THE RF DEFLECTOR FOR THE CTF3 DELAY LOOP

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Abstract

In the CLIC Test Facility 3 (CTF3), a 42 m long ring, called Delay Loop (DL), is used to halve the distance between bunches in the drive beam. The compression is obtained by merging two adjacent bunch trains from the linac deflected in opposite directions by an RF device, in such a way that the first train is forced to perform a full revolution in the DL, while the second one passes through. The length of the ring is an odd multiple of half the distance between bunches in the beam from the linac. The RF deflector (RFD) consists of two identical cavities connected to the RF power source through a hybrid junction that equally splits the power and isolates the klystron from reflections. Its innovative design, the results of electromagnetic simulations and expected performances are described, together with low level RF measurements for test and characterization of the device before installation. Preliminary recombination results with the CTF3 beam are also shown. The RFD has also been used to measure the length of the accelerated bunches.

DEFLECTOR SYSTEM DESCRIPTION

The RFD is essential in the bunch frequency doubling process that takes place in the DL [1].

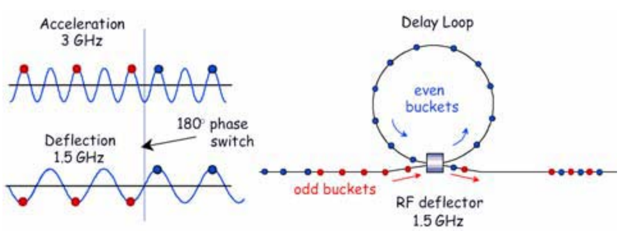

Figure 1: Sketch of the bunch frequency multiplication in the CTF3 Delay Loop.

Referring to the scheme illustrated in Fig. 1, the beam coming from linac is composed of an alternate sequence of so called even and odd trains, which differ for a 180° phase jump between each other. This sequence of 140ns long sub-trains is realized by a pre-bunching system. The RF deflector gives kicks of the same amplitude but opposite sign to the incoming even and odd trains. The even trains are injected into the ring and, after a turn, they are extracted and interleave with the following odd train.

The RFD system deflects of ±15mrad beam with energy up to 300MeV. The total train length is 1.4µs and the deflection given to the bunches is uniform within 1%. Peak power and duration of the RF pulses feeding the RFD are 20MW and 5µs respectively.

The RFD has been conceived [2] as two cavities fed by the same klystron through a 90° hybrid junction (HJ). Being the cavities $(1+1/4)\lambda_{RF}$ apart, where λ_{RF} is the free space wavelength at the RF frequency (1.499275GHz), the beam takes the same deflection in the two gaps. The cavity deflecting mode is the TM_{110}. The Q is determined by proper dimensioning of the input coupler and the chosen value results from a compromise between the needs to have enough shunt impedance and sufficiently fast rise time as response to the RF pulse. The cavities reflect back the incident power both during the transients (the resonance has finite bandwidth) and the flat-top of the pulse (the input coupling coefficient is $\beta \neq 1$). However the HJ isolates the klystron from this reflected power, while it is dissipated in the load.

DEFLECTOR DESIGN

All the waveguide components of the system have been manufactured by Mega Industries [3] and are WR650 standard products. They are reinforced to stand the 3 bar SF6 over-pressure. Only the HJ has been externally dimensioned to fit the separation between the two cavities. Four directional couplers have been inserted close to the cavities, the load and the klystron to have a monitor of the forward and reflected power.

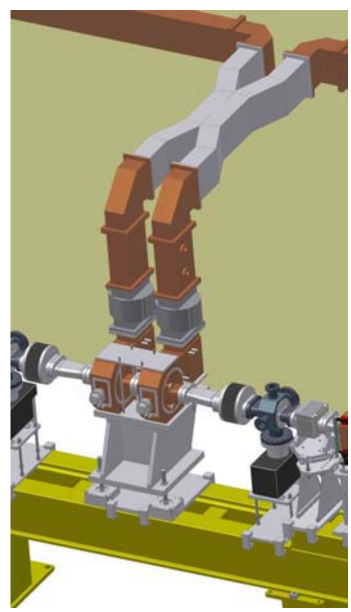

Figure 2: CAD drawing of the Delay Loop region with the RF deflector system.

In the drawing of Fig. 2 the two vacuum windows that separate the SF6 from the vacuum environments are also visible (in grey, flange coupled to the cavities). Their manufacture has been made by Thales [4] on the same design of the window on the klystron output. In the two branches between the cavity couplers and the HJ the RF wave configuration is partially standing, being the cavities over coupled. Then, for safety reasons, the window position has been chosen in correspondence of a minimum of the fields along the waveguide line.

The cavities (see Fig.3) have a pill-box shape with a rectangular beam pipe. The input coupler is realized with a section of WR650 waveguide terminated on a short circuit and it is placed to one side of the cavity.

Waveguide and cavity volumes communicate through a coupling hole. The position and the diameter of this hole determine the coupling coefficient β.

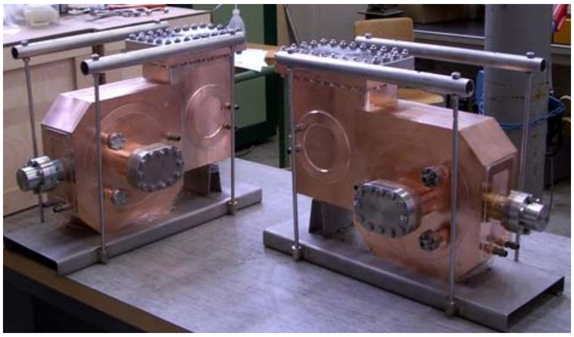

Figure 3: Picture of the two RF cavities of the deflector.

On the opposite side respect to the coupler, the cavities have a 15mm diameter cylindrical tuning plunger. It can be manually moved to vary its penetration into the cavity and to adjust the frequency of the deflecting mode. The frequency sensitivity to the tuner penetration is about 150 kHz/mm.

Two probes, which monitor the field inside the cavity, are placed on the external flat plate of each cavity.

The cavities have been completely designed with the HFSS code [5]

The cavities, fabricated in Poland by the A. Soltan Institute [6] according to the electromagnetic and mechanical design developed at Frascati, are made of OFHC copper and are provided with five coils where the water for temperature stabilization (30±0.1°C) flows.

TUNING UP AND MEASUREMENTS

The frequency responses of each component of the system have been measured to verify their correspondence with the design specification and with the results obtained from HFSS simulation code.

In particular, the most critical parameters, such as the phase relation and the balancing between the HJ output ports or the load SWR, have been verified to be within the specified tolerances.

Moreover, to optimize the isolation of the klystron from the reflected power, all the components connected to the two lower branches of the HJ (cavities, windows, bends and drift waveguides), must be as identical as possible, so that the impedance sees from those ports of the HJ is the same. For this reason an accurate tuning of the resonant frequency of the cavity operating mode is necessary.

The frequency response of each of the two cavities has been measured with a network analyzer connected between the input port (the klystron side port) of the HJ and the cavity probes. After the installation, with the vacuum pumps switched on and the temperature of the cooling water stabilized, the transmission response has been centred at the working frequency for both the cavities acting on the tuner penetration depth. In Fig. 4 the measured frequency response of one of the two cavities after its tuning is reported.

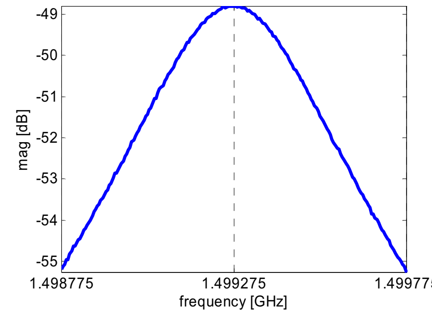

Figure 4: S21 from HJ input port to one cavity probe.

The cavity Q values are evaluated from S21 measurements as well; they differ for less than 7% but are within the range (3000-3500) fixed as requirement. The resulting cavity rise times are fast enough to limit the drop of the deflecting voltage along the 1.4 µs train at less than 1%. Fig.5 shows the time domain signal monitored from one cavity when the 5 µs RF pulse is applied. The voltage in the last 1.4µs of the pulse is flat enough.

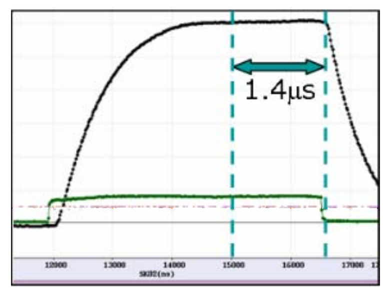

Figure 5: Cavity voltage vs. time with 5ns input pulse.

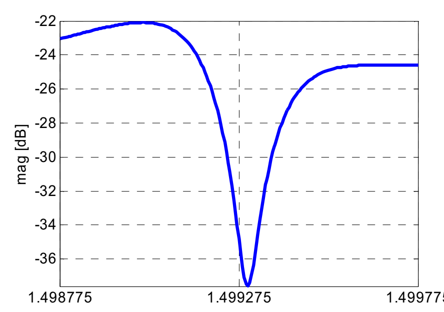

Figure 6: S11 HJ input port after fine tuning.

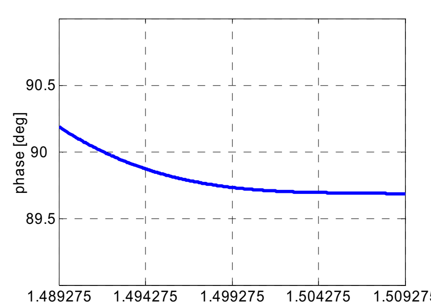

Figure 7: phase difference between the signals taken from the two cavities fed through the HJ.

In Fig.6 and Fig. 7 the reflection response at sinusoidal CW excitations measured at the HJ input port and the measured phase difference between the signals in the two cavities are shown respectively.

OPERATION PERFORMANCES

The RFD has been successfully used during the first phases of the DL commissioning. It started to work for a few days in November ’05 only for beam injection and extraction in and out the DL. In the following shift of operation, when the bunch trains from the linac had the right phase encoding and they are differentiated between even and odd trains, the recombination was soon obtained and then improved within the period of a couple of weeks.

Fig.8 illustrates the results of recombination procedure. The beam current, equally distributed along the ten incoming sub-trains, results almost doubled where the trains are recombined and near to zero elsewhere.

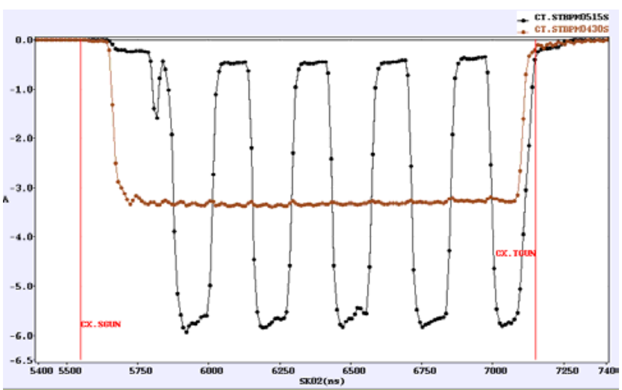

Figure 8: The beam current in the transfer line before the DL (brown) and after recombination (blue).

The RFD can be used as a diagnostic device to measure the bunch length: if the RF phase is 90 deg shifted respect to normal operation condition, the bunches cross the cavities where the field amplitude is zero and time derivative is maximum. Then the field in the RFD induces a strong correlation between particle longitudinal position in the bunch and transverse position after the kick; a measurement of the beam profile downstream of the RFD gives direct information of the bunch longitudinal length before the kick.

Fig.9 shows two beam images taken on the first OTR after the RFD when it was switched off and fed at 10 MW respectively.

Figure 9: Unprocessed bunch images. Left: RFD switched off. Right: RFD on, at zero-crossing phase.

If the phase is different from the zero-crossing condition, the even and the odd bunches receive deflections with opposite direction and the image presents two separated beam.

The images of Fig.9 and others obtained at different phases (±5°, ±10° and ±15°) have been processed [7] to get the measure of the bunch length that, at this stage of machine commissioning, results 5.45mm.

CONCLUSIONS

The RF Deflector system for the CTF3 Delay Loop is a non conventional device realized with two SW TM_{110} resonating cavities connected to the RF power source through a 90° Hybrid Junction. This device has the twofold function to feed with the right phase relation the cavities and to isolate the klystron from the power reflections. Very good results have been obtained from low power measurements, which have confirmed the predictions of simulations and the feasibility of this scheme.

The deflector has started to work successfully at about half of maximum input power since the energy of the beam has not yet reached the 300MeV upper limit. First results of the train recombination indicate that the deflector performances fulfil the expectations.

ACKNOWLEDGMENTS

All the CTF3 team at CERN has given a fundamental contribution to the realization of the deflector: several discussions with the project leader G. Geshonke and RF group people have led to the definition of parameters; special thanks to G. Mc Monagle and G. Rossat for the technical information about plants and the logistic support and S. Mathot for the suggestions concerning the brazing procedure.

As in the case of the Combiner Ring deflector, the collaboration with Soltan Institute for the fabrication of the cavities has given very good results.

Thanks also to D. Filippetto e B. Preger for the post-processing of the raw images of the beam in the bunch length measurement.

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[2] F. Marcellini, D. Alesini “Design Options for the RF Deflector of the CTF3 Delay Loop”, EPAC’04, Lucerne, July 2004, p. 689, http://www.jacow.org.

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[7] D.Filippetto and B. Preger: *private communications.*