

ERADICATION OF MERCURY IGNITRON FROM THE 400 kA MAGNETIC HORN PULSE GENERATOR FOR CERN ANTIPROTON DECELERATOR

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Abstract

The CERN Antiproton Decelerator (AD) produces low-energy antiprotons for studies of antimatter. A 26 GeV proton beam impacts the AD production target which produces secondary particles including antiprotons. A magnetic Horn (AD-Horn) in the AD target area is used to focus the diverging antiproton beam and increase the antiproton yield enormously. The Horn is pulsed with a current of 400 kA, generated by capacitor discharge type generators equipped with ignitrons. These mercury-filled devices present a serious danger of environmental pollution in case of accident and safety constraints. An alternative has been developed using solid-state switches and diodes. Similar technology was already implemented at CERN for ignitron eradication in the SPS Horizontal beam dump in the early 2000s. A project was launched to design and set-up a full-scale test-bench, to install and test a dedicated solid-state solution. Following the positive results obtained from the test-bench, the replacement of ignitrons by solid-state devices in the operation AD-Horn facility is currently under preparation. This paper describes the test-bench design and results obtained for this very high current pulser.

INTRODUCTION

The AD magnetic horn is located in the AD target area, where the antiprotons are produced in order to be injected into the antiproton decelerator (AD) ring. Its main purpose is to focus the diverging antiproton beam generated in the production target.

The maximum current of 400 kA, which powers the horn, is produced from 18 parallel capacitor discharge circuits. They generate a half-sine pulse with a rise-time of 18 μ s. The 18 circuits are divided in 6 groups of 3 in enclosures (so called cubicles). Each circuit operates at a maximum voltage of 7 kV and is composed of power capacitors, a main switch and a freewheel diode with an energy dump resistor in series to ensure requested speed of current decay. So far, both the switch and freewheel diode are mercury-filled ignitrons. Such devices are less and less available from the market and present serious environmental issues. A modernisation of the power circuits with the replacement of ignitrons by solid-state devices has therefore been decided.

As a first step, the full-scale test bench to be recommissioned for the AD horn development is used to fully develop and test the replacement solution.

AD-HORN DESCRIPTION

A very low inductance stripline connects the AD horn to the 400 kA pulse generator. The power pulse is synchronized with the PS 26 GeV/c proton beam impinging on the target.

The nuclear interactions between the proton beam and the spallation material of the target are responsible for the production of secondary particles, among which antiprotons. The secondary particles emerge from the target with a large spectrum momentum and angular distribution. A fraction of the charged particles entering the magnetic volume generated in the horn can be deviated into a parallel beam towards the magnetic spectrometer in the target area which further selects the particle momentum to $3.57 \text{ GeV}/c \pm 3\%$. This volume is enclosed between two coaxial conductors, the inner conductor being responsible for carrying the current. The biconical horn shape of the inner conductor produces a toroidal magnetic volume between the two conductors where the entering charged particles are bent by the magnetic field and antiprotons are focused in the forward direction [1] (Fig. 1).

The magnetic horn inner conductor material is a high strength aluminium alloy chosen for its high tensile strength under dynamic stresses, since the horn should resist high mechanical loads and work in an intense radiation field. The thickness of the inner conductor has been optimized in order to be as small as possible to decrease the antiproton reabsorption (3.5 mm thickness in the neck and 1.4 mm in the wide end downstream).

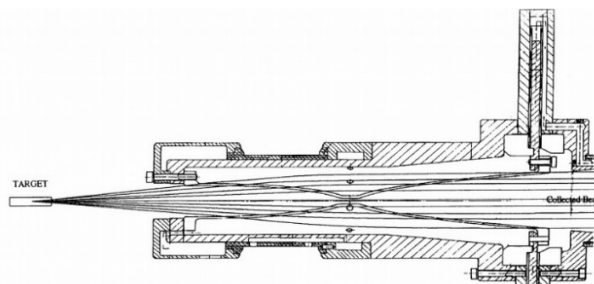


Figure 1: Horn assembly and schematic of beam focusing.

POWER GENERATOR

The full-scale test bench is identical to the operational system, consisting of 6 cubicles of 3 power branches each. However, the energy storage capacitors have 25% higher capacitance in order to allow tests with total current exceeding 400 kA.

For the solid-state version, the circuit layout and most of the generators have been kept. The main switch ignitron has been replaced by a stack of 4 Fast High Current Thyristors (FHCT), and the freewheel ignitron by a fast diode stack. The eradication of ignitron definitely improves the safety of the installation, avoiding risk of mercury leak during manipulation and evaporation in case of fire. The operation will be simplified, as ignitrons required infrared heating of the anode and oil cooling of the cathode. In addition, the use of semiconductors with sufficient derating will significantly reduce the probability of self-triggering.

The electrical schematic of a generator is shown in Fig. 2. The parallel power capacitors C_{11} and C_{12} are discharged by the main switch T_{11} . The freewheel diode branch R_{11} - D_{11} ensures controlled output current decay, reduces negative charging of the capacitors and de-energizes the circuit. A snubber circuit C_{31} - R_{81} has been added in order to avoid ringing and dangerous reverse voltage on the switch T_{11} in case one of the 18 parallel circuits does not switch on.

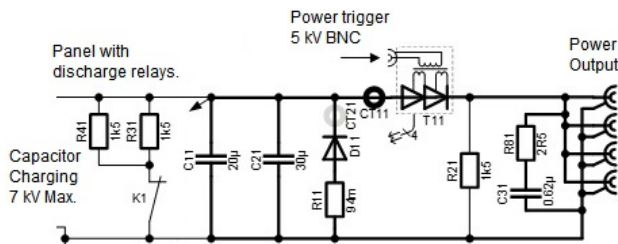


Figure 2: Simplified power generator schematic.

Main Switch

Fast High Current Thyristors (FHCT) have been chosen for their acceptable turn-on speed and capability to conduct required currents of more than 20 kA. The semiconductor switch consists of a stack of 4 FHCTs, together with snubber capacitors, a voltage divider and a trigger transformer (Fig. 3, top part). This stack has been developed at CERN in 2001 for the SPS horizontal beam dump sweeper [2] and has successfully been in operation since then.

In the present case, a stack of only 3 devices would be sufficient, but using the full the SPS stack allows the compatibility of spares and avoids the redesign of the trigger transformer.

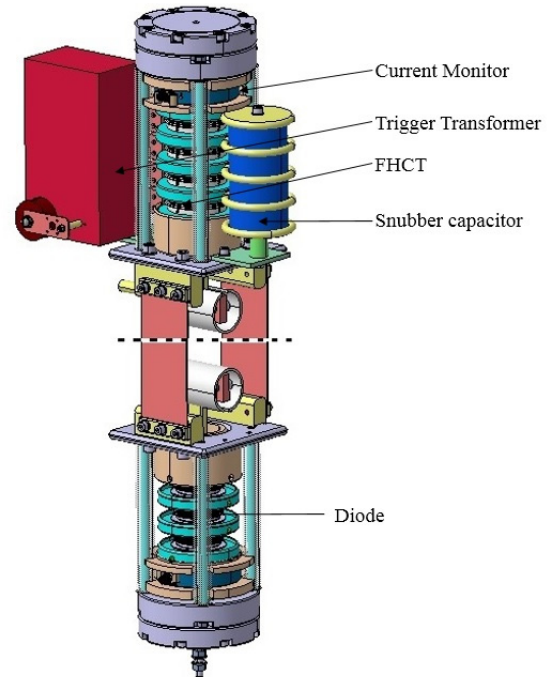


Figure 3: 3D model of an active branch.

Trigger Transformer

As the original design of the switch aims at a high reliability, a fully passive trigger transformer has been chosen. It was designed for the di/dt and the amplitude of the gate current and the gate pulse duration [2]. Identical coupling between the primary side of the transformer and each floating secondary winding is achieved by a primary being divided into four separate windings. They are connected in parallel, with each primary winding coupled to one of the secondary windings.

Diode

The most important parameter for the choice of the diode is the surge forward current for the pulse length. The device should withstand a maximum current of 23 kA during 60 μ s, which is easily obtained with the chosen diode as shown in the Fig. 4.

During our preliminary test the generator was tested up to 27 kA without any problem.

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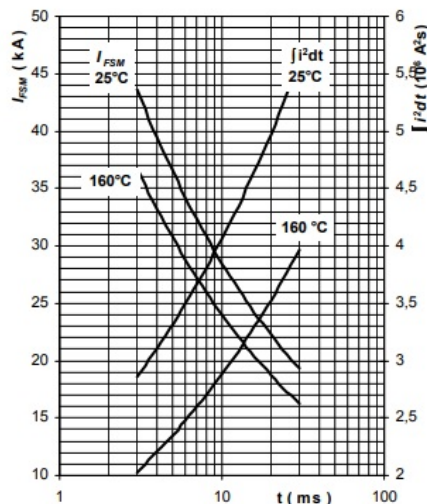


Figure 4: Surge forward current vs. pulse length.

TESTS RESULTS

All components for the 18 circuits have been installed and connected in the 6 cubicles of the test bench in September 2017 (Fig.5).



Figure 5: Cubicle with 3 active branches.

On the following month tests begun, first with the trigger circuit. As expected, the initial dI/dt of the gate current is $250 \text{ A}/\mu\text{s}$, with the peak current reaching 450 A , which represents 1.25 times the trigger transformer primary current. The power tests started with progressive increase of the charging voltage. So far, the system was successfully tested up to 5 kV , representing a switch current of 19 kA in each circuit and a total horn current of 340 kA . Some waveforms of a switch are shown in Fig. 6. A full description of the system and detailed test results are presented in [3].

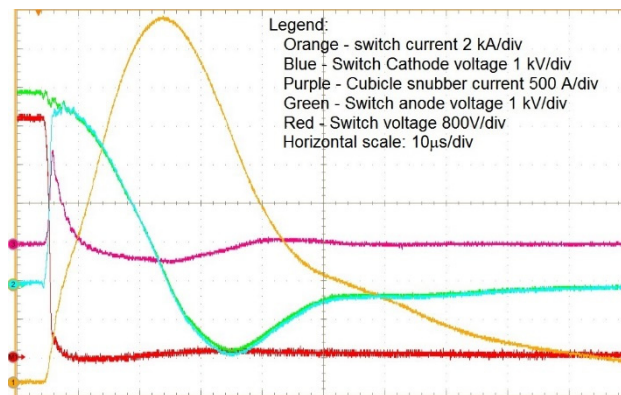


Figure 6: Switch Power test.

CONCLUSION

Solid-state devices that increase the safety level of the equipment and offer an easier operation with less maintenance can successfully replace ignitrons for the AD magnetic horn pulse generator. A full test bench is now working with a level of current close to the nominal operation and will still be increased above nominal. Following these positive results the eradication of ignitrons in the operational system is at this moment under preparation for installation during the CERN Long Shutdown 2 period.

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