Design and Testing of the SPES Target – Ion Source Temperature Monitoring System

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INTRODUCTION

The INFN SPES project is aimed at the production at LNL of radioactive ion beams employed for basic nuclear physics research and many other experimental applications in different fields of science, such as astrophysics and nuclear medicine [1].

The Target – Ion Source (TIS) unit (Fig. 1) is the core of the SPES facility, whose interaction with a stable proton beam generates the aforementioned radioactive ion beams (RIBs).

It consists of an UC4 production target, connected to an ion source and installed inside a water cooled vacuum chamber [1, 2, 3]. The SPES production target will normally operate at high temperature, between 2000°C and 2300 °C [4, 5], when it is impinged by the primary proton beam (PPB), which provides the heating power required. Over-temperatures have to be avoided, because they may lead to the unwanted target sublimation, while under-temperatures will affect the overall RIB production efficiency. As a consequence a dedicated diagnostic system is required in order to monitor the TIS unit components temperature. This study is aimed to the design and testing of such a diagnostic system [4,6].

THE TIS UNIT TEMPERATURE MONITORING SYSTEM

The TIS unit temperature monitoring system was designed taking into consideration the specific context of ISOL facilities and the high working temperatures.

Since optical and electronic sensors such as pyrometers are not allowed in the radioactive environment characterizing the TIS unit, only thermocouples and thermistors were adopted for the temperature monitoring system described in this work. In particular, the production target temperature generally varies between 1400 and 2300°C [4, 5, 6], therefore only type C thermocouples can be used, with an operational limit of 2300°C. Accordingly, a type C thermocouple has been positioned in the rear side of the target (see the TC1 label in Fig. 2), where the numerical model indicates temperatures always below 1600°C. Another type C thermocouple (see the TC2 label in Fig. 2) has been installed in the graphite diagnostic block represented in Fig. 2. In nominal operation conditions, all the PPB power is absorbed by the target. However, if one or more disks break, part of the PPB pass through the target, impinging the diagnostic block. In this case, the residual PPB power should cause a slight temperature increase as compared to the nominal temperature level of the diagnostic block, fixed approximately at 500°C. Furthermore, since the residual PPB is associated to an electric current, a metallic pin (see the I_{imp} label in Fig. 2) capable to detect it has been connected with the diagnostic block in addition to the thermocouple. This additional sensor will allow to increase significantly the reliability of the information coming from the monitoring system, since it is based on a completely different working principle.

Another critical issue is the monitoring of the status of the vacuum chamber’s main O-ring (Fig. 2). In fact, dedicated transient simulations demonstrated that in case of sudden interruption of the water cooling system it would rapidly heat up to 150°C, i.e. the temperature limit of the polymeric material it is made of, provoking a high risk of vacuum degradation and radioactive contamination. A PT100 thermo-resistance has been installed on the vacuum chamber external surface close to the O-ring (as shown in Fig. 2), in order to monitor its temperature.
Such a monitoring system is able to provide some local information on the TIS unit components temperatures. In order to estimate the overall temperature distribution on the TIS unit, the results of representative numerical simulations will be used to define an analytical model of its response, where the temperature signals coming from the monitoring sensors will be used as input variables. As an example, the temperature of the seven target disks will be estimated starting from the target thermocouple output, according to the concept illustrated in Fig. 3.

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Fig. 3: the sensors used for the TIS unit monitoring. TC1: thermocouple for the target temperature measurement; TC2: chamber dump thermocouple for the indirect target status monitoring; I_dump: PPB residual current detector pin; PT100: thermo-resistance for the chamber main O-ring monitoring.

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TESTING

Some tests were performed with the aim to evaluate if the designed monitoring system is capable of providing some reliable information on the TIS unit status. Since the tests were performed at the off-line SPES front-end test bench, a PPB was not usable. The thermal power required to heat the target was provided only by Joule effect (1300 A heating current), simulating the so-called conditioning phase, which consists in the stabilization at high temperature of the production target, preparing it to be impinged by the PPB.

Fig. 4 shows some examples of results collected during the tests, aimed to evaluate the repeatability, the stability and the transient response of the sensors (comparing the experimentally calculated response curve with corresponding numerical results from the FEM model).

Generally, all tests confirmed the reliability and accuracy of the chosen sensors, consequently the TIS unit temperature monitoring system will be implemented in addition to the existing safety and control systems.

CONCLUSIONS

The presented monitoring system was widely studied in the off-line test bench, and its reliability and accuracy were proved. However future on-line tests (with a PPB) will be required to study the influence of the radioactive environment on the sensors characteristics and dedicated numerical simulation will provide information to fix their appropriate upper limit values. If a temperature exceeds the fixed limit, then the monitoring system will send a warning which can be connected to some interlock signals to switch the PPB off.