OPERATION OF THE VERSATILE ACCELERATOR DRIVING THE LOW POWER ADS GUINEVERE AT SCK●CEN

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Abstract

GUINEVERE is a low power accelerator driven system (ADS) consisting of a versatile neutron source, GENEPI-3C, driving the fast sub-critical core, VENUS-F, in SCK•CEN (Belgium). GENEPI-3C is an electrostatic accelerator generating 14 MeV neutrons by bombarding a 250 keV deuteron beam onto a tritium target located within the reactor core. This accelerator produces alternatively continuous beam (up to 1 mA DC), possibly chopped with fast and adjustable interruptions, or short and intense deuteron bunches (~25 mA peak, 1 µs). This paper presents the facility and assesses the 2 years of coupled operation of the accelerator to the reactor.

INTRODUCTION

The Generator of Uninterrupted Intense NEutrons at the lead VEnus Reactor (GUINEVERE) facility is devoted to experimental studies of Accelerator Driven System feasibility. It aims to investigate on-line reactivity monitoring, sub-criticality determination, which are major safety issues, and operational procedures [1]. It is based on a low power facility representing an ADS demonstrator: an experimental reactor of SCK•CEN (Belgium) modified into a fast lead core, VENUS-F, is coupled to a versatile accelerator driven neutron source developed by CNRS/IN2P3 (France). The accelerator operates in pulsed or continuous beam mode, the latter being more representative of a powerful system. GUINEVERE provides a unique facility in Europe for fast sub-critical reactor physics investigations. The facility, under operation for the experimental program for more than 2 years, has led to the first physics results. After presenting the facility, this paper assesses the coupled operation and discusses the sensitivity of the reactor to the accelerator operation.

REACTOR CORE

For sub-critical operation, the VENUS-F reactor is loaded with 93 square fuel assemblies (FA). Each FA is composed of uranium metal highly enriched in ^{235}U (30%) and solid lead rodlets acting as a fast system coolant. The core is composed by a cylindrical arrangement of FA (~800 mm in diameter, 600 mm in height), surrounded by axial and radial lead reflectors [1]. The central core region is left empty to host the terminal section of the accelerator beam line. This insertion channel holds a small lead buffer surrounding the beam pipe supporting the target. The reactor is equipped with 6 safety rods and 2 control rods. Rods are located as close as possible to the centre without interfering with the vertical structure of the accelerator.

ACCELERATOR FACILITY

The Generator of Neutrons Pulsed and Intense-3C (GENEPI-3C) is an electrostatic accelerator producing and transporting a deuteron beam onto a tritium target located at the core center, creating 14 MeV neutrons by $T(d,n)^4He$ reactions. The machine is fully presented in reference [2].

To fulfill the requirements of the experimental program, this machine produces alternatively (cf Table 1):

- short and intense deuteron pulses with adjustable repetition rate,
- continuous (DC) beam, possibly chopped with adjustable programmable interruptions.

Table 1: Beam specifications

Pulsed mode	**DC interrupted mode**
Beam bunches	With beam interruptions
I peak ~25 mA	I mean: ~50 µA – 1 mA
Rate: 10 Hz- 5kHz	Interrupt. rate: 0.1 – 200 Hz
Width ~ 0.7 µs	Interrupt. duration: ~20 µs – 10 ms
Reproducibility ~1%	Interrupt. transition duration ~1 µs

Deuteron beams with different time structures and intensities are generated by a unique duoplasmatron ion source. The main differences between pulsed and DC beam modes, concern source efficiency and beam transport. The ion source and electrodes sit within a high voltage platform and connect to the 250 kV accelerating

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structure. After a first horizontal beam line section, a dipole magnet selects the D^+ ions and bends them down. Beam is transported vertically ~7 m to the target at the core center (Fig. 1). This 90° bend magnet, supported by a mobile frame, can be rolled away to crane the vertical beam line section out of the reactor bunker for maintenance. Beam transport is ensured using 12 electrostatic quadrupoles and 4 magnetic steerers.

Neutrons are produced in a thin layer of TiT (12 Ci) deposited on the target, where beam current and temperature are measured continuously. A cooling system dissipates the beam power (up to 250 W) using compressed air only. The compactness of the core imposes a dense interface holding accelerator target cooling system and current measurement, as well as reactor safety and control rods (Fig. 2).

Two silicon detectors measure neutron production. A detector (within the beam pipe, facing directly the target) provides an absolute measurement of the neutron rate by detecting the associated alpha particle. A proton recoil telescope is set atop the dipole magnet, in the target line of sight at a distance of ~7 m. It provides a direct monitoring of the 14 MeV neutrons emitted backward after their conversion into protons and their detection.

The machine is driven with a lab-developed software (LabWindows, DIM protocol). It interacts with custom hardware with embedded software and operates a graphical user interface running on various PC's. The system is organized with a distributed architecture centered on the PC, with data transmitted via 100 MHz Ethernet links.

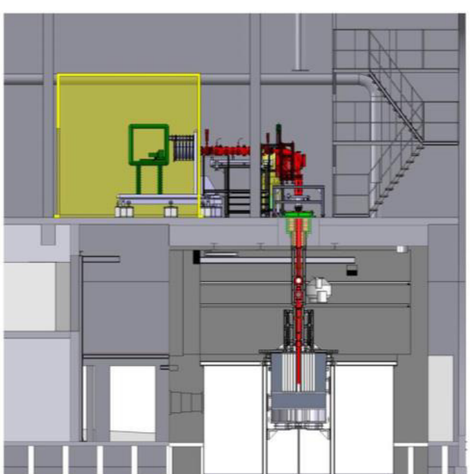

Figure 1: Facility layout (end section of the accelerator beam line inserted in the reactor core).

COMMISSIONING AND 1ST COUPLING

After initial tests at LPSC, the accelerator was transferred and assembled at SCK•CEN (2010). First, the machine commissioning was performed on a dummy target with an unloaded core (no FA). After installation of a tritium target, 14 MeV neutron rates were measured in excellent agreement with expectations, reaching for a new target ~ 10^{11} $n.s^{-1}.mA^{-1}$ (DC beam up to 1.1 mA).

Figure 2: Vertical beam line inserted in the core.

Once the commissioning of the accelerator was fully completed (mid 2010), the vertical beam line was removed and the core was loaded for critical operation after nuclear safety approval (early 2011). After core certification, the experimental program in critical mode was performed until the summer. The authorization for reactor and accelerator coupling was finally granted (September). The first coupling was performed (October) with the accelerator operating in pulsed mode at 200 Hz repetition rate. The neutron flux in the reactor was recorded as a function of time while the reactor rods lifting sequence was initiated: 6 safety rods were lifted one by one, then 2 control rods simultaneously to their reference height. This 30-minute long sequence is identical for all VENUS-F reactor start-ups. As all rods were up, it was verified that the measured reactor power increased according to the accelerator repetition rate.

ACCELERATOR PERFORMANCES

After the initial coupling, the different beam modes were optimized in the coupled configuration. Since April 2012, the accelerator is operated for the experimental program, which imposes the beam mode.

Operating the accelerator to produce short high charge bunches generates no operational difficulty, even though space charge is fully handled. Beam production is reliable, but the pulse peak current is limited to ~25 mA. This is imposed by limiting the diameter of the anode hole in the ion source to optimize the beam extraction in DC mode. This limitation was verified to have minimal impact on the physics program. The bunch width measured on target T_{pulse}~550ns (FWHM) remains stable with $\sigma(T_{pulse})/T_{pulse}<1\%$ over day long runs and the stability of the pulse frequency is excellent ($\sigma(f)/f < 10^{-5}$). Most of the experiments were run at 200 Hz repetition rate. However, a slow decay of the beam current is observed over the first couple of hours of operation, regardless of the beam mode: a thermal effect related to the ion source is suspected.

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Alternatively, the accelerator produces DC beam with programmable adjustable interruptions. Fig. 3 displays the time profile of the beam on target at cut-off (top) and at ignition after the interruption (bottom). The transition time from ‘beam ON’ to ‘beam OFF’, critical parameter for the physics data, is on the order of 1 µs as required for the experimental program. Typical settings used are:

- Beam current : $I_{average}$ = 200-400 µA,
- Interruptions: 300 µs at 200 Hz, or 2 ms at 40 Hz.

Under these conditions, the beam operation was fairly stable, apart from high voltage (HV) discharges (see below). Best running days can generate a daily charge as high as ~ 10 C, corresponding to ~8 hours of beam, the facility being operated during day shift only.

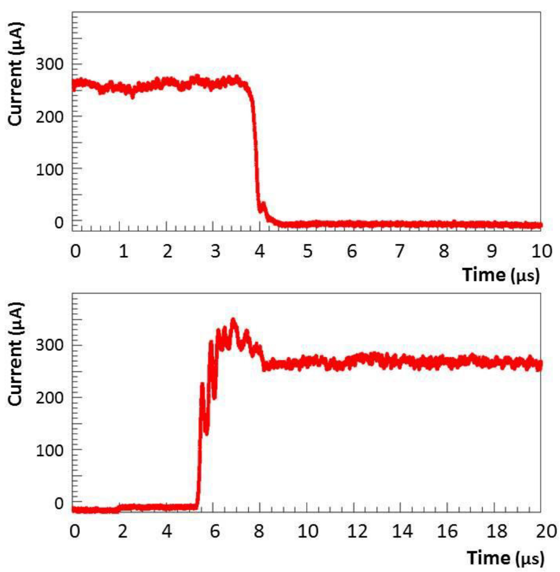

Figure 3: DC beam current on target as a function of time (arbitrary reference) for 2 ms long interruptions repeated at 40 Hz: cut-off (top) and ignition (bottom).

FEEDBACK ON COUPLED OPERATION

Producing DC interrupted beam remains tricky, partly because this beam mode was run for the first time at SCK•CEN, so operating issues were discovered during data taking. Numerous HV discharges occurred, both internally and externally. Solutions to treat the poor air conditions (humidity, temperature) are underway to minimize external discharges. Moreover, fine beam tuning was implemented gradually over months of running to optimize beam transport and therefore limit discharges in the region of the source extraction and focusing electrodes.

While some are not harmful to the beam delivery, a number of discharges cause accidental beam trips. If beam is lost on target, the neutron production in the reactor drops within tens of µs. If the interruption is long enough (~s), the neutron depletion affects the reactor monitors count rates. If beam is restored, the monitors detect a sudden increase. If the neutron multiplication rate exceeds a limit imposed for reactor safety, then the reactor emergency shutdown is triggered, dropping all safety rods (reactor SCRAM). Nearly all accidental beam trips cannot be recovered by the accelerator pilot fast enough to prevent the SCRAM. As explained previously, restarting the reactor requires about half an hour while the facility is operated 8-hour days. Therefore the number of SCRAMs dramatically impacts the experimental campaign and is the leading cause of downtime. Nearly no SCRAM occurs in pulsed mode, while high current DC beam can generate up to 6 or more SCRAMs per week during bad running periods. After the last machine optimizations, no SCRAM was recorded during the last 2 weeks of operation, even in DC mode.

The safety conditions of the VENUS-F reactor were designed for a critical reactor, including the trigger of SCRAMs upon beam loss. However, these very penalizing conditions are unnecessary when operating an ADS as the reactor remains subcritical regardless of safety and control rods positions. Most likely, it will be possible to loosen this stringent constraint in the future.

CONCLUSION AND OUTLOOK

For more than 2 years, GUINEVERE has been operated as a low power ADS facility. While some improvements remain to be done on the beam current stability, machine specifications are largely met. Running a unique ion source allow quick changes between beam modes (~15 minutes). As a drawback, it constrains the machine performances: the mechanical parameters of the ion source are determined as a compromise between the 2 modes, therefore degrading beam transport. The main operational limitation is the downtime caused by severe electric discharges. Improvements were implemented to minimize these discharges. Furthermore, safety rules of the reactor should be optimized for ADS operation. Thus we expect enhanced availability for the coming runs.

The experimental program is progressing and yields first physics results [3]. In spite of limited availability, the performances of the accelerator are excellent. An extensive experimental campaign is programmed for the coming years. Finally, global analysis of the operation of this low power facility provides some valuable feedback for the ADS demonstrator project MYRRHA [4].

REFERENCES

[1] A. Billebaud et al., “The GUINEVERE Project for Accelerator Driven System Physics", Proc. of the Global 2009 conference, Paris, France (2009).

[2] M. Baylac et al., “A versatile neutron source for the low power ADS GUINEVERE", Proc. of the International Topical Meeting on Nuclear Research Applications and Utilization of Accelerators (AccApp ‘11), Knoxville, USA (2011).

[3] S. Chabod et al., “Prompt decay experiments analyzis for ADS reactivity monitoring at VENUS-F”; N. Marie-Noury et al, “Reactivity monitoring using the area method for the VENUS-F subcritical core”, Proc. of TC-ADS2, Nantes, France (2013).

[4] http://myrrha.sckcen.be/

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