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Development status of the Ignition System for Vinci

G. Frenken, E. Vermeulen
Stork Product Engineering B.V.
P.O. Box 379, 1000 AJ Amsterdam, The Netherlands

F. Bouquet, B. Sanders
TNO Prins Maurits Laboratory
P.O. Box 45, 2280 AA Rijswijk, The Netherlands

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Abstract

The development status of ignition system for the new cryogenic upper stage engine Vinci is presented. The concept differs from existing upper stage ignition systems as its functioning is engine independent†. The system consists of a spark torch igniter, a high-pressure igniter feed system and an exciter. First igniter hardware is presented and test results of igniter and exciter are discussed.

Abbreviations

DPx	Design Point number x
ECCU	Engine Control and Command Unit
EMC	ElectroMagnetic Compatibility
EX	Exciter
FMECA	Failure Mode, Effect and Criticality Analysis
HV	High Voltage
IS	Ignition System
IGFS	Igniter Feed System
IG	Igniter
O/F	Mixture ratio (Oxidizer/Fuel)
SPE	Stork Product Engineering B.V.
TCA	Thrust Chamber Assembly
TNO PML	TNO Prins Maurits Laboratory

1. Introduction

The Vinci engine will be a restartable expander cycle engine to be used in the ESC-B stage of Ariane 5. In contrary to the restartable expander cycle engines developed in Japan and in the USA, the Vinci engine will feature an ignition system that is independent of the engine cycle with respect to propellant supply to the igniter.

For the Vinci Ignition System a High Pressure Blow down System has been selected as most suitable. The selection of this concept has been presented and discussed in previous publications [1][2].

The ignition system exists of three main parts:

1. The Igniter Feed System (IGFS); storage of hydrogen and oxygen under high pressure and transportation to the igniter; The IGFS design is based on off-the-shelf components as much as possible.

2. The Igniter (IG); a small combustion chamber in which the igniter gasses are ignited by a spark plug and transported to the exit at the injector face plate of the engine

3. The Exciter (EX); electrical device delivering the energy to the igniter spark plug.

After Stork Product Engineering (SPE) and Astrium performed a highly successful demonstrator campaign in 2000, the development of the complete system has started by SPE in the second half of 2001. The current design status of igniter, feeding system and exciter is presented together with the results of the first development tests. The igniter tests have been performed in the first half of 2002 at the test facility of the TNO Prins Maurits Laboratory. The primary objectives of these tests are the proof-the-principle of the igniter and to increase confidence in the robustness of the chosen design. As the Igniter feed system uses a blow down propellant feeding (no pressure regulator to minimize number of components) the igniter has to operate on 5 design points corresponding to five ignitions with varying feeding pressures and mass flows.

† Patent number 00115375.8-2315

2. Development approach

2.1 Requirements

The main requirements for the Vinci Ignition System are shown in Table 1.

Requirement	Value	Dimension
Thermal power	440	kW
O/F (overall) of igniter flow	> 8	-
Number of ignitions (one flight)	5	-
Life time	30	# Ignitions
Duration of ignition	2	s
Interface temperature to injector igniter tube	< 1000	K
Igniter to fit in 'igniter pod' of the engine injector		
Gas storage cylinders to be separately filled and mounted on the upper stage shortly before roll out		

Table 1 Main requirements Vinci Ignition System

2.2 Igniter Feed System

For the Igniter Feed System the so-called demonstrator program [2] proved the blow down principle (Figure 1). The experience from this program gave the first assumptions for the igniter design points and provided insight in the critical points of the system design. In order to meet the Ariane 5 recurring cost targets the Igniter Feed System will have to be based upon off-the-shelf components. This requires frequent challenging of the requirements and the system design in order to deal with the specifications of existing hardware.

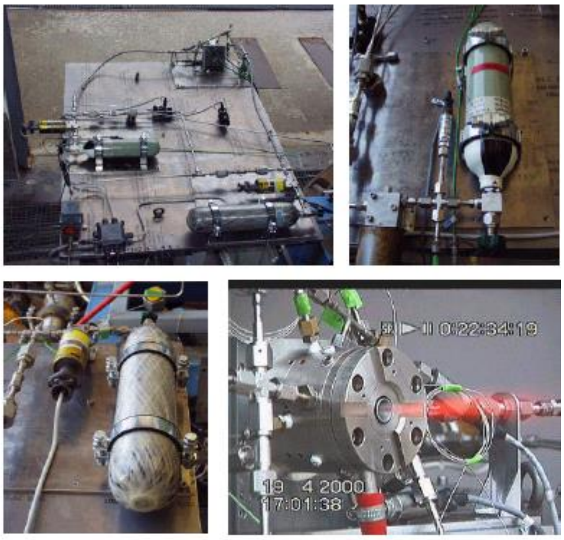

Figure 1 A demonstrator of the Igniter Feed System has been tested in May 2000

2.3 Igniter

In the beginning of the development the focus has been put upon the development of the igniter and the exciter because of the request for a functional representative igniter for engine thrust chamber and engine testing. Initially development models (also called breadboard models) were foreseen to verify technical design choices only. Because of the compact time schedule it was decided to apply this hardware also for thrust chamber ignition testing at Astrium.

For the igniter a concept has been chosen with an oxygen rich core flow (O/F>30) that is ignited by a spark plug and a hydrogen cooling flow around the igniter tube. With this concept the power requirement can be met on one hand while meeting the thermal interface requirement on the other hand. For the igniter injector a combined dump/impinging concept is chosen (Figure 2). The oxygen is injected around the electrode of the spark plug while hydrogen is injected under an angle from six injection holes. In [3] a similar concept has been found, however with lower mass flows and designed for only one operating point.

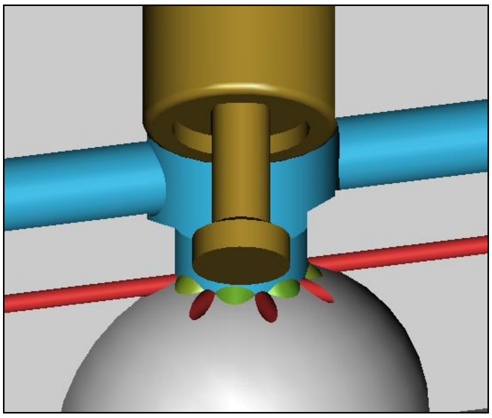

Figure 2 The injector concept with oxygen injection around the spark plug and six hydrogen injection points

With respect to the small envelope available in the igniter pod of the engine injector it was also a challenge to fit in all functions of the igniter. Not only the spark plug and a high voltage lead coming from the Exciter have to be connected to the igniter but also two feed lines from the IGFS and a pressure transducer.

The technical design choices to be verified with the first breadboard igniter were:

1. Igniter injection concept

→ Show a fast and reproducible response for all 5 design points

2. Igniter tube cooling

→ Show resistance against the thermal load for all 5 design points

2.4 Exciter

The exciter development is planned to have a minimum of new developments or components (while meeting the reliability requirement) to maintain cost effectiveness. The focus during the first phase was on the high-voltage generating circuits, including HV switch, HV cable and HV transformer. Tests have been performed with exciter hardware in combination with the breadboard igniter. To get an early insight into the EMC behavior of the exciter, an exciter prototype was developed specifically for an EMC test. This hardware was used to test different types of HV cables, shielding, and EMI input filters.

3. Development Status

3.1 Igniter

In addition to the functional and geometrical requirements, some special requirements needed to be taken into account for the first igniter design:

1. As the igniter injector design was to be optimized by the first tests, the injector needed to be exchangeable. Therefore an injector with o-ring type seals was applied instead of a brazed-in injector as foreseen for the flight type.
2. An essential element of the igniter injector concept is the spark plug electrode. To allow easy electrode modification, a spark plug was designed around the ceramic insulator of an automotive spark plug. For the flight type igniter a spark plug with similar geometry will be applied, but with a special HV-connector for application in vacuum.

Figure 3 The first Vinci igniter, featuring a replaceable injector and spark plug electrode

The first Vinci igniter, delivered to Astrium in March 2002, is shown in Figure 3. The igniter design has the following features:

- Combustion in Igniter chamber and at the igniter tube outlet (where hydrogen used for tube cooling is mixed with the hot oxygen rich core flow)
- Choked gas flow, application of throat at outlet of igniter tube
- Heat sink cooling for Igniter chamber and convective cooling concept for Igniter tube
- Injection with dump/impinging flows
- Spark plug with central electrode located in annular pre-mixed lean flow

The interaction between the igniter and engine injector flow is crucial for achieving reliable ignition of the engine. Astrium is analyzing this topic by means of CFD analysis in combination with cold flow and ignition tests that are foreseen for the first thrust chamber tests [4].

3.2 Exciter

The functional exciter design is shown in Figure 4.

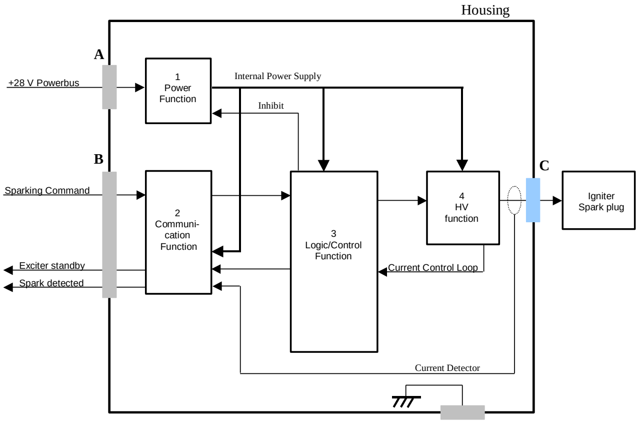

Figure 4 The functional design of the exciter shows 4 main functions.

The main functions of the exciter are:

- Power
- Communication
- Logic / control
- High Voltage generation

After switching on the power, the exciter reaches a standby mode. At the desired moment of sparking a discrete electrical signal is generated by the ECCU (Engine Control and Command Unit) and sent to the command inputs of the exciter. When the exciter has received this sparking command from the ECCU it generates a burst of high-voltage discharges through the spark plug. The number of sparks and the spark energy are fixed and the total operation lasts no longer than 0.2 seconds.

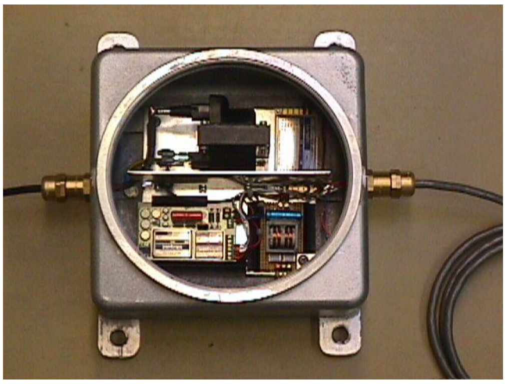

Figure 5 Exciter for development testing with explosion proof housing

Figure 5 shows the first development exciter as has been delivered to Astrium in March 2002. Especially for first development tests, this exciter is equipped with a robust explosion proof housing.

3.3 Igniter Feed system

The development of the Igniter feed system has been started based upon the system concept as shown in Figure 6. This concept is currently being detailed with several issues to be resolved.

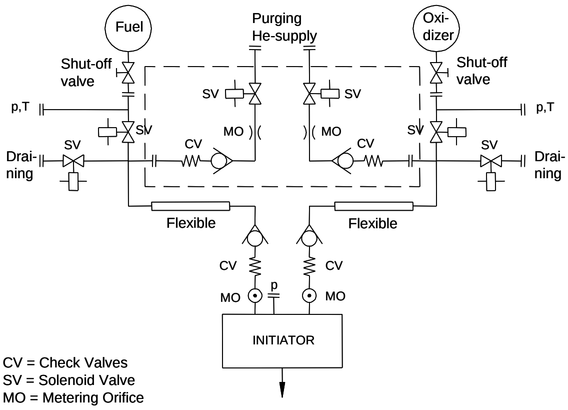

Figure 6 Initial concept of the Igniter Feed System

The layout of the Igniter Feed system depends on the layout of both the engine and the ESC-B upper stage (where the gas bottles and the valves will be positioned). A working group has been established to elaborate a IGFS layout that is acceptable for all parties involved. This working group consists of Astrium Bremen (stage design), Snecma Moteurs (engine design), Astrium Ottobrunn (Thrust Chamber Assembly design) and SPE (Ignition System design).

In the IGFS a high working pressure of maximum 200 bar is applied in combination with the media hydrogen, oxygen and helium. Therefore special attention has to be paid to the safety aspects of this system, especially during the latest phase of launcher integration. At this time the system will already be pressurized while people will still be present. With help of a detailed FMECA and additional safety assessments the IGFS architecture is currently being evaluated and optimized.

Already before the start of the development it was recognized that off-the-shelf components can be applied for the IGFS. However, this requires continuous challenging of the component requirements to prevent additional development and qualification effort. Especially the required temperature envelope, the proof and burst pressure levels are currently thoroughly assessed.

4. Tests

4.1 Operational conditions

The flight type igniter shall have a lifetime of 30 ignitions of 2s duration, five of which are in-flight. In flight, a blow down storage system of reactant gases will feed the igniter. In each of the five ignitions, the flow conditions will shift continually. The beginning and end points of the five ignitions together define six Design Points, DP0 (first instance of first ignition) to DP5, last instance of final ignition).

The power requirement of 440 kW has to be met at the start of the fifth ignition. The selection of a blow-down system for feeding therefore results in a power excess at the first four ignitions. The first ignition is therefore the thermally most severe condition.

The igniter should not only function correctly at the Design Points, but also within an envelope around these points. This envelope is determined as a function of possible deviations from the nominal operational conditions. These deviations might occur from differences in blow-down characteristics of the feeding system, which are at this moment estimated to be 90% of the minimum and 110% of the maximum values of the mass flow and overall mixture ratio. Figure 7 shows the Design and Envelope points.

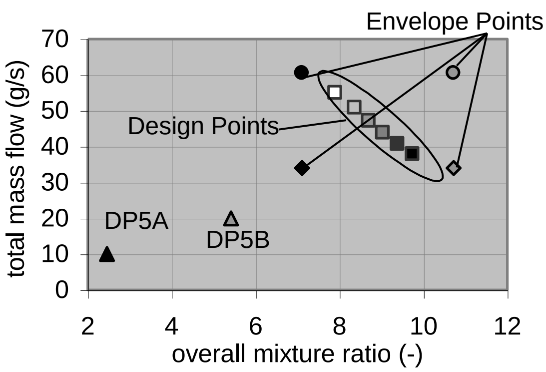

Figure 7 Graphical representation of the Design and Envelope Points

4.2 Test philosophy

To limit the risk during testing of the igniter, it is tested at the six design points, starting at the point where thermal loading is least severe, i.e. the condition at the end of the last ignition (DP5). To start every test series at very moderate conditions, two additional Design Points are defined where the total mass flow is reduced with respect to the fifth Design Point. These DP's, which are purely for safe testing and do not hold any resemblance to actual flight conditions, are at approximately 30 and 60% of the mass flow of DP5. These points are denoted DP5A and DP5B, respectively, and are also shown in figure 1. Also the burning time of the igniter is increased from 0.2 to its required operating time of 2s at each design point. Each hot firing test is preceded with a cold flow test to check test settings.

4.3 Test facility

In 2002, the Vinci igniter tests were carried out in the indoor rocket test stand of TNO PML, in Rijswijk, Netherlands. This test stand is equipped with a gas feeding system that can provide many different gases at high pressures. The gas feeding system is thoroughly instrumented with pressure transducers and thermocouples to allow for accurate control of the gas feeding sequence and precise registration of actual mass flows, gas temperatures and valve sequences.

The tests with the igniter are executed with an interface representing (part of) the injector. This is shown in Figure 8.

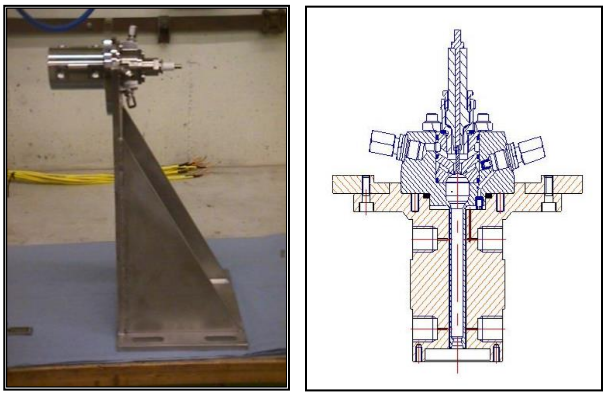

Figure 8 Test interface representing the engine injector

4.4 Test results

Figure 9 shows an ignition test of the breadboard model igniter, which was performed in February 2002. In the breadboard test campaign, tests were performed up to a burning time of 0.6s. During this time, the minimum required power output of 440 kW was exceeded. In total 21 tests have been performed with a total burning duration of 7.8 s.

Figure 9 Hot test of the first Vinci Igniter

The test campaign gave new insights in the design of the igniter injector. To improve the gas injection efficiency, the injector head has been adjusted for a second igniter model. After minor structural adjustments were made, the second igniter was tested in May – June 2002. Operational times of 1.2s were tested for this igniter up to 50% of the maximum thermal loading. In total 25 tests have been performed with a total burning duration of 14 s. These tests gave new insights in the flow, combustion and heat transfer phenomena in the igniter to be able to further improve the design.

A valve sequence has been applied with an hydrogen lead of 0.2 seconds and start of sparking at the moment of oxygen valve opening. Successful ignition was achieved at all design points with similar very smooth and fast pressure built up. The duration of the tests has been up to 1.2 seconds. The igniter tube did not show any significant wear for this duration. However the igniter injector did show some wear after several tests at the longer durations. A small modification of the injection angle of hydrogen is thought to be sufficient to avoid this.

The same igniter with a new, improved version of the igniter injector is scheduled for testing in July 2002. These tests are used to further verify the maximum thermal loading case.

Exciter Testing

Two types of tests have been performed:

1. Tests in combination with the Igniter
2. Test to investigate EMC behavior.

The exciter H/W used with igniter testing was based on existing SPE hardware from previous technology programs. The exciter performed without any problems. Figure 10 shows first sparking tests with the spark plug mounted in the replaceable injector. The tests showed that sparks occur at the complete circumsphere of the spark plug electrode in a random fashion.

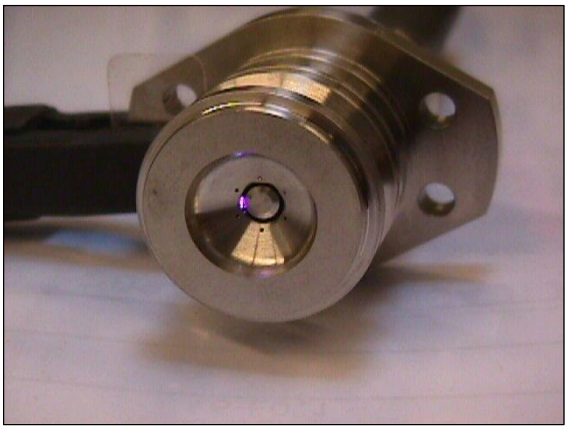

Figure 10 Sparking tests with spark plug / injector assembly

The EMC tests have shown that filters have to be applied in order to stay within the EMC requirements. It was also concluded that the length of the HV lead is not free to choose as it can cause EMI in a forbidden zone. This gives a direct constraint for length of the lead and position of the Exciter box.

5. Conclusions

The development programme shows good progress; already 6 months after the start of the programme the first hardware has been delivered to Astrium (in March 2002). While the detailed design of the Igniter Feed System is ongoing, tests have already been performed on igniter and exciter hardware.

Tests on the igniter have shown reliable ignition on all operational points, and tests at extended burn times are ongoing. With this test series it is expected that the functional design of the igniter can be proven for all operational points.

The sparking energy applied by the exciter was sufficient for reliable, instantaneous ignition at all design points. Discharge voltage measurements during igniter hot tests provide valuable insight in the practically required maximum voltages. It is now analyzed in how far the energy level and discharge voltage can be lowered. It can also result in increasing the spark gap to simplify the igniter injector design.

It is shown that the EMC requirements not only have impact on the internal exciter design, but also on the length of the HV lead. This leads to requirements for the location of the exciter in the total engine layout.

6. Acknowledgements

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