Stability behaviour of a cylindrical rocket engine combustion chamber operated with liquid hydrogen and liquid oxygen

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Abstract

The phenomenon of high frequency combustion instabilities is investigated experimentally at DLR Lampoldshausen with different model combustors. Newest member of the family of model combustion chambers used for combustion instability investigation is the BKD with the injector head L-42, operated at the high pressure test facility P8 at DLR Lampoldshausen (see Figure 1). The combustion chamber is operated with the propellant combination LOX/GH_2 and LOX/LH_2. The BKD is a multi-injector engine with 42 shear coaxial injectors, a cylindrical combustion chamber with a diameter of 80 mm and a combustion chamber pressure of up to 80 bar which means super critical injection conditions for the liquid oxygen. This corresponds to representative operation conditions of liquid propellant rocket engines with cryogenic fuels. The cylindrical shape of the combustion chamber allows rotating tangential acoustic modes. The combustion chamber has been equipped with a newly designed measurement ring carrying eight dynamic pressure sensors allowing detailed and precise characterisation of the acoustic oscillations in the chamber as well as their dependence on operation conditions.

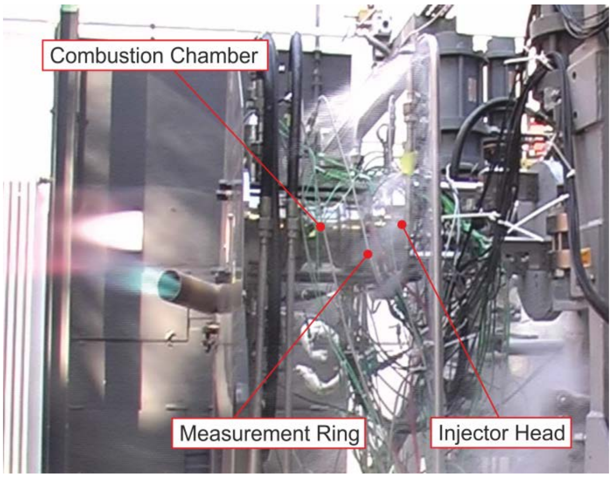

Figure 1: Combustion Chamber BKD with injector head L-42 during a test run on the P8 test bench at DLR Lampoldshausen

Compared to other model combustors used for the investigation of high frequency combustion instabilities the BKD is not equipped with an excitation system. Instead it could be found that the combustion chamber can be reproducibly operated at stable and unstable operation points [1]. The unstable operation points show peak-to-peak-values of the dynamic pressure of up to ±10 bar (see Figure 2). The gliding RMS signal in Figure 2 shows unstable operation for the load points 80 bar ROF 6 and 70 bar ROF 6. In [1] a test run with the propellant combination LOX/GH_2 is analysed. During this test campaign the combustion chamber has been supplied by the gaseous hydrogen interface of the P8 test bench. The hydrogen injection temperature of the test run presented in [1] was 115 K.

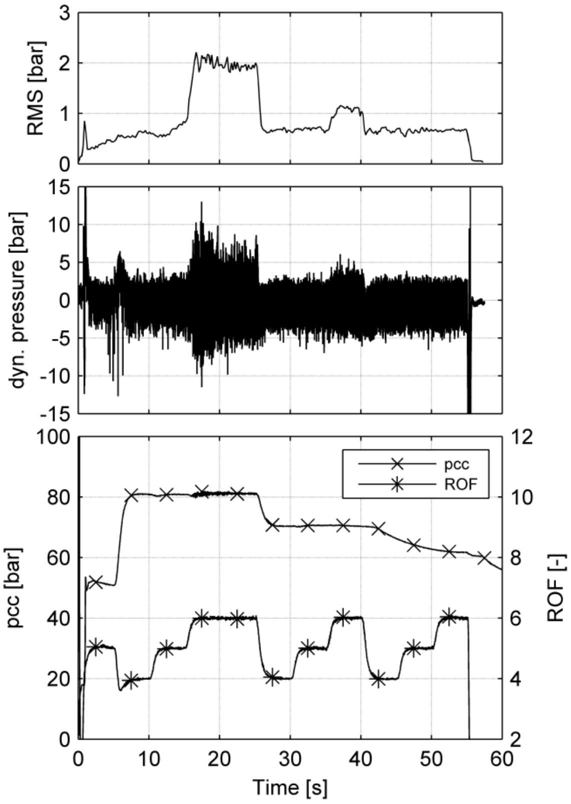

Figure 2: Gliding RMS signal in dependence to operation conditions for a test run with gaseous hydrogen (GH_2) [1]

In a second test campaign with the same combustion chamber the propellant combination LOX/LH_2 has been used. The hydrogen has been provided from the liquid hydrogen interface of the P8 test bench. In the hydrogen dome a temperature of around 75 K was achieved. Literature about the influence of the hydrogen temperature on combustion instabilities suggests, that colder hydrogen has a higher potential for triggering high frequency combustion instabilities [2], [3]. Indeed, a significant difference in the stability behaviour of the combustion chamber has been observed, but opposite to what has been expected concerning [2], [3]. All test runs with liquid hydrogen show in general lower amplitudes and no unstable operation points could be observed. As presented in [1] the unstable load points are characterized by a concentration of the oscillation energy in one single mode, the 1T mode, which is a typical indicator of self-excited high frequency combustion instabilities [3]. This behaviour could not be observed during the test runs with liquid hydrogen.

Figure 3 shows for an example test run with liquid hydrogen the signals of the combustion chamber pressure, the mixture ratio ROF, the dynamic pressure and the gliding RMS of the of the dynamic pressure signal. Comparing Figure 3 with Figure 2 already shows the significant difference between both test runs. It should be noted that in both figures the scaling of the dynamic pressure signal axis and of the gliding RMS axis is identical to point out the difference. The unstable load point 80 bar ROF 6 of Figure 2 can also be found in Figure 3. But in this test run no change in the amplitudes of the dynamic pressure signal can be observed. The load point which shows unstable operation for gaseous hydrogen shows stable operation with liquid hydrogen.

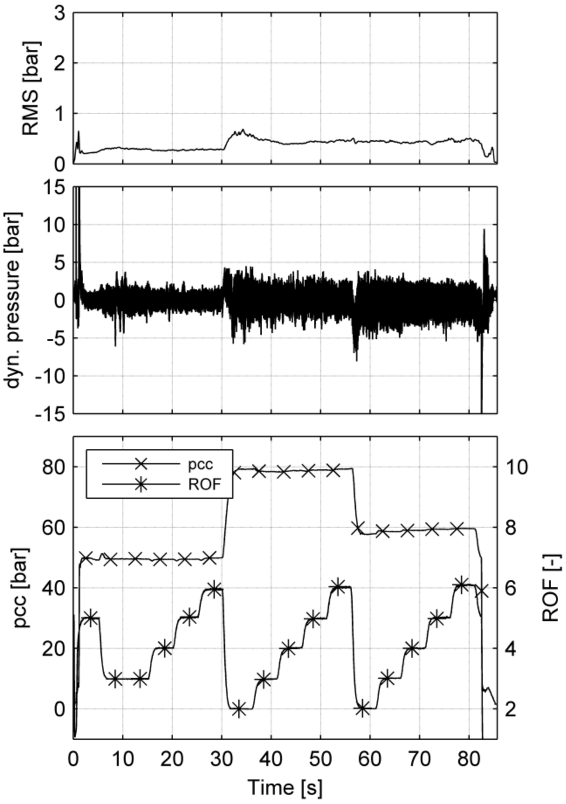

Figure 3: Gliding RMS signal in dependence to operation conditions for a test run with liquid hydrogen (LH_2)

The detailed analysis which has been carried out in [1] for a test run with gaseous hydrogen will be presented in this paper for different liquid hydrogen test runs. This analysis is then followed by a comparison of the results for the gaseous and liquid hydrogen test runs. The analysis includes a general analysis of the dependence of the dynamic pressure amplitudes on operation conditions as well as a detailed spectral analysis of the dynamic pressure signals. Using a RMS calculation of band pass filtered dynamic pressure signals the oscillation energy in specific frequency bands and its change due to load point changes is analysed and compared for the two different hydrogen temperatures. Finally a pressure field reconstruction algorithm [4] is applied to the dynamic pressure signals to reconstruct the pressure field of the 1T mode. With this reconstruction algorithm is was possible to show that different types of rotating 1T modes appear in the combustion chamber. In [1] it was shown, that the rotation character of the 1T mode depends on the operation conditions. In this paper also the influence of the hydrogen temperature will be analysed.

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