Experimental campaign to test the capability of STARDUST-Upgrade diagnostics to investigate LOVA and LOCA conditions

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Introduction

An important issue related to future nuclear fusion reactors is the large amounts of dust produced by PMIs [1-7]. Re-suspension phenomena in case of LOVAs/LOCAs can cause serious hazard to the health of the operators (since particles are radioactive and of breathable size [9, 10-12]) and can cause explosions [13]. Experience achieved on reproducing thermo fluid-dynamic consequences of a LOVA [14-31] allowed the QEPM Research Group to develop an improved [32-34] facility ("STARDUST-Upgrade", Small Tank for Aerosol Removal and Dust – Upgrade) to reproduce dust re-suspension phenomena and to test diagnostics capability to investigate not only LOVAs but also LOCAs and their consequences as reported in the GSSR Report for ITER [35].

1. STARDUST-Upgrade facility overview and experimental methods

"STARDUST-Upgrade" facility (Small Tank for Aerosol Removal and Dust – Upgrade) is composed of a stainless steel vacuum chamber connected with diagnostics and a data acquisition system that ensure thermo fluid-dynamic conditions (pressure, temperature, local air velocity, pressurization rate) comparable to that expected in an ITER-like vacuum vessel during LOVA and LOCA events as reported in the GSSR Report [35]).

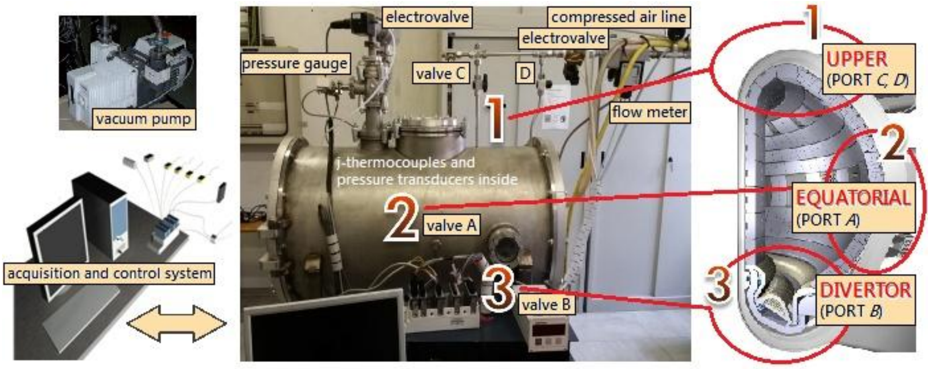

Fig.1 "STARDUST-Upgrade" facility overview

During each vacuum failure accident experiment, the following signals have been acquired at a frequency of 50 Hz,: J-thermocouples temperature [°C], actual internal pressure [Pa], air flow rate [l/min], and differential pressure transducers output [Pa] used to calculate local air velocity [m/s] [8]. The "velocity transient time" (Table 1) was calculated in order to have information on the time range in which mobilization is expected. It was defined as the time at which the pressure transducer voltage signal returned to 0.50 mV, corresponding to its maximum acceptable zero point. This velocity, namely "v(0.50mV)", is equal to the minimum air velocity detectable by the system above the signal-to-noise ratio (SNR). Finally, the upper ports of “STARDUST-Upgrade” were used as inlet ports, reproducing LOVAs/LOCAs consequences from the upper ports of an ITER-like vacuum vessel. Pressurization experiments were performed at different air flow rates to achieve several pressurization rates from about 100 Pa/s to 400 Pa/s, including rates expected in GSSR Report in case of LOVA event [35].

2. Results

Internal pressure trends and corresponding pressurization rates are presented in Fig.2.

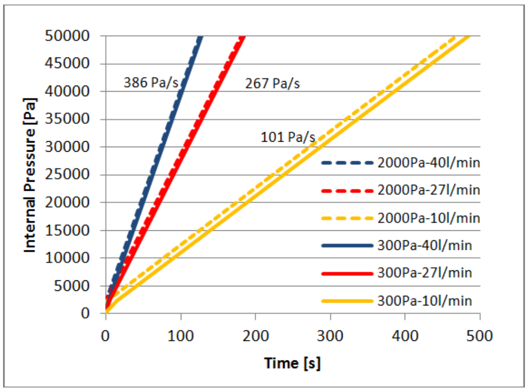

Fig.2 Internal pressure trends measured by Pirani gauge inside “STARDUST-Upgrade” facility

Air velocity trends for first 25 seconds of air intake are reported in Fig.3 that shows a velocity peak in the first four seconds. The corresponding pressurization rates are that shown in Fig.2.

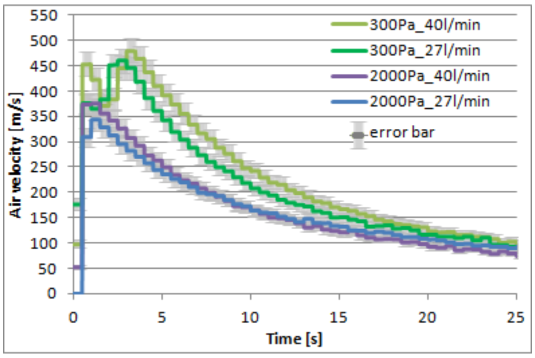

Fig.3 Air velocity trends calculated for pressurization experiments in “STARDUST-Upgrade” facility

Table 1 summarizes the results on air velocity calculations. The maximum velocity value [m/s] is presented for each run along with corresponding time [s] at which the maximum was observed.

*Initial Pressure **300 Pa***	Flow rate [l/min]	**40**			**27**		
	Replication	*#1*	*#2*	*#3*	*#1*	*#2*	*#3*
	Max velocity [m/s]	481.88	479.92	480.87	457.69	459.71	458.55
	Time [s]	3.36	3.36	3.36	2.80	2.80	2.80
	Transient velocity time [s]	58.69	57.78	55.56	45.97	49.17	48.20
	v(0.50mV)	48.32	37.68	40.23	56.35	49.12	45.93
*Initial Pressure **2000 Pa***	Flow rate [l/min]	**40**			**27**		
	Replication	*#1*	*#2*	*#3*	*#1*	*#2*	*#3*
	Max velocity [m/s]	377.91	407.19	375.34	339.93	334.84	342.45
	Time [s]	1.40	1.40	1.40	1.40	1.40	1.40
	Transient velocity time [s]	44.54	66.53	44.06	52.50	51.36	54.55

	v(0.50mV)	40.03	30.52	40.18	42.92	49.67	42.84

Table 1 Air velocity calculation data sheet for 27 l/min and 40 l/min air flow rate at two different initial internal pressures (300 Pa and 2000 Pa) of the chamber of "STARDUST-Upgrade" facility.

Fig.4 and Fig.5 compare pressurization curve and air velocity trends measured experimentally with CFD model predictions. Experimental and numerical results show substantial agreement for the first 20 seconds of pressurization. However, due to numerical viscosity effects, the numerical velocity predicted peak in the first seconds is lower than the experimental one.

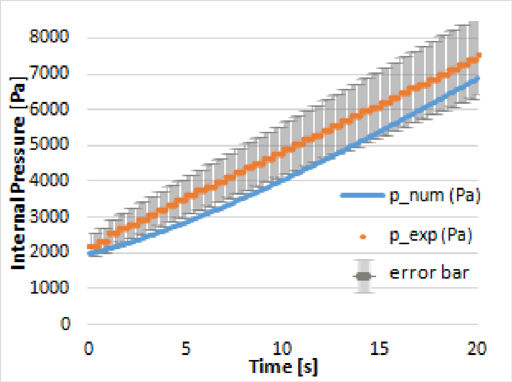

Fig.4 Measured internal pressure of the chamber with error bars (p_exp) compared to model prediction (p_num) for air intake at 27 l/min at 2000 Pa initial internal pressure.

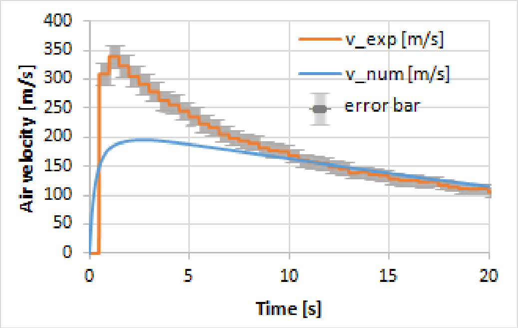

Fig.5 Measured air velocity at the outlet of port C (v_exp) compared to model prediction (v_num) for air intake at 27 l/min at 2000 Pa initial internal pressure.

3. Conclusions

Pressurization of the chamber achieved through air intake from upper ports evidenced that "STARDUST-Upgrade" facility is able to reproduce a wide range of pressurization rates including what expected in GSSR Report [35], not only from the lower and equatorial level [1-7, 17] but also from the upper section of the vessel. Using upper ports also allows to replicate pressurization consequences of a LOCA from coolant system in the upper section of an experimental fusion plant, using air as model fluid. In the present work, a LOCA causing vacuum failure from the upper section is supposed to produce almost the same pressurization rates as LOVAs, but no experimental evidences are available at this time. The Transient velocity time shown in Table 1 resulted smaller than 60 seconds for all replications demonstrating that investigation of dust mobilization is crucial in the first seconds. Furthermore, Fig.4 and Fig.5 show a substantial agreement between numerical and experimental results. It is observed that the simulated air velocity trend does not reach the same measured peak value, and that the predicted pressurization rate is lower than the experimental one. This could be due to an insufficiently fine grid, which produces numerical viscosity. Future model development should improve the numerical accuracy. In conclusion, “STARDUST-Upgrade” facility is shown to be capable of reproducing the thermo fluid-dynamic consequences of a LOVA from lower, equatorial and upper part of the vessel, and the pressurization consequences of a LOCA from the upper part of the vessel. Since the fluid expected to enter the vessel during a LOCA could be different from air, next experimental campaigns will involve different fluids (e.g. steam) to properly reproduce a LOCA event.

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