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THE EXTENDED OPERATIVE RANGE OF THE LNF LINAC AND BTF FACILITIES*

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Abstract

In 2020 the INFN-LNF LINAC and BTF have performed long-term runs for test beams and fixed-target experiments. The scientific needs of these items have been leading our groups to continuous improvements of the LINAC operative range both in pulse time at maximum energy and on the minimum transported energy, until the reset to DAΦNE injections at the beginning of 2021. We will also show the BTF recent developments in the transported beams and the second beamline installation.

EXPERIMENTAL ACTIVITIES

The pandemic emergency had interrupted machine operation from March 2020 up to May 2020. In this period, only logistics, software upgrade, maintenance operations took place, coordinated with the LNF safety service and allowed by the national legislation for the pandemic status. Starting from May 2020, we performed the operations as presented in the list below:

- Maintenance and consolidation of the LINAC;
- Reset BTF1 line for PADME run;
- DAΦNE run (end Feb. 2020, restart on Feb. 2021);
- Experimental runs (Jul. 2020-Jan. 2021);
- E-rad project (from Jun. 2020, run in Dec. 2020);
- Build a second beam-line and experimental hall (from Feb. 2021, up to now);
- LINAC positron beam pulse lenght up to 300ns;
- LINAC electron beam energy down to 150 MeV.

BTF Activities

The Beam-Test Facility (BTF) is an infrastructure mainly dedicated to the development and testing of particle detectors, providing electron or positron beams with tunable energy from 30 MeV to 800 MeV, while the intensity (multiplicity) can be varied from 10^{10} particles/pulse, down to a single particle per pulse in a Poisson stochastic regime. The facility was successfully running with an average of 200 beam days/year, 25-30 experimental groups, 150-200 users booking since 2004 apart from a few minor stops. It is commonly booked for several applications ranging from detector development, characterization and calibration, to beam-diagnostics testing [1–3]. Less frequently, BTF hosted high-intensity runs for electrons and neutrons photo-production irradiation purposes, high-intensity studies of electro-magnetic phenomena, photon-beam testing, and fixed-target experiments. Starting from the second half of 2017 the Beam-Test Facility (BTF) of the Frascati accelerator complex DAΦNE was the object of three topics:

- A fixed target experiment with permanent installation, PADME.
- A major upgrade, with the main purpose of splitting the existing beam-line and adding a second experimental hall for user activities.
- And minor experimental periods for external users.

Since 2017, a good portion of the activities were devoted to the PADME experiment beamtime, in 2018 its commissioning and installation, starting in April. In the meantime the BTF group developed and prepared the doubling line project and its installation[4], stopping the user activities until June 2019. The commissioning of the BTF beam for the PADME experiment occurred in July 2018, at the end of the PADME technical commissioning. The BTF started delivering secondary positron beam in September 2018 for the first PADME run, achieved in March 2019. At the end of the RUN1, during beam setup trials was clear that the PADME detectors probably gain a better signal to background ratio if the positrons beam will be produced in the LINAC positron converter target and not as a secondary beam by the BTF target, close to the BTF Hall 1 area and source of secondary unwanted photons. So we implemented a new way of transport primary long beam with a limited energy spread by tuning LINAC modulator and gun timing parameters for primary positrons beam. After the DAΦNE duties with SIDDHARTINO run and achieved the BTF 2019 users call, the LINAC had been turned to new PADME parameters, with a lower beam energy demand and the duty to improve gamma background on PADME detectors, thus using a conditioned primary positron beam from LINAC.

LINAC Activities

The S-band linear accelerator (LINAC) was built to be an electron and positron source for DAΦNE whose injection needs had to satisfy only a few hours/day, emitting macrobunches with time duration of 10ns, 50Hz pulse rate [5]. The LINAC and the transfer line were upgraded in the past also being used to support the Beam Test Facility (BTF) out of the standard way of main rings operations via using the LINAC spare pulses. The original design of the TITAN BETA system for the FRASCATI LINAC employed a conventional DC high-voltage power supply based on a full-wave bridge diode assembly and a resonant charging circuit. The main component of high voltage charging power

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consists of a 3-phase variable phase control (SCR), a high voltage step-up transformer, a rectifier assembly and a charging inductance. After more than twenty years of operation, some components are no longer in good condition and circuit failure occurred often. With extensive field-tests, the modulator's high-voltage charging system has been redesigned to use a constant-current, high-frequency inverter power supply (EMI-303), which has 30 kJ/sec charging capability. Nowadays two modulators (ModB and ModD) have been upgraded in the final configuration, the ModC at 50% and ModA in the initial configuration [6].

LINAC Setup Change for PADME In February 2020 a fault in the Variac of the filament power supply of klystron on modulator C was the clue that the klystron must be substituted after 11 years, for a short circuit of the klystron filament. The new klystron was installed and in 3 days thus the LINAC restarted to produce electrons and positrons for DAΦNE.

Unfortunately after 1 month of operations, this new klystron had vacuum issues in the tube that led the klystron repaired by the factory.

The installation of the new klystron was done few days again before the pandemic lockdown and the conditioning procedure was interrupted by the lockdown itself. The conditioning restarted in June 2020 but vacuum activities in the RF waveguide between the klystron and the SLED took a long time to be conditioned and they were the principal source of LINAC downtime. The maximum outputted power from the plant during the PADME run was 27 MW that reduced the maximum beam energy. During the 2020 winter shutdown and 2021 LINAC power up for DAΦNE injections [7], a slot time for klystron conditioning was implemented leading the outputted power up to 35 MW, even with klystron output window leaking detected. The reached power fulfilled the positron beam energy required with a suitable faults rate due to discharges.

LINAC Extended Pulse In 2020, in accordance to the PADME experts, the beam centroid energy was lowered, due to the explained klystron problem, from the maximum transportable in these conditions, formerly around 460 MeV, thus getting a lower faults rate, faults not fully recoverable in the PADME assigned time slot. The arduous requirement imposed from the PADME experiment in RUN2 was the maximization of positron beam centroid energy vs macrobunch pulse length, with lower limits of 430 MeV and 250 ns respectively. Unavoidable LINAC feature, to get energy lower limit is using the SLED compression, so we had to manage the beam pulse flatness (i.e. I(t)) and macrobunch pulse length through distributing beam loading with different modulator timing and pulse time advance in the thermionic GUN pulse (around 200 ns in respect to the nominal one). The beam loading in the electron part of the LINAC and the reciprocal phases of the two involved modulators (ModA and ModB, before positron converter target), returned the pulse flatness control over the gained 350 ns macrobunch length. The remained part of the LINAC was used to improve the positron pulse energy trying to maintain pulse time as high as possible. Beam energy spread measurements at the end of the LINAC using a multistrip secondary emission monitor (hodoscope) after a high dispersion magnet (60° DHSTS001) and prior BTF injections, returned a average energy of 445.3±3.7 MeV with a low energy tail in the charge distribution over energy. This beam showed a pulse length vs charge intensity vs energy distribution as longitudinal coupling due to beam loading, SLED and GUN/Modulator timing effects since the GUN pulse length is comparable to the RF filling time in the accelerating sections. This feature has given a pulse length vs energy selection possibility by exploiting this high longitudinal chromaticity beam just after first BTF dipole steering.

BTF Extended Pulse Conditioning This LINAC-BTF operations procedure and parameters were structured to reduce the radiation damage of the active elements, controls of the collimators and other plastic elements, as the safety mylar window, in the transfer line near the BTF target, hardly interested during the PADME RUN1. This duty was accomplished by lowering to minimum the gun emitted current (i.e. under the sensitivity of BPMs), letting few essential diagnostics elements in range to detect primary beam data.

The beam impinging from LINAC, after setting appropriately the first two BTF dipoles (DHPTB101 and DHSTB001), put the longitudinal distributed energy spread vs pulse time, in the transverse plane. Using horizontal scrapers, thinning the gap between them, we perform the selection of the energy bin which lasts longer in the overall pulse envelope, via using the hodoscope information in the time domain. So we got 432.5 ± 2.2 MeV final beam pulse on experiment target over 280 ns.

During PADME RUN1, attention was towards the vacuum window that divided the dynamic vacuum of PADME (that is at the level of (10^{-7} mbar) from the vacuum of the transfer line(10^{-10} mbar). This septum was identified by the experiment as a possible source of Bremsstrahlung interaction in a good portion of the impinging beam, leading to an increase of the beam energy spread at low energy, thus leading to beam undesired interactions with vacuum pipes after and in the middle of the DHSTB002 final steering. Accordingly to PADME experiment experts, the vacuum window was replaced in a new place, in LINAC tunnel upstream final scrapers (SLTB003 and SLTB004), with full pipe aperture and made by a single 0.125 mm MYLAR foil. This was crucial for implementing online diagnostic to get the delivered luminosity to the experiment: detecting the charge released by Bremmstrahlung photons and calibrating it to the equivalent pulse charge in a dedicated campaign, we got predicted positrons on PADME target (PoT) shot by shot without destructive measurements. So, in 2020, PADME needed a former technical run (Tech-RUN2) to test their upgraded detectors and to investigate the new primary positrons conditioned beam from the BTF beamline. This technical run lasted from 3^{rd} July to the 8^{th} of August 2020 where BTF

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delivered $(1.0 \pm 0.1) \times 10^{+12}$ PoT, with a dedicated spot of a few squared millimeter area selected by PADME experts matching the PADME target hit requirements.

At the end of this technical run, PADME reported that these two main improvements (conditioned primary beam and Mylar window) were crucial to minimize the secondary photon background. In the summer vacation, our group performed the needed overhauling of the exhausted LINAC elements and started new conditioning set to increase emitted power leading to an increased pulse time and energy beam centroid. These two parameters were pushed up to 320 ns pulse length and 440 MeV but PADME preferred to remain to the well-studied Tech-RUN2 beam parameters for scientific and technical reasons. The scientific run, RUN2, injected PoTs starting on the 14^{th} September up to 3^{rd} December 2020 where BTF delivered $(6.6 \pm 0.6) \times 10^{+12}$ PoT, within a new dedicated spot of few squared millimeter area selected by PADME experts harmonizing again new PADME target requirements. The remaining parameters, as discussed earlier, were the same as the Tech-RUN2.

Primary Beam Down to 160 MeV The first setup of the lower energy user beam ever reached with this LINAC is around 165 MeV was done at the end of 2020, immediately after the scientific PADME RUN2. The LINAC setup was deeply changed from the DAΦNE one to obtain this energy with a primary electron beam with enough pulse charge that fulfills irradiation test requirements: the last four sections of the LINAC were put in counter phase to the previous ones for reducing beam spread and energy centroid. The beam improvements will continue in 2021 and 2022 with dedicated beam time to be assigned exclusively, out of DAΦNE and users beam time, to take part in the eRAD project whose general aim is the use of electron sources to measure the behavior and resistance of electronic components intended to be subjected to radiation in the aerospace environment. The project was funded by a regional fund [8].

BTF DOUBLING LINE PROJECT

The aim of this project is the splitting of the existing Frascati beam-test facility (BTF) into two branches (so-called BTF-1 and BTF-2), allowing two different beamlines for serving two different experimental areas (further called BTFEH1, the existing area, and BTFEH2, the newer one) and thus creating a new equipped experimental hall, the related shielding and a new control room (Fig. 1).

This is realized by sharing the beam from the LINAC employing a pulsed 15° dipole (<100 ms ramp, DHPTB102) and a two-way vacuum pipe, on two new beamlines, with a second set of beam diagnostics for the monitoring of the beam intensity, the transverse spot size and the beam centroid position. The design of the two beam-lines, the project of all-new elements [9], the improvement of the vacuum, power, cooling and conditioning systems, as well as the modifications to the building has been completed in-house by the Frascati staff.

In the new configuration, DHPTB102 steers pulses in BTF2 away the slightly modified original BTF1 with different beam optics to cope with different target experiments:

- The BTF-1 is dedicated to medium and long-term (more than few weeks, up to several months) installations or high-intensity applications requiring the extraction of the full LINAC beam, and essentially replicates the existing beamline.
- The BTF-2 is intended instead for short-term (from one to few weeks) beam-tests, at medium and low beam intensity.

The final design of the new beam-lines has been carefully optimized to get the required beam parameters on both branches, in particular, around millimetric beam spot size and less than 1 mrad beam divergence at 500 MeV. The main characteristics of the new beam-lines are fully described in [10]. The upgrade activities in 2020 were continued following pandemic restrictions, getting all the needed items at the end of June and preparing halls and services to be ready for the BTF2 installation, In 2021, at the end of the BTF experimental activities, has been started the BTF2 installation: nowadays the main parts have been deployed and technical commissioning (magnets, fluids, power, interlocks and vacuum) has been done before May and all the subsystems are actually in the tolerance limits foreseen by the project. Shieldings have been fitted in the experimental areas and in the externals surrounding: the concurrent safety system installation will be completed this month. Following there, will be the safety trials and eventually the beam commissioning.

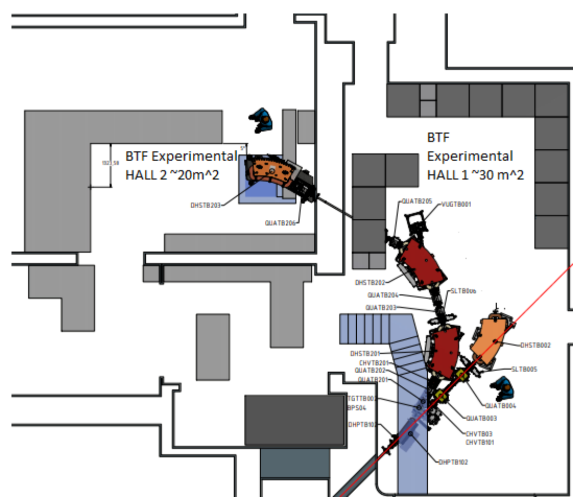

Figure 1: BTF Experimental Hall (BTFEH) layout: BTF1 and BTF2 lines are shown.

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