Therefore if the manufacturer specification are full filled the fuel cell have to work properly. There is not possibility of take part in the fuel cell control (stochiometry, humidification, hydrogen recirculation....).

Manufacturer specifications:

1. Electrical power supply: 100W 12VDC during 20 seconds.100W just when the fuel cell is warming up
2. Air Supply: A maximum rate of 1000 standard liter per minute. In a range of temperatures between 10 and 40ºC
3. Hydrogen supply: A maximum rate of 115 Standard liters per minute at 5 - 6 bars. With a purity of 99.99%. .
4. Cooling: De-ionized water have to be supplied at maximum temperature of 65ºC. The maximum flow admitted is 15 liter per minute

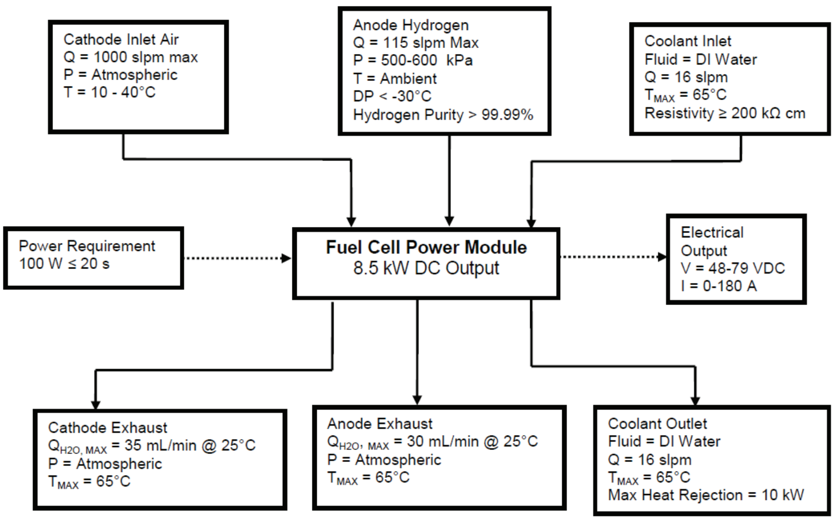


Figure C.3: Fuel Cell input/output flows

How the demands are supplied:

1. The electrical demand is directly supplied with a 12VDC 50Ah battery. That is also used to supply energy for the control and monitoring systems.
2. As the fuel cell have a filter and a fan itself the ambient air is enough to supply the air demand
3. The hydrogen is stored in the car in a 200 bar 5 liter cylinder (race rules). A pressure reducer keeps the input pressure to the desired value (5-7 bars).The flow is filtered to ensure that no particle is coming into the fuel cell. There is also installed a high pressure valve to close the hydrogen supply when needed. All the hydrogen pressure system was designed in ´´Solid Works“ (3D design program)[?] to optimize the volume occupied in the vehicle (Appendix ??)

4. A De-ionized water colling circuit was installed. It consist on a pump that moves the fluid, a radiator that evacuates the heat, a de-ionized water filter and pipes that fits all together with the Fuel cell.(figure C.4)

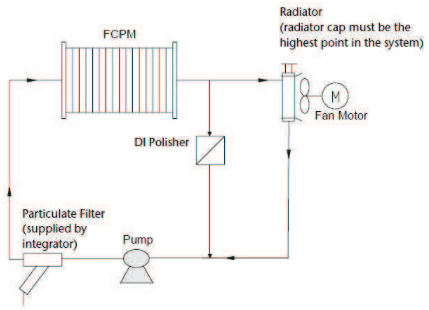


Figure C.4: Cooling circuit sketch

Moreover mentioned signal it is also necessary other signals to ensure the properly working of the fuel cell.Signals and controls needed:

- FCPM Enable: Is a 12VDC signal. It indicates that the user wants to switch on the fuel cell. It have to be hold at 12 VDC all the time the fuel cell is switch on
- System E-Stop: It is a signal that works like FCPM. But its proposal is to ensure that all the security system are OK so the fuel cell can be on. It is connected at the end of the life line (SectionC.2.1).
- Cooling Fan Control: This output signal controls via PWM the radiator fans to ensure a correct temperature in the cooling circuit.
- CAN Bus Communication: The fuel cell status is sent via CAN bus so it can be monitored. The same CAN bus is used to receive orders (switch on, switch of , ..). It also gives the Current Draw Allowed (CDA) that indicates the maximum current that the fuel cell can supply in the next time step. If the current demand is lower than the CDA the manufacturer ensure that the fuel cell is working properly.
- Load Enable: This is a signal that the fuel cell uses to connect or disconnect itself from the load. That signal is directly operating 2 relays that disconnect the capacitors and the motors from the rest of the circuits.

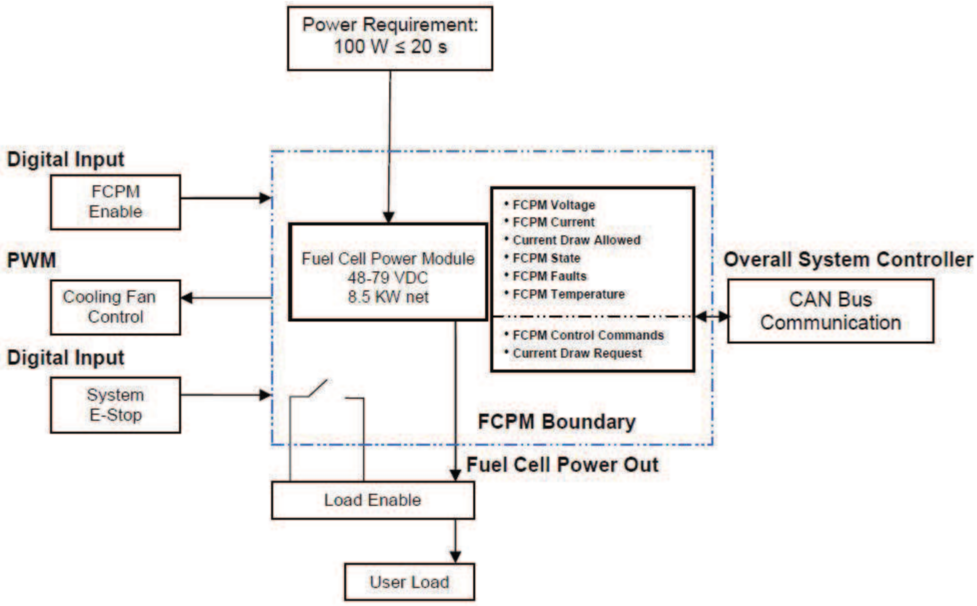


Figure C.5: Fuel Cell control sketch

Fuel cell data sheet can be seen on apendix **??**.

C.2.1. Life line

The first priority in every car have to be the security. As security criteria the fuel cell switch-off if something goes wrong. Because of this, a life line was designed. It is a single 12VDC wire that ends in the fuel cell, it switch of if this life line circuit is open. Also the super capacitors are disconnected from the system with the same signal.There are different security devices that opens this circuit in case of danger:

- Crash sensor: It measures the acceleration of the car, if it is greater than a crash value (fixed) it opens the life line.
- Driver out sensor: It detect if there is driver or not using a mechanical device. If the driver isn´t in the car, this sensor opens the drive line.In case of crash, if the driver jump out of the car the life line is also opened.
- ON switch: The pilot have to push this button to switch on the car.
- Emergency stop switch pilot (S1/A): In case of emergency the pilot can pulse this button to open the life line.
- Emergency stop switch team (S1/B):In case of emergency the team can pulse this button to open the life line.

When current is passing trough the life line is also holding open a hydrogen solenoid valve. if one of the security system is activated and it opens the life line, the fuel cell stops and the hydrogen supply is disabled.

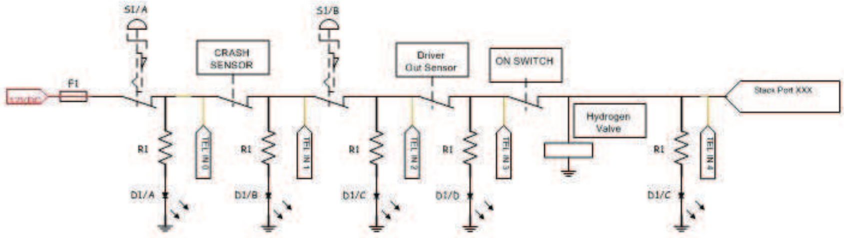


Figure C.6: Life line sketch

C.3. Motors and Controllers

The motor is a permanent magnet DC machine, because of the high power weight ratio of permanent magnet machines. In every mobile application the weight is a significant factor, as less weight of the car as less energy needed to accelerate the car. The motors (in case of full power demand) have to transmit to the car the power from the fuel cell and the capacitor together:

- The maximum peak power of the fuel cell is 8,5 Kw
- The capacitors can supply until 3500 amperes in a peak. But then the capacitors are discharged in less than one second. Lets assume that at least 15 seconds of capacitor power is needed. If the capacitors are fully discharged in 15 seconds it gives a power of 18Kw.

So the maximum power demanded by the motors have to be 26,5KW. The motors selected characteristics can be seen in figure C.7. The car have two of this motors , one for each rear wheel. Each motor has a nominal power of 7,22 Kw but its can be operated at twice its power for a period no longer than 10 minutes. As the formula zero races are less than 10 minutes it can be assumed that each motor has 14,44Kw nominal power..Therefore the dispensable mechanical power in the wheels is 28,88 Kw.

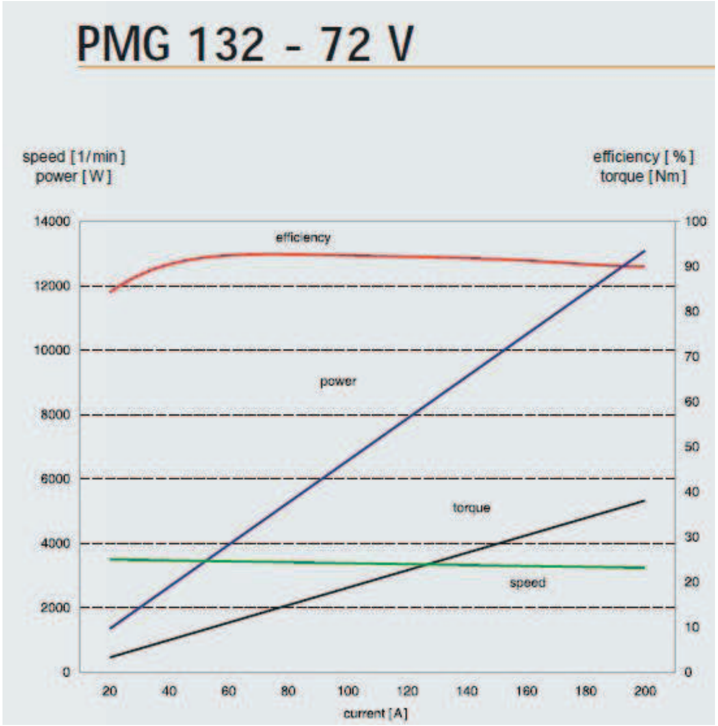


Figure C.7: Motor characteristics

To operate the permanent magnet motors a motor controller is needed.The most important controlled parameters are:

- Gas pedal signal(Accelerator):: It controls the velocity of the motor with a voltage input signal.
- Brake: It controls the deceleration and regenerative braking with a voltage input signal. (This function is disconnected in our case because there is not regenerative braking)
- Maximum input current: It is a variable fixed previously. It can´t be controlled when driving
- Response time: It fix the time from and acceleration order to achieve the desired velocity.
- Maximum motor speed:It is a variable fixed previously. It can´t be controlled when driving.

The motor data sheet can be seen in the apendix **??**.

C.4. DC/DC converter (Step Up)

For the voltage control of the capacitors an DC/DC converter connected to the fuel cell is necessary. It has two different functions:

- Control the voltage on the capacitor terminals. To control the capacitor it supply or store energy when needed.
- Ensure that the current from the fuel cell is lower than it maximum. So the fuel cell doest´t stops and works in a properly working point.

An ideal voltage control have to allow the maximum variation in the voltage, so most of the energy stored in the capacitors is used. The capacitor voltages are limited by the motor controller(Figure:C.1), it can admit an input voltage from 25 volts to 96V (Appendix: **??**). The optimal device for this task is an step up and down so the output voltage can be lower and greater than the fuel cell one (Fuel cell voltage 49-79V).

Due to the lack of time it was only possible to obtain an step-up, so it can supply voltages always greater than the fuel cell one.Because of the capacitor limitations rules (Section C.5) the maximum voltage is limited to 72 volts. So finally the step-up output voltage can be controlled from the fuel cell voltage to a maximum of 72 volts.

A Zahn Electronics Step Up DC/DC converter was chosed (Appendix: **??**). It can operates in the needed voltage range and the power is appropriate to the fuel cell power. In this converter the output voltage can be controlled with an analog reference signal. It can also limit the input current, so the fuel cell is never working out of his limits.

The output voltage is controlled, until the input current is equal to the limit imposed. Then if the current demanded rises the output voltage decreases (So the voltage control is lost, the voltage is less 72V).

In case the output voltage falls until being lower than the input voltage the current control is also lost. Then the system is uncontrolled, because the fuel cell current can rises too much and force the fuel cell to stops.

To sum up:

- The output voltage have to be always greater than the input, otherwise the current limit control is lost.
- The input current limitation affect to the output voltage if the demand is to high.

If the voltage control is lost, the voltage decreases so the capacitors supplies energy. Therefore this case is a desired one in some situations.

If the current control is lost the fuel cell is on stop risk, so this is not a desired situation.

C.5. Capacitors

The race rules limits the energy that can be stored in batteries and super capacitors. As the target in this car is to increase power and reduce the weight, super capacitors are the best solution. The use of Maxwell capacitors was decided because those are one of the most power full capacitors (Figure:C.8) in the market and its technology is accepted by the race rules.The energy that can be stored on is limitated to 250.00 Joules. Each capacitor has a capacity of 3000 Farads and it can support 2,7 volts (Appendix:**??**). The number of capacitor was calculated not to store more energy than the maximum allowed. To get the voltage necessary for the motors the capacitors was connected in parallel(eq:C.1).

$$\frac{1}{C_{tot}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} ... \tag{C.1}$$

Where $C_{tot}$is the total capacitance of all the capacitor´s connection and C_i is the capacitance of each capacitor.

The energy stored is calculated in the equation C.2.

$$E = \frac{1}{2} C V^2 \tag{C.2}$$

To install 30 capacitors and operate it at 72 volts was decided, so the maximum energy stored is 259 200 Joules. It is a little bit more energy stored than the allowed by the rules.But the capacitance will be decreasing with use so for the race the rules will be followed. The maximum voltage allowed by the capacitors is 81 volts so it is a safe system because the operating voltage is far from the limits.

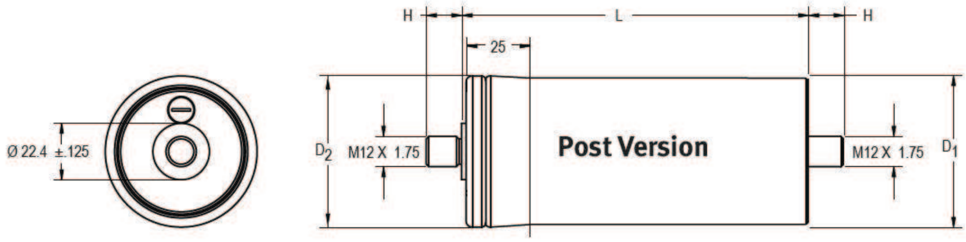


Figure C.8: Maxwell Super capacitor

Dimensions not fixed in the drawing, see appendix ??.

C.6. Chassis and mechanical parts

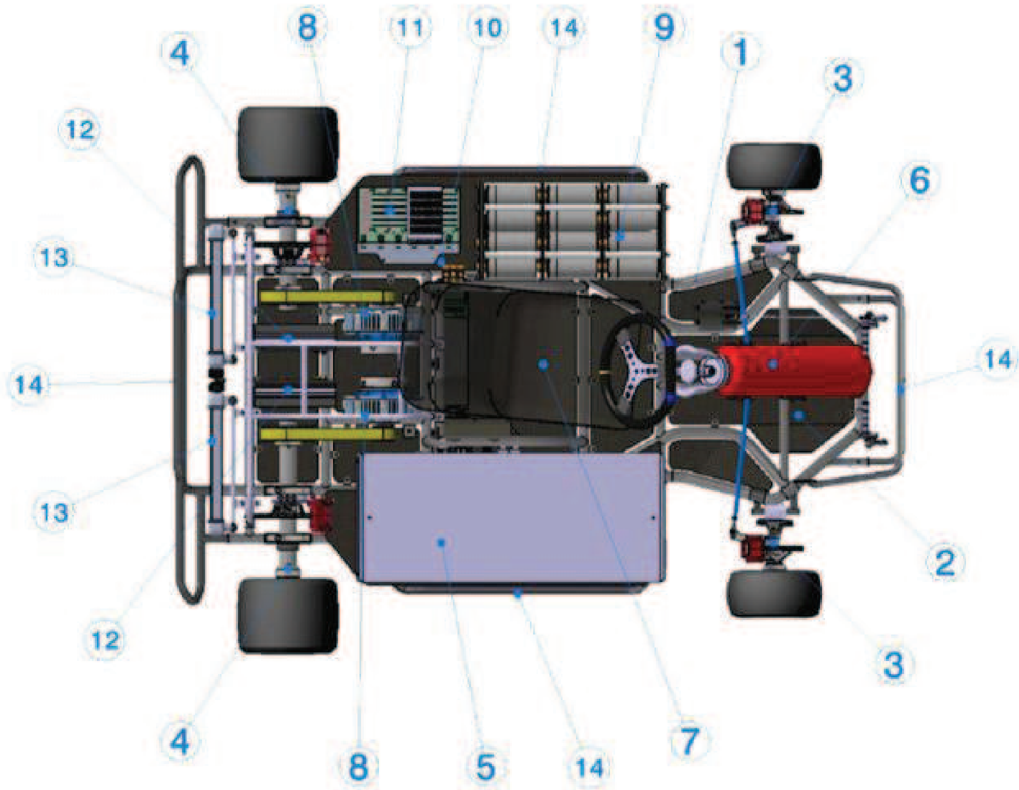
The main target of the chassis is to allow the pilot to drive as fast as possible and hold all the element well fixed in a crash case.

To get this objectives a steel tubular chassis is design The chassis shape is an super go kart chassis reinforced to support the extra weight of a fuel cell powered car. All the elements are positioned as close as possible to the floor. In that way the center of gravity is also closer to the floor and it increases the curve stability. To compensate the fuel cell weight the pilot position is displaced to keep the center of gravity in the middle of the car, improving by this way the car dynamics.

The bumpers was tested to support the crash force demand fixed by formula Zero.

Each of the two motors are connected on rear wheel by a chain.

The brake system consist on two separated hydraulic circuits (One for the rear wheels, one for front ones)



MARK	QUANTITY	DENOMINATION	CAD CODE
14		BUMPERS	11
13		COOLING	10
12		CONTROLLER	9.5
11		DC FILTERS	9.3
10		STEP UP	9.2
9		BOOSTCAPS	9.1
8		DRIVE TRAIN	8
7		COCKPIT	7
6		HY CYLINDER	6.2
5		HY CELL	6.1
4		REAR TRAIN	4
3		FRONT TRAIN	3
2		CHASSIS PLATES	2
1		CHASSIS	1

Figure C.9: Chassis design

Appendix D

Presure Box

During the project it was also designed a pressure box. It contains all the high pressure pipes and valves. It was designed with the 3D design program Solid Works.

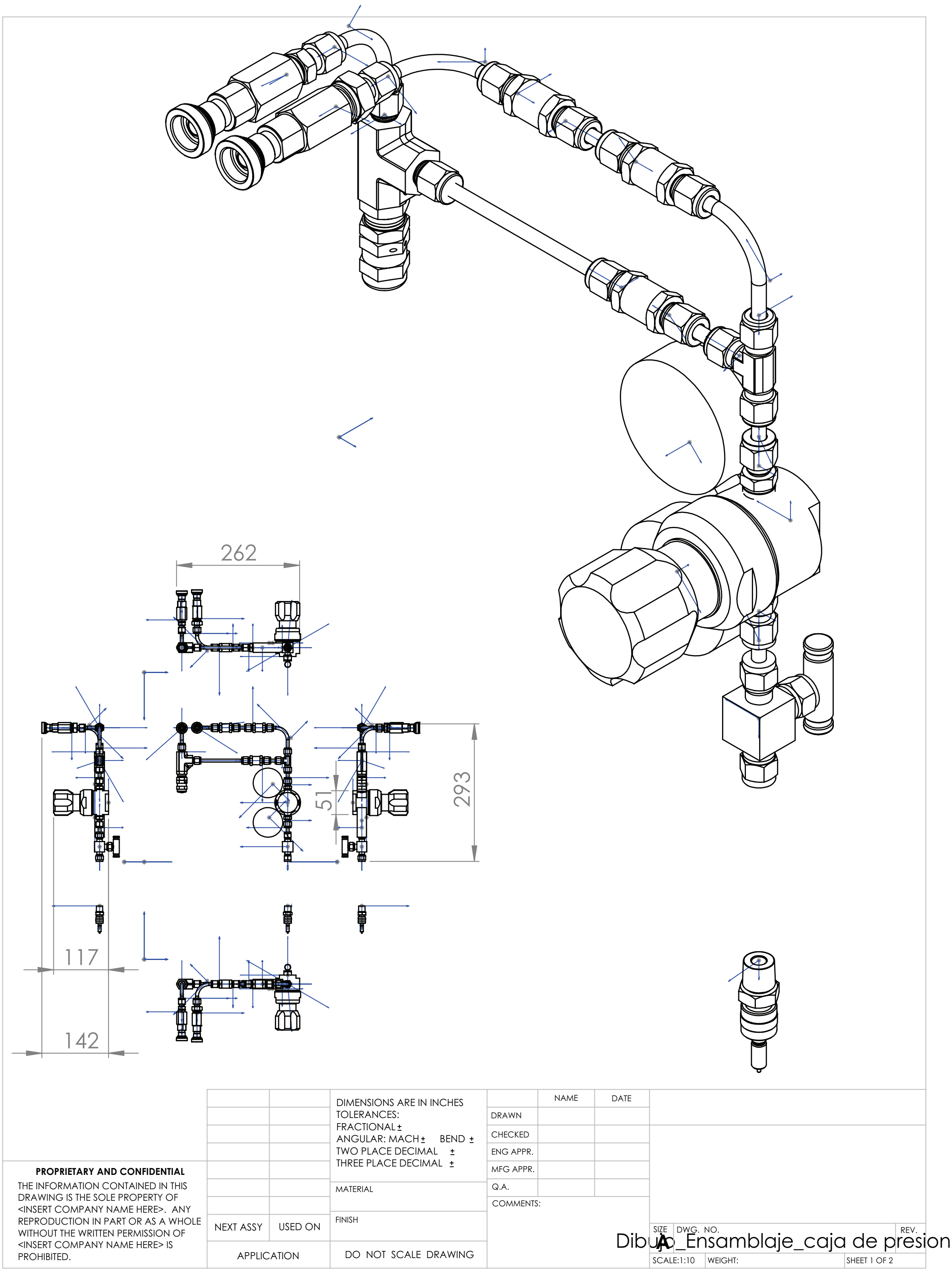


Figura D.1: Pressure box (solid work design)