Introduction

The high altitude simulation facility P4.1 is used to test the new powerful cryogenic European upper stage engine VINCI. Airbus Safran Launchers is responsible for the engine development program. It is powered by an expander cycle which uses the evaporating hydrogen in the cooling channels of the thrust chamber wall as hot gas to drive the turbines of the turbo pumps. This cycle is very efficient. The engine is also equipped with a newly designed carbon composite nozzle. VINCI is re-ignitable and reaches a thrust level of 18 tons in vacuum conditions.

Finished beginning of the year 2005 the test facility P4.1 immediately started its operational phase with a first chill down test of the first VINCI engine on 11th of March in 2005. Up to now 91 tests have been performed, the last on 22nd of August in 2014.

Function

The test facility P4.1 fulfills two main tasks:
- Simulation of the launcher by supplying the VINCI engine with all necessary supplies (e.g. propellants)
- Simulation of the environment of the VINCI engine as it is functioning in high altitude (= vacuum) conditions.

At the test facility it is possible to test all configurations of the VINCI engine (with or without nozzle). The maximum reachable running time of the Vinci engine is about 770 seconds. Re-ignition tests can also be performed under vacuum conditions.

Engine supply system

The VINCI engine uses liquid hydrogen (LH₂) at a temperature of 20 K and liquid oxygen (LOX) at a temperature of 90 K as propellants. The P4.1 has a LH₂ run tank with a capacity of 135 m³ and a LOX run tank with 50 m³ respectively. The feed lines which connect the VINCI engine to the tanks are vacuum insulated and ensure that the propellants reach the turbo pumps of the VINCI engine in liquid conditions. Due to the use of cryogenic propellants as liquid oxygen and liquid hydrogen all bench and engine lines have to be chilled down before the engine can be ignited.

The tanks themselves are pressurized by gaseous hydrogen and gaseous nitrogen.

The VINCI engine also needs several different gases like nitrogen, helium, hydrogen or oxygen with defined mass flows and under different pressures. These gases are necessary for example for:
- Venting actions on the bench or on the engine
- Command pressure for engine and bench valves
- Supply for the ignition system of the VINCI engine igniter and also for the steam generator igniters
- Insurance of safety pressurization of all bench and engine lines.

After the test for safety reasons all the lines which were exposed to the propellants LH₂ or LOX have to be vented and inertized either by helium or by nitrogen.
High altitude simulation

The VINCI engine is mainly operating under vacuum conditions outside the earth atmosphere. These conditions have an influence on the behaviour of the engine especially concerning the ignition under reduced pressure, development of higher thrust under vacuum, different thermal conditions as no convection exists. Therefore it is important to simulate as close as possible the real vacuum conditions around the VINCI engine during its running phase. This is realized by usage of steam operated ejector pumps. The process steam is provided by steam generators, developed by DLR, which evaporate water by combustion of alcohol with liquid oxygen.

Functional principle of the vacuum simulation at P4.1:

1. The engine is located inside the vacuum chamber and connected to all necessary supply systems.
2. The vacuum chamber is evacuated to a pressure of a few millibar by means of conventional vacuum pumps up to a vacuum flap in front of the primary ejector stage.
3. The cooling water system for the diffuser is started (2000 l/s). It is used to protect the diffuser as the VINCI engine burns hydrogen and oxygen to water vapour with a temperature of about 3500°C.
4. The cooling water system for the condenser is started (3500 l/s). It is used to condense the incoming exhaust gases from the VINCI engine and from the steam generators.
5. All steam generators are ignited. They supply about 100 kilogram steam per second to the primary ejector stage and about 55 kilogram steam per second to each end stage ejector.
6. If the pressure at the vacuum flap is only a few millibar, the flap is opened. The system is now running stable.
7. The VINCI engine is ignited. In nominal conditions it burns about 6 kg/s hydrogen and 34 kg/s oxygen to water steam. This exhaust jet is leaving the engine with about 3500°C in supersonic conditions. The exhausts gases of the engine are directed into the supersonic core diffuser, which is located directly below the engine, and are sucked out by the ejector system. Around the engine a pressure of a few millibar are maintained during this running phase.
8. After the VINCI engine is shut down, the high altitude simulation system is also shut down with the reverse sequence as during the start up.

Control of the test facility

The complete test facility is controlled by redundant computer systems. A test can be supervised by the operators from a control room which is located in a separate shelter in around 200 metres distance from the test facility.

More than 1500 measurements with scanning rates of up to 100.000 Hz are archived during test. All measurements are available in real time for further treatment like real time calculations or supervision of limit values by sequences.

The accuracy of command sending is 1 ms. During the chill down and firing of engine and steam generators the test facility is completely under control of the computer system by means of sequences, loops, calculations, etc.