14th International Particle Accelerator Conference,Venice, Italy JACoW Publishing
ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-THPA162

NEW PULSE FORMING LINE AND TRANSMISSION CABLES FOR THE CERN PS BOOSTER EXTRACTION AND TRANSFER KICKERS

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Abstract

The CERN PS booster features four extraction kicker systems, one for each of the four superposed rings and three transfer kicker systems for recombination of the beams when being transferred towards the PS. Each of these systems consist of SF_6 gas filled Pulse Forming Lines (PFL) which are resonantly charged and then fast discharged by thyratron switches into SF_6 gas filled transmission cables, transferring the pulse to the magnets. This paper outlines the future refurbishment of PFL and transmission cables with the constraint of minimizing SF_6 gas usage. The pulse requirements are presented since they limit the choice of technology together with the development cost for alternative SF_6 free technologies. The optimization potential regarding technical pulse requirements versus beam performance is discussed. The paper concludes with the choice made and the technical design outline for the refurbishment of the PSB transfer and extraction kickers.

INTRODUCTION

The replacement of SF_6 gas filled cables used for CERN's PS complex kicker applications is a major concern since decades. It has been tried to tender replicas of the existing design since more than 10 years. However, procurement attempts failed as the cable industry changed fundamentally since the 1970s (when these cable types were developed) and as a result production facilities are not readily available anymore. The more stringent F-gas regulations as well as climate protection considerations suggest also that investments in reengineering and new production facilities need to be critically evaluated. As a matter of consequence, the CERN strategy for the replacement of those SF_6 gas filled cables has been adapted and the focus has shifted to identification and development of alternative technologies. On the one hand side the development of conventional PE-insulated large diameter cables is followed whilst on the other hand a completely new pulse generator architecture employing the inductive adder principle is being developed as well. For the PS Booster extraction systems the maximum voltage of 60 kV suggests a replacement by the conventional PE insulated coaxial cables as these seem feasible and would be less costly than a full generator replacement by an inductive adder design.

PSB Extraction and PSB to PS Transfer Kickers

The four superimposed PS booster (PSB) rings each feature an extraction kicker (KFA14) composed out of four modules whilst the recombination of the four beams is guaranteed by the transfer line kickers KFA 10 (2 kickers each consisting of 2 modules) and KFA 20 (one kicker, 2 modules). The individual modules are powered by pulse generators, if required in parallel such the magnet, generator and cable impedance stays matched. Table 1 shows an overview of the relevant kicker parameters for LIU beams. A more detailed description of the extraction and recombination processes and parameters is given in [2].

Table 1: PSB Kicker Parameters and Requirements [1, 2]

Parameter	KFA14	KFA10	KFA20
Z_{Magnet} [Ω]	26.34	12.3	12.3
$Z_{Generator}$ [Ω]	6.25	6.25	6.25
2.0 GeV t_r/t_f (2-98%) [ns]	105	105	105
Flat top length 2 GeV [ns]	447	447	1078
Max. ripple [%]	±2	±2	±2
Max. B.dl [T.m]	0.073	0.082	0.052
Max. system Voltage [kV]	60	60	60

All generators utilize a pulse forming line (PFL) consisting of a SF6 gas filled coaxial cable for energy storage and thyratron driven main and dump switches (MS, DS). Figure 1 illustrates modules of the KFA14 generator (KFA10 and 20 are of the same type).

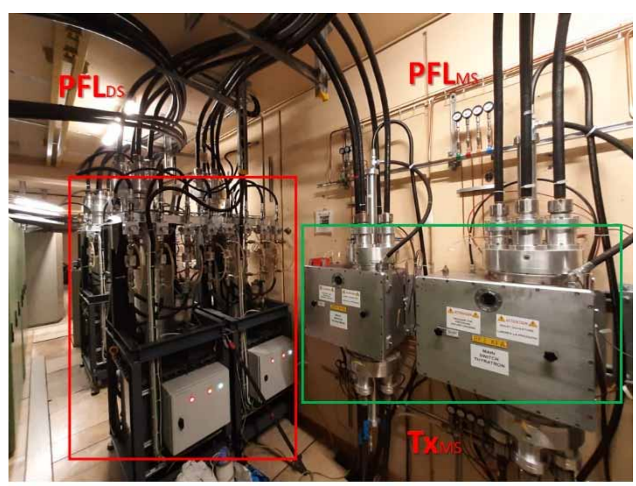

Figure 1: KFA14 Generator 1 & 2: Main Switch MS (green box), Dump Switch DS (red box) and PFL cables between MS and DS as well as Tx cables to the magnet.

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-THPA162

The pulse transmission to the magnet uses SF_6 gas filled transmission cables (Tx) of the same type.

For this system topology the Tx lines are always stressed to half the PFL voltage level. Therefore, the PFL cables are subject to higher electric field stress and define the dielectric requirements. The required attenuation is defined by the PFL too. Due to the longer length of the PFL, the total attenuation and losses are an order of magnitude above the Tx cables which impacts the pulse flattop droop. Although relaxed attenuation and breakdown voltage (BDV) levels could be considered for the TX cables, resulting in a different design, using cables of the same type and batch makes sense in terms of precise impedance matching and higher reliability for the Tx application (where cable exchange is a lengthy and difficult procedure). Figure 2 shows the currently installed PFL cables on 3.6 m large cable drums in the adjacent shed about 30-50 m away from the generators underlining the significant footprint and infrastructure consumption.

Figure 2: KFA14 (left) and KFA10,20 (right) PFL cable drums in the B305 cable shelter.

This cable type has a capacitance of 190pF /m and attenuation values of 5.5 dB/km measured at 10 MHz. The different configurations and cable lengths are outlined in Table 2. Take note that the many parallel cables with short lengths result in significant investments for gas tight cable heads, connectors and connection boxes compared to the total cost.

Table 2: Installed Cables for PSB Kickers (per Generator)

Parameter	KFA14	KFA10	KFA20
Z_{Cable} [Ω]	25	25	25
Nb. of Generators	4	2	1
PFL length [m] / nb. of cables	158/ 4	158/ 4	285 /4
Tx length [m] / nb. of cables	18 / 4	34 /4	26 / 4

REPLACEMENT OPTIONS

Several replacement options have been investigated and are outlined below. For all options (except A) the replacement of the magnet connection box to feature compatibility to the new cable connectors is a crucial item since the suppression of SF_6 gas as an insulation medium requires the thorough development of a new or reworked feedthrough solution to the magnet vacuum.

Option A: Replacement by the Same Gas Filled Cable Type

Since standard procurement on the market failed in the past, this option would require a complete redevelopment of the installed cable design and its production facilities. This requires major investments in both development and facilities and would again reemploy SF_6 gas as dielectric. Consequently, this option hasn't been further followed. A replacement of SF_6 by novel insulation gases has been considered, but was not followed either due to degraded performance parameters and as it would require lengthy tests to conclude on the compatibility of the new compounds with the existing materials in radiation environment. In addition, the long-term stability within 280 m long PE-foil structures would need to be studied, altogether not solving the issue concerning production facilities.

Option B: Replacement by Existing Conventional Cables

This option would replace the installed 25 Ohm cables by existing CLP50 type cable. To match the impedance each SF6 cable would need to be replaced by two parallel CLP50 cables. Subsequently the cable and connector quantity would double. Whilst this option would be suitable for the transmission cables in terms of BDV it doesn't suit the PFL application which requires twice the BDV of the Tx cable. A product would exist to overcome this issue, but in terms of the higher attenuation of this CLP50 like cable the long PFL lengths would create a too large droop of the pulse flattop.

Option C: Replacement by a New Conventional Cable Design

As shown in previous papers [3] a new conventional design with a larger diameter and employing a field screen would satisfy both the BDV and attenuation requirements. A short prototype length has been prepared for validation of the principle followed by a tender to industry. Whilst for the smaller CLP50 like diameters the field screen principal has been validated on an industry produced prototype length the larger CLPF25 diameter is still under validation. Especially the foil bonding mechanism on the larger diameters turns out to be a source of issues as well as the larger 17 mm inner conductor causes reasons for further optimization. Details are outlined in [4]. Since the so far used SF_6 gas filled cables have not shown any issue in more than 40 years of operation the lifetime question for new "PE only" insulated cables is a crucial one. Analytical considerations for AC cables exist but experience for pulsed application is

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limited. Out of this context an accelerated cable test stand has been built and is about to be commissioned [5]. This facility will also cover the reliability aspects of the needed new SF_6 gas free connectors.

Option D: Replacement by an Inductive Adder Generator

A replacement of the currently used PFL/thyratron driven generator by an Inductive Adder design is an attractive option. Inductive Adder prototypes have been developed for CLIC and FCC [6, 7] already and a first application at higher voltage for the PS extraction is being investigated. Such a generator would not only replace the PFL cable but also the thyratrons and auxiliaries, thus leading to a significant reduction in footprint. Compared to PS requirements (80 kV, 3 kA) The required 60 kV PFL voltage and short pulse lengths of below 1 µs in the PSB will make it easier to develop and employ an inductive adder for beam transfer applications. New transmission cables and SF6 gas free connection boxes would need some development, nevertheless. This option is a complex replacement also involving the generator timing and controls. Therefore, as a complete R&D project it requires the highest investment but yields the most innovative solution.

EVALUATION AND SELECTION OF PREFERED VARIANT

The presented options have been evaluated and a selection was done on cost, risk and benefit considerations.

Optimization of Requirements

Prior to the selection of the preferred variant the PSB kicker requirements have been checked for optimization potential. It has been identified that the KFA20 provides capability of flat top lengths of up to 2.6 µs whilst the latest LIU specifications demand only 1.12 µs. A reduction of the PFL cable length from currently 285 m is therefore proposed.

Preferred Variant

Option A has been disregarded already because of the investment for production and the use of SF_6 gas. Option B has difficulties handling the PFL voltages and creates too much droop hence is only a solution for very short cables. Option D, the inductive adder is estimated to be twice as expensive as Option C, the replacement by new conventional low attenuation cables with field screen. Option C has therefore been selected and supported by the consideration that the inductive adder technology deployment is constraint by resources which need to be strategically focused on the PS complex cable replacement where for the replacement of the 80 kV SF_6 gas filled cables no other solution than the inductive adder exists so far. Therefore, to reduce future risks for the PS complex the deployment of an inductive adder system has been prioritized and the more cost-effective cable solution was selected for the PSB kickers.

Implementation

After cable prototyping and validation, a first batch is foreseen for installation in the accelerated aging cable test stand as well as for replacing the SF_6 gas filled cables in the laboratory test generator. For both a year of testing and operation is foreseen.

The first system to be converted is the KFA20 with one generator during LS3, followed by KFA10 and finally KFA14. A new location for the cable reels closer to the generator is being investigated.

CONCLUSION

As part of the PSB beam transfer system consolidation the replacement of the currently installed SF_6 gas filled coaxial high voltage cables with low attenuation has been studied. The important system parameters have been outlined together with several replacement options. Development work for both the conventional PE insulated cable project as well as for the Inductive Adder generator has been summarized. Cost and benefits have been stressed and the proposed solution has been discussed. The replacement by conventional PE cables has been identified as the preferred variant for the PSB whilst the inductive adder technology will be deployed in the PS. The development of the new cable is progressing with the 1st prototype being produced and tested together with industry.

REFERENCES

[1] B. Goddard *et al*., "Specification for Kicker Systems for 2.0 GeV PSB to PS Beam Transfer", Functional Specification, CERN EDMS, Geneva, 2015.

[2] T. Kramer *et al*., "Considerations on the Fast Pulsed Magnet Systems for the 2 GeV Beam Transfer from the CERN PSB to PS", in *Proc. IPAC'15*, Richmond, VA, USA, May 2015, pp. 3876-3878. doi:10.18429/JACoW-IPAC2015-THPF082

[3] T. Stadlbauer *et al*., "Performance Tests of Polyethylene Insulated High Voltage Low Attenuation Coaxial Cables for Pulsed Applications", in *Proc. IEEE 3rd International Conference on Dielectrics (ICD)*, Valencia, Spain, Jul. 2020, pp. 617-620. doi:10.1109/ICD46958.2020.9341951

[4] T. Stadlbauer *et al*., "Development and qualification of a novel high voltage high frequency pulsed coaxial cable for kicker systems at CERN", to be presented at Jicable23, Lyon, France, 2023.

[5] J. Riveiro Herrero, T. Kramer, T. Stadlbauer, 2023, "Development of an Accelerated Ageing Test Bench for HV Fast Pulsed SF6-Free Coaxial Cables for Kicker Systems at CERN", Jicable23, Lyon, France, 2023.

[6] J. Holma, "A Pulse Power Modulator with Extremely Flat-top Output Pulses for the Compact Linear Collider at CERN," PhD thesis, University of Aalto, CERN-THESIS-2014-359, https://cds.cern.ch/record/2130258?ln=en

[7] D. Woog, "Inductive Adder for the FCC Injection Kicker System," PhD thesis, Darmstadt, Technische Universität, CERN-THESIS-2019-363, https://cds.cern.ch/record/2723499?ln=en doi:10.25534/tuprints-00011726