LIPAC RF SYSTEM: ON THE VERSATILE USE OF PHOTOMULTIPLIERS*

J.-P. Adam†, CEA, DAM, CEA-Gramat, F-46500, Gramat, France
L. Maurice, CEA Paris-Saclay - Etablissement de Saclay, Saclay, France
F. Scantamburlo, Fusion for Energy, Rokkasho, Japan
K. Hirosawa, National Institutes for Quantum Science and Technology, Rokkasho, Japan

Abstract

As part of the Linear IFMIF Prototype Accelerator (LIPAc) and its Radio Frequency (RF) system protection, three applications of PhotoMultipliers (PMs) are presented.

INTRODUCTION

LIPAc (Linear IFMIF Prototype Accelerator) in Rokkasho, Japan, an accelerator designed to provide a 125 mA deuteron beam up to 9 MeV in CW (Continuous Wave), is an important step to study materials that will withstand the intense neutron flux coming from the fusion plasma of future Tokamaks [1].

Modern photomultipliers (PMs) are affordable, highly sensitive, easy to operate, compact with convenient form factors, and sufficiently robust for demanding accelerator environments. For LIPAc Radio Frequency (RF) subsystem which delivers over 2 MW of RF power distributed among all the accelerating cavities (Fig. 1), these characteristics make PMs particularly effective for monitoring components prone to multipacting and micro-discharge. The light produced by these phenomena is detected even at very low levels, enabling detailed investigation and fast triggering of interlocks.

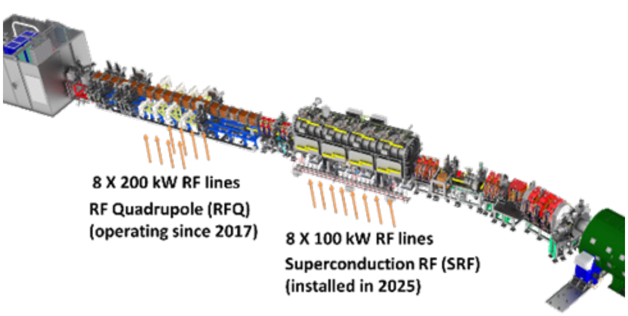

Figure 1: Overview of LIPAc.

APPLICATION 1: SRF LINAC COUPLERS

At LIPAc, the Superconducting RF (SRF) accelerator currently being commissioned is fully equipped with PMs for early arc detection, enabling a fast RF power shutdown and thus avoiding severe damage caused by arcs. As shown in Fig. 2, the detectors are located at a T-shaped transition and at the RF window. This latter part separates the vacuum section from the air section of the power coupler, and it can be a weak point as well as a location where multipacting occurs on its vacuum side.

This is the standard setup for power couplers designed by CEA/Saclay [2]. This fact made a specific PM easily available on-site (Hamamatsu photomultiplier tube module H10721) and made the other applications presented here possible.

Small sized PMs can be installed very close to the power coupler to significantly reduce the fiber length. Short optic fibers have significant advantages: reduced attenuation due to fiber aging (see part 3 of this document) and no false trigger due to the Cherenkov effect in fiber as reported in [3]. However, some drawbacks need to be considered: the PMs are not specifically designed as radiation-resistant and their driver circuit needs bulky control cable bundles with 5 lines and sufficient EMC shielding.

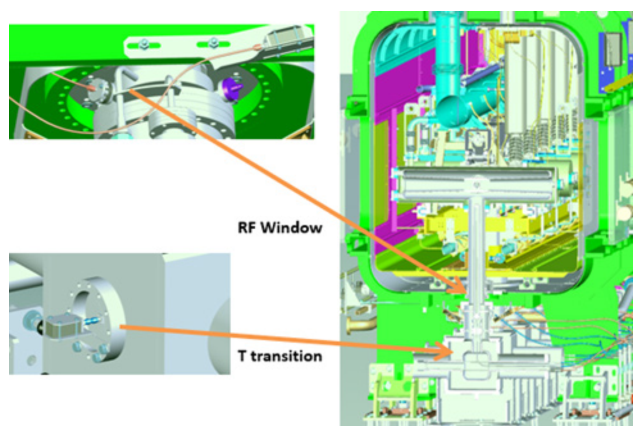

Figure 2: Locations of the PMs installed in the SRF of LIPAc. The 8 SRF cavities have the same setup. For the RF window, the PM is not directly on the viewport (short orange fiber) for accessibility.

APPLICATION 2: HIGH POWER TEST BENCH

PMs have also been successfully used in a temporary test bench for the conditioning of RF Quadrupole (RFQ) couplers. The setup is described in detail in [4]. Since power couplers are involved, this application is naturally derived from part 1 of this document. The first version of the protection system was based on commercially available arc detectors; however, their sensitivity was not suitable for multipacting analysis. The setup was easily converted to a

*This work was undertaken under the Broader Approach Agreement between the European Atomic Energy Community and the Government of Japan.
†jean-pierre.adam@cea.fr

PM-based version using a 3D-printed holder (Fig. 3) and standard electronic components (Fig. 4).

In addition to interlock triggering, the output signal was used to confirm vacuum pressure rises caused by multipacting, providing valuable inputs for the conditioning procedure. As visible in Fig. 5, the new setup provides a better sensitivity.

Figure 3: PM secured with a 3D printed holder in front of a viewport, monitoring the vacuum side of the window of a power coupler.

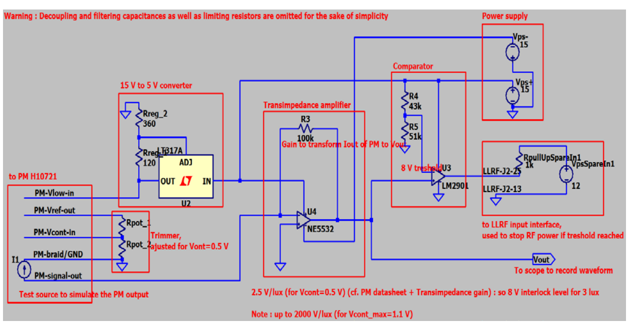

Figure 4: PM driver schematic built around a transimpedance amplifier. This is a stripped-down version of the protection system used at CEA/Saclay.

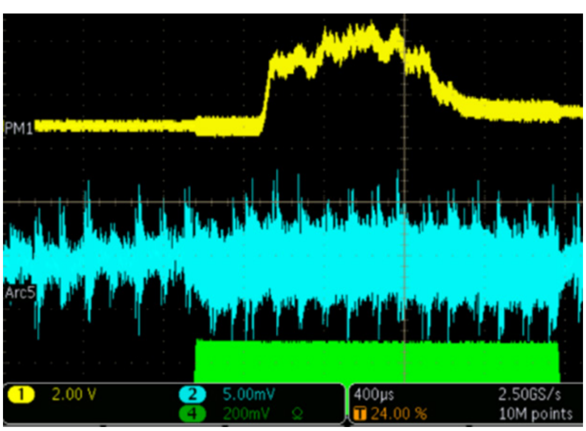

Figure 5: Output signal for a similar level of multipacting. (yellow: new version; blue: initial version; green: RF pulse; all three have different amplitude scale).

APPLICATION 3 (PROPOSAL): RFQ ARC DETECTOR UPGRADE

Currently, the LIPAc RFQ cavity (8 viewports) and its 8 power couplers (1 viewport per coupler) are monitored by off-the-shelf arc detectors connected through long (30 m) optical fibers. While this is a reasonable design, it can be desirable to upgrade this system based on the experience acquired in part 1 and 2 of this work. The main motivations are the aging fibers with higher attenuation and the moderate sensitivity of the detectors.

Actually, arcs in the RFQ may have gone undetected during previous operational phases: fast cavity voltage drops occurred without the arc interlock being triggered. A better light detection system could have confirmed or discarded the arc occurrence hypothesis.

In addition, the low sensitivity of the current detector (estimated 0.025 mV/lux) makes difficult the coupler multipacting analysis, although not impossible as reported in [5].

The opportunity of upgrade is currently under investigation. In the meanwhile, a lightweight PM setup was used to assess the attenuation of aging optical fibers. An average transmission loss of 14 dB compared to new fibers (same manufacturer) was confirmed. A similar setup was used for an additional check in order to verify that the cavity viewports are still transparent by measuring the transmission through the RFQ and comparing it with a theoretical value (no losses and a uniform light distribution over a quadrant were assumed for this estimation).

CONCLUSION

PMs have been successfully implemented at LIPAc for high power RF system protection.

As these devices will operate very close to the beam line, their performances may be affected. Maintenance will be scheduled once more feedback on radiation-induced degradation becomes available.

REFERENCES

[1] H. Dzitko et al., "Status and future developments of the Linear IFMIF Accelerator (LIPAc)", *Fusion Engineering and Design*, vol. 168, 2021 doi:10.1016/j.fusengdes.2021.112621

[2] O. Piquet et al., "First results of the IFMIF/EVEDA-SaTHoRI tests", in *Proc. SRF2017*, Lanzhou, China, Jul. 2017, pp 262-265. doi:10.18429/JACoW-SRF2017-MOPB086

[3] C. Maiano et al., "Commissioning of ESS superconducting linac", in *Proc. SRF2025*, Tokyo, 2025

[4] L. Gonzalez-Gallego et al., "Performance on high-power test bench of RF couplers for the LIPAc's RFQ", in *Proc. IPAC'25*, Taipei, Taiwan, Jun. 2025, pp. 1907-1909. doi:10.18429/JACoW-IPAC2025-WEPB077

[5] F. Grespan et al., "RF and multipacting analysis of the high-power couplers of IFMIF/EVEDA RFQ and ESS DTL", in *Proc. LINAC2024*, Chicago, IL, USA, 2024, pp. 457-460 doi:10.18429/JACoW-LINAC2024-TUPB067