



Risultati della campagna sperimentale sull'impianto ELTL di Oarai per la rilevazione dei fenomeni di cavitazione

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RISULTATI DELLA CAMPAGNA SPERIMENTALE SULL'IMPIANTO ELTL DI OARAI PER LA RILEVAZIONE DEI FENOMENI DI CAVITAZIONE

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Summary

This document describes the experimental activities performed with the ENEA CASBA-2000 detector equipment for the monitoring of the insurgence of cavitation phenomenon in the ELTL lithium loop at OARAI research centre.

It deals with the following topics:

1. Scope of the experimental test campaign;
2. Set up of the experiment;
3. Test matrix;
4. Experimental results;

List of Acronyms

- CASBA Cavitation or Boiling Rate Analyser
- DACS Data Acquisition and Control Systems
- EMP ElectroMagnetic Pump
- IFMIF International Fusion Materials Irradiation Facility
- TA Target Assembly

1 Introduction and background

The main objective of the EVEDA Lithium Test Loop is to validate the IFMIF design, in particular with respect to a fast, reliable and stable flow of lithium on the back plate of the target assembly. All the characteristics of the EVEDA loop are similar to the one foreseen for the IFMIF Li target flow, except its flow width on the target back plate, reduced to about 1/3 of the full scale.

One of the main issues in operating the loop is the possible occurrence of cavitation phenomena at pump inlet or target outlet. For this reason the experimental programme planned for the EVEDA loop includes also a task for the detection of the cavitation occurrence as it was recognised to be of importance for the safer operation of IFMIF.

The monitoring of the insurgence of lithium cavitation in the EVEDA lithium test loop by the ENEA CASBA-2000 equipment [1,2], at least at the inlet of the EMP and on the inlet/outlet channels of the TA, was performed in 2014 with the aim to determine the Best Operational Point of the loop to guarantee a reliable operation.

Two test campaigns have been executed on the ELTL loop at Oarai, the first one in January 2014 and the second one in June.

This document deals with the experimental program carried on the ELTL loop at Oarai (JP).

2 Scope of the experimental test campaign

The main objective of this experimental test campaign is the determination of the operational range in which the cavitation phenomena should occur in the ELTL. In particular cavitation testing will be carried out at critical speed/pressure combinations to define the cavitation/no cavitation regimes in two specific locations of the plant.

2.1 Selection of the positions of the Casba sensors

In the first cavitation experimental test campaign two positions in the ELTL loop were investigated:

- At the inlet of the target assembly, and
- At the inlet of the EMP

The outcomes obtained during this first test campaign have clearly excluded any cavitation phenomena at the inlet of the EMP while flow instabilities were observed, at the lithium flow speed below of 5 m/s, in the TA. Cavitation was also detected by the sensors installed by JAEA in the outlet channel of the TA.

Accordingly with the aim to confirm the results already obtained for this latter area and to qualify the Casba system as well, in the 2nd test campaign the Casba system was installed in the following positions:

- The first Casba was already installed at the inlet of the TA and will be kept in the this position;
- The second Casba was installed on the outlet channel at the beginning of the elbow, where it was expected the lithium flow will impact on the tube

Positions of the Casba system in the second campaign are related to Bar#1 and Bar# 4 as illustrated in the Fig. 1

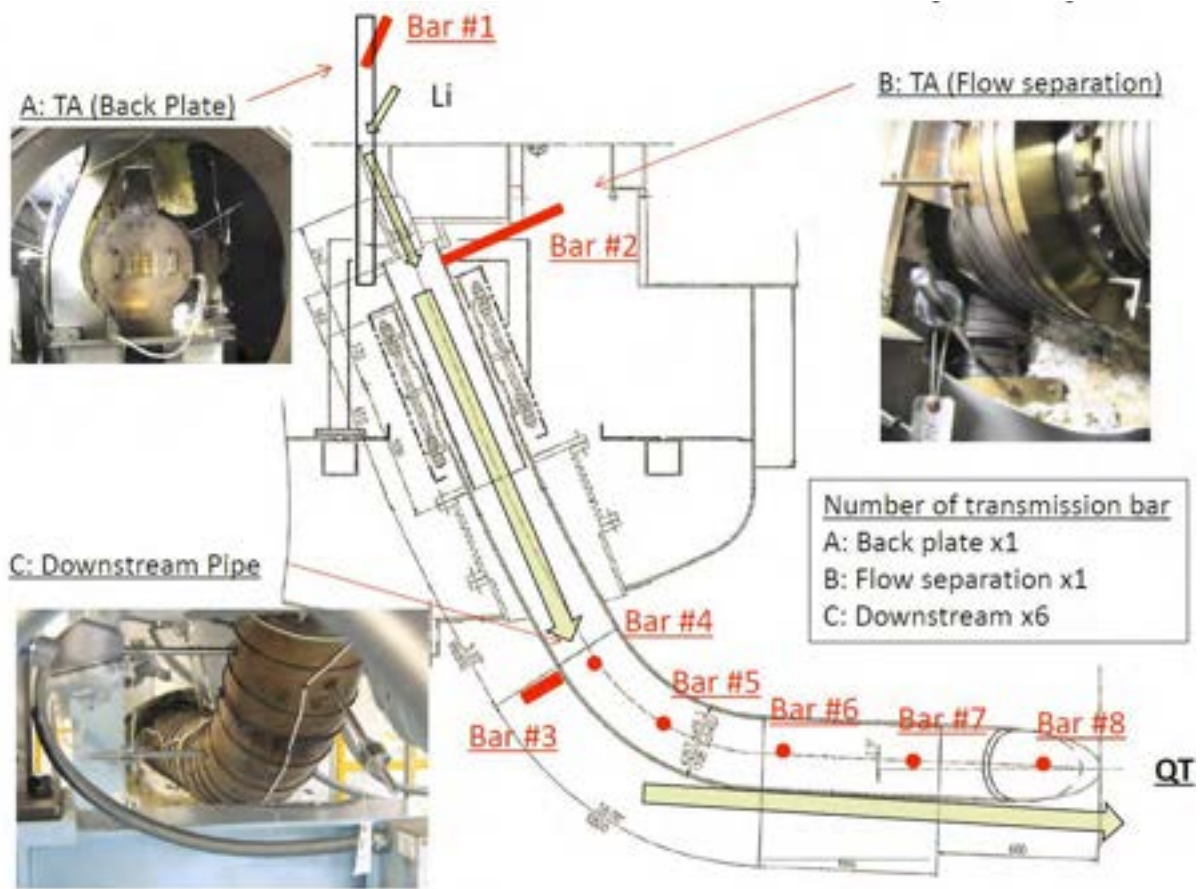


Fig. 1 Positions of CASBA installation.

2.2 Test Matrix and test execution

In the experimental data obtained in the former cavitation test campaign in 2012, critical values of operation pressures and jet velocities which shown an incipient cavitation have been identified. In the fig. 2 the operation pressures vs the cavitation numbers at the nozzle exit for different jet velocities are displayed. Moreover the experimental values of operation pressure and jet velocity that shown an incipient cavitation are displayed. The interpolation curve of the experimental incipient cavitation points could be used to evaluate the incipient cavitation conditions at different velocities. Different operation conditions for an incipient cavitation have been evaluated as in Tab. 1 and 2.

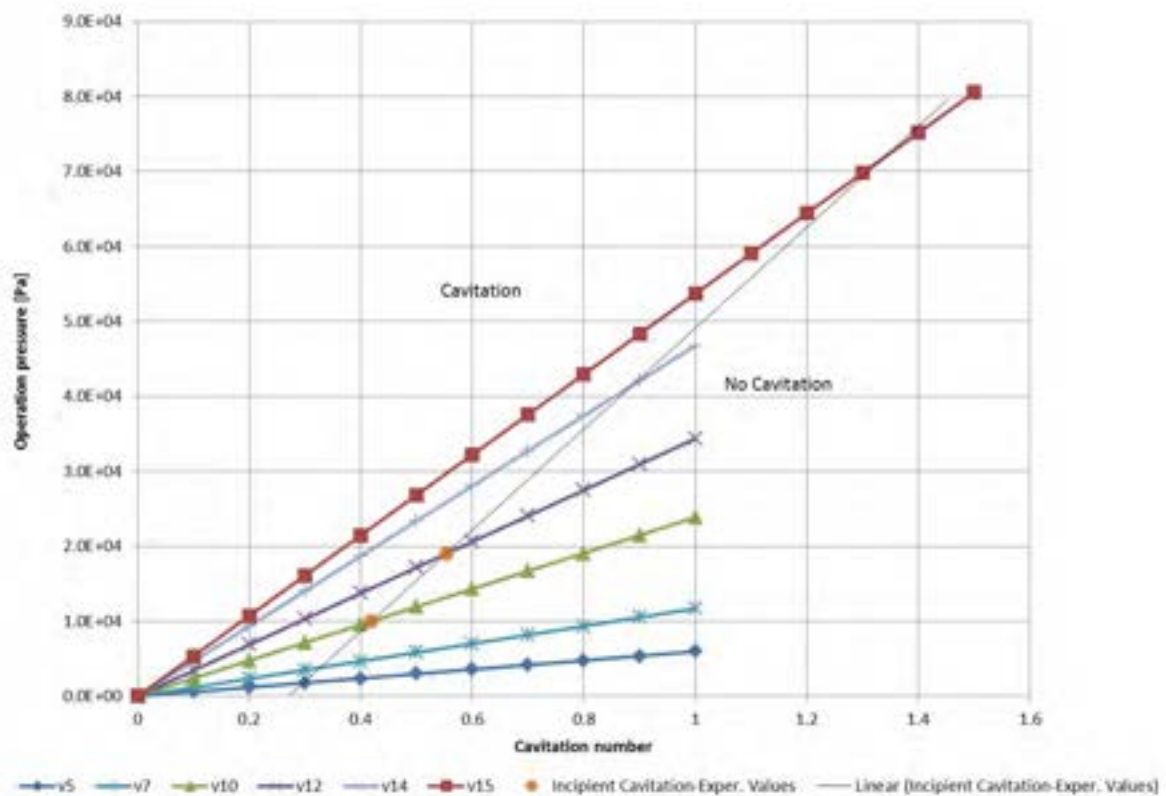


Fig. 2 Operation pressures vs the cavitation numbers at the nozzle exit

Table 1 Predicted operation values for incipient cavitation

	P[Pa]	V[m/s]
1	1770	5
2	3826	7
3	10000	10
4	19000	12
5	41545	14
6	72000	15

A test matrix was proposed to verify the prediction of incipient cavitation as in tab 1.

The tests will be executed using the flowing procedure:

- the plant is pressurized at 73000 Pa and the velocity of the jet is increased up to 15 m/s,
- then the pressure is reduced with steps of 500 Pa up to verify the detection of the incipient cavitation.
- after the detection of the cavitation noise the velocity is reduced to 14 m/s where the cavitation noise should disappear. then the pressure is again reduced with steps of 500 Pa up to verify the detection of the incipient cavitation at 14 m/s.
- The procedure is repeated reducing pressure and velocity up to cover the points in the tab. 1.

3 Test results

3.1 *Fist test campaign (27th Jan 2014 – 7th Feb. 2014)*

Prior to start with the experimental test campaign installation of additional instrumentation and commissioning of the cavitation measurement system were performed. In detail the following integration and installation were carried out:

- 1) Two CASBA sensors: one installed on the target assembly (inlet side) and another one on the inlet of the electromagnetic pump;
- 2) Two CASBA signal preamplifiers;
- 3) One power supply and signal splitter
- 4) One signal booster.

These components are shown in the following figures.



Fig. 3 CASBA sensor



Fig. 4 CASBA sensor and pre- amplifier



Fig. 5 Two channels power supply / signal splitter



Fig. 6 Two channels signal booster

The final scheme of the implemented measurement system is shown in Fig. 7.

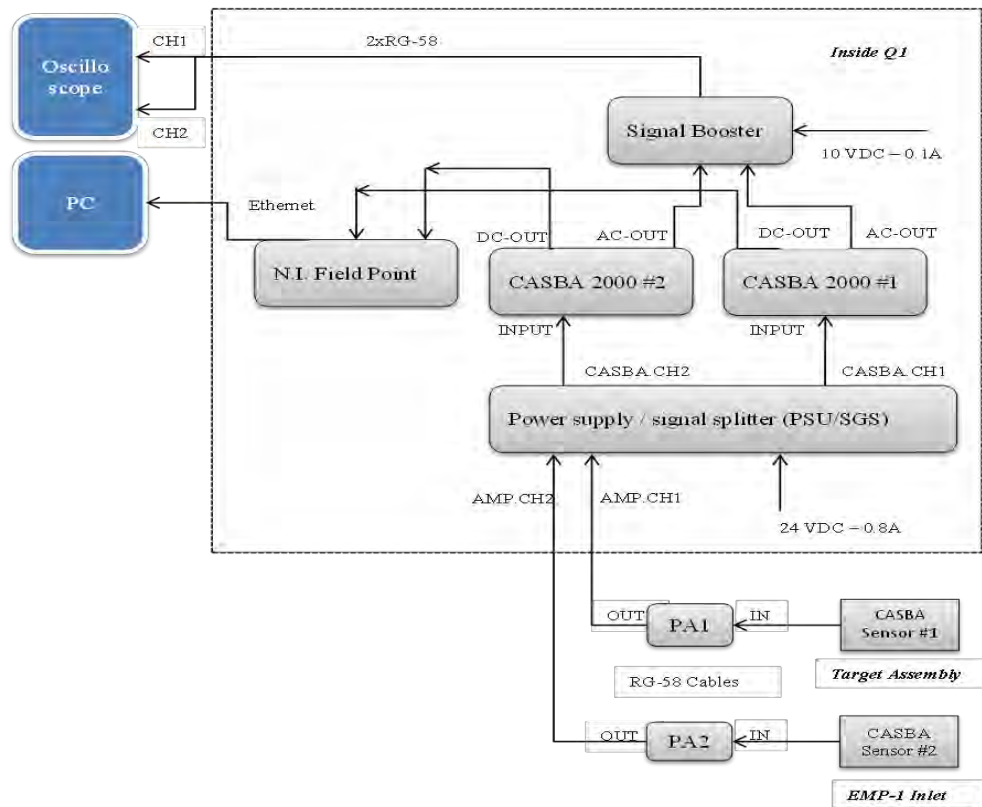


Fig. 7 Logic scheme (blocks diagram) of the measurement system for the cavitation detection

3.1.1 Commissioning

After the installation, all components of the CASBA cavitation measurement systems have been commissioned using experimental test procedures. A signal generator has been used (at the place of the CASBA sensors) in order to simulate the cavitation signal. The signal path has been checked using a portable oscilloscope. Calibration of the CASBA measurement system has been verified using a signal generator and a precision (1% accuracy) 0-60 dB variable attenuator.

The two CASBA sensors have been tested – after installation – using external mechanical excitation produced hammering on the transmission bar. In fig. 8 the signals coming from the CASBA (single and multiple excitation) and displayed on the screen of the oscilloscope are shown.

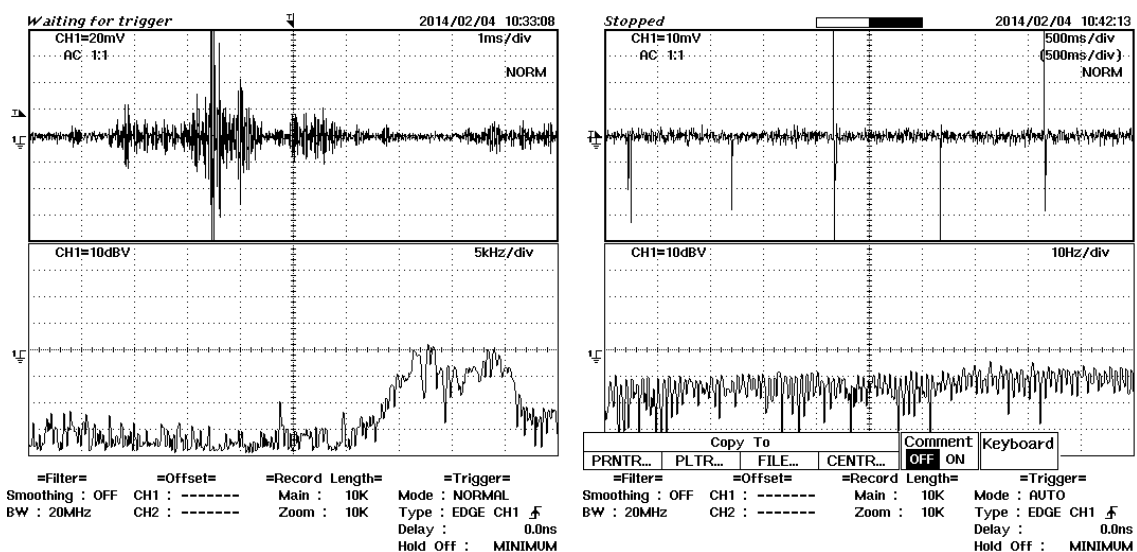


Fig. 8 Single ping / Multiple ping

3.1.2 Experimental test

The experimental activity is composed by two sets:

- "30_Jan": a test on the EPM-1 (two stages electromagnetic pump) working on the bypass line with Argon at atmospheric pressure
- "05_Feb" and "06_Feb": two complete runs in high vacuum condition and operation parameters close the IFMIF configuration. The "06_Feb" experiment is not reported because its results are basically equal to the previous "05_Feb" experiment.

The ELTL-EVEDA team has provided experimental data acquired by their data acquisition system (pressure, flow, temperatures, etc.) in a format compatible with the CASBA one. The following discussion is based on the analysis of both data set.

30 January experiment

We will not discuss in details the results of this experiment because the CASBA sensor has not registered any interesting signal (cavitation or plant noise). Also the subsequent experiments have shown the absence of any cavitation phenomena at the EMP-1 inlet, therefore we consider the EMP-1 zone free from any cavitation related phenomena.

5 and 6 February experiment

Basically, the two experiments share the same planning. Each one is composed by three phases: ramp-up, steady state and ramp-down.

05 February RAMP UP

The top graph in Fig. 9 shows the lithium flow (liters/minute). The FIT-01 electromagnetic flow meter is installed after the EMP-1 outlet; the reading of the flow meter is not reliable below 500 l/min. The bottom graph shows the two CASBA readings.

At low flow regime (below 750 l/min) the flow is unstable. This instability generates a lot of plant noise (CASBA#1 TA, up to 50 dB); increasing the flow, the instability disappears and the plant noise drop to normal values (between 25 and 35 dB).

CASBA#2 does not register any significant signal.

05 February STEADY STATE

Top graph in Fig. 10 shows the lithium flow (liters/minute). The flow is constant.

The bottom graph shows the two CASBA readings.

Both readings are constant, oscillating only few decibel and no cavitation is detected.

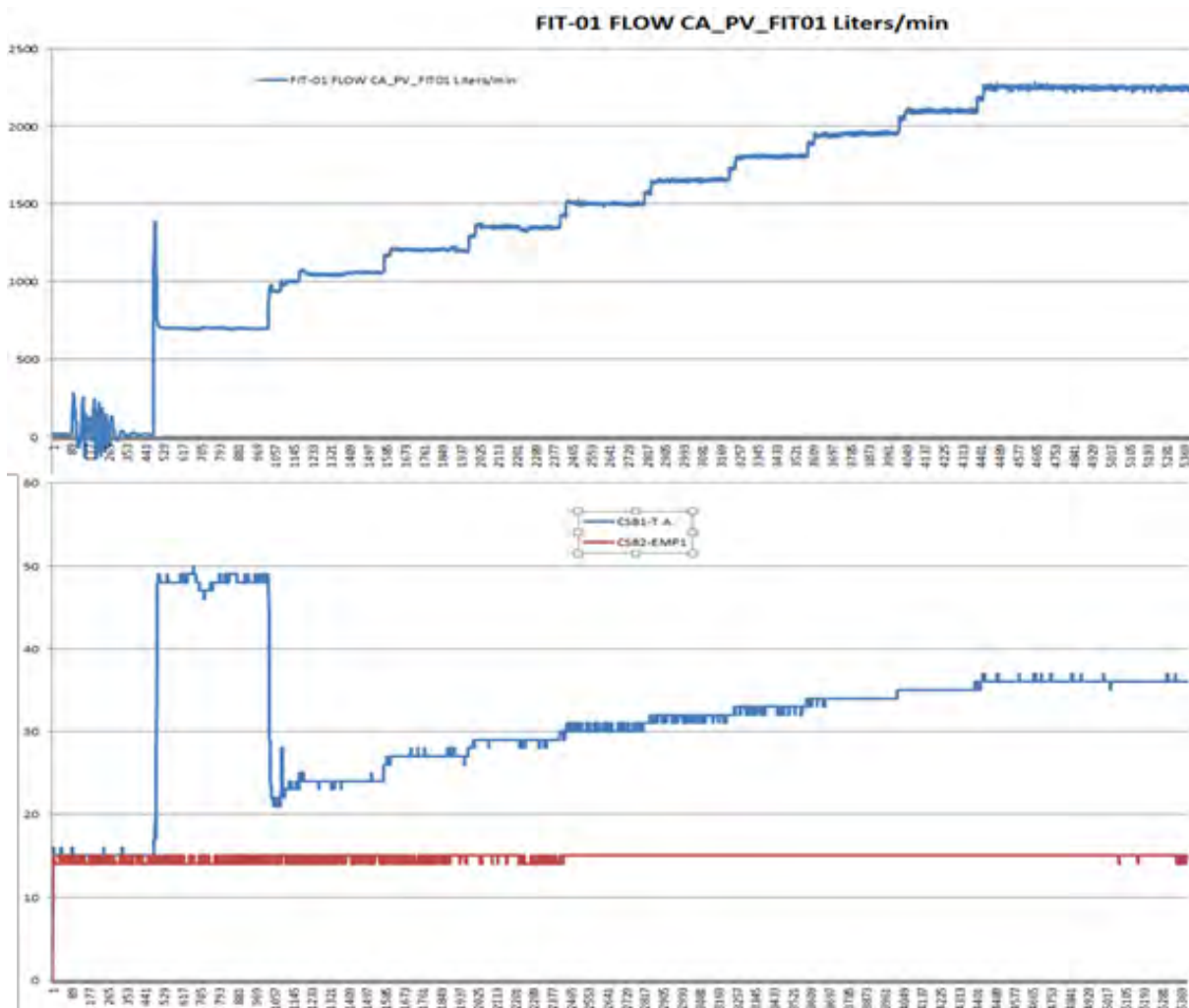


Fig. 9 Lithium flow (l/min)/ CASBA readings (db) during rump up

05 February RAMP DOWN

Top graph shows the lithium flow (liters/minute). The reading of the flow meter is not reliable below 500 l/min.

The bottom graph shows the readings of the two CASBA sensor.

CASBA#1(TA) shows transient and steady instabilities at low flow regimes as previously registered during the ramp-up phase.

CASBA#2 (EMP-1) shows a very quiet reading, constant at all regimes and no cavitation detected.

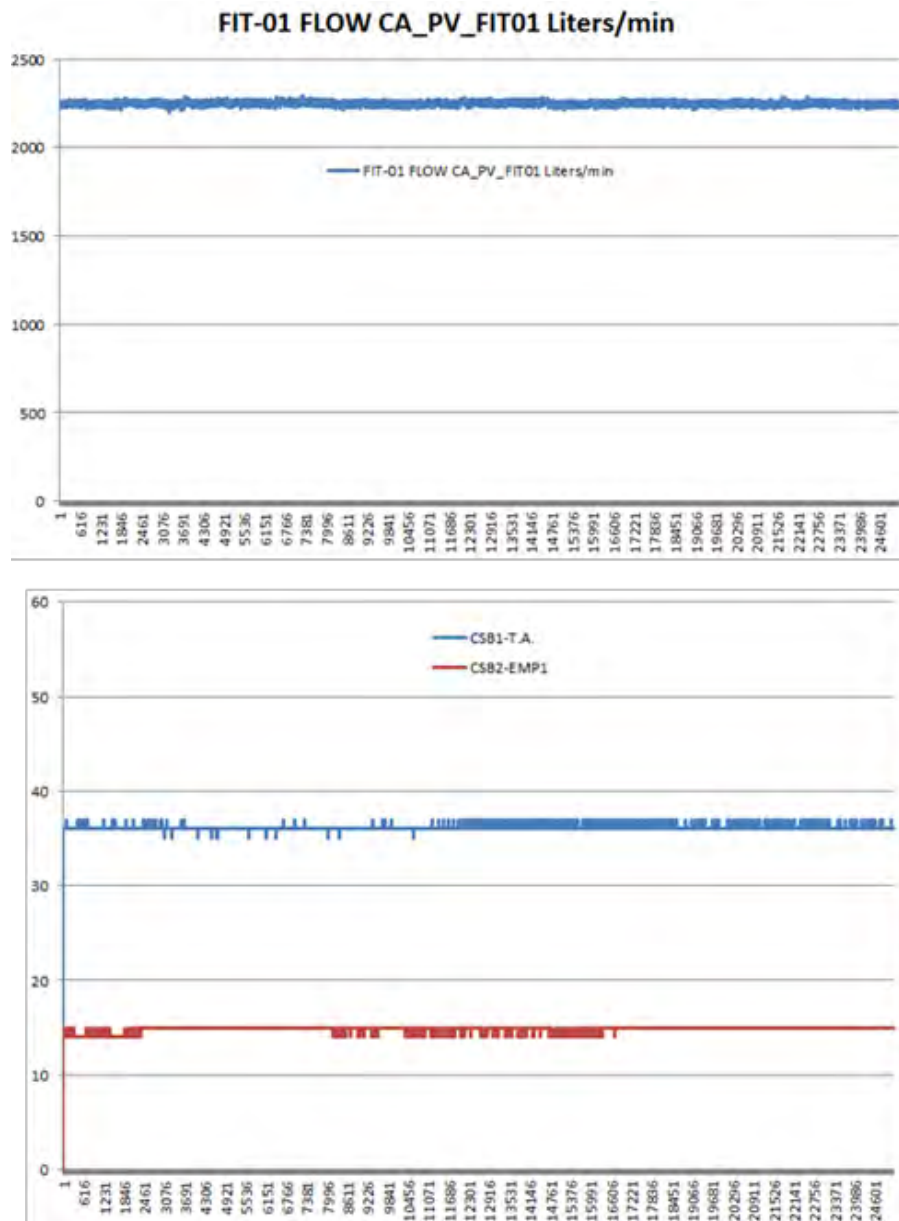


Fig. 10 Lithium flow (l/min)/ CASBA readings (db) –during steady state regime

05 February RAMP DOWN

Top graph shows the lithium flow (liters/minute). The reading of the flow meter is not reliable below 500 l/min.

The bottom graph shows the readings of the two CASBA sensor.

CASBA#1(TA) shows transient and steady instabilities at low flow regimes as previously registered during the ramp-up phase while also in this case CASBA#2 (EMP-1) shows a very quiet reading, constant at all regimes and no cavitation have been detected.

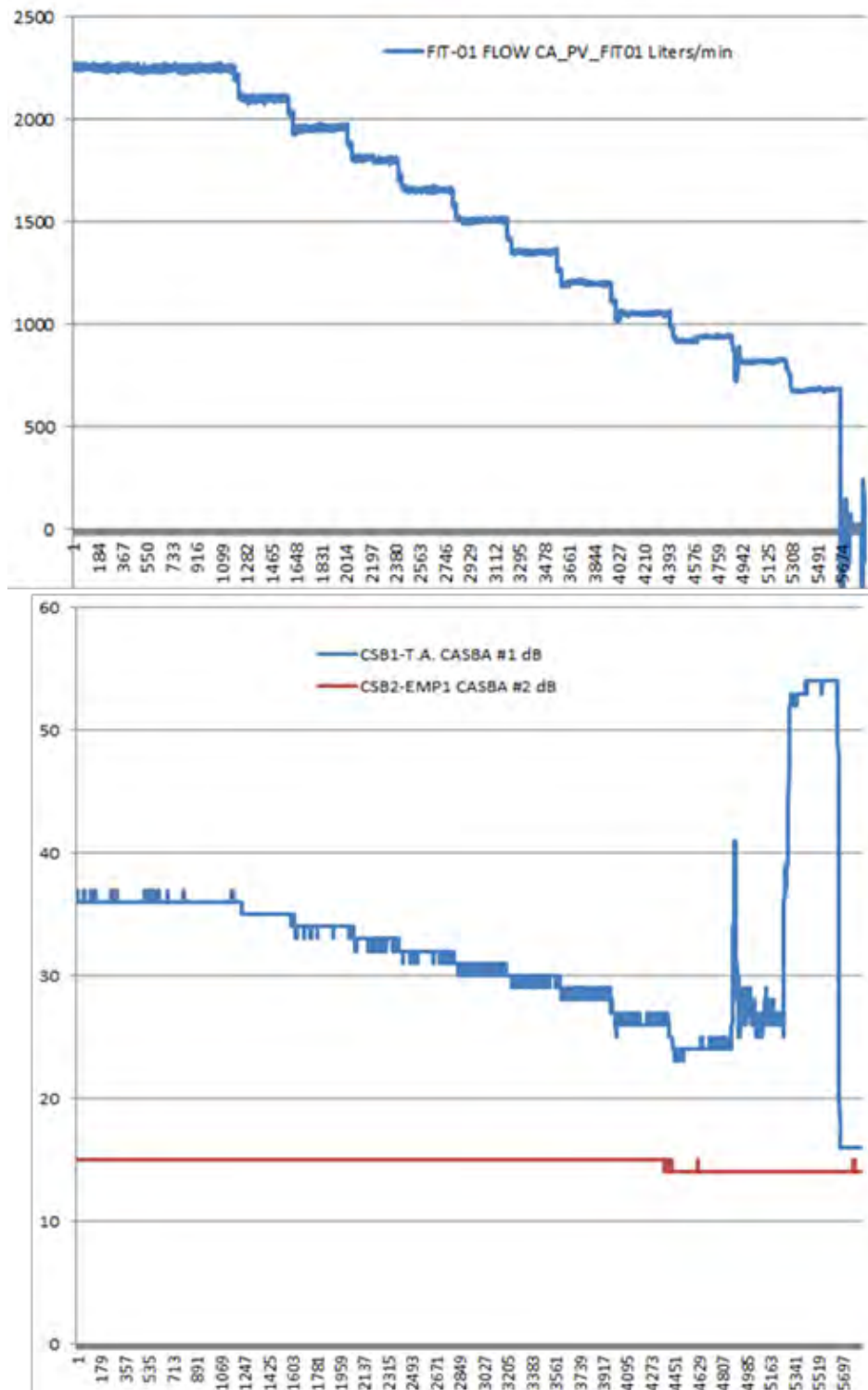


Fig. 11 Lithium flow (l/min)/ CASBA readings (db) –during ramp down

3.2 Second Test Campaign (24th – 25th June 2014)

The 2nd test campaign on the cavitation detection was held in June 2014. The experiment adopted the same configuration of the previous one, a part of the position of the CASBA sensor on the electromagnetic pump that was moved on the exit of the TA. This modification was mainly driven by the results already obtained in the first cavitation test campaign and previously reported. Also the commissioning of the system was performed as previously reported.

The test procedure agreed with the personnel in charge to the ELTL loop of JAEA is in the next Tab. 2. In this table the test matrix together the preliminary results obtained are reported. In Figs. 12 and 13 graphs of the data obtained for the CASBA on the inlet and outlet channels of the TA are shown. The first conclusion that could be said is that almost the results obtained in the previous test campaign in the inlet of the TA (nozzle) are confirmed: no cavitation occurred.

Tab. 2 Test Matrix and experimental results of the 2nd test campaign.

	24-giu-14	24-giu-14	24-giu-14	24-giu-14	24-giu-14	24-giu-14	25-giu-14	25-giu-14
	250°C	250°C	250C	250C	250C	250°C	250°C	250°C
(kPa)	15m/s- CASBA-1	15m/s CASBA-2	12m/s CASBA-1	12m/s CASBA-2	10m/s CASBA-1	10m/s CASBA-2	7m/s CASBA-1	7m/s- CASBA-2
100	31	24	28	16	27	15	25	15
90	31	23	28	16	27	15	24	15
80	31	23	29	16	27	15	24	15
70	31	23	29	16	27	15	24	15
60	31	23	29	16	27	15	24	15
50	32	22	29	16	28	15	25	15
45	32	21	30	16	28	15	25	15
40	34	22	31	16	29	16	25	15
35	37	21	31	16	29	15	25	15
30	43	21	31	16	29	15	25	15
25	48	24	32	16	30	15	26	15
20	53	28	36	17	30	16	26	15
15	56	31	45	21	32	15	27	15
10	58	32	53	27	40	18	28	15
5	60	35	56	31	52	27	34	16
0,4							50	26
0,3							51	27
0,2							52	28
0,1							53	28

In the figures 14 and 15 the full data set is presented.

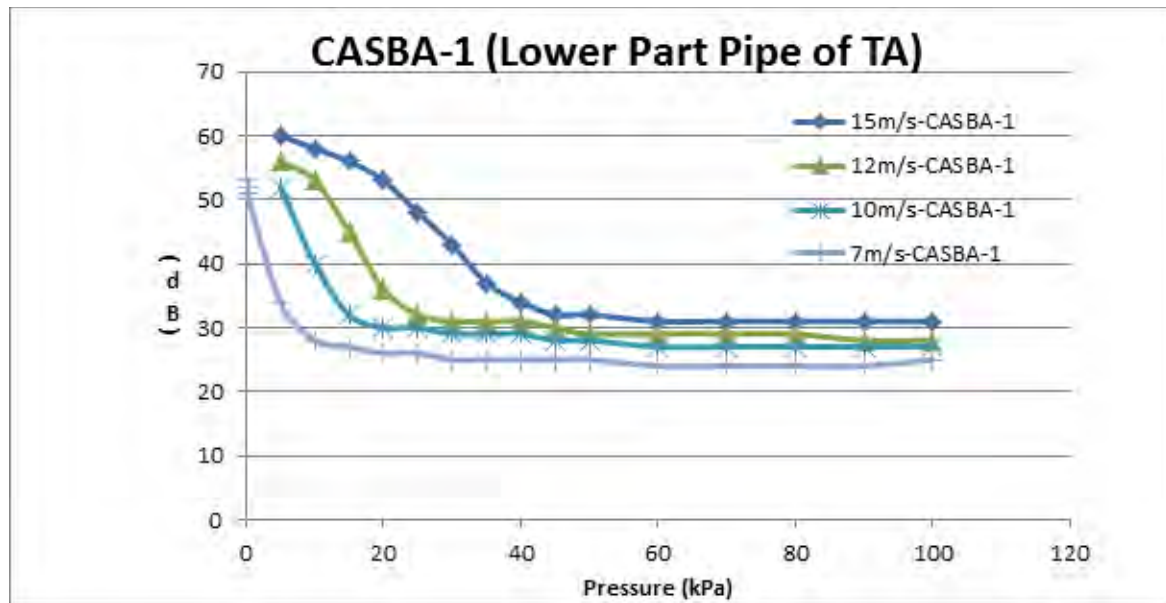


Fig. 12 Signal detected by the CASBA 1 sensor

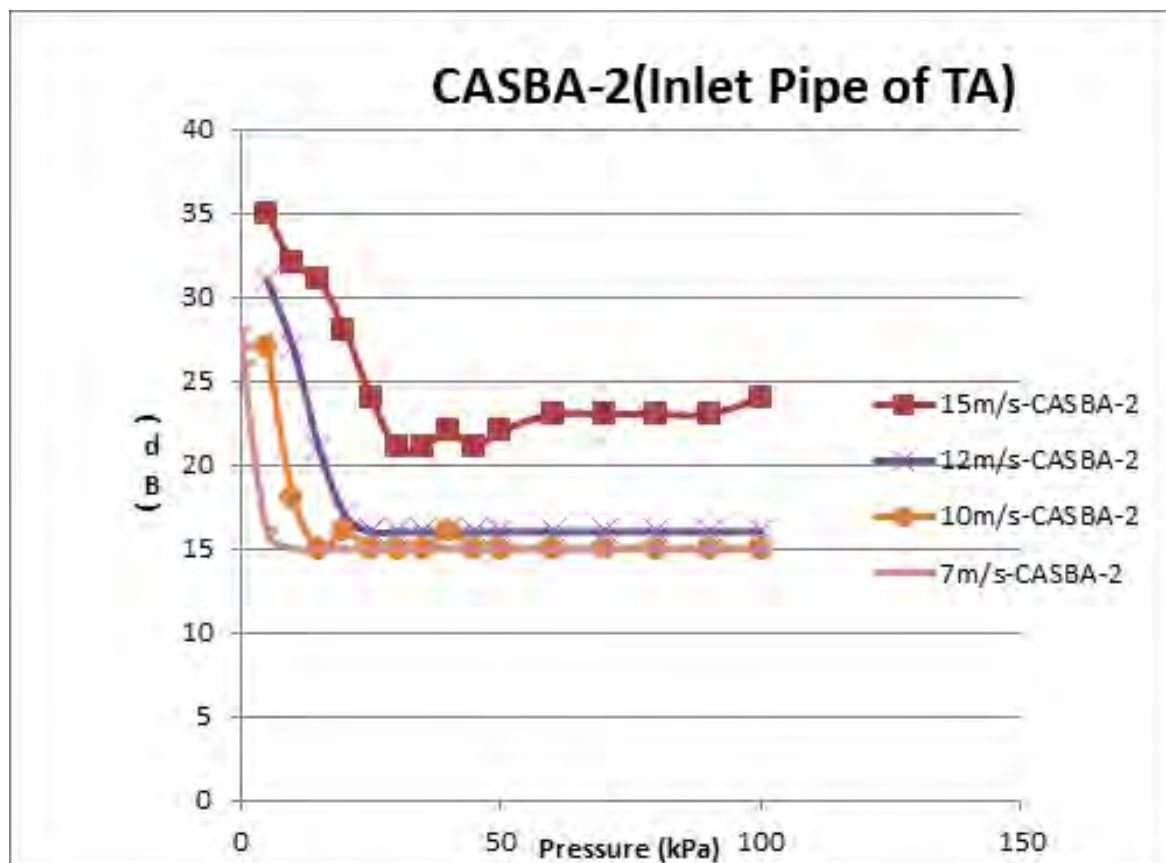


Fig. 13 Signal detected by the CASBA 2 sensor

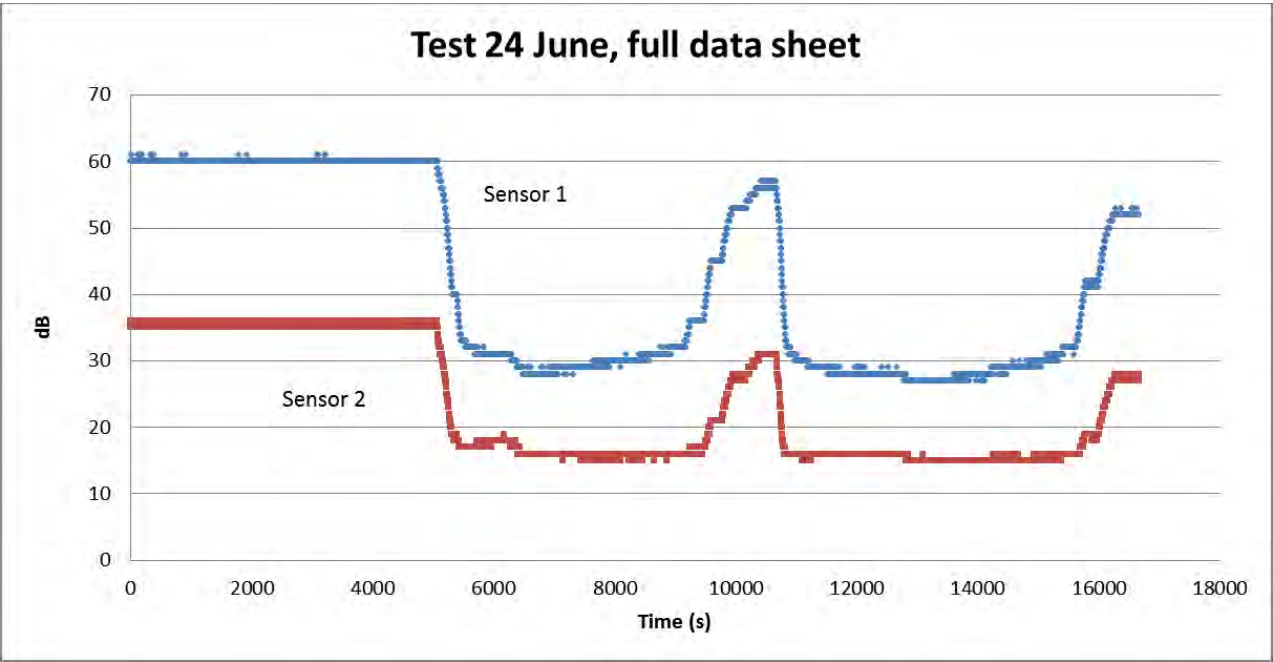


Figure 14: Full data sheet of the experiment

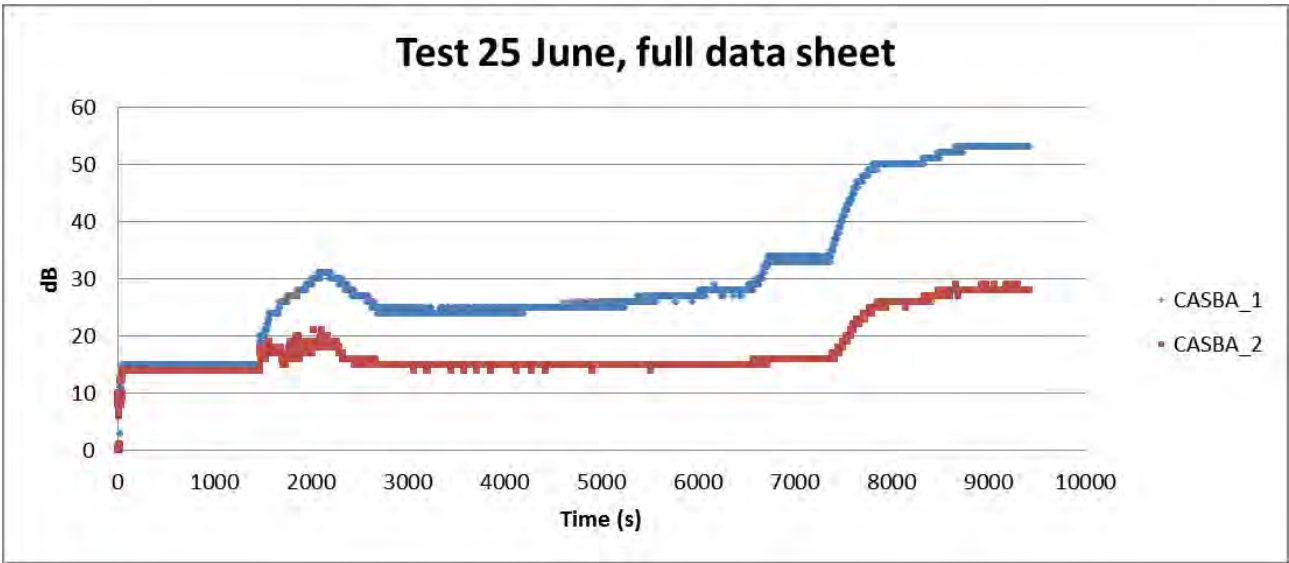


Figure 15: Full data sheet of the experiment

Tab. 3: resume of the different operational parameters tested during the second experimental campaign

Date	Time [h:m:s]	Flow [l/m]	Speed [m/s]	Pressure [Pa]	Note
24-June	9.15	0	0	170000	Start pressure reduction to 100KPa
	9.24			100000	100KPa achieved
	9.27				EMP -ON (Voltage is increased)
	9.30				Start Li Circulation in the TA
	9.33	900	6	100000	During the transition 0-900 l/min the signal increases of about 8 dB on the Casba1 (pos 3)
	9.37	1050	7	100000	Variation of signal: Casba1=23; Casba2= 18
	9.39	1200	8	100000	
	9.40	1350	9	100000	
	9.41	1500	10	100000	
	9.42	1650	11	100000	
	9.43	1800	12	100000	
	9.44	1950	13	100000	
	9.45	2100	14	100000	
	9.46	2250	15	100000	Variation of signal: Casba1=31 dB Casba2=24 dB
	9.52	2250	15	100000	Pressure reduction starts(10 Kpa each step)
	9.55	2250	15	90000	no cavitation
	9.59	2250	15	80000	no cavitation
	10.02	2250	15	70000	no cavitation
	10.07	2250	15	60000	no cavitation
	10.12	2250	15	50000	Casba1= 32; Casba2=21
	10.20	2250	15	45000	
	10.27	2250	15	40000	
	10.32	2250	15	35000	
	11.03	2250	15	30000	
	11.08	2250	15	25000	Casba1=49 dB; Casba2=24 dB
	11.15	2250	15	20000	Casba1=52 dB
	11.26	2250	15	15000	Casba1=56 dB
	11.32	2250	15	10000	Casba1=58 dB Casba2=57 dB
	11.42	2250	15	5000	Casba1=60 dB; Casba2= 35/36 dB
	11.45				Stop acquisition
	13.25	2250	15	100000	Start to increase the pressure from 5KPa to 100KPa
	13.45	2100	14	100000	Start to decrease the speed
	13.47	2050	13	100000	
	13.48	1800	12	100000	
	13.53	1800	12	90000	speed is kept constant up to 5 Kpa

	13.56	1800	12	80000	
	13.58	1800	12	70000	
	14.03	1800	12	60000	
	14.08	1800	12	50000	
	14.12	1800	12	45000	
	14.16	1800	12	40000	
	14.21	1800	12	35000	
	14.25	1800	12	30000	
	14.30	1800	12	25000	
	14.34	1800	12	20000	Cavitation test started
	14.40	1800	12	15000	
	14.46	1800	12	10000	
	14.54	1800	12	5000	
	15.30	1800	12	100000	Start speed decrease.
	15.35	1500	10	100000	10 m/s achieved
	15.36	1500	10	100000	
	15.39	1500	10	90000	
	15.41	1500	10	80000	
	15.43	1500	10	70000	
	15.47	1500	10	60000	
	15.52	1500	10	50000	
	16.00	1500	10	40000	AVG counts set to 16
	16.03	1500	10	30000	
	16.08	1500	10	25000	
	16.13	1500	10	20000	
	16.17	1500	10	15000	
	16.23	1500	10	10000	AVG counts set to 32
	16.31	1500	10	5000	
25-June	9.00				Casba system Switched on
	9.23	0	7	100000	Li circulation starts
	9.34	2250	15	100000	15 m/s -100 Kpa are Achieved
	9.44	1050	7	100000	Lithium flow is reduced to 7 m/s
	9.46	1050	7	100000	Start the cavitation test
	9.51	1050	7	90000	AVG Count set to 16.
	9.53	1050	7	80000	
	9.55	1050	7	70000	
	10.00	1050	7	60000	
	10.05	1050	7	50000	
	10.09	1050	7	40000	
	10.15	1050	7	30000	
	10.22	1050	7	25000	
	10.27	1050	7	20000	

	10.33	1050	7	15000	
	10.40	1050	7	10000	
	10.50	1050	7	5000	
	11.11	1050	7	400	
	11.26	1050	7	100	

Comparing the operational data in tab. 3 with the curve in fig. 15, while the difference between sensors signal is more or less constant, even at 7m/s, decreasing the pressure below 10000 Pa this difference sudden increases. It should be said that this 'divergence' of sensor 2 is due to cavitation. Also in this case the operational conditions in which this phenomenon occurs are very far from the usual operational parameters of the loop.

4 Discussion of the experimental results

A few general considerations about the electrical environment:

- oscilloscope traces (time domain and frequency domain) show very clean signals with very low background noise;
- no spurious electrical disturbance have been detected
- considering the presence of a big, two stages, electromagnetic (induction type) pump, electrical ground has been carefully designed and realized; all the possible electromagnetic compatibility countermeasures have been correctly implemented.

During the first experimental campaign, the signal from the CASBA #2 (EMP-1 inlet) is steady and very quiet in all the phases of both experiment, therefore NO CAVITATION in proximity of the EMP-1 electromagnetic pump inlet has been detected.

The signal from the CASBA #1 (T.A.) is more complex:

- during the steady state phases the signal is constant; the measured noise power is just "normal plant/fluid noise" or cavitation noise from zones relatively far (more than 1 meter) from the position of the sensor;
- during the ramp-up and the ramp down phases, experiments shown critical speed (at low regime) where the plant noise is very significant (+50 dB)
- the source IS NOT a cavitation phenomenon because, when the flow is increased, the noise disappear. With high level (+50dB) plant noise, in case of cavitation, the noise MUST increase if the flow increase (this one of the reasons because the CASBA has a 100 dB scale).

The conclusions are:

- NO CAVITATION in proximity of the T.A. (CASBA sensor #1);
- Possible cavitation in the 1-5 m range from the sensor #1.

Starting from the results of the first experimental campaign, the test matrix of the second one was defined. The main difference is in the position of the first sensor, placed at the TA Assembly outlet. In this position, or very close to it, it was expected the insurgence of cavitation on the basis of some tests post analysis on the outlet pipe of the target. The results of the CASBA campaign confirmed this starting assumption, but only in extreme conditions:

- very low pressure (well below 10 KPa);
- very low velocity (7 m/s).

In this operational range cavitation occurs very close to the sensor position. This is also indirect validation of the first experimental campaign, in which the presence of cavitation was hypotised at about 1-5 meters form the sensor.

5 Conclusions

Results coming from the CASBA experiment on the ELTI loop in Arai demonstrated the high quality and reliability of this system. The observation of the possible occurrence of cavitation close to the TA outlet confirmed that this phenomenon should be possible cause of the erosion observed on the TA outlet during the refurbishment of the loop.

6 References

1. G. Dell'Orco, E. Rapezzi, "Cavitation occurrence experiment at Osaka University lithium facility", ENEA Report IM-G-R004 (2004).
2. G. Dell'Orco, A. Tincani, "Final Report on theoretical study on the conditions for cavitations generation in various parts of the IFMIF Li-loop", ENEA Report IM-G-R007 (2005).