Agenzia nazionale per le nuove tecnologie,
l'energia e lo sviluppo economico sostenibile

Ministero dello Sviluppo Economico

Realizzazione e qualifica dell'impianto sperimentale per prove di corrosione/erosione in litio (LIFUS6)

A. Tincani, A. Aiello, S. Mannori, C. Lenzi, G. Fasano, M. Muzzarelli

Report RdS/2013/124

REALIZZAZIONE E QUALIFICA DELL'IMPIANTO SPERIMENTALE PER PROVE DI CORROSIONE/EROSIONE IN LITIO (LIFUS6)

A. Tincani, A. Aiello, S. Mannori, C. Lenzi, G. Fasano, M. Muzzarelli

Settembre 2013

Report Ricerca di Sistema Elettrico

Accordo di Programma Ministero dello Sviluppo Economico - ENEA
Piano Annuale di Realizzazione 2012
Area: Produzione di energia elettrica e protezione dell'ambiente
Progetto: Attività di fisica della fusione complementari a ITER
Obiettivo: *b.2 Campagne sperimentali a breve-medio termine (2000/4000 ore) per corrosione/erosione da litio*
Responsabile del Progetto: Ing. Aldo Pizzuto, ENEA

Indice

Indice delle figure

Sommario

Il presente rapporto descrive le principali modifiche intervenute nella realizzazione dell'impianto sperimentale a Litio fluente Lifus 6, descritto in [1], nel corso dell'ultimo anno.
In particolare è stata ottimizzata l'idraulica del sistema attraverso l'installazione di una nuova pompa elettromagnetica appositamente realizzata e perfezionato il sistema di purificazione e campionamento mediante la realizzazione di una nuova trappola calda con un sistema dedicato di prelievo del litio.
Tali modifiche miglioreranno l'affidabilità del sistema e la sua sicurezza, garantendo una più elevata qualità della sperimentazione.

1 INTRODUCTION AND ACTIVITY OBJECTIVES

In the framework of the Broader Approach Agreement and the EVEDA/IFMIF Project, ENEA CR Brasimone was in charge by F4E to carry the Procurement Arrangements (PAs) LF03 and LF04 EU.
The goals of these PAs are respectively:
1. to measure the erosion and corrosion rates of selected materials in relevant conditions, with the aim to provide evidence that these values can be achieved with the materials and operating conditions selected. In fact the investigation of a possible subsequent corrosion/ erosion effect is of importance for the EVEDA phase in order to assess the lifetime of the exposed target components; in particular of the nozzle and the back plate. Local shape modifications due to erosion/corrosion could give rise to flow instabilities leading to uncontrolled Li film thickness or massive spills, leading to a beam trip off and stop of IFMIF's operation.
2. to experimentally validate the purification systems foreseen for trapping the non-metals impurities (nitrogen, oxygen, carbon and the hydrogen) from liquid lithium.

For this purpose, ENEA has designed and constructed a new lithium facility to test both specimens of RAFM steels (Eurofer 97 and F82H) under EVEDA conditions (liquid lithium at high velocity 15 m/s and temperature of 350°C) and after the action of the liquid lithium purification systems.
The construction and the acceptance tests of the Lifus6 facility have been carried out between the end of 2012 and first half of 2013. In particular, at the end of 2012 the Ferretti Firm, contracted by ENEA to build the facility, has realized and installed at ENEA CR Brasimone the main loop of lifus6.
Moreover at the beginning of 2013, ENEA has issued the furthers contracts/orders for the procurement of: a new EM pump (by SaaS); two Fans for the two air-coolers; additional Heating cables; mechanical modification of Lifus6 and installation of new EM Pump; a Micro Turbine MF40; a new R- Meter; two lithium level gauge; Swagelok valves for the hot trap sampler and filters.
The procurement of Software and Hardware components for the control and acquisition system of the loop was completed.
In the meanwhile, ENEA has realized the lithium leak sensors for valves and main components of the loop and made compliant to Fire Protection rules the experimental hall in which the loop will be installed.

2 DESCRIPTION OF THE LIFUS6 FACILITY

The constructed facility is basically constituted by three parts: the main loop, devoted to corrosion tests and compatibility studies between RAFM steels and high temperature flowing Lithium; the secondary loop, aimed at the cold purification of the liquid metal from non-metals impurities (carbon, oxygen and hydrogen) and an hot trap (a tank filled with titanium sponge) with the purpose to remove as much as possible the nitrogen in liquid lithium. A 3D view of the main loop is shown in Figure 1.The P&ID of Lifus 6 is shown in Figure 2.
The Lifus 6 facility, in its operational configuration appears as a ring installed on a steel frame. The facility is not accessible during the operational phases. According to Figure 1, the Lithium flow at the pump outlet is divided in two parts. The main flow is driven to the test section and come back to the pump. A limited flow, about 1% of the total flow, enters in the dedicated purification loop, where it passes through the Cold Trap (operated at 200°C) to be continuously purified, essentially from carbon and oxygen.

Table 1 - Lifus 6 facility main parameters

Requirement	Main loop	Secondary loop (cold trap)	Hot trap	Unit
Processed fluid	Lithium	Lithium	Lithium	
Design pressure	0.4	0.4	0.4	MPa
Design temperature	400	400	750	°C
Operational pressure	0.12	0.12	0.12	MPa
Operational flow rate	28	0.3	stagnant	l/min
Max Operational Temperature	350	350	650	°C
Air Cooler power	3	2	-	kW

The main loop is constituted by:

- a drain/storage tank mounted on mobile supports to compensate the thermal expansion of the pipes. It is complete of electric tracing, thermocouples for regulation, safety and measure of the wall temperature, nozzles for connection to the piping. In normal operation the storage lithium is maintained melted at about 300°C;
- an electromagnetic pump;
- an air cooler of 3kW,
- two flow meters: the first one is a Vortex volumetric type, calibrated for a minimum flow velocity of 0.08 m/s and maximum 2.7 m/s corresponding to 0.40 – 5.4 m3/h; the second one is a Coriolis mass flow meter, with a range of 0-4000 kg/h of liquid metal;
- a Test section, in which the liquid metal reaches the foreseen testing conditions of velocity.

The secondary loop is mainly constituted by:

- a micro-turbine flow meter;
- a resistivity meter;
- an air cooler 1.64;
- a cold trap.

The dedicate tank for the nitrogen trapping mainly constituted by:

- a flanged tank;
- a filtering sieve;
- a dedicate Lithium sampler.

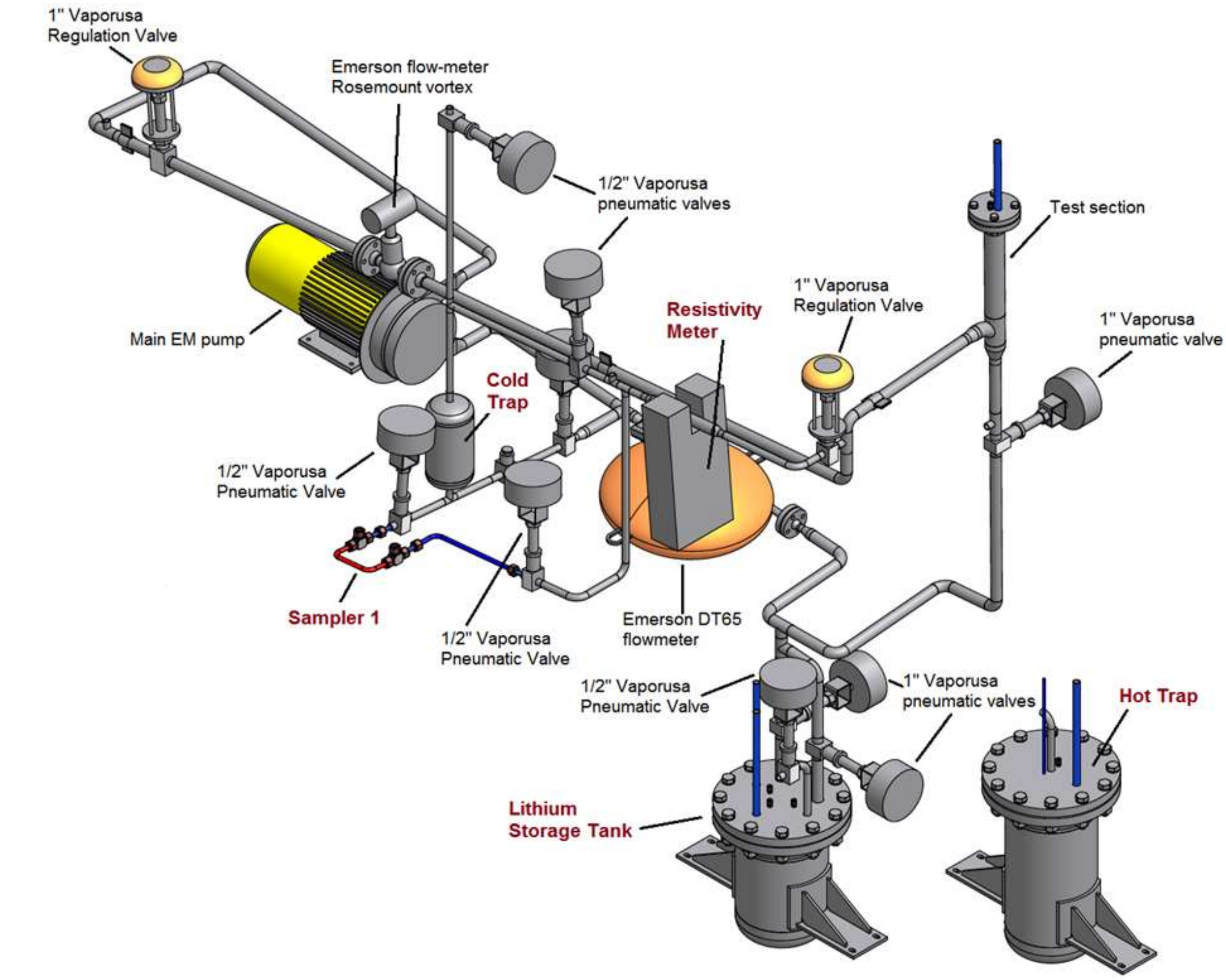

Figure 1 - Lifus 6 main loop 3D configuration

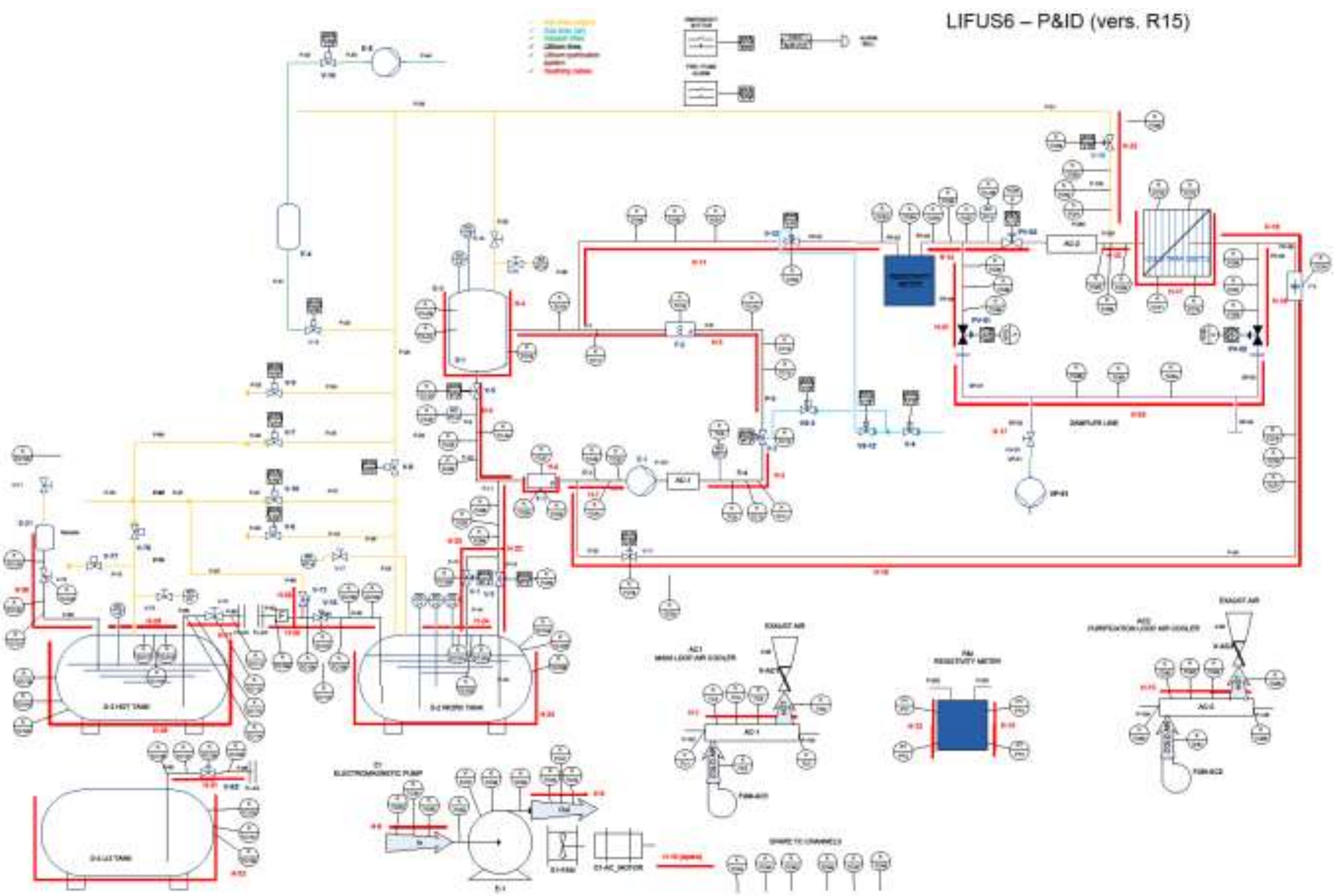

Figure 2 - P&ID of Lifus 6

3 DESCRIPTION OF THE MAIN INSTALLED COMPONENTS

3.1 EM Pump

The SaaS electromagnetic pump installed in to the main loop of the LiFus6 Facility is able to supply the volumetric flow rate of lithium of about 30 l/min necessary to have 15m/s in the test section for the erosion/corrosion tests with a minimum pressure head of at least 0.22 MPa in order to overcome the pressure drop of the loop (see, the loop theoretical hydraulic characteristic in Figure 3).

The electromagnetic pump geometry has to guarantee that the loop (including the pump) will be always drainable by gravity.

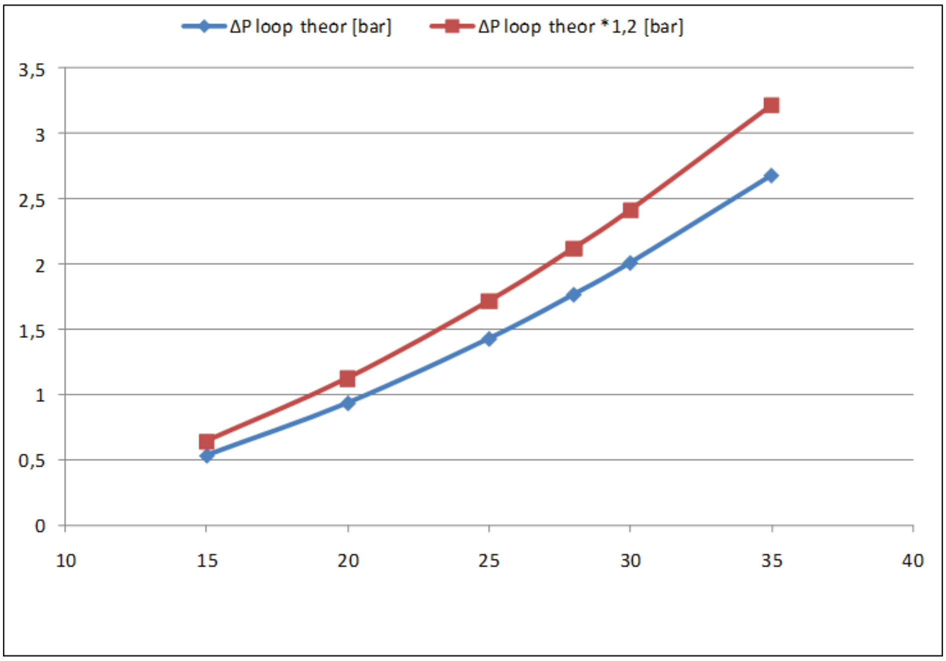

Figure 3 - Theoretical hydraulic characteristic of the selected pump

For the pump installation in to the lithium loop the following dimensional constrains must have been considered: maximum vertical dimension 300 mm and maximum horizontal dimension 400 mm. The inlet and outlet tubes are made by a 1 inch. sch. 40S circular pipe and they are connected to the piping of the circuit by TIG weldings (see Figure 4).

The EM pump is instrumented with four temperature sensors (type K thermocouples) and it is controlled by an inverter with control unit.

Figure 4 - installation of the pump and final configuration

3.2 The lithium/air Heat exchanger

The new pump requires 3kW of electrical power in operation and it is characterized by 60% of efficiency. In order to remove from the plant the heat inevitably released to the fluid and to carry out an accurate temperature control, an air cooler has been installed downstream of the pump. The air cooler has a tube in tube configuration; the air and lithium are in counter current (Figure 5).

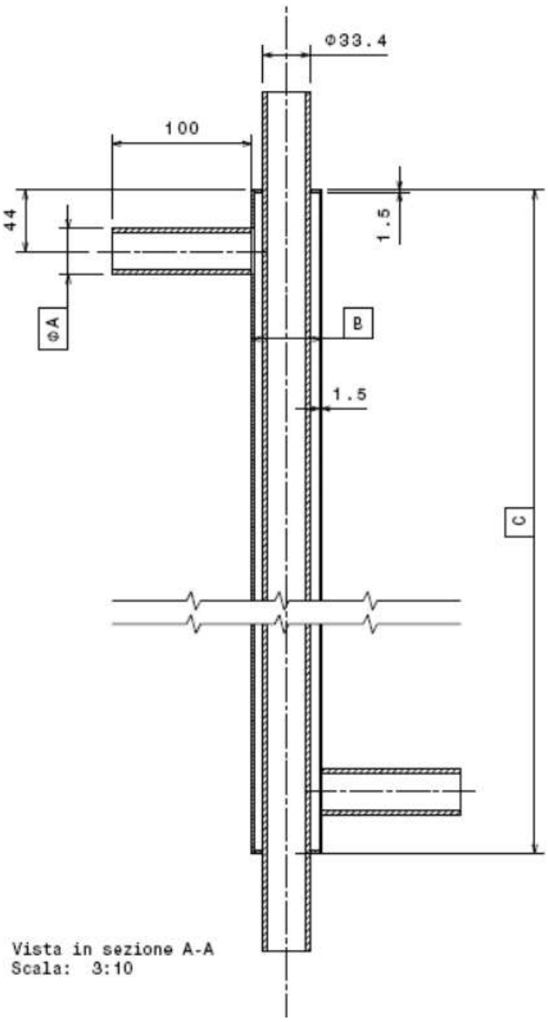

Figure 5 - design of the lithium/air heat exchanger

3.3 The test section

For what concerns the test section, a picture of this is shown in Figure 6. The specimens have a cylindrical shape and are mounted on a rod fixed in the upper part to a removable centering plate, and supported on top and bottom of specimens' assembly with centering systems. The centering plate is completely uncoupled with respect to the upper flange, to maintain the possibility to easily remove the upper flange and to use an extraction system to remove the specimen assembly, which will be surely stuck due to the presence of lithium.
With this solution it is realized a meatus in which the lithium flows at the design speed of at least 15 m/s. The triple anchoring of the support rod prevents the occurrence of vibrations in turbulent flow conditions. The outer diameter of the specimens is 20 mm, with a central hole of 8 mm, for the rod, and a height of 8

mm. The channel that hosts them has a diameter of 21 mm, with an external diameter corresponding to the one of a 1" standard pipe. The upper part of the test section, for a height of about 300 mm, is filled with Ar, in order to prevent any contact between the lithium and the sealing area of the flange. The pressure during operation will be about 2 bar, to compensate the pump head at test section inlet maintaining a constant level of lithium also during the startup of the pump. A double-level sensor is installed in the test section to control any accidental level climbs. The samples can be extracted by draining the system, opening the flange while maintaining the circuit in an inert atmosphere and removing the rod sample holder. This procedure ensures a limited contamination of the circuit and the maximum safety for the operators, reducing downtime for the replacement operations.
There is the possibility that lithium will reach the sealing area. That is the reason why the use of spiral wound sealing was preferred to ring joint, giving a higher guarantee on the clearness of the sealing area.
The connection with the circuit piping at inlet is made with a saddle-shaped coupling with 2” diameter to reduce the fluid velocity and the turbulence in the upper part of the test section about 5 cm of lithium are foreseen upper the joining to realize as much as possible calm fluid conditions and static free surface. This is necessary to avoid the transport of gas bubbles that should promote specimens erosions and pump cavitation.
The gas volume will act also as expansion tank in case of thermal expansion of lithium increasing the temperature or when launching the pump.

Figure 6 - test section

3.4 Lithium storage tank

The Lithium storage tank is the component in which the liquid metal will be charged/drained to/from the main Lifus 6 loop. It is electrical traced, thermocouples for regulation, safety and measure of the wall temperature, nozzles for connection to the piping and three lithium level sensors.
In normal operation the storage lithium is maintained melted at about 300°C.
The material of the storage tank is AISI 316.

3.5 Cold trap

The cold trap, (shown in Figure 7) is mainly constituted by a 5” schedule 40 trap body with an empty volume of 3l; 64 filtering sheets; 64 spacer rings and a holed disc. The entire cold trap is made by AISI 316.

Figure 7 - cold trap assembly

3.6 R-Meter

A new Resistivity Meter has been constructed, based on the design parameters provided by the University of Nottingham. This new RM, being not contaminated by the alkaline metal, will permit to evaluate at the initial stage the electric resistance of the empty steel capillary alone and to extract it from the total measured resistance, when filled by Lithium during later stages.

A minor modification has been introduced in the new RM: the connection points of the electrical leads to the plates are shifted in the geometrical center of each plate, in order to enhance the symmetry of the circuit and make the two segments of the capillary geometrically equivalent. In the following Figure 8 is shown the new RM installed.

Figure 8 - R-meter installation on the purification branch

3.7 Sampler of purification loop

The lithium sampler employed for taking some Lithium from the plant is constituted by an U-tube pipe, characterized by an inner volume of about 25 mL, connected through *Swagelok* joints to a small auxiliary circuit working in parallel with the purification line and filled by Lithium only at the time of sampling.

3.8 Air cooler

In order to lower Lithium temperature along the auxiliary purification line, so to make it reach the required optimal Cold Trap Temperature (200°C), an air cooler (1.64kW) has been conceived. This additional component has been inserted to have an active control of Lithium cooling and not based only on the dimensioning of the pipe, on the heating wires and on the insulating material around the pipe. The air cooler has a tube in tube configuration, the air and lithium are in counter current.

3.9 Hot trap

The Hot Trap is constituted mainly by a flanged vessel with an inner volume of about 30 L, a narrow grid steel structure that will be filled with the Titanium sponge getter, allowing an easy removal of the whole getter as a unique element. The material of construction (AISI 321) allows operating the purification at 650°C. Rising the Temperature, it is possible to enhance the kinetic mechanism responsible for the adsorption of Nitrogen from Lithium solution and to reduce the time required for the purification.
A picture of the hot trap is reported in Figure 9.
Moreover, the Hot Trap is linked directly to the a sampler for Li offline analysis.
The hot trap is also equipped with the lithium sampler.

Figure 9 - hot trap assembly

3.10 Instrumentation

The instrumentation system consists mainly of:

- Standard type K thermocouples, mounted on pipes surface;
- Vortex Flowmeter Rosemount Model 8800, Scale 0.08 - 2.7 m/s;
- Mass Flow Meter Coriolis type Micro Motion DT 65, scale 0-4000 kg/h
- Three Liquid metal pressure gauges Gefran IE2-S-6-M-B01D-4-4-D-0-0, piezoelectric type, scale 0-10 bar;
- Conductive level sensors in the storage tank, test section and hot trap;
- Micro-turbine flow meter for the purification loop;
- Lithium leak sensors.

Instruments have been selected to be safe and suitable for use in lithium, at temperatures up to 350 ° C, and are provided with analog or Modbus type output, obviously excluding the thermocouples, or digital output.

3.11 Control and Acquisition System of Lifus6

The control system is based on National Instruments products. In particular for the PLC have been selected modules of the family CompactRIO able to guarantee the required performances.
The CompactRIO system is comparable to the market standard Siemens S7 on small systems such Lifus6, in which it is requested the management of a limited number of points. It has a greater ease of use being able to be fully programmed by NI LabView Real Time.
The loop will be remote controlled connecting the PLC via a standard TCP-IP address. Moreover, as happens on all PLC systems, in case of loss of network connection the system will maintain the last safe configuration set with a full management of abnormal situations and alarm.
The accurateness of the control system will be verified performing a series of tests in water, to determine the time of response of the pump/test section/ flow meter system.
After the IDR the Control and Acquisition System of the loop has been strongly reviewed and implemented, in order to be able to control the new EMP and also the fans of the two air-coolers.

3.12 Safety System of the experimental hall

To prevent injuries to personnel due to lithium leaks several safety measures have been adopted:

1. The experimental hall is completely isolated with safety doors during loop operations. The presence of personnel is not foreseen when the lithium is circulating, and the loop is remotely controlled.
2. A smoke reveal system can fast identify the gaseous products of a reaction between lithium and environment.
3. Pipes are protected with a leak detection system based on the use of electrical contacts.
4. Valves are protected with a leak detection system.
5. Steel tanks are installed under the loop to avoid contact between lithium and concrete.

ENEA has also contacted an Italian firm for the design and realization of fire extinguishers system.

4 LIFUS6 ACCEPTANCE TESTS AND GUARANTEE

All the supply has been submitted to a quality assurance follow up and to these final acceptance tests performed at ENEA CR Brasimone on the LiFus6 facility:

- Visual inspection of the component to verify the integrity after the shipment;
- Electrical tests;
- An hydraulic test;
- An helium test;
- Working check of the installed instrumentation.

All the external procurements will be guaranteed for a period of 24 months maximum starting from the Final Acceptance Tests.

5 LIFUS 6 BLANK TESTS AND COMMISSIONING PLAN

In this part of the report is described the commissioning of the LIFUS3 experimental plant.
The main scopes of the commissioning are:

I. Tests of DACS functionalities: the data acquisition and control system shall be tested at each interlock subsystem level with dummy signal, monitoring and data acquisition subsystem on flow rate, temperature, pressure and valves operations.
II. Tests of the main loop: the performance of the main lithium loop shall be measured testing the evolution of normal operation from start-up to shutdown, the flow control in the main loop and the emergency lithium drain. The operation shall have a flexibility to allow a reasonable variation of the parameters.
III. Tests of the diagnostics and purification systems: performance of the resistivity meter and purification systems shall be measured
IV. Integration test: the integration test shall be done operating the whole system of the lithium loop to check safety operation.

After the completion test by the local fire department which permits operation of the loop, the tests of the main loop and the purification loop will be conducted.
In advance to the tests of the loop, the control system is tested with dummy signal (preliminary blank tests) and inspected on site.
Tests of the diagnostics and purification systems shall be defined in each commissioning or validation program.
The commissioning is organized in the following (strictly) sequential phases:

I. Initial conditions,
II. Blank tests;
III. Burning up;
IV. Lithium loading.

5.1 Initial (plant) conditions

LIFUS6 experimental plant fully assembled (mechanical, electrical cabinet, sensors and actuators operatives); lithium sampling systems fully installed and operatives; thermal insulation completed; S-3 Hot Tank connected with S-2 Work Tank via FL-2/FL-1 flanges; DACS (Data Acquisition and Control System) operative with (at least) basic software; internal piping previously cleaned with water; internal piping at ambient temperature (15-20 °C), filled with atmospheric air (20% oxygen, 80% nitrogen); compressed air for pneumatic valve available (main manual valve initially closed), Argon available (main manual valve initially closed); automatic fire detection and suppression system fully operative (disarmed in all the phases where the liquid lithium is still solid in S-4 Lifus3 storage tank).

5.2 Blank tests

Preliminary blank test: plant in initial conditions, electrical apparatus fully powered, DACS operative.

- Individual test of heating systems from H1 to H30; set an end point temperature 10°C higher than the initial temperature; power on the heating system; verify the correct readings of all the temperature sensor; wait until thermal equilibrium
- Special procedure for H31 and H32 (the heating systems of the S-4 Lifus3 storage tank)
- Individual test of the two cooling system
- Test of the compressed air distribution system
- Test of the Argon distribution system
- Individual test of all the gas pressure gauges (air, argon and lithium loops filled with Argon)
- Individual test of all flow meters (readings should be near to zero)
- Individual test of all the electromagnetic valves (air)
- Individual test of all the electromagnetic valves (Argon)
- Individual test of all the on/off pneumatic valves
- Individual test of all the pneumatic proportional valves
- Test of the vacuum subsystems
- Test of the resistivity meter electromagnetic pump
- Test of the resistivity meter nano ohm meter
- Individual test of all the lithium leakage sensors
- Simple start/stop and self-heating capability of E-1 main electromagnetic pump; check self-heating capability up to 250 °C max; check the E1-AC FAN (for E1 motor cooling) and the E1-FAN (for permanent magnet emergency cooling).
- Test of the manual emergency button
- Test of the external alarm inputs

5.3 Burning up tests

At least three complete thermal cycles required to “cook” the plant and test the heating/cooling systems with real operating conditions .

5.4 Lithium loading

Critical sections:

- Vacuuming at room temperature;
- Baking and vacuuming;
- Confirmation of attained vacuum and time;
- S4 Lifus3 storage tank heating (lithium fusion);
- First lithium loading;
- First lithium circulation;
- Instruments calibration (pressure and flow);
- Primary loop tests;
- Target assembly tests;
- Secondary loop tests (purification, including resistivity meter, AC-2 air cooler and cold trap operations);
- First continuous 24h operations;
- First 7 days continuous operations.

6 Conclusions

A strong design review was performed on the loop at the beginning of 2013. This caused the introduction of some design modifications, and the substitution of a critical component like the pump.
The loop is being completed and the experimental activities are expected to start in January 2014.

7 References

1. A. Aiello, A. Tincani, P. Favuzza, F.S. Nitti, L. Sansone, G. Micciché, M. Muzzarelli, G. Fasano, P. Agostini, Lifus (lithium for fusion) 6 loop design and construction, in press on Fusion Engineering adn Design