DESIGN OF THE PALMER PICKUP FOR STOCHASTIC PRE-COOLING OF HOT RARE ISOTOPES AT THE CR

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Abstract

We report on the design of a Faltin type pickup for the stochastic pre-cooling of rare isotope beams at 740 MeV/u, using a bandwidth of 1-2 GHz, for the Collector Ring (CR) in the FAIR project at GSI. The design difficulties inherent in Faltin rails at these frequencies are described. Measurements of prototypes and HFSS simulations are compared, to check the simulations, and show good agreement. The pickup impedance and signal output phase with respect to ions traveling at 0.83c are simulated and presented for the final design both with and without the use of damping material, showing the need to damp unwanted modes present in the beam chamber.

INTRODUCTION

The CR is designed for 6D stochastic cooling of antiprotons at 3 GeV or rare isotopes beams (RIBs) at 740 MeV/u [1]. The CR stochastic cooling system will operate in a frequency band of 1-2 GHz. For the noise-limited antiproton cooling, slotline pickups and kickers are foreseen [2]. RIB cooling in the CR is limited by the undesired mixing for which the Schottky bands overlap, so that only the Palmer method [3] can initially be applied. After the momentum spread is decreased so as to fit into the acceptance of the notch filter, cooling will proceed with the slotline pickups down to the final beam quality. The RIBs must be cooled from $\varepsilon_{xy} = 35$ mm − mrad and $\delta p/p = 0.2\%$ to $\varepsilon_{xy} = 0.125$ mm − mrad and $\delta p/p = 0.025\%$ (all values are 1 σ values) within 1.5 s.

6D Cooling at the Palmer Pickup

The Palmer pickup is placed at a point of high dispersion in the ring so as to fulfill momentum cooling as envisioned by R. Palmer in 1975, private communication. The signals at the pickup are combined so as to extract vertical error signals and combined horizontal and longitudinal error signals as shown in Fig. 1. Figure 1 also shows an added time of flight (TOF) option for longitudinal cooling.

The Palmer pickup tank will be equipped with Faltin type pickups which are favorable due to their low number of feedthroughs, robustness and ease of manufacture.

Faltin Electrode

The Faltin electrode [4] is a rectangular coaxial waveguide with slots which couple to the beam. Figure 2 shows a diagram of a section of the Palmer pickup tank containing four Faltin rails intended for horizontal and vertical difference measurements. Figure 2 also shows the horizontal and vertical beam apertures of 400mm and 132mm respectively,

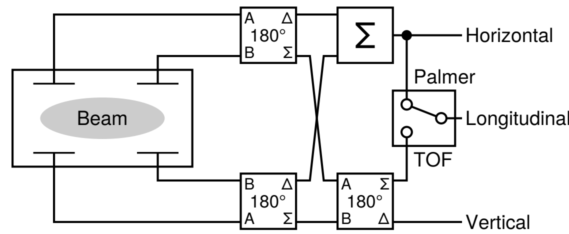

Figure 1: Diagram of the Palmer cooling method (including an optional TOF method) as foreseen in the CR showing the combination of signals in sum and difference modes.

and the position ferrite absorbing material needed to damp unwanted modes in the beam chamber.

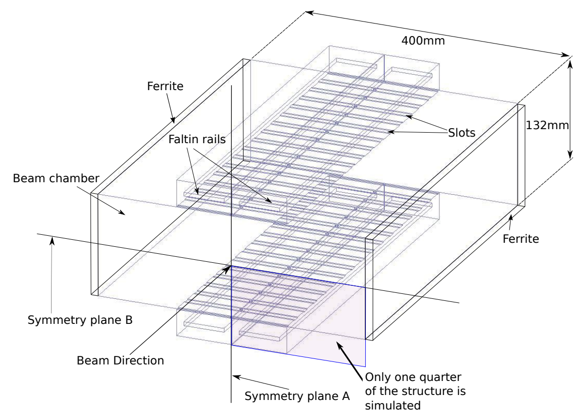

Figure 2: Diagram of a section of length of the Palmer pickup showing Faltin rails, beam chamber, ferrite absorbing material and symmetry planes used during simulations.

The wave in the pickup induced by the beam travels parallel to the beam and at the same velocity such that induction from beam to waveguide through each slot adds constructively. Therefore, in a Faltin type pickup (or any traveling wave pickup), it is crucial that the phase velocity in the waveguide approximately equals the particle velocity across the desired frequency band of operation.

Previous work on these type of pickups has included analytical approaches to calculating the coupling and the characteristics of induced waves [5, 6]. Experimental results were later published for a slot to TEM type pickup [7]. In addition, simulations using HFSS have been performed on similar structures for use in the SPS at CERN [8].

Pickups for stochastic cooling require an output signal with a large but flat amplitude over the band, and a linear phase with respect to the particle. The larger the amplitude

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of a pickup output signal the faster the cooling can be. The more linear the pickup output signal is with respect to the particle the easier it is to correct allowing a kick to the particle to be made with the correct phase, again leading to faster cooling. In order to design and optimize pickups, a coupling impedance can be defined, which is proportional to output signal amplitude and can be defined as

$$Z_{pu} = \frac{P_{pu}}{I_b^2} \quad (1)$$

where P_{pu} is the power from the pickup and I_b is the current in the beam. The amplitude and phase of the relevant signal is contained within P_{pu}. Both the coupling of the waveguide to the beam (through the slots), and the phase velocity of the wave in the waveguide as a function of frequency determine the output signal amplitude. Therefore Z_{pu} and phase are the primary parameters to be optimized.

In general, the Faltin rail suffers from the fact that as Z_{pu} is increased the phase of the associated signal becomes more non linear with respect to the particle. In our case, we are limited by electrical length between pickup and kicker, meaning there is limited space allowed for phase correctors. Therefore we limited ourselves to a maximum non linear phase deviation of approximately 40° at the pickup output. Within this limit, our task was then to maximize Z_{pu}.

An advantageous modification was to split each rail into two sections and combine the signals outside the vacuum, such that approximately the same Z_{pu} would be attained but with half the non linear phase deviation. Although this modification would increase the number of vacuum feedthroughs from 8 to 16, it is necessary to gain acceptable values of Z_{pu} and phase.

The large size of the aperture in the Palmer tank (see Fig. 2) supports strong TM modes within 1-2 GHz which interfere with the horizontal and vertical difference signals and must be damped. To damp these unwanted modes, lossy ferrite TT2-111 from Trans-Tech will be used. Ferrite is placed far from the rails (see Fig. 2) so as not to damp wanted signals.

PICKUP SIMULATION METHOD

The pickup is designed as a kicker (which is possible due to reciprocity between kicker and pickup) using High Frequency Structural Simulator, HFSS [9]. A power of 1 W is input into the waveguide and the accelerating voltage is found by integrating the electric field along a particle trajectory above the slots. The input power and voltage then yield the kicker impedance, Z_k, which is then converted to Z_{pu}. Only one quarter of the pickup is simulated as indicated in Fig. 2. Although the pickup is a horizontal and vertical difference pickup, when simulating as a kicker it is necessary to determine the longitudinal kick. Choosing planes A and B (see Fig. 2) as electric and magnetic field symmetry planes respectively, forces a particle on symmetry plane B to feel a longitudinal kick, and also corresponds to a pickup in horizontal difference mode.

While simulating as a kicker, to extract phase one measures the phase of the integrated accelerating electric field, experienced by a particle, with respect to a plane wave traveling at the velocity of the particle. To find the nonlinear components of the phase data with respect to the particle a straight line is fitted between 1 and 2 GHz only, and then subtracted.

RESULTS

Figure 3 shows pickup impedance and phase with respect to the particle per unit length for two different Faltin rail structures. The relevant dimensions of the structures are detailed in Table 1.

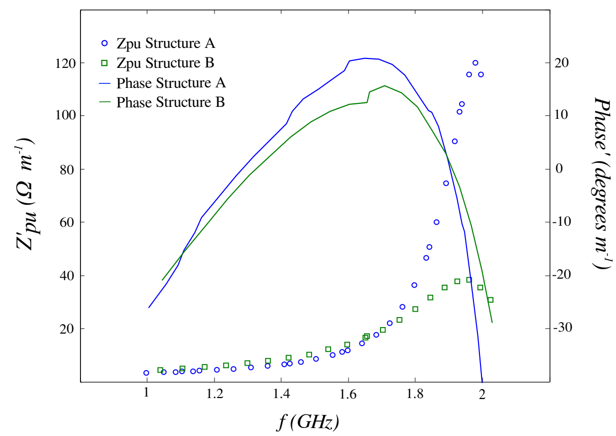

Figure 3: Pickup impedance and nonlinear phase deviation per unit length for two different designs of Faltin rails, structures A and B.

Table 1: Faltin Rail Dimensions for Structures A and B

Structure	A	B
Slot length	30.1 mm	10 mm
Slot width	65.7 mm	50 mm
Cell length	43.9 mm	15 mm
Inner Conductor width	59.7 mm	36 mm
Inner Conductor thickness	5 mm	5 mm
Outer Conductor width	65.7 mm	60 mm
Outer Conductor height	34 mm	35 mm

The maximum pickup impedance per unit length, shown in Fig. 3, is $Z'_{\mathrm{pu}} = 120\,\Omega/\mathrm{m}$ and $Z'_{\mathrm{pu}} = 40\,\Omega/\mathrm{m}$ for structures A and B respectively, which both occur at approximately 1.97 GHz. If these structures were used to fill the available tank space (1.47m), structures A and B would result in total pickup impedances of $Z_{\mathrm{pu}} = 177\ \Omega$ and $Z_{\mathrm{pu}} = 59\ \Omega$ respectively.

Between the frequencies of 1.64 GHz and 1.99 GHz, Fig. 3 shows a maximum nonlinear phase deviation of 63.4°/m and 32.6°/m for structures A and B respectively. If these structures were used to fill the available tank space, the total

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non linear phase deviation would be 93.45° and 48.05° for structures A and B respectively.

Figure 3 therefore shows that structure A has a larger pickup impedance but a worse phase, while structure B has smaller pickup impedance but better phase. The reasons for this can be seen in the structures dimensions shown in Table 1 which shows that structure A has a much larger slot size relative to structure B which increases the coupling to the beam, increasing the pickup impedance. The larger slot size also has the effect of decreasing the phase velocity in the waveguide. To compensate this, the size of the inner conductor of structure A was increased resulting in a small gap between inner and outer conductor of approximately 3mm. This small gap alters the TEM mode of the waveguide more towards a quasi-TEM mode, which results in a rapidly varying phase when operating near cutoff.

In order to test initial designs and the accuracy of HFSS, prototypes of the pickup were made and tested. Figure 4 shows a photograph of one such prototype.

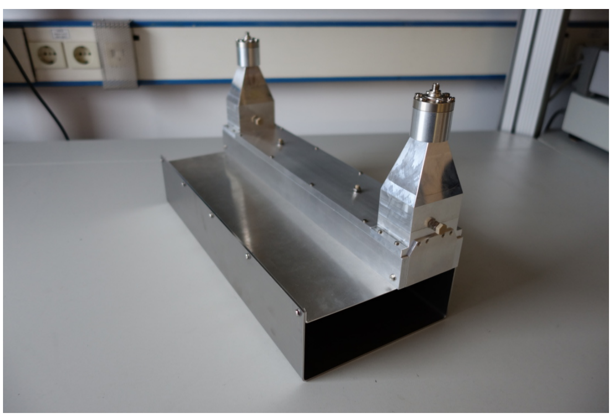

Figure 4: Photograph of a prototype made to test the design and the accuracy of HFSS. The prototype is only one quarter of the full pickup.

Figure 5 compares measurements of transmission coefficient made using a network analyzer on the prototype shown in Fig. 4 and lossless simulations made using HFSS. Figure 5 shows that there is general agreement between HFSS and measurements of the prototype apart from a difference in magnitude which is due to the fact that the simulation was lossless. Figure 5 also shows a divergence in agreement between the two traces at higher frequencies which can be attributed to small physical differences (bad connectors for instance) between the prototypes and the HFSS model which have larger effects at smaller wavelengths.

Due to the fact that we are limited by electrical length (which is a physical limit) rather than cooling time (which is a requirement), the structure with the smallest nonlinear phase deviation, structure B, was chosen. Allowing additional length for impedance matching pieces, a maximum number of 98 slots of structure B can be fit in to the available tank space. Therefore the final design of the Palmer pickup tank consists of two Faltin rails (in each quadrant) comprising

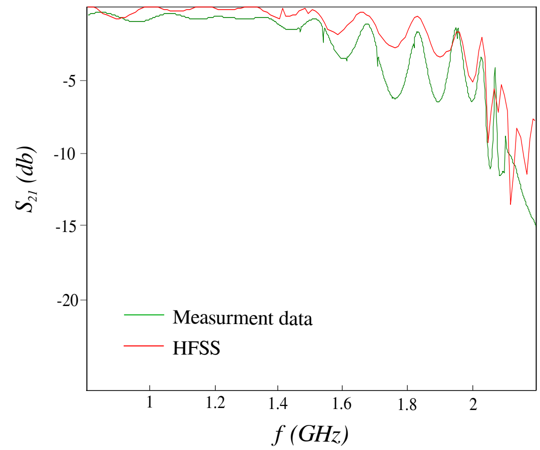

Figure 5: Comparision of transmission coefficient, S_{21}, from prototype measurments and HFSS simulations.

49 slots each, of dimensions of structure B, whose pickup signals will be combined.

Figure 6 shows the total combined pickup impedance and phase, from simulations, for the final design both with and without the presence of lossy ferrite.

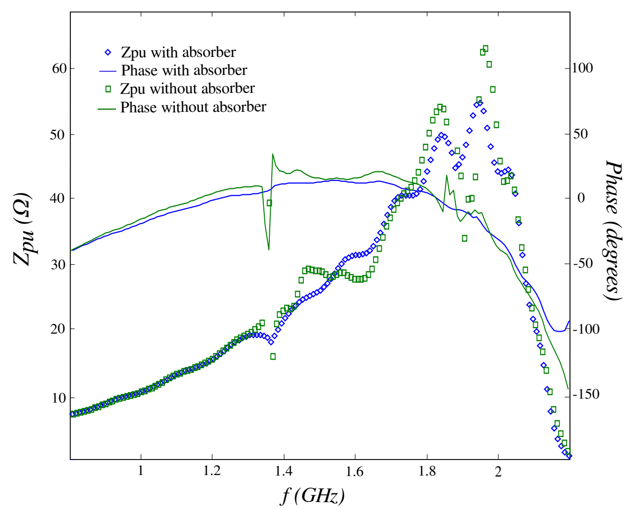

Figure 6: Pickup impedance and nonlinear phase deviation for Faltin rail structure B consisting of two rails of 49 slots each whose signals have been combined. The performance both with and without the presence of ferrite damping material is shown. Simulations are done with a beam centred vertically and with horizontal offset of 40 mm.

When lossy ferrite is added Fig. 6 shows maximum and minimum pickup impedances of Z_{pu} = 54 Ω at 1.94 GHz and Z_{pu} = 10.24 Ω at 1 GHz respectively. Figure 6 also shows that when lossy ferrite is used to damp unwanted modes the pickup produces a maximum nonlinear phase deviation of 44.2° between 1.57 GHz and 2 GHz.

Figure 6 shows that the Z_{pu} with and without a ferrite absorber are comparable. However, the case without the

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ferrite shows increased interference with unwanted modes at 1.38 GHz and 1.9 GHz which can also be seen in the phase data. The nonlinear phase component shown in Fig. 6 without the ferrite shows rapidly changing values at 1.38 GHz and 1.9 GHz which is undesirable for the stochastic cooling system. In addition the ferrite also damps other unwanted modes not included in the simulation results shown in Fig. 6 such as in the vertical difference mode case or travelling waves from adjacent tanks.

The output signal phase of the pickup would benefit by further splitting the rail into rails of less slots and adding the signals. However, this would require more feedthroughs, extra design, and is not necessary.

CONCLUSION

The problem of increasing nonlinear phase deviation with respect to particle when increasing the pickup impedance of Faltin rails has been shown. Transmission coefficient measurements of prototypes were shown to give good agreement to HFSS simulations indicating the simulation results to be reliable. Due to limitations of nonlinear phase deviation of output signals, pickup impedance was sacrificed, and an acceptable final design was chosen consisting of two separate rails whose signals will be combined outside the tank. The simulation results for the final design were shown with and without the presence of damping material indicating interference between wanted and unwanted modes in the beam chamber. The design including ferrite comprises an acceptable nonlinear phase deviation and pickup impedance for the stochastic pre-cooling of heavy ions in the CR. The design stage of the pickup is finished and is now entering the fabrication and testing stage.

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