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Fast valve for mitigating disruptions in tokamaks

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Introduction

Disruptions are known to be very undesirable for every machine and may present a danger especially for large tokamaks. By now they have already caused significant damage[1,2]. Different attempts have been made either to avoid the coming disruption, or to mitigate the disruption consequences, that is to cause a controlled external termination of a discharge. With respect to the latter, fast gas puffing is investigated in this work. Injecting helium may turn out to be preferable, since it possesses high recycling and the low sticking probability to the walls, besides, helium is sometimes anyway present in the machine as a gas for glow discharges. Other gases or even their mixtures may also be favourable. In this contribution, we describe an electromagnetic valve specially worked out for fast gas puffs, starting to open 0.5 ms after a trigger signal and being fully open after 1 ms. There are no ferromagnetic materials included in the construction, so the operation close to the vessel with the presence of a strong magnetic fields does not present a difficulty. The amount of injected gas can be varied by the volume of the gas reservoir (5 – 250 cm^3) and the pressure in it (typically a few bar); the throughput is high enough to bring about a density limit immediately. The high pressure of the reservoir guarantees a fast gas stream and a fast reaction time. On the other hand such a quantity of gas in such a time does not disturb pumping equipment (e.g. cryo-pumping). The valve has been applied successfully on TEXTOR and on ASDEX-Upgrade.

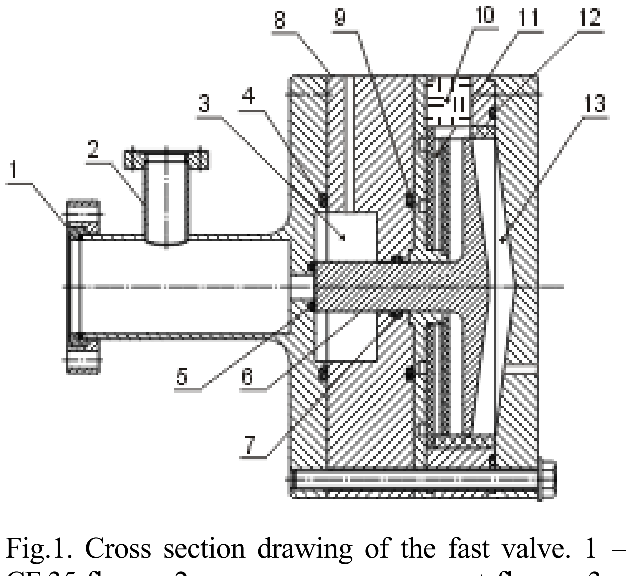

Fig.1. Cross section drawing of the fast valve. 1 – CF 35 flange; 2 – pressure measurement flange; 3 – working reservoir; 4, 5, 7, 9, 12 – o-rings; 6 – piston; 8 – case; 10 – HV coil input (filled with epoxy); 11 – coil; 13 – closing gas volume.

Construction of the valve

Fig.1 shows a drawing of the valve: In the normal state an aluminium piston (6) pushed by the excessive pressure in the chamber (13) separates the working volume (3) from the discharge vessel. Once the valve coil (11) (pan-cake type) is activated, eddy currents are induced in the piston and it is pulled back thus opening a path for the gas flow. After the decay of the induced currents the piston is again driven under the action of the gas in the volume (13) which brings

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it into the original position. The electrical current is supplied by a capacity with C_{load} = 0.180 mF charged at a voltage of up to U_{load} = 2 kV; the circuit is switched by an ignitron after a trigger signal. The fuelling gas reservoir can be varied (by machining) between 5 and 250 ml. The fuelling pressure should be high enough, enabling a fast gas flow into the discharge; the working pressure is selected between 1 bar and 30 bar. O-ring (5) seals separate the reservoir from the discharge chamber, and (7) — the reservoir from a back volume (13); the pressure in this back volume guarantees a fast closing of the stem after its activation. Towards the discharge chamber, the valve is equipped with a high vacuum CF 35 flange (1) in order to obey the normal tokamak requirements. An additional measurement flange (2) was foreseen as well. The total length of the valve amounts to 20 cm and its diameter - to 17 cm.

An important feature of the present design of the valve is the avoidance of any ferrite material, because then it can be installed very close to a tokamak with its full magnetic field. In our case on ASDEX-Upgrade the valve has operated successfully in the full field of 2 Tesla. Mounting the valve directly on a tokamak vessel results in a faster reaction time, since there is no distance separating the valve from the vessel. Other valves may use a ferromagnetic stem, which is attracted into a coil. This mount with ferromagnetic stem is smaller and has a higher coupling to the electric circuit; but its disadvantage is that e.g. the tokamak toroidal magnetic field saturates the ferrite stem such that it cannot operate directly at the machine.

Valve operation and characteristics

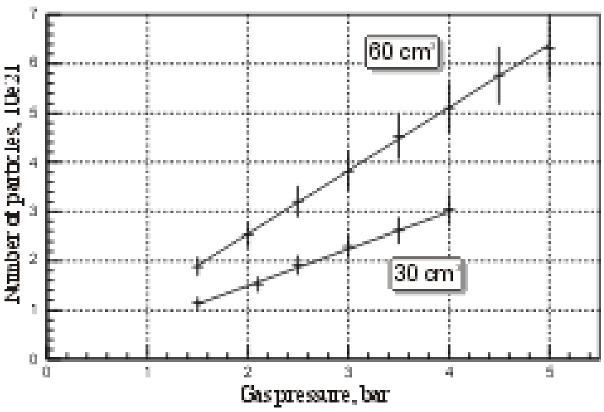

Fig.2. Number of injected particles vs. gas pressure for two different working volumes (note the pressure is in absolute units).

To determine how much gas flows out from the working volume per one shot a scan over the gas pressure has been made. The calibration curves for two different cases (namely, for the 30 cm^3- and 60 cm^3-volumes) are shown in Fig.2. The other parameters are 1.5 kV to activate the valve coil and 5 bar Helium for closing. The absolute accuracy of the amount of the injected gas is about 10% , mainly given by the irregular shape of the target volume (11), into which the gas was released. For the operational range, the amount of the injected gas is linear proportional to the gas in the filling reservoir. Experiments on ASDEX-Upgrade (with the total vessel volume 14 m^3) have shown that already about 30 mbar*l ($7.5 \cdot 10^{20}$ particles) of a gas is sufficient to generate reliably the disruption; on the other hand, the amount of the injected gas is low enough to shut the pumping system (e.g. turbo-pumps) down or provoke a detrimental heat load at cryo-pumps. Important valve parameters are the gas throughput and the reaction time. Piezoelectric valves[3] have an ideal short response time but their throughput is too small. Therefore a valve with a piston is required. In order to obtain the opening characteristic of the valve, we utilised the following method: we inserted a glass fibre into the bore hole which lead to the filling reservoir, then we illuminated the glass fibre and detected the light at the valve exit by mounting a photomultiplier at the CF flange of the valve. The light from the glass fibre is reflected many times diffusely at the reservoir walls; therefore the multiplier signal is

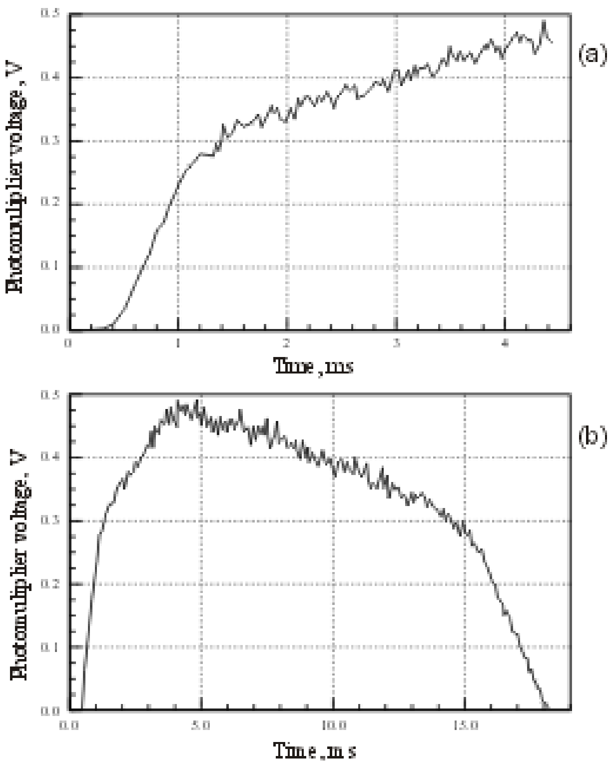

Fig.3. Opening characteristics of the fast valve. a) – initial stage with the extended time scale, b) – full process.

directly proportional to the opening of the valve. Represented in Fig.3, a,b are the very beginning of this opening with the extended time scale as well as the full process. One sees that the valve starts to open 0.5 ms after the trigger signal. After about 1 ms it is nearly completely open and after 18 ms is closed again due to the repulsive pressure in the back volume.

The curve of the electrical current through the valve coil is of interest as well and is given in Fig.4. The current maximum is reached after 400 μs and then the signal decays with the rate of a critically damped oscillation. Since the opening of the valve starts at about the maximum of the valve current, i.e. the stem reaches its maximum kinetic energy also close to this time, the energy transfer from the electrical circuit to mechanical energy is close to its maximum. This means, the capacitance C is well chosen for the given inductance of the valve. The electrical circuit is switched by an ignitron; this tube switches only one polarity of the current. The fact that the valve current is critically damped is therefore very favourable because a less damped circuit would generate high voltages when the current wants to pass through zero. This high induced voltage can be dangerous for the circuit because it may create short cuts e.g. in the pan cake coil and damage it.

In order to check, whether the valve behaves itself the same over the long operation period, in particular, whether it remains vacuum-tight, continuous test shooting was undertaken. A pressure of 2.5 bar helium was applied for both pushing the closing stem and injecting gas. 2 kV voltage is used for activating. Shots followed one after another with the frequency of one shot per 40 seconds, what was conditioned by the charging time of the capacitance and the pumping rate of the turbopump. The pressure signal, measured by a baratron in the volume, where the gas was injected to, was linked up to a plotter. In total about 1000 shots were performed within the frames of this test and no change in the character of operation was found. Up to now about 500 gas puffs more have been done during experimental programmes, again, without causing any breakage.

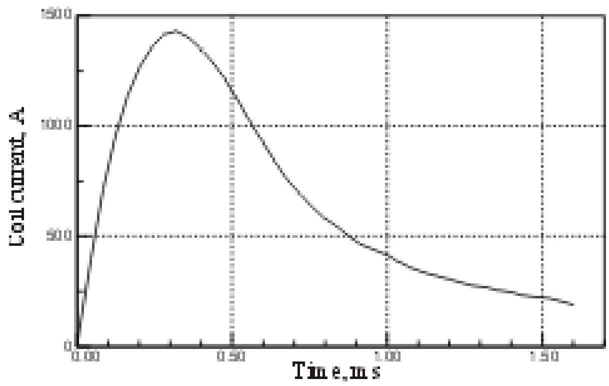

Fig.4. Trace of the electrical current through the valve coil.

Example of a mitigated disruption

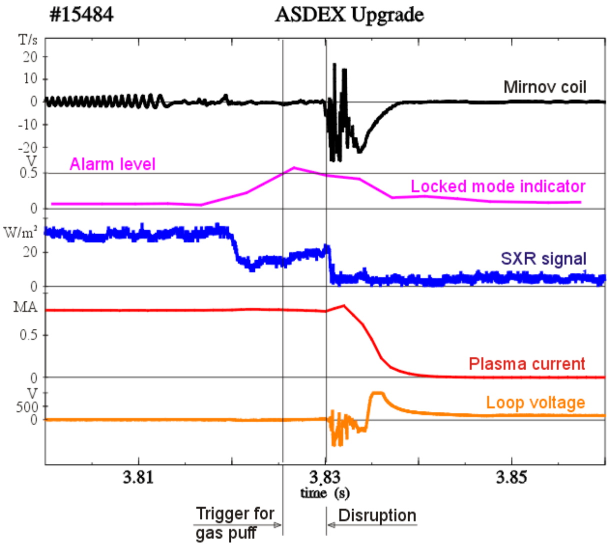

Fig.5. Realization of mitigation based on a locked mode trigger.

An example of the use of the valve to mitigate disruptions on ASDEX Upgrade is shown in Fig.5. This is a successful attempt to carry out the mitigation as a whole, that is to inject gas using a disruption warning signal which is in this case a locked mode indicator. As the locked mode grows, the integrated radial field, measured by the saddle coils, increases. As soon as its amplitude exceeds given threshold (here at t=3.826 s), the valve is given a command to shoot. It takes a while until the gas reaches the plasma and brings about a disruption (t=3.83 s), what is typically seen on the temperature, current and loop voltage signals. Namely, in this shot the effort of mitigating resulted in reducing halo currents and mechanical forces by a factor of 2. For details please refer to the contribution[4] of *G.Pautasso*, this conference.

Summary

A fast gas valve for mitigating disruptions, has been constructed and tested at TEXTOR in FZJ Juelich. Its main features are:

- response time: 0.5 ms,
- amount of injected gas: variable, 2...1000 mbar*l,
- linear dependence of the number of injected particles on the gas pressure,
- sort of gas: any,
- capability of working in a strong magnetic field,
- no harm to the vacuum system and cryopumps of a machine.

The valve has the standard CF 35 flange, commonly used in vacuum engineering. All the details, that have a contact with vacuum, were made of stainless steel, except for the closing aluminium piston. To prevent direct gas leaking from the bottles to the experimental vessel there are also two safety valves, chopping them off before the shot. The required control equipment includes a high power supply and the combined block for the safety valves and baratrons, both being able to work with TTL control signals. During the tests and experiments on TEXTOR and ASDEX-Upgrade the valve showed successful operation with three gas types: He, Ne, Ar.

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