DETAILED DESIGN, MANUFACTURING AND TESTING OF A STRIP-LINE EXTRACTION KICKER FOR CTF3 COMBINER RING *

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Abstract

The first calculations to design the CTF3 Combiner Ring extraction kicker are reported elsewhere. The last computing step before fabrication is the wakefield analysis, to determine if the bunch disturbance is acceptable. Two different codes have been used for cross-checking: CST Particle Studio and GDFidl. The computation is challenging because of the long structure (2.4 m) with a short bunch (3 mm). Besides, both transitions are not equal, as a result of different straight sections of the input and output beam pipe, and then the solution method is more complex. On the other hand, the main challenges for manufacturing are the long electrodes support by ceramic stand-offs and the flexible electrical connections to allow for electrodes thermal differential displacement. Special tooling has also been developed for assembly within the required tolerances. The device has been successfully leak tested. High frequency transmission coefficients and dielectric strength were also measured.

IMPEDANCE ANALYSIS

The first kicker calculations are reported in [1]. The last stage related with those calculations is the wakefield analysis [2]. This device will be installed in the CTF3 combiner ring (CR), to extract the recombined beam after four turns. This kicker is a very long device with internal discontinuities and, therefore, the impedance analysis constitutes a necessary calculation to avoid beam instabilities. Nevertheless, long range wakefield effects are not expected to be dangerous as they do not have enough time to resonate. Moreover, the structure is fully done in stainless steel and the quality factor of the resonant modes is very low. So that, even matched high order modes should quickly decay [3].

Simulations in GDFidl and CST Particle Studio were developed using several models. Since the device is very long (about 2.4 m, flange to flange) compared to the bunch size (sigma = 3 mm), the finite difference method commonly used in time-domain simulation must use plenty of elements in the sake of a good accuracy. Indeed, at least twenty elements per wavelength are needed to get good time-domain simulation. That yields an enormous memory requirement, not affordable by standard computers. That is why the problem was divided into smaller parts which were first studied independently: the input section (Fig. 1), the output section, and a full model using a higher sigma bunch, all of them using CST Particle Studio. The end cross section of partial simulations was modelled with an absorbing port to simulate an infinitely long structure, without wake reflection. All the models were configured with absorbing ports in the coaxials, which damps the wakefields for the coupled frequencies up to first hundred coax. modes.

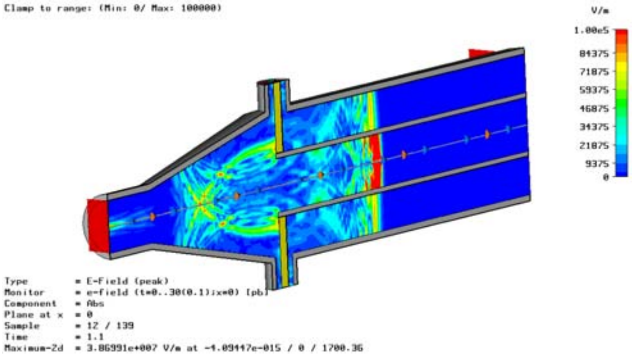

Fig. 1: Old input section simulation in CST Particle Studio

First Transition Calculations

Originally, the transitions between the beam pipe and the kicker chamber were done by two identical conical transitions (Fig. 1). The results of the wakefield simulations for this geometry were obtained in CST Particle Studio for longitudinal wakes (Fig. 2) and GDFidl for transverse wakes (Fig. 3).

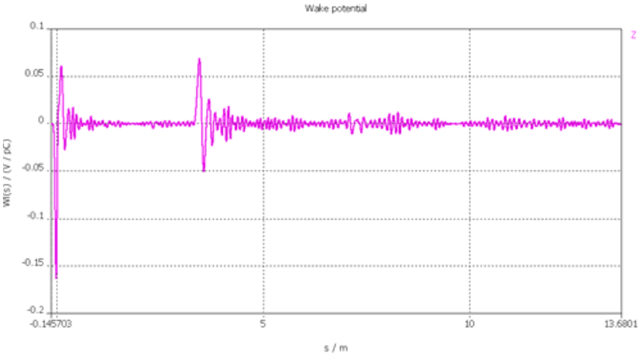

Fig. 2: Long range longitudinal wake in CST software

The absorbing effect of the simulation coaxial ports in the second reflection of the wake is clearly shown in Fig.2. The distance between the first two peaks is about twice the device length.

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No major problems are expected after analyzing wake impedances around resonating frequencies and, therefore, no high order mode damping seems necessary.

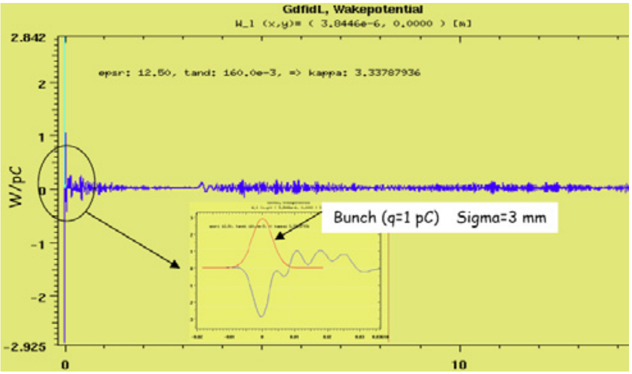

Fig. 3: Long range transverse wake in GDFidl

Definitive Transition Calculations

Due to some modifications on the ring layout, the definitive transitions are not symmetric. One half meter long conical transition was designed to fit inside a steering quadrupole aperture while improving the beam impedance. The other end was made with a short circular to racetrack transition.

Calculations using new transitions were only developed with GDFidl (Fig. 4) at CERN because of their complexity. Indeed, the required memory is even higher due to the new length of the device using the new transitions. Moreover, the CPU processing time is also higher because of the different input and output transitions, which makes the Shobuda-Napoly integration applied to 3-D [4] necessary for good precision.

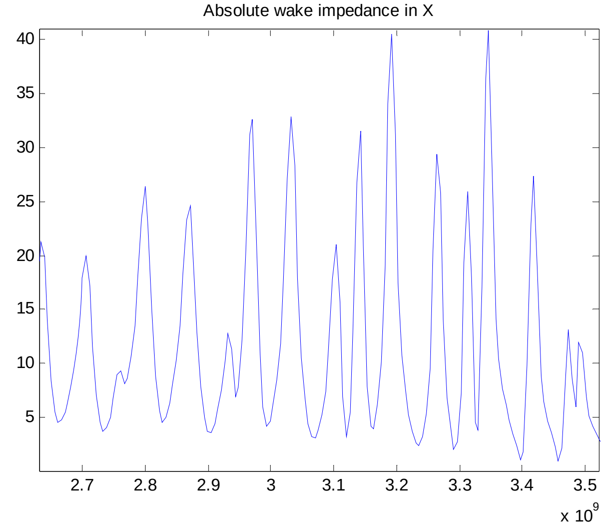

Fig. 4: Transverse wake impedance around 3 GHz

Analyzing these results, it can be concluded again that no major problems are expected in frequencies close to the beam frequency spectrum (3GHz and multiples).

MAIN FABRICATION CHALLENGES

It was necessary to address several problems during the manufacturing of the kicker, mainly related with mechanical aspects of the ceramic supports, electrode connections and welds. The manufacturing of the kicker was made by a Spanish company, named G&P Vacuum Projects.

Ceramic Supports

Five supports per electrode have been used for the kicker. Only the central one is fixed, the others are sliding to allow electrode thermal displacement. The insulating ceramic stand-offs are made of a ceramic material named steatite and they have low precision threaded holes. In order to achieve better binding to the kicker tube and improve support stiffness, a thermal interference fit method was used for the ceramics. The steatite was supported by an interference fit case screwed to a steel cap which is welded to the kicker tube (Fig. 5). The sliding supports have been provided with a copper washer between the ceramic and the electrode to reduce friction.

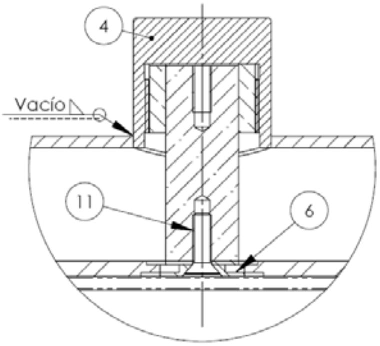

Fig. 5: Interference fit method for ceramics

Electrode Connections

A flexible connection between the feedthrough and the electrode is needed for possible mild bake out. Differential thermal displacement is not expected to be higher than 1.5 mm at each electrode edge (ΔT=100 ºC). The preferred connection method is a small piece of highly flexible copper cable fixed to a Ceramaseal set screw contact (Fig. 6).

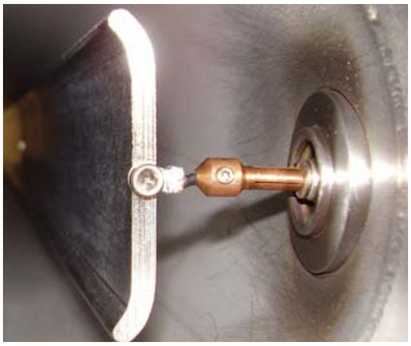

Fig. 6: Electrical connection of electrodes

Welding and Assembly

The kicker full assembly (Fig. 7) has a lot of vacuum welds, some of them not easy to do because of their dimension and/or precision. The vacuum welds between the kicker tube and the stand-off caps are quite challenging because of the steel contraction after welding, which can affect to the position of the electrodes. In the same way, the welds between the feedthrough and the kicker tube are also demanding. A dummy tube was used to test the weld contraction before actual welding and assembling the device.

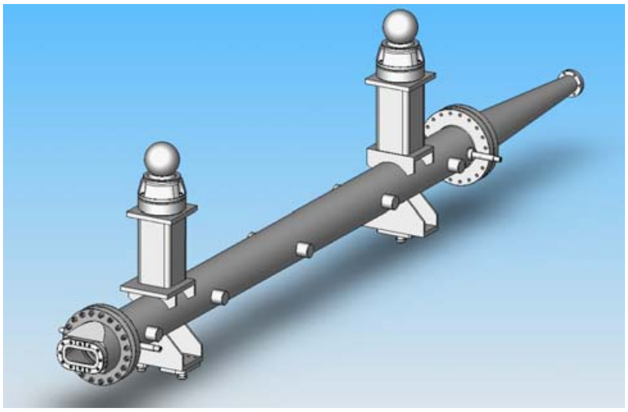

Fig. 7: 3D model of the final kicker

The assembly of the electrodes is not a straightforward process. A long special tool has been developed to hold the electrodes at the correct position before screwing the caps and final welding.

DEVICE TESTS

The tests include leak detection, RF measurements and High Voltage dielectric tests. The first test was done at the company, while the rest were done at INFN/Frascati.

Vacuum Tests

The leak detection was successfully done down to a value of $1.2\text{x}10^{-10}$ mbar.l/s. Concerning the vacuum limit, $2\text{x}10^{-7}$ mbar were achieved after 3 days pumping with a turbo pump prior to bake out.

The vacuum test was repeated at CERN when installing the kicker in the CR. A mild bake-out was needed in order to achieve the required level (10^{-8} mbar). The bake-out was done very slowly up to 100 ºC to avoid dangerous stresses in ceramics and electrode connections.

RF Tests

Both S-parameters measurements and high voltage pulser tests were carried out. The network analyzer RF tests returned low frequency S parameters as expected, with very low reflection up to 35 MHz (less than 0.2% of input power). This frequency range represents the pulse frequency content, which means good transmission of the pulser power. High frequency testing was a bit more challenging over 1 GHz because of problems with RF cables and hybrids specifications. However, results up to 1 GHz agreed HFSS simulations [1].

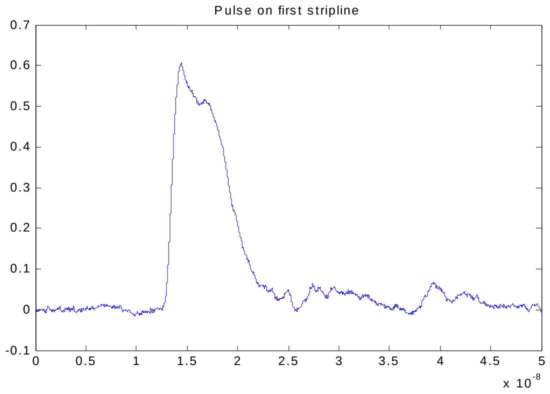

Fig. 8: Fast pulse after passing through the kicker

Fast high voltage pulser tests were also successful. The very fast pulse (~5 ns, 16 kV) that passed through the kicker was barely modified by the own kicker (Fig. 8), arriving at the 50 Ohm load loosing only frequencies over 2 GHz.

High Voltage DC Tests

Each kicker plate was tested up to 18 kV DC voltage (no current) in $2\text{x}10^{-7}$ mbar vacuum. No major problems were found in both strip-lines, only some sparks at the beginning of the test probably because of small impurities on the electrodes.

CONCLUSION

- Successful wakefield simulations have been presented. No major problems are expected.
- All the fabrication challenges have been solved and the know-how will be used in future devices.
- Kicker tests have reported good behaviour in vacuum, RF and high voltage subjects. The device has already been installed at the CTF3 Combiner Ring and it will soon be operating.

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