THE BEAM SAFETY SYSTEM OF THE PSI UCN SOURCE

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Abstract

At PSI, a new and very intensive Ultra-Cold Neutron (UCN) source based on the spallation principle was commissioned in December 2010 and will start production in 2011. From then on, two neutron spallation sources, the continuous wave SINQ and the macro-pulsed UCN source, both furnished with a solid state target, will be operating concurrently at PSI. The 590 MeV, 1.3 MW proton beam will be switched towards the new spallation target for about 8 s every 800 s. Safe operation of the UCN source is guaranteed by two independent interlock systems. In fact, beside the well established machine protection system, a new fast interlock system has been designed following the experience gathered with the MEGAPIE (Megawatt Pilot Target Experiment) project. The goal of this additional system is to preserve the UCN target and the complete beam-line installation by ensuring correct beam settings and, at the same time, to avoid any accidental release of radioactive material. After a brief introduction of the PSI UCN source, this paper will focus on the motivations as well as the principle of operation of the UCN beam safety system.

INTRODUCTION

A new UCN source based on the spallation principle has been constructed at PSI [1] and its commissioning was successfully carried out in December 2010. Routine operation is expected starting from June 2011, after the winter shut-down of the accelerator facility. The beam macro pulse is produced by diverting the 590 MeV, 2.2 mA proton beam coming from the PSI ring cyclotron into a dedicated beam line. The switching procedure will be based on a regular scheme of 8 s beam pulse every 800 s (duty cycle of 1 %). During the remaining 99 % of the time, the beam will follow the usual path through the two meson production targets and to the SINQ neutron spallation target. During the UCN pulse, neutrons will be produced by a spallation target, then thermalized in D_2O and finally cooled down to UCN in a solid deuterium crystal at 5 K. The generated ultra cold neutrons will be stored in a tank and then guided to experiments devoted to the measurements of the electric dipole moment as well as the lifetime of the neutron The estimated UCN density is larger than 1000 UCN/cm^3 in a typical experiment, which corresponds to an increase of almost two orders of magnitude with respect to the best source currently available (ILL). The UCN source employs a solid state target made of lead-filled zircaloy tubes whose design is very similar to the one of the SINQ target [2].

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OVERVIEW OF THE BEAM LINE

A schematic view of the UCN beam line is given in Figure 1. The 1.3 MW proton beam extracted from the ring cyclotron is normally transferred to the targets M, E and SINQ via the proton channel. An electrostatic splitter (EHT) [3] can deviate a small portion of the beam (up to 20 μA) through a magnetic septum (ABS) providing the deflection towards the nearby UCN line used till 2005 for medical proton therapy or proton irradiation [4,5]. The full-intensity beam can be diverted to the UCN line thanks to a fast kicker magnet installed in front of the splitter for this purpose in 2002 [6]. Downstream of the last bending magnet (ABK2) the beam is blown up by the quadrupole magnet QBB7 and then collimated before reaching the UCN target, where the beam spot will have a 4 σ diameter of about 160 mm.

Fast beam position monitors allow the beam trajectory to be checked during a 5 ms pilot pulse. Moreover, signals generated by several beam loss monitors, a halo monitor, two harps as well as one current monitor are connected to the machine protection system. If the amplitude of one of those signals moves outside of the required window an interlock is generated in less than 5 ms.

Behind ABK2 a beam dump has been placed which can absorb the full intensity beam for about 10 ms. This enables to test the kicking procedure and the beam diagnostics independently from UCN operation.

THE UCN BEAM SAFETY SYSTEM

The well established PSI machine protection system guarantees safe operation of the accelerator facility preserving the installation from severe instantaneous beam losses and from prohibitive activation generated by large integrated losses. Nevertheless, this system is not conceived to fully protect an experimental setup like the UCN source. A sudden change of the beam optics or trajectory, as well as the failure of the UCN kicker magnet could be a harmless occurrence for the accelerator but a very dangerous event for the UCN source with potential release of radioactive material. Based on the MEGAPIE experience [7,8], it has therefore been decided to design a second independent fast interlock system (UCN-SAS), which, at the same time, protects the UCN kicker magnet from potential overheating.

At full beam intensity (2.2 mA), the peak current density at the UCN target is 22 μA/cm^2, a value which lies below the 30 μA/cm^2 of the SINQ target[1]. During the very challenging MEGAPIE test, simulations had suggested not to exceed the safety limit of two times the nominal current density over a maximum time of 100 ms.

[1]The experience gathered with SINQ has shown that this kind of target can withstand a current density of 70 μA/cm^2 over eight hours.

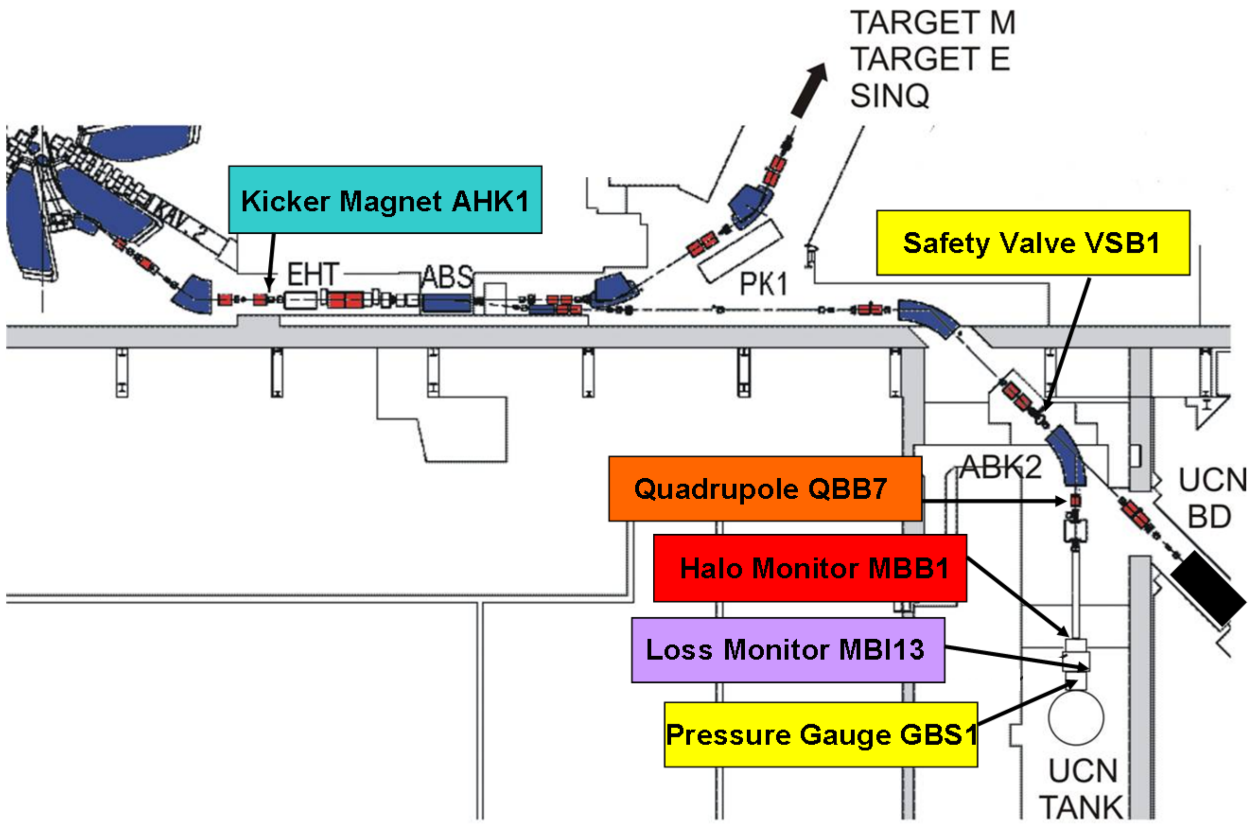

Figure 1: A schematic view of the UCN beam line. The 590 MeV, 1.3 MW proton beam delivered by the ring cyclotron is diverted to the UCN beam line by means of the fast kicker magnet AHK1 followed by the septum magnet ABS with a duty cycle of 1 %. The elements belonging to the UCN-SAS beam safety system are displayed in the coloured boxes.

For the UCN-SAS it has been decided to adopt a very similar requirement, demanding that the beam must be kicked away if the maximum current density exceeds 50 μA/cm^2 over a period of time longer than 100 ms. The UCN-SAS system employs signals from several beam-line elements and monitors as displayed in Figure 1. A schematics of the UCN-SAS in shown in Figure 2.

The beam widening and centring is monitored by the halo monitor MBB1. This device, mounted on the upstream end of the UCN collimator, delivers four signals corresponding to its four sectors. These signals are read out and compared to the beam intensity, measured by the current monitor MBC1, by a LOGCAM data acquisition module. If the beam optics is properly set and the beam is centred, MBB1 should collect about 5 % of the beam current.

Additionally to MBB1, the UCN-SAS employs the signal coming from the beam loss monitor MBI13. A displaced or too concentrated beam would be immediately recognized by a change of the measured loss rate. As in the case of MBB1, also the signal of MBI13 is read out and compared to MBC1 by a LOGCAM module.

The size of the beam spot at the UCN target is determined by the quadrupole magnet QBB7. The current delivered by the magnet power supply is monitored by the UCN-SAS; an interlock signal is generated if the current drops below 90 % of its nominal value.

A rupture of the UCN target window would result in a sudden release of radioactive material into the beam-line with consequent contamination of the accelerator facility. In order to limit the damages related to such an occurrence, the safety valve VBS1 has been installed upstream of the last bending magnet ABK2. The valve is controlled by a unit which is triggered by the pressure gauge GBS1 located just upstream of the UCN target. Besides shutting the valve, the control unit generates an interlock signal stopping the proton beam. The delay from the detection of the pressure increase by GBS1 until the VBS1 valve is completely closed is less than 10 ms, i.e. less than the time needed by the pressure front to reach the location of the valve.

The UCN fast kicker magnet AHK1 is an air cooled ferrite yoke dipole magnet which was design in order to be operated at the typical UCN duty cycle of 1 % and for a maximum pulse length of 8 s. In order to avoid magnet overheating, the AHK1 power supply is constrained at firmware level both in terms of duty cycle as well as maximum pulse length. A failure of the limiting system of the power supply would result in an excessively long beam pulse with potential damage of the kicker magnet. For this reason, an external counter monitoring the kick length has been installed at the level of UCN-SAS. This system generates a beam interlock if the pulse length exceeds 8.1 s.

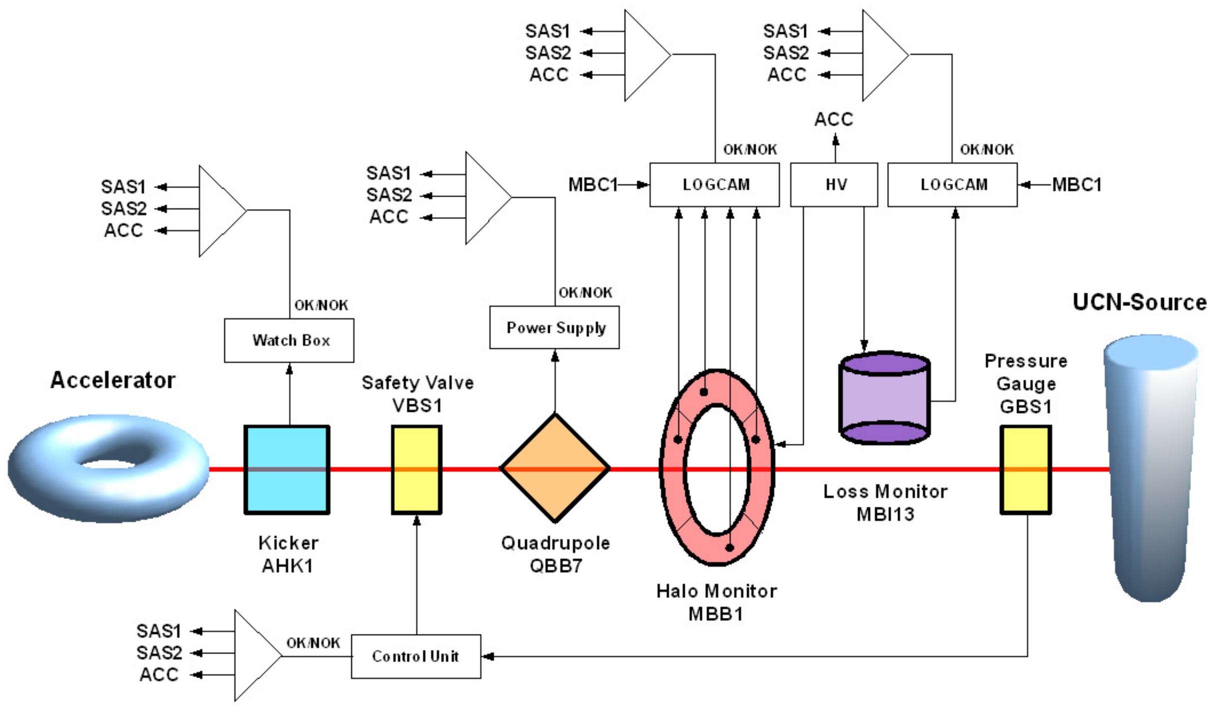

Figure 2: Schematics of the UCN-SAS beam safety system.

Along with the signals coming from the beam-line elements, the UCN-SAS receives the OK/NOK signal from a second safety system called UCN-LAS (slow interlock system). The UCN-LAS monitors parameters from different subsystems of the UCN source (heavy water, cryogenic, vacuum, D_2 and N_2 gas, ventilation and radiation monitoring systems) that require a typical reaction time of 1 s.

Redundancy is guaranteed by the fact that each OK/NOK signal (the five beam-line elements plus the UCN-LAS) reaches the UCN-SAS through two independent lines (SAS1 and SAS2). Moreover, every signal is brought directly to the machine protection system over a third line (ACC). The beam interlock is achieved by switching on the kicker magnet AWK1 and moving in the beam blocker BW2, both located in the 870 keV transfer line. This process has typical reaction time of less than 5 ms. In case of failure of the AWK1 power supply, the accelerator ion source is switched off within 10 ms.

CONCLUSION

The UCN-SAS fast beam safety system has been conceived in order to protect the new PSI UCN source as well as the beam line from any inappropriate proton beam setting and to ensure fail-safe operation of the UCN kicker magnet. The system has been successfully commissioned with beam during the UCN test in December 2010 and it is now ready for routine operation.

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