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Testbed for the Pellet Launching System for JT-60SA

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A B S T R A C T

As part of the European contribution to the large size superconducting tokamak project JT-60SA, a new Pellet Launching System (PLS) is designed and built. The aims of the PLS are to provide efficient fuelling to the plasma and to control and mitigate Edge Localised Modes (ELMs). Two pellet sources, one for fuelling pellets, one for pacing pellets, are delivering pellets to a centrifuge launcher. The centrifuge enables precise launch of pellets according to already proven control schemes. Furthermore, this system opens a way towards a test bed for the EU-DEMO fuelling system. The new PLS has to be completed and commissioned first at the IPP Garching pellet lab and then to be shipped to QST Naka site after having demonstrated its performance. This dedicated test bed has been set up, providing suitable vacuum conditions to operate the PLS in similar conditions (except magnetic field and radiation). Maximum hydrogen throughput is about 400 mbar·L/s per pellet source. Safety issues must be considered for hydrogen inventory of pellet sources (~100 bar·L each). In a first step, the pellet sources will be put on a test vessel providing inherent safety by a huge volume (10 m^3) which makes sure that the hydrogen concentration is below 1% under all circumstances. A hydrogen safety survey prior to assembly confirmed the concept to be followed by an assessment after the installation in order to get the required license for operation. The PLS as a whole, for the time being equipped with two pellet sources, is to be certified according to explosion prevention rules (ATEX) as a product to be shipped to Naka site. To obtain this, an appropriate declaration of explosion zones inside the vacuum system and the use of suitable and certified equipment is mandatory. Such, the integration of this system can be planned and assessed on a clear technical and regulatory basis.

1. Introduction

The Pellet Launching System (PLS) for JT60-SA is part of the Broader Approach enhancement program and first of its kind [1]. The procurement is managed by F4E while EUROfusion covers manpower expenses. The conceptual design has been developed with a strong focus on the Research Plan of JT-60SA.

An example design was provided by IPP in order to illustrate the conceptual design and to support the procurement process as well as tasks for space reservation in JT-60SA torus hall.

As part of the step-ladder approach for a pellet fuelling system from ASDEX Upgrade to EU-DEMO, an important function of the new system is to support the development, commissioning and operation of powerful actuators for plasma density control. Hence, the system layout is considering as a multi-source and multi-purpose system. Up to three cryogenic hydrogen pellet sources can be hosted by the centrifuge, equipped with a stop-cylinder. The nature of acceleration (form closure principle) provides high precision independently from the pellet mass [2]. Force transmission (in this case for acceleration of the pellet) by form closure is by nature without any slip, in contrast to a transmission using force closure. In the initial step, the system is equipped with two pellet sources: one for plasma core fuelling and one for ELM pacing purposes [3].

The procurement of components is up to F4E, in particular the two pellet sources (awarded to PELIN) and the centrifuge and diagnostic system which is awarded to SENER.

The MasterPLC (Programmable Logic Control) and the gas valve matrix is in the responsibility of IPP. The MasterPLC integrates the subsystems and provides full control to the PLS. The aim of the gas valve matrix is to connect each pellet source to one of three available gases, e. g. protium, deuterium or any mixture thereof. There is also a strong interest to produce hydrogen pellets with some admixtures of e.g. neon, argon or xenon [4].

The completion as well as the integration of the system is foreseen to take place in the pellet lab at IPP Garching. There, the commissioning of the single pellet sources as a preparation of the integration into the centrifuge as well as the full commissioning of the PLS prior to shipment to Japan takes place.

The following tasks have to be covered by the testbed:

- Host pellet sources one by one.
- Host centrifuge.

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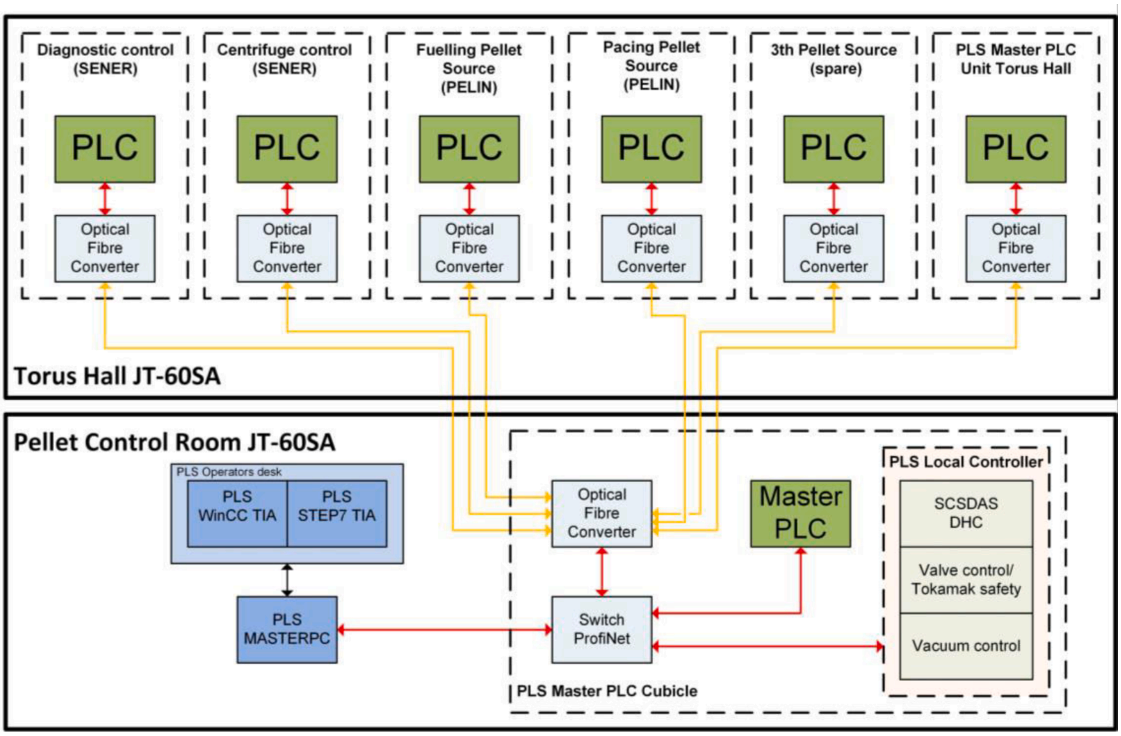

Fig. 1. PLC architecture block diagram. The devices are connected via PROFINET using optical fibres (yellow) in order to provide electrical potential separation. The operators' desk is located in the pellet control room as well as the CPU of the MasterPLC. The interface to JT-60SA control systems DHC (density and heating controller) and SCSDAS (supervisory control system and data acquisition system) provided by the PLS local controller, serving as interface.

- Support integration of pellet sources and centrifuge to the Pellet Launching System (PLS).
- Implement all functions to Master Programmable Logic Control (PLC).
- Make the system operational.
- Address hydrogen safety for the whole system for shipment to Japan.
- Diagnose the pellet integrity and size.

As the testbed is mimicking the QST environment at Naka site, a proper definition of interfaces for discharge control system, mains, water, gas supply, vacuum is essential.

The PLS for JT-60SA is regarded as an important step towards the EU-DEMO fuelling system. Findings are to be considered for the EU-DEMO inner fuel cycle testbed DIPAK-PET, planned to be established at KIT, Germany.

2. Control room / MasterPLC

The testbed has to mimic the conditions at Naka site as close as possible. The Centrifuge and pellet sources are installed in the experimental hall.

The pellet operators' desk with the Human Machine Interface (HMI) using WinCC is located in the pellet control room. Close to this desk is the CPU of the MasterPLC. The connection to the components in the experimental hall is done using optical fibres and the related interface modules. This is in order to mimic the situation at JT-60SA site, where a safe separation from torus hall potential is to be provided.

The subsystems (pellet sources, centrifuge and diagnostics) are controlled by their own PLC, in principle able to run the subsystem in an autonomous way. The PLC of a subsystem is connected via PROFINET field bus (industrial Ethernet) to the MasterPLC (see Fig. 1).

3. Commissioning & hydrogen safety: pellet sources only

The pellet sources are expected to arrive at the laboratory consecutively. In a first step, the pellet source cryostat has to be installed on a dedicated test vessel. Three water cooled cryo-cooler compressors per source are to be installed. The gas supply system is to be connected to the valve matrix. The PLC of the pellet source provides the control of the subsystem.

3.1. Vacuum system

Pellet source operation needs a vacuum containment, for thermal insulation as well as for hydrogen safety. The high vacuum is provided by turbomolecular pumps, mounted on both vessels: test bed and expansion volume. The latter is a vacuum tank with a volume of 10 m^3. All hydrogen mass flow is directed to a collector tube and compressed with one single dry screw pump (Leybold DV650) up to atmospheric pressure.

In a next step, the hydrogen safety must be achieved. In areas with a pressure below 10 mbar during operation, no dangerous atmosphere is considered under undisturbed conditions. Therefore, no explosion prevention zone has to be declared in all areas upstream the valve in front of the screw pump (V-PCollector, see Fig. 2). As a consequence, there are no dedicated requirements regarding hydrogen safety for instrumentation (e.g. vacuum gauges).

The pellet source test vessel is connected to the expansion volume, the 10 m^3. The hydrogen content of one single pellet source is stated to be 100 bar·L at most (fully filled with solid hydrogen). This inventory has to be released across the vacuum system in case of an incident, e.g. loss of electricity followed by loss of cooling power. Hence; the hydrogen concentration cannot exceed a level of 1% considering the expansion vessel volume of 10 m^3. Such a concentration is considered safe. However, hydrogen safety assessment is required according to ATEX rules [5]. For this process, explosion zones are stated: zone 2 for the plumbing upstream the pump and zone 1 for the pump and the exhaust line (see Fig. 2).

The described concept of limited hydrogen concentration relaxes the requirements to determine and monitor process parameters which are

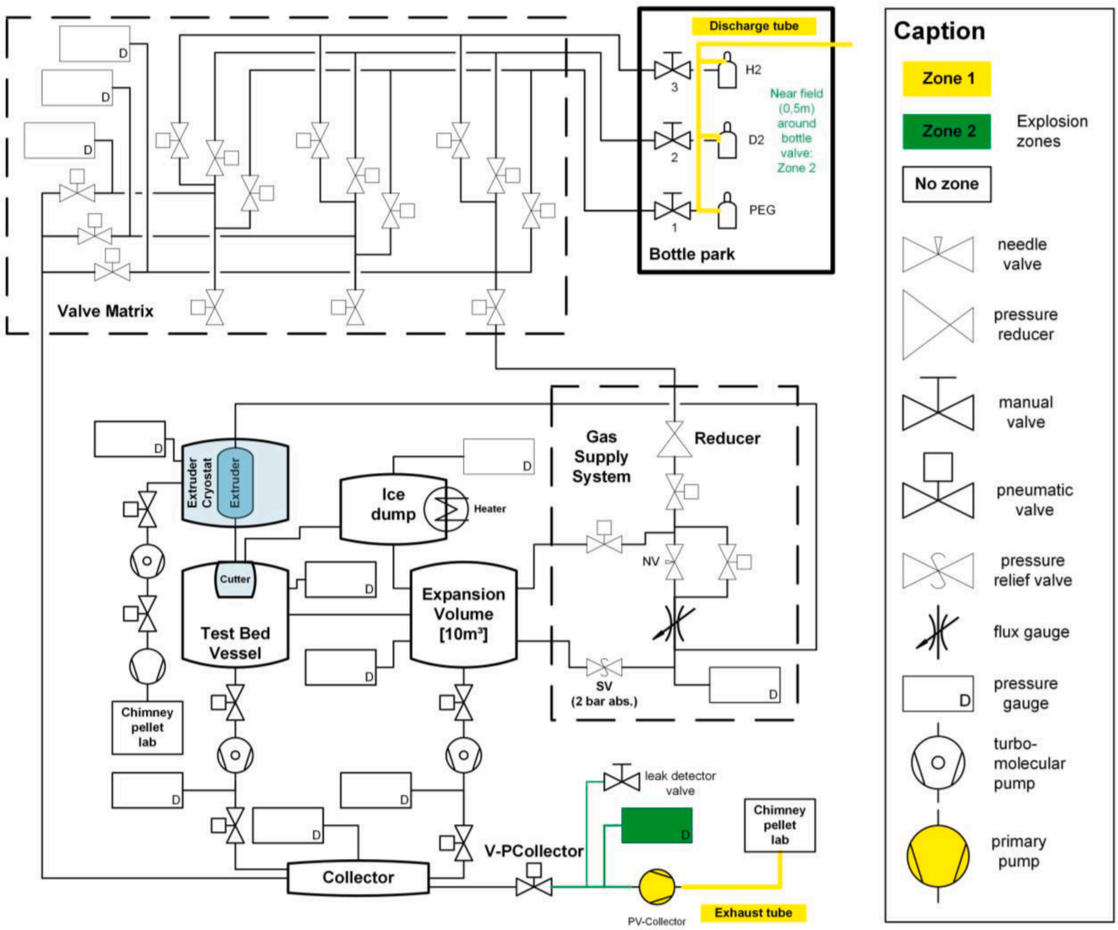

Fig. 2. Block diagram of test bed configuration to host one single pellet source. One channel of the Valve Matrix is used to provide gas to the pellet source gas supply system. The pellet source is mounted on the test bed vessel. Green elements are stated to be zone 2, yellow ones being zone 1.

relevant for hydrogen safety. This is favourable in particular for the initial commissioning phase, where detailed operation conditions are not yet settled.

3.2. Commissioning

The commissioning of the pellet sources will be the next step. Its aim is to learn how to run the sources in a way, that pellets are produced with the required quality, quantity and repetition rate. Special attention has to be put on the time jitter of the pellet production in view of delivery them to the stop cylinder of the centrifuge.

The pellet sources are to be integrated into the MasterPLC. All relevant parameters must be accessible by the operators' desk HMI of the MasterPLC.

The final acceptance of the pellet source is performed by delivering pellets triggered by the MasterPLC. This trigger is basing on a signal which is mimicking the centrifuge synchronisation signal.

4. Commissioning & hydrogen safety: Pellet Launching System

The subsequent step after commissioning of the pellet sources is to integrate them to the centrifuge accelerator. This is envisaged in the pellet lab of IPP Garching. It is very important that the PLS is set up in the test bed completely with all subsystems and similar to the situation in the JT-60SA experimental hall. For this purpose, the IPP pellet lab has to mimic the QST environment at Naka site. Besides the required space, the lab has to provide rough vacuum, gas supply, cooling water as well as electric power. Required electric power is about 150 kW, mainly due to the use of cryocoolers for the pellet sources. Hence, the capacity of the installed water-cooling heat exchanger was expanded to the same level.

4.1. Vacuum system

For full commissioning of the PLS, a robust vacuum system is already available in the lab. It will mimic the QST vacuum system installed at Naka site. The expected maximum hydrogen throughput is 40 Pa·m^3/s per pellet source. This flow is distributed between the ice dump and the buffer tank depending on the duty cycle of the source.

For the commissioning phase of the PLS, the expansion vacuum tank is mimicking the JT-60SA vacuum vessel. The pellets will be fired into this vessel with the according volume buffering the pressure rise due to the evaporated material (See Fig. 3).

4.2. Hydrogen safety

For this system, the concept of limited hydrogen inventory and thus hydrogen concentration is not an option any more. The hydrogen inventory from up to three pellet sources has to be considered.

Therefore, the declaration of explosion prevention zones is mandatory. All equipment installed must meet the according specifications.

In a first step, the hydrogen safety assessment is subject to ATEX rules (European Union), as the system is operated in the IPP Garching lab. This work has to be done as a parallel process with the PLS development and commissioning. Centrifuge design is still in an early stage; hence no result is available yet. The successful finalization of this assessment allows the start of commissioning with hydrogen.

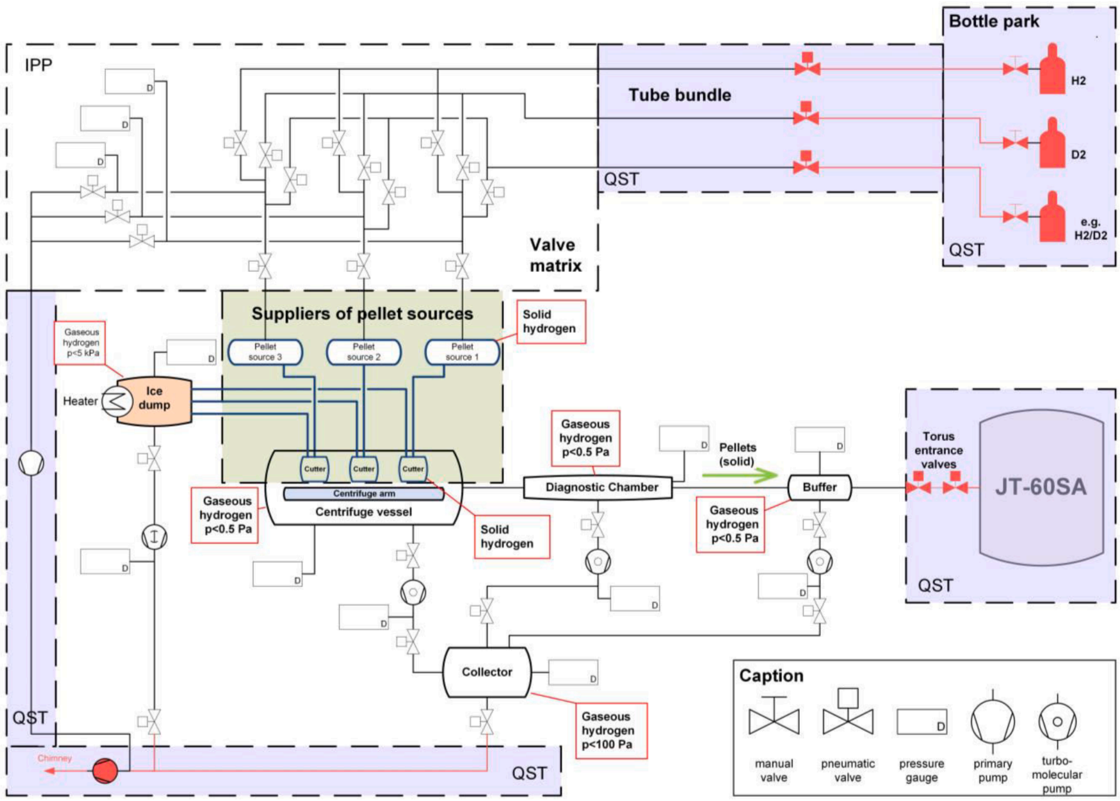

Fig. 3. Block diagram of PLS in testbed at IPP Garching. The system is displayed with the three maximum possible pellet sources (initial delivery will be only two of them). The boxes labelled with "QST" are expected to be provided at Naka site under responsibility of QST. The components in the box "Suppliers of pellet sources" are to be provided by PELIN. The Valve Matrix is an IPP contribution, the remaining parts: centrifuge and vacuum system is up to SENER.

The second step is targeting on the installation and operation of the PLS in the JT-60SA torus hall. The aim is to certify the PLS as a product in line with ATEX requirements. Based on this, certification according to Japanese rules JPEx is desired. This would facilitate the implementation of the PLS skid at QST Naka site.

4.3. MasterPLC

The MasterPLC has access to all parameters of the subsystems PLC using dedicated interface program modules. The architecture is shown in Fig. 1. In the course of the arrival of sub systems, the MasterPLC

Fig. 4. IPP pellet lab with 10 m^3 vacuum tank ready to host PLS for JT-60SA. Primary vacuum setup is installed on basement.

program code will be developed in order to integrate these systems step by step into the PLS. Optical fibres and related converters are providing the link between the components.

The MasterPLC has full access to all parameters of the subsystems via dedicated interface program modules. These parameters are displayed, recorded and controlled by the HMI (WinCC) at operators' desk. During commissioning at IPP lab, the structure of HMI is to be refined and finalized. The HMI operators' desk allows control of:

- Fuelling and ELM pacing pellet source.
- Centrifuge (accelerator) and Diagnostic section.
- MasterPLC, operators' desk, Valve Matrix and all network devices.

4.4. PLS local controller interface

After full commissioning of the system, the link to JT-60SA tokamak control systems SCSDAS and DHC has to be established. This is expected to be realized by using a device called "PLS local controller", to be provided by QST. The aim of this device is to transmit all relevant information in both directions by compiling protocols and signal levels on both sides.

In the test bed stage, the interface to this device has to be prepared as much as possible. Its final adaption is planned to take place during installation and commissioning of PLS in QST Naka site.

5. Conclusion

The test bed for the Pellet Launching System at IPP Garching is prepared and ready to host the components to be delivered (see Fig. 4). The main purpose of this lab is to provide a proper environment for completion of PLS. A basic hydrogen safety assessment of the laboratory setup (gas supply, vacuum system and PLC) has been successfully passed for the use with ASDEX Upgrade pellet source. This is a good basis for the following hydrogen safety assessments: (a) for use with a single pellet source and (b) of the complete PLS.

The components of the PLS are under procurement managed by F4E: the fueling pellet source, the ELM pacing pellet source as well as the centrifuge with related diagnostics. The lab is mimicking the spatial setup and the communication infrastructure at QST Naka site.

Commissioning and integration activities will start as soon as the components arrive. The completed and commissioned PLS will be shipped to Japan mounted on a skid in order to facilitate its installation at tokamak JT-60SA.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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