Considerations about the static fire of the RATTworks H70 rocket motor

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by Terrassa Rocket Team

Sponsors

Introduction

On the aeronautical engineering degree students improve their theoretical knowledge about this discipline. But the feeling among the students is that we can't apply this knowledge until we finish studying and start working. This is the reason why some of us join a students team such as Terrassa Rocket Team (TRT) where we can join other students interested in rocket modeling. Together we improve our skills in making different types of rockets like a two-stage rocket, a supersonic one, rockets with deployable wings, etc. Some of us inside TRT are focusing on a new challenge: a hybrid rocket. All the same, before launching a rocket with a hybrid motor, we''ve organized a static fire to assess the thrust curve and test the launching process.

Objectives

The main objectives that need to be accomplished with the static fire are:

- Perfect the launch and ignition sequence and assesses its correct operation. The work on this sequence is not done from scratch since several years ago former and current students of the TRT already ignited the hybrid motor. All the same, they never managed to fly a rocket with the motor.

- Familiarize the part of the team that has never worked with this engine with the sequences, peculiarities and behavior of this type of rocket engines.
- Improve the security measures. Since the operation of this rocket engine requires high-pressure oxidant gas security measures are more important than ever.
- Improve the thrust curve quality. The completely new test bench and electronics will ensure more reliable and constant data.

How does the engine work?

First of all, we will explain how is connected the gas circuit, then the ignition sequence and finally, how the combustion starts.

Gas circuit

The gas circuit begins in the tank, where we can find the gas at the approximate pressure of 60 bars (depending on the tank temperature). A tube joins the tank with the engine chamber, passing through the nozzle and the rocket candy (made of white sugar and potassium nitrate). The rocket candy is connected to an ignitor, when fired, it provides the necessary energy to start the combustion. Before the tubes enter the engine it has to go through an electro-valve that is remotely controlled. To ensure that the valve works, there are two pressure sensors before and after the electro-valve. These sensors will send their readings to the control panel. If the valve fails to open or stops before the tank is full, a pressure difference will be detected thanks to the pressure sensors.

Ignition sequence

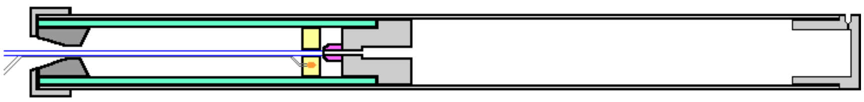

Figure 1: Empty motor

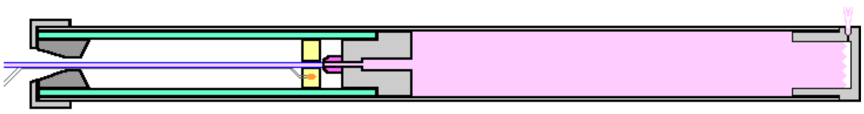

Figure 2: Motor filled with N_2O and venting

The ignition sequence starts by checking the ignitor continuity through the control panel. Once this is done the system is ready to be filled with gas. In order to fill the engine tank with gas, the tank valve must be manually opened and the electro-valve must be opened remotely from the control panel. Once both valves are open the engine tank will fill as seen on Figures 1 and 2. Once the chamber is full, the electro-valve and the tank valve will be closed.

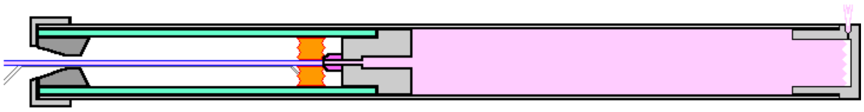

Figure 3: The ignitor starts the combustion of the solid grain

Finally, the countdown to the ignition is started through the control panel and the ignitor will be automatically triggered when the countdown reaches 0. The start of the ignitor can be seen on Figure 4

Combustion

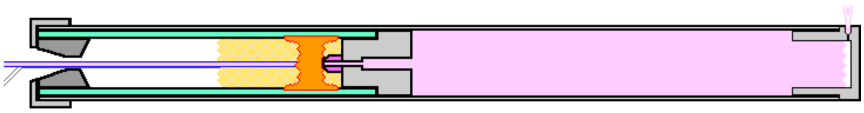

Figure 4: The combustion of the solid grain burns the gas tube

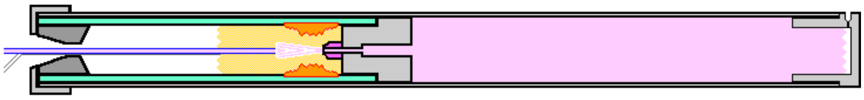

Figure 5: The gas leaks through the tube

The combustion starts with the spark of the ignitor, which is close to the rocket candy as seen on Figure 4. The rocket candy, which is solid fuel, burns rapidly, destroying the walls of the gas tube as seen on Figure 5.

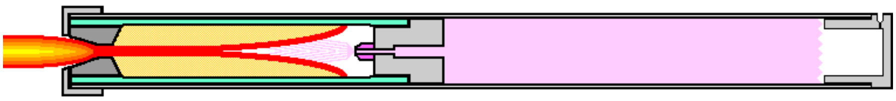

Figure 6: The motor is now functioning

This damage causes a leak of gas from the tube that burns rapidly too. Finally, this existing flame is able to continue burning the gas of the chamber in conjunction with the polypropylene in the gas chamber, the rocket fully ignited can be seen on Figure 6

Gas considerations

Gas state and pressure

A basic theoretical study of the gas state and pressure inside the tanks has been conducted. To do so, the properties of the N_2O have been extracted from [3]. With the equations presented on the former source, a simple Matlab code has been built that generate the chart in Figure 7, said code can be found in [2].

It''s important to realize that it''s difficult to measure the amount of nitrous oxide remaining in the tank because the pressure inside the tank remains constant until the tank is almost empty. The reason why this happens is because inside the tank there is N_2O in both vapor and liquid states. When this happens the pressure inside the tank remains constant at a value named vapor pressure.

This state where the two phases co-exist can only happen at a given pressure temperature and specific volume of the substance. A graphic representing this can be seen on the figure 7.

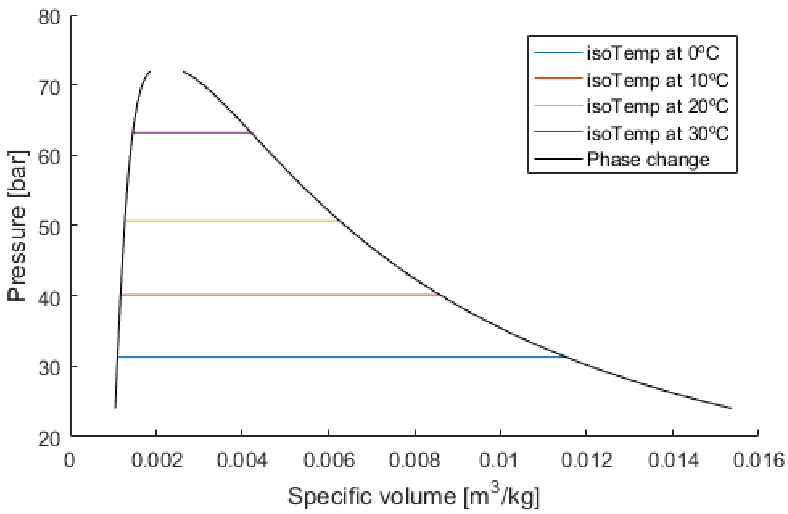

Figure 7: N_2O pressure vs specific volume chart

The tank currently used to supply the gas is 5L and stored 3.75Kg of gas when it was full. That is $(0.005m^3)/(3.75kg) = 0.00133m^3/kg$. Looking at the previous chart it''s possible to see that this point was at the limit of the vapor-liquid zone and thus the tank was probably full of liquid at atmospheric temperature. However, this tank has already been used once and it''s estimated that one-fourth of the content is gone. Then, the current specific volume is $(0.005m^3)/(2.625kg) = 0.0019m^3/kg$. This value ensures that the substance will remain at vapor-liquid phase at any reasonable temperature.

When the rocket engine is connected to the gas tank and the valves are open, the pressure and the specific volume stabilize between the two recipients; this fills the engine integrated tank with liquid and vapor nitrous oxide.

The previous graph also shows the vapor pressure of the gas at different temperatures. It‘’s important to notice the difference in pressure between common atmospheric temperatures. The current loading system has been prepared to withstand up to 70 bars plus security margins. This means that the launch or test ignition should be delayed if the temperatures are superior to 34.7žC.

However, it must be noted, that thanks to the security margins and the fact that the gas colds down when expanded, the system would probably withstand a launch at more than this ambient temperature. All the same, security is a top priority and ANY LAUNCH WILL BE DELAYED if it‘’s not possible to assure a tank temperature lower that.

Engine position

When considering whether the position of the rocket is relevant or not it must be noted that the important factor is the flow rate of the oxidizer into the combustion chamber. This flow rate is directly affected by the position of the engine since the liquid part of the $N2_O$ will always sink to the bottom of the tank. If the engine is in vertical position the expulsed $N2_O$ will always be from the liquid phase whether if its horizontal this cannot be guaranteed. If it‘’s horizontal, the expulsed N_2O at the beginning will be liquid and, as the level lowers, the expulsed oxidizer will become gas.

It may INCORRECTLY be argued that position of the engine is irrelevant because the phase of the oxidizer is irrelevant too. This argument may be backed by the fact that the oxidizer will vaporize in the combustion chamber if its liquid (and, since it will become gas anyway, it‘’s irrelevant if it was liquid or gas in the oxidizer tank). Another INCORRECT argument may be that the pressure is equal for both liquid and gas (this is correct) and for that reason the flow of oxidizer will not change if the tank is full of liquid or gas, since both are at the same pressure (this is not true).

It is true that the liquid will be vaporized when it enters the combustion chamber and it‘’s also true that both liquid and vapor are at the same pressure. However, the density of the gas and the liquid are different and this will change the flow ratio that enters the combustion chamber.

For that reason, it imperative to test the engine in a vertical position since this will ensure that the oxidizer leaking to the combustion chamber is always from the liquid phase.

Control system

In order to control the launch remotely, a simple electronic system has been build. This system is connected to different power sources and to a data-logger that connects to a computer acting as a server.

Software

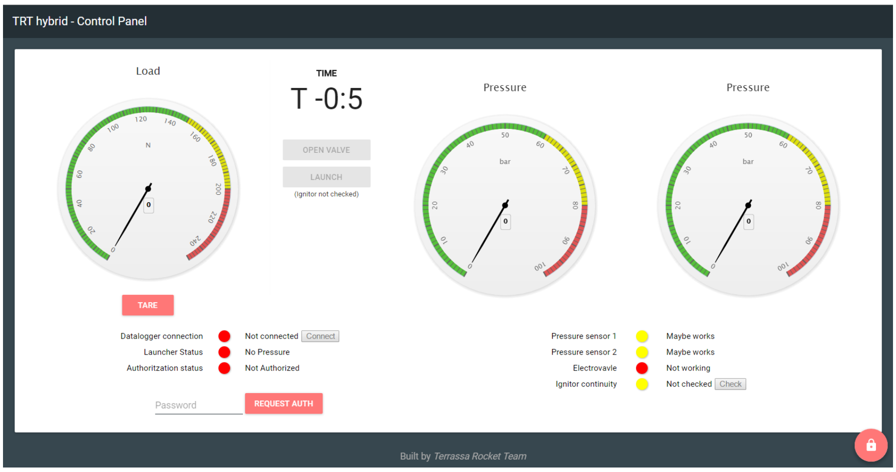

Figure 8: Software screenshot

After the server is initialized, clients can connect to it using a standard web-browser from any device. Any client is able to see the data from the sensors and, after proper authentication, they are able to control the gas valve and, the continuity check of the ignitor and the ignitor trigger. The data is always stored in the server at the full sampling rate, but the clients only receive the mean of the last 0.1 seconds.

The server is implemented using javascript and node.js. The server connects to the serial port using the "serialport" package and uses "websockets" to send the sensors data in real time to the clients. The interface between the data-logger and the server has been specially developed for this program based on previous experience writing an open-source library for Matlab for the same data-logger.

The clients web pages are implemented in React and Redux from Facebook. The charts use the library "highcharts".

The full implementation of the code can be found on [1]. A screenshot of the clients software can be seen on Figure 8.

Electronics

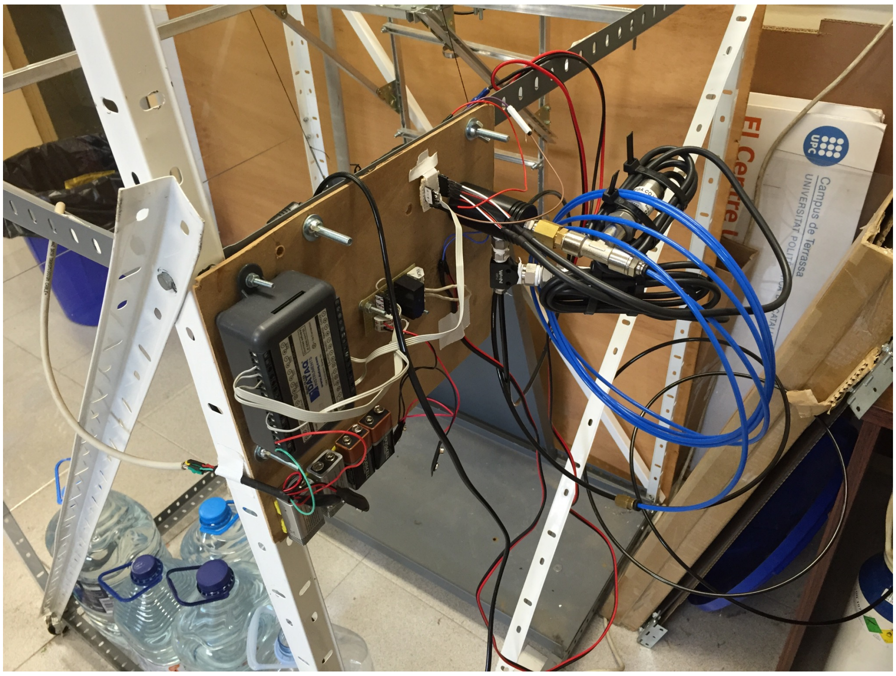

Figure 9: Electronics

The electronics to connect the sensors and actuators with the DI-155 data-logger from DataQ are also custom for this case.

There are 4 sensors attached to the fire test machine:

- 2 pressure transductors provided by Omega.
- 1 load cell for measuring up to 50Kg of force.
- 1 continuity check for the ignitor

And 3 actuators:

- 1 ignitor check trigger
- 1 ignitor fire trigger
- 1 gas electrovavle trigger

An image of the electronics can be seen on the previous Figure 9.

Safety concerns

In this section, some of the safety concerns of the static launch will be addressed. If any of these concerns fail to pass the test, the test will have to be postponed until they are solved.

As previously mentioned one of the safety concerns is related to the temperature and the pressure inside the tanks. As stated, the plumbing system can only safely withstand 70 bars. For this to happen, the gas -and the tank- must be at less than 34.7žC; any higher temperature will overpass the limit pressure.

Another safety concern has to do with the risk of explosion of the combustion chamber. The main reason why the chamber would explode is if nozzle gets obstructed and the pressure in the chamber starts to build up. This engine, however, does not have the fuel and the oxidizer in the same chamber like solid rockets do. For this reason, when the pressure is higher than the pressure in the oxidizer tank, no more oxidizer is let into the chamber and the combustion stops. However, if the pressure in the combustion chamber climbs too fast, the security valve of the oxidizer tank would kick in and start venting in order to lower the total pressure inside the oxidizer tank and the combustion chamber.

For further security, both the N_2O tank valve and the electro-valve will be closed when performing the test.

The test location has also been carefully selected. The test will be performed on a stainless steel bench, anchored on a concrete ground. Away from inflammable materials or people. Also, the motor itself will be covered with stainless steel mesh to protect from fragments of a possible explosion.

References

[1] Pep Rodeja Ferrer. *Hybrid Control Panel - source code*. 2016. URL: `https://github.com/TerrassaRocketTeam/hybrid-control-panel-web`.

[2] Pep Rodeja Ferrer. *Matlab code for generating the P-V chart of N2O*. 2016. URL: `https://github.com/TerrassaRocketTeam/H70-rattworks-previousReport/tree/master/matlab`.

[3] *Thermophysical properties of nitrous oxide*. 1991. URL: `http://edge.rit.edu/edge/P07106/public/Nox.pdf`.