RAPID REACTING VALVES FOR APPLICATIONS IN AVIATION AND SPACE FLIGHT

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The aerodynamics of aircrafts, the combustion of fuel in gas turbines and the control of rocket engines can be improved with the help of rapid reacting valves.

In the aerodynamic rapid reacting valves can be used to influence boundary layers of a flow around bodies like airfoils, high lift devices and rotor blades by directed non steady sucking and blowing of air. It is for example possible to shift boundary separation on the strong bended trailing edge of an airfoil down stream by periodically blowing and sucking air through a slit to reduce aerodynamic drag [1, 2].

In compressors of gas turbines, from the housing of the compressor, the controlled blow out of gas can influence the compressor blade tip eddies to improve the characteristics of the compressor and to reduce compressor noise [3, 4].

In case of fighter aircrafts we can think of the generation of rapid gas pulses to release rockets from the mountings, which is more suitable than with the small explosives currently used.

In gas turbines rapid reacting valves can be used to control the fuel supply into the combustion chamber and to influence the flow of combustion air, with the objective to optimize the combustion with respect of the emission of pollutants, noise emission and efficiency. We can also think of the calculated modulation of the heat production to create direct combustion chamber noise and especially indirect noise, so called entropy sound [5], to destroy tonal sound components generated by the turbine by the sound and anti sound principle by destructive interference.

Rapid reacting valves can be used to control the fuel supply of rocket engines; especially steering nozzles can be served with fuel, to generate the required thrust very precisely. In this connection cold gas steering nozzles should especially be emphasized.

Appropriate valves for aviation and space flight, for the applications described, must have, beyond good switching properties, a high reliability, and should be compact and light, with low energy consumption.

In the DLR (Deutsches Zentrum für Luft- und Raumfahrt) rapid reacting valves for gases and liquids have been developed with promising properties for aviation and space flight applications [6].

The valves are constructed in a manner, that the plug of the valve, here a valve ball, is pressed into the valve seat only by a pressure difference between the valve input and the valve output. The valve will be opened by rolling the valve ball from the valve seat. The closing process is caused by the streaming of gas or liquid through the valve, which carries forward the valve ball and move it back to the valve seat.

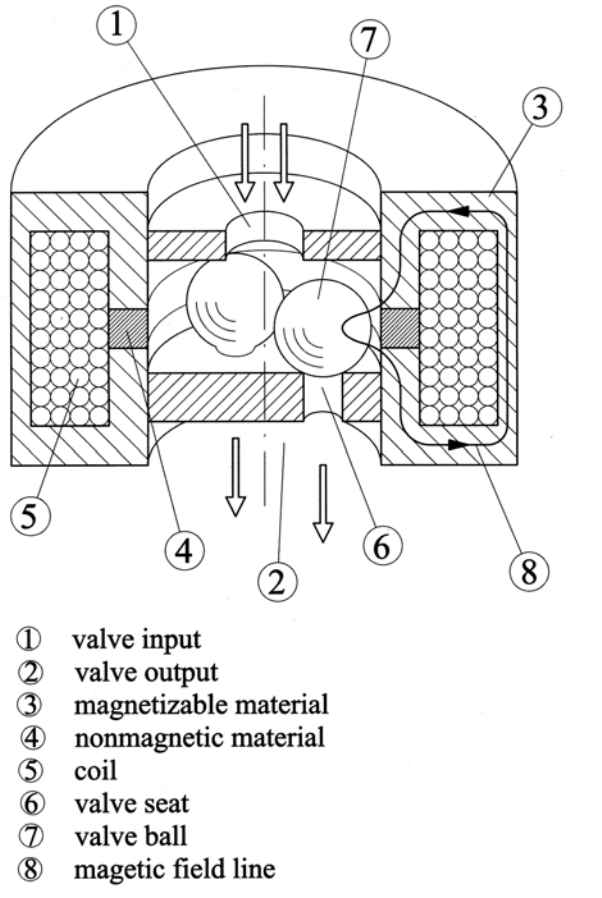

Figure 1 Schematic drawing of a rapid reaction magnetic valve with three valve balls. The shape of a magnetic field line is shown.

In figure 1 the principle set up of a rapid reacting valve of the DLR is shown in a schematic drawing. A valve with three valve balls is visible, only two of them are visible in the sectional drawing. The valve balls are lying on the valve seats and are kept to the seats only by the pressure difference between the valve input and the valve output. The valve is opened by rolling the valve balls from the

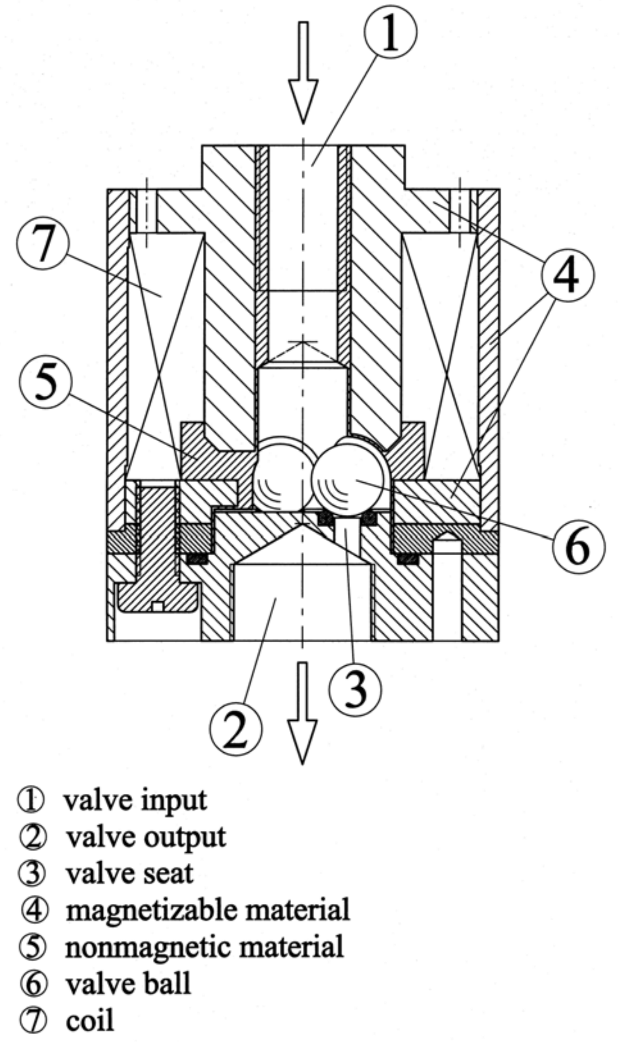

Figure 2 Cut through a rapid reacting magnetic valve with three valve balls. Valve opening: 3 x diameter 1.8 [mm], diameter of the valve: 27 [mm]

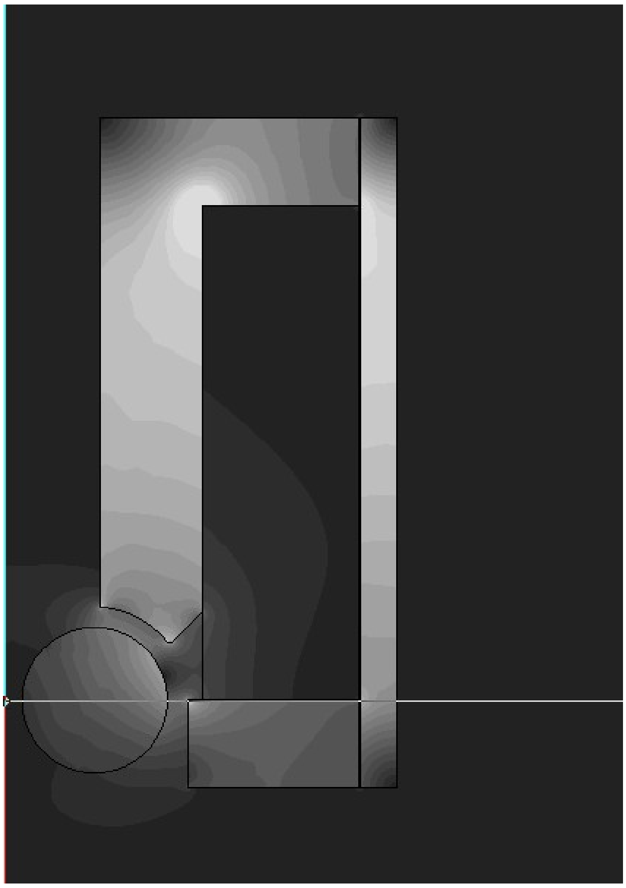

Figure 3 Model of the magnetic circuit of the magnetic valve shown in figure 2. The qualitative distribution of the value of the magnetic field $\vec{B}$ was calculated and shown as grey levels. The lighter the grey level the stronger the magnetic field strength.

valve seats due to the interaction with a magnetic field which, related to the axis of the valve, lateral effects the valve balls. This is why the valve balls must be magnetizable.

By lever action the valve balls are rolled from the valve seat very efficiently. The lever arm reaches from the middle of the valve ball to a contact point of the valve ball on the valve seat. By the lever action the valve balls can be moved from the valve seats by a small effort, if compared with the effort necessary when the valve balls have to be lifted from the valve seats. The magnetic field acting lateral on the valve balls is caused by a current through a coil and is guided in a magnetic circuit made of a magnetizable material which shows a gap made of a non magnetizable material on the same level as the middle of the valve balls. The non magnetizable material causes that magnetic flux from the magnetic circuit to be guided through the magnetizable balls and creating a force on the valve balls. To close the valve, the valve balls have to be reliably carried back to the valve seats by the streaming, which is achieved by limiting the free space where the valve balls can be moved, which keeps them close to their respective valve seats, in areas with high streaming velocities.

In the rapid reacting magnetic valve the valve balls are the only moveable parts.

The rapid reacting magnetic valves can be designed to have one or several valve balls. In this paper valves with three valve balls will be described.

The streaming of gaseous or liquid media transports the valve ball back to the valve seat. With high viscose media friction forces are the dominant forces acting on the ball. In case of low viscose media high streaming velocities next to the ball, close by the valve seat generate pressure differences which moves the ball. The liquid media can be cryogenic liquefied gases like liquid oxygen or liquid hydrogen.

The drawing of a rapid reacting magnetic valve, with the design of the valve described in figure 1, is shown in figure 2. The compact design of this valve uses three valve balls which is equivalent to the valve in figure 1. Compared with the valve in figure 1 the magnetic circuit close to the valve balls was changed, to increase the magnetic force on the valve balls. The valve balls have 5 [mm] diameter. The gap width between the valve ball and the inside wall is only 0,5 [mm], so the valve balls have to move only a short distance to open the valve, an important condition for a rapid reacting valve.

The magnetic force acting on the valve ball is calculated from the magnetic force density:

$$\vec{f} = -\left(\vec{H}\right)^2 \cdot grad \ \ \mu$$

$\vec{H}$: magnetic auxiliary field strength
μ : magnetic permeability

Out of the formula of the magnetic force density the importance of the magnetic auxiliary field strength $\vec{H}$ becomes clear, a small gap width between the valve ball and the inside wall favour, with a given current through the coil, a high magnetic auxiliary field strength $\vec{H}$. The calculated distribution of the absolute value of the magnetic field strength in the magnetic circuit of the rapid reacting valve is shown in figure 3. To simplify the calculation a rotation symmetric model of the valve was used, in the model the valve balls were replaced by a magnetizable ring.

The pressure difference between the valve input and the valve output, the diameter of the valve seat and the diameter of the valve ball determines the force necessary to roll the valve ball from the valve seat. In figure 4, related to the rapid reacting magnetic valve shown in figure 2, the minimum necessary electrical power input of the magnet coil, to open the valve, is shown as function of the pressure difference. A linear relation between the pressure difference and the power consumption is visible, in agreement with the mentioned formula of the magnetic force density. The value of the auxiliary magnetic field strength is proportional to the square root of the electrical power consumption of the magnet coil, and therefore the magnetic force density proportional to the electrical power consumption. The simple relation between the pressure difference and the minimum necessary electrical power to open the valve can be used to measure pressure differences with the rapid reacting magnetic valve.

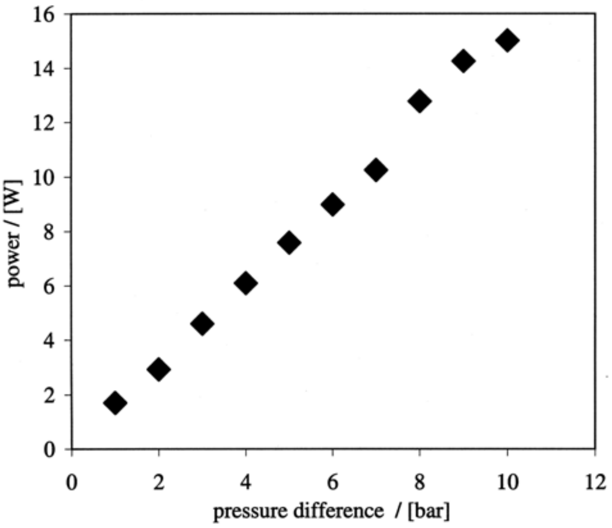

Figure 4 Relation of the minimum necessary electrical power to open the rapid reaction valve shown in figure 2 as function of the pressure difference.

With the assumption, that, related to figure 1, the mentioned gap in the magnetic circuit of the valve is not changed, a doubling of the length of the magnetic coil halves the necessary electrical power consumption to open the valve. This is a result of the fact that a doubling of the length of the magnet coil halves the necessary current intensity through the magnet coil, the ohmic resistance doubles and due to the fact that the electrical power is proportional to the square of the current intensity the necessary electrical power halves.
This consideration is true if the magnetic permeability of the magnetizable material in the magnetic circuit is very high if compared with the non magnetizable material and the magnetic stray losses can be neglected. Therefore we have a connection between the minimum electrical power to open the valve and the dimension of the valve, which has to be considered in the construction of rapid reacting magnetic valves for aviation and space flight applications. A compact and therefore also light magnetic valve has higher electrical power consumption.

With the rapid reacting magnetic valve from figure 2 gas pulses (nitrogen) were generated and measured with a hot wire anemometer, to investigate the switching properties of the valve. The wire of the hot wire anemometer was connected to a constant current source and the resistance changes of the wire, a consequence of temperature changes due to the streaming, measured. In figure 5 a result of these measurements is shown. The magnet coil was driven by a rectangular voltage pulse marked with S: frequency 10 Hz, duty cycle 10%. Marked with H, the voltage drop over the hot wire as function of the time is shown. It becomes clear from figure 5, that the rapid reacting magnetic valves does not opens simultaneously with the increase of the voltage S, a time delay of approximately 2.5 [ms] is observed.
The time delay is a consequence of the inductivity of the coil, which delays the current increase in the coil and therefore also the magnetic field generation, which can clearly be shortened by an as low as possible inductivity of the coil and an increased starting voltage. The valve closes immediately with the switch down of the voltage supply of the coil, here only a small time delay (<1[ms]) can be observed.

With a rapid reacting magnetic valve, similar to the valve in figure 2, only with the magnet coil length doubled, gas pulses with 500 Hz frequency were generated. The gas pulses were detected with the mentioned hot wire anemometer (figure 6).

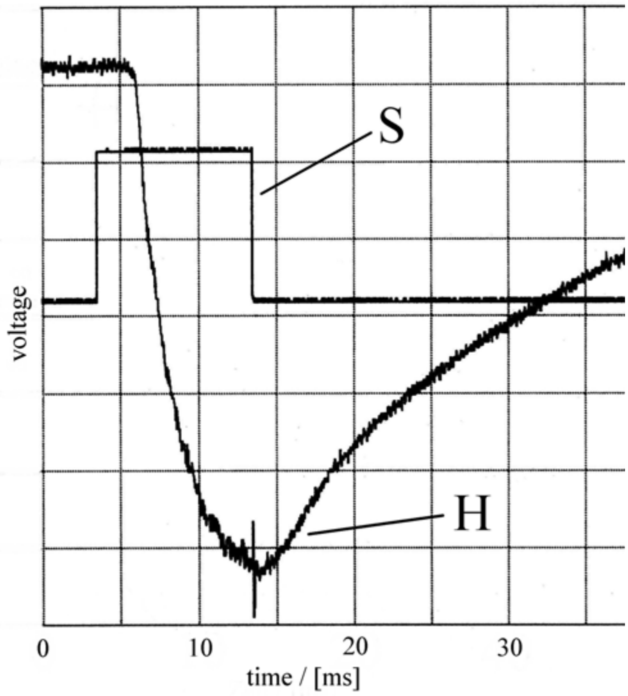

Figure 5 Switching properties of the rapid reacting valve shown in figure 2. The voltage on the magnet coil S and the voltage on the blown hot wire H is plotted as function of the time.

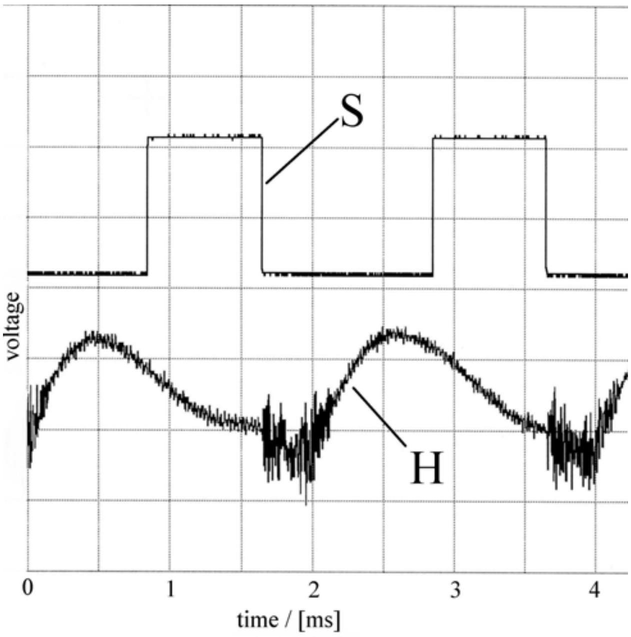

Figure 6 Switching properties of a rapid reacting valve with a design similar to the valve shown in figure 2. The voltage on the magnet coil S and the voltage measured on the hot wire H is shown as function of the time. Switching frequency: 500 Hz, duty cycle: 40%.

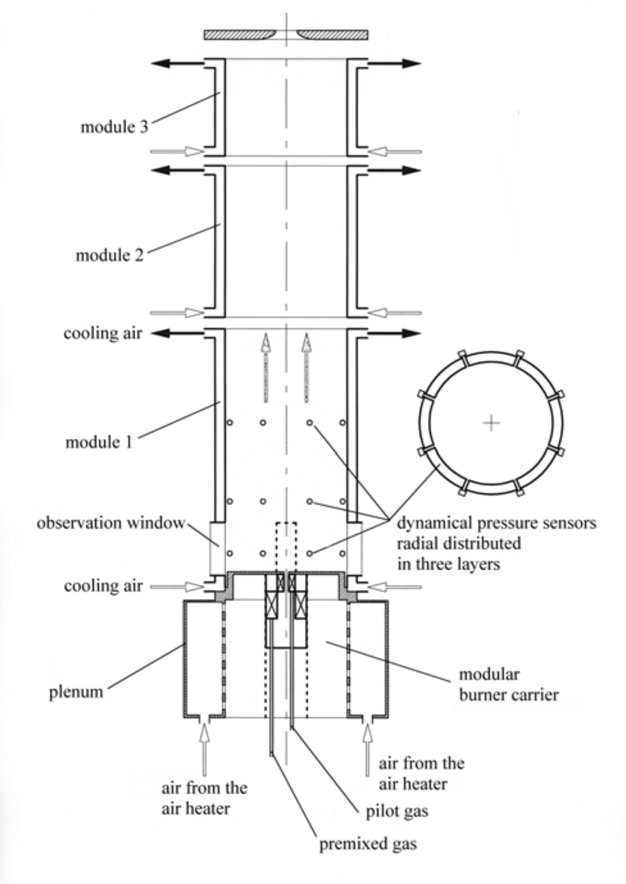

Figure 7 Convective cooled acoustical adjustable burning chamber test bed with a modular burner carrier suitable for different gas turbine burners. (Atmosphärische Sektor Brennkammer, ASC)

With the same valve (only the valve seat was changed a little) first experiments to influence the combustion in the combustion chamber of a gas turbine were performed.

Thermo acoustic vibrations in a combustion chamber have been influenced. The respective experiment was performed as supplement of a research project in the combined research project “AG-Turbo II”. The atmospheric sector combustion chamber (ASC) of the Institut für Antriebstechnik of the DLR, equipped with a burner of the Siemens AG (figure 7) was used.

The burning chamber with the Siemens-burner shows a distinct pressure vibration, whose frequency, related to the geometry of the chamber, clearly points to a standing $\lambda/2$–wave. The ASC burning chamber test bed was designed in a way that the technical and geometrical very different burners of our technical partners Alstom and Siemens can be mounted and served with a main air mass stream of 625 [g/s].

For the combustion chamber the air of combustion can be preheated up to 740 [K]. The modular design of the combustion chamber, up to three, different long, convective cooled modules with 500 [mm] inside diameter can be combined, make possible an acoustic adjustment of the burning chamber related to the experimental needs.

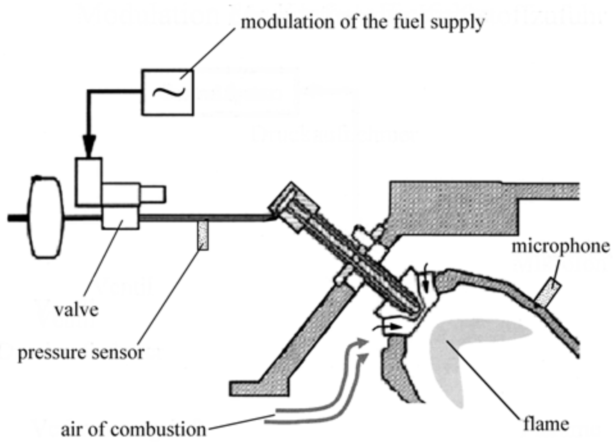

Figure 8 Burning chamber of a gas turbine with a rapid reacting valve to modulate the fuel supply rate.

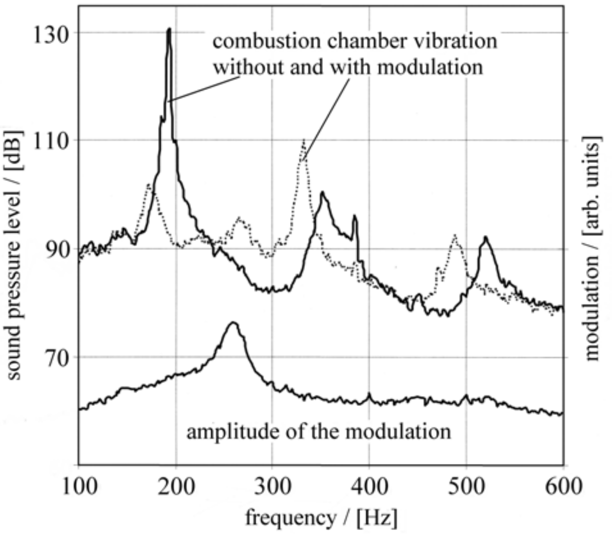

Figure 9 Two spectra of the pressure vibrations in the burning chamber (ASC) with and without modulation of the fuel supply rate and the amplitude of the modulation as function of the frequency. The main vibration at approximately 190 Hz is strongly damped (30 dB) by the modulation.

In the respective experiment natural gas was burned in the combustion chamber and for the modulation of the fuel supply rate a rapid reacting magnetic valve was integrated in the natural gas supply line. The setup is shown in figure 8. In figure 9 two acoustic spectra of the vibration in the burning flame are shown. The acoustic spectra without modulation of the fuel supply rate shows a clear thermo acoustic vibration in the burning chamber at a frequency of approximately 190 Hz.

The fuel supply rate was then modulated with 260 Hz by which the previously observed main vibration in the acoustic spectrum of the burning chamber was strongly damped (figure 9). However, accompanied with a frequency shift to lower frequencies, a weaker vibration, observed at 350 Hz without modulation, gained strength. But in total a clear reduction of the amplitude of the thermo acoustic vibration was achieved.

The effect used here to damp a thermo acoustic burning vibration by a rapid modulation of the fuel supply rate is well known since a long time [7]. In practice it was nearly not used, because suitable rapid reaction valves were not available. But the high potential of this procedure is obviously clear, therefore the DLR institutes Institut für Raumsimulation and Institut für Antriebstechnik will investigate rapid reaction valves in detail in the future.

Modern designs of gas turbines burning chambers are driven, if possible, with a meagre fuel/ air mixture in the primary zone of the combustion to reduce the emission of pollutants; this applies for the aviation gas turbine as well as for the stationary gas turbine. The meagre and even more the meagre premixed burning in a combustion chamber are susceptible for burning vibrations. We can observe therefore, on the manufacturer side of gas turbines, a tremendous interest in devices and techniques to damp these vibrations. Here the rapid reacting valve from the DLR can make a contribution.

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