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BEAM MEASUREMENTS OF A PALMER PICK-UP FOR THE COLLECTOR RING OF FAIR

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Abstract

The stochastic cooling system of the **C**ollector **R**ing (CR) of the future FAIR facility will have three **p**ick-**u**p (PU) tanks and two kicker tanks. For the pre-cooling of very hot RIBs, a pick-up tank with eight Faltin-type structures for Palmer-cooling has been constructed by GSI. The structures have been designed using **H**igh-**F**requency **S**tructure **S**imulator (HFSS).

The Palmer PU tank has been tested with $\beta = 0.83$ proton beams at the **Co**oler **Sy**nchrotron (COSY) of the FZJ. This publication presents the results of measurements with beam and compare them with simulations (HFSS and Microwave Studio).

The pick-up operates at room temperature. But it has artificial cold loads instead of normal terminators. The results of the noise temperature measurements are also be presented.

PALMER PICK-UP

For very hot rare isotope beams, the distance from the slotline pick-ups to the kickers is too large. The undesired mixing prevents cooling. Therefore a Palmer pick-up with smaller distance to the kicker permits an high acceptance for the start of the cooling cycle.

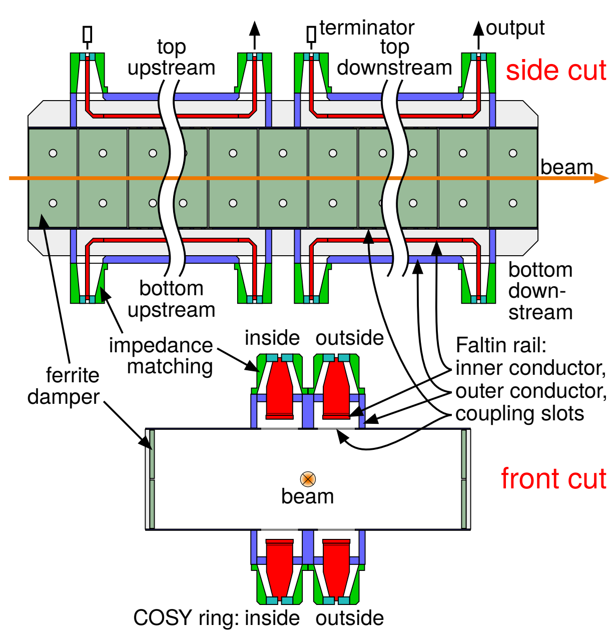

Figure 1: Layout of the Palmer pick-up tank.

Figure 1 shows the schematic layout inside the palmer pick-up tank. It uses Faltin type structures for coupling and has been developed using HFSS FEM field calculation program [1]. Faltin rails show an high dispersion. To archive an octave bandwidth the four long rails of the Palmer arrangement, the rails are divided into identical upstream and downstream parts. A lot of ferrite material (Ferroxcube 4S60) has been installed to damp undesired wave modes. The dampers are on the side walls, far from the coupling slots, to avoid reduction of the shunt impedance.

MEASUREMENT SETUP

To verify the design performance, the CR Palmer pick-up tank has been installed in the COSY ring, as shown in Fig. 2. We have used stored proton beams for our experiment. The beams were weakly bunched to allow the **b**eam **p**osition **m**onitors (BPM) to work. Table 1 shows the parameters typically used here.

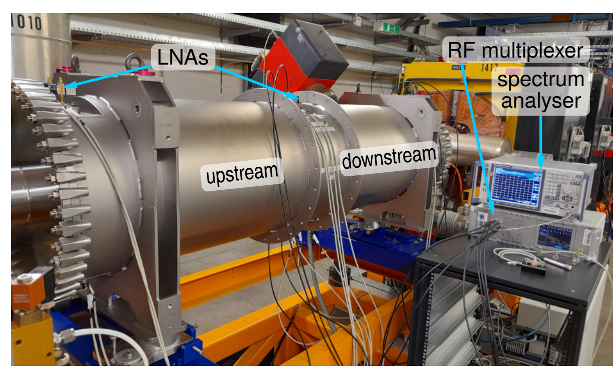

Figure 2: CR Palmer pick-up tank installed in COSY ring.

Table 1: Typical Beam Parameters

velocity factor	$\beta = 0.830$
number of protons	$N = 1.7 \cdot 10^{10}$
(measured for each run)	
beam dimensions	$\Delta x = 5.3\,\mathrm{mm}$
	$\Delta y = 3.9\,\mathrm{mm}$
dispersion at Palmer-PU	$D = 0\,\mathrm{m}$
RMS momentum spread	$\Delta p/p = 2.2 \cdot 10^{-4}$

For the measurements, the tank has been equipped with all eight Faltin rails and the low noise amplifiers (LNAs), but without the subsequent Palmer signal processing. Figure 3 shows a block diagram of the measurement setup.

To prevent additional noise from cable damping, the low noise amplifiers (LNAs) were installed directly on the vacuum feedthroughs. The LNAs at the outputs of the Faltin rails were used as normal amplifiers for the Schottky signals.

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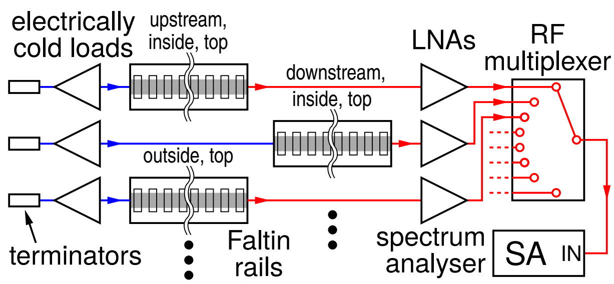

Figure 3: Measurement setup.

The inputs of the Faltin rails have to be terminated, normally by resistors. Instead of this, we have terminated it by inputs of additional LNAs. The noise power density dP/df of a normal resistor as terminator is the product of the Boltzmann constant k_B and the absolute temperature T. Due to the second law of thermodynamics this is true for passive devices. An active circuit can behave like a noise source with different noise power density. Due to the internal negative feedback, the input of an LNA can behave like a noise source with much lower noise power density [2]. The installed LNAs (Miteq AFS3-01000200-07-10P-GW-APM) have a specified noise figure $NF \leq 0.7$ dB. The measured values are 0.4 to 0.65 dB in the frequency range 1 to 2 GHz. This corresponds to a noise temperature of 28 to 47 K.

A remote controlled RF multiplexer selects measurement signal from the main control room. The spectrum analyzer (Rohde & Schwarz FSV) is also remote controlled.

MEASUREMENT AND DATA ANALYSIS

We have tested the pick-up with different beam positions and some β-variations. For each beam setup and each Faltin rail we have recorded 220 spectrum sweeps with center frequencies from 0.3 to 2.3 GHz at harmonics of revolution frequency. Table 2 shows the parameters.

Table 2: Spectrum Analyzer Parameters

sweep span	1.5 MHz
points	1001
resolution bandwidth	10 Hz
video bandwidth	20 Hz
detector	RMS

The raw data are a composition of characteristics of the pick-up and measurement setup. We have removed the errors from the frequency depending damping and gain of most RF components. Errors due to reflections are not considered.

The gain curves of the LNAs have been measured for each individual device. For the cable from the amplifiers to the RF multiplexer (3 m Suhner SX04272D-02) we have considered a measured attenuation curve of a typical cable. For the cable from RF multiplexer to spectrum analyzer (50 cm Semi-Flex .141) we have assumed the attenuation curve from data sheet. For the transmission path of the multiplexer together with both cables we have measured the attenuation at 1 GHz using a power meter (Rohde & Schwarz NRX with test generator option NRX-B1 and power sensor NRP18S).

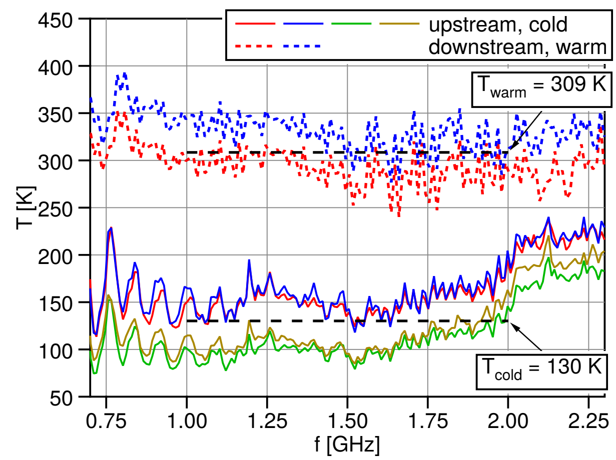

Figure 4: Noise temperatures.

The power per point values from the spectrum analyzer have been translated into spectral power densities. The filter response of spectrum analyzer has been checked with the test generator. The power density curves are a composition of noise and Schottky signals.

To get the frequency dependent noise temperature we have calculated the mean spectral power density without the main and side peaks of Schottky signal. Divided by k_B this is the temperature of a normal resistive terminator at the input of a noise free amplifier. This means, the noise of the LNA at output is included in the calculated noise temperature.

For the shunt impedance calculation we have subtracted the mean noise around each harmonic. The integral over the main and side peaks gives the line power P_{line}. The longitudinal shunt impedance $R_{\|}$ in circuit convention for N protons (q_e) circulating with revolution frequency f_{rev} is

$$R_{\|} = \frac{P_{line}}{2 \cdot N \cdot (q_e \cdot f_{rev})^2}. \quad (1)$$

ELECTRODYNAMIC FEM CALCULATION

We have made simulations using **M**icro**W**ave **S**tudio (MWS). The pick-up has been simulated as kicker in time domain with subsequent FFT. For arbitrary beam positions we used the full geometry. The model includes the impedance matching cones but not the ferrite dampers. For cross checking we also have made a simple quarter structure HFSS calculation in frequency domain without the matching cones.

RESULTS

To test the efficiency of the artificial cold terminators, we had installed LNAs at the inputs of the four upstream Faltin rails and normal passive terminators at the two top side downstream rails. The rails at the bottom side had a problem which could not be fixed quickly. Figure 4 shows the results of these measurements.

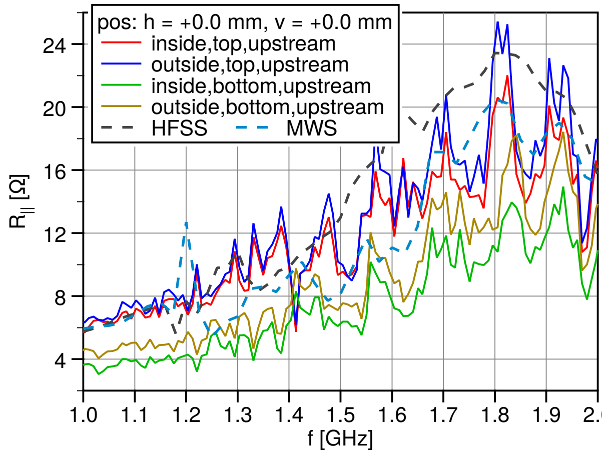

Figure 5: Shunt impedance with beam on axis.

The mean noise temperature of the four artificial cold rails in our frequency range is 130 K. This has been achieved with all components at room temperature. The contribution of the LNAs at the inputs and outputs is approximately between 56 to 94 K. The remaining noise is from losses of the Faltin rails, matching, and feedthroughs. As expected, the normally terminated rails have a noise temperature above the room temperature.

To test the pick-up and to verify the calculations, we have made single rail measurements with different beam positions and β-variations. All values are longitudinal pick-up shunt impedances in circuit convention. The shunt impedance values of the whole tank would be 8 times these values. The Palmer mode is not part of this publication. Figure 5 shows the measurements with beam on axis compared with HFSS and MWS calculations. There is a good agreement with MWS and a reasonable agreement with the simpler HFSS calculation. No electrical adjustments has been done. Therefore, a beam on mechanical axis is not exactly on electrical axis.

Figure 6 shows the results for some of the measurements with beam off axis. The measurements also have a good agreement with MWS. Finally, Fig. 7 shows results from β variation. From the point of magnitude, the PU is still usable for these β values, but phase could not be measured.

CONCLUSION

The CR Palmer pick-up for FAIR has been tested successfully in the COSY at the FZJ. The presented measurement results show a good agreement with simulations. The active artificial cold loads work as expected.

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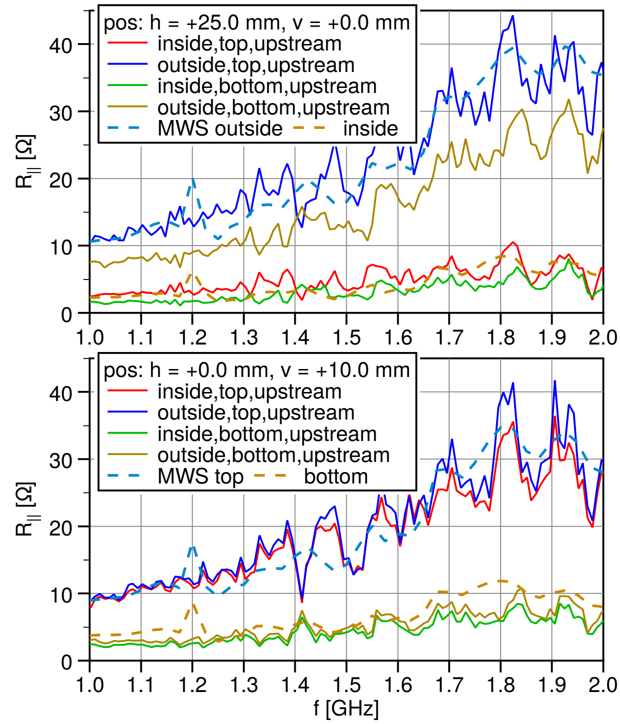

Figure 6: Shunt impedance with beam off axis.

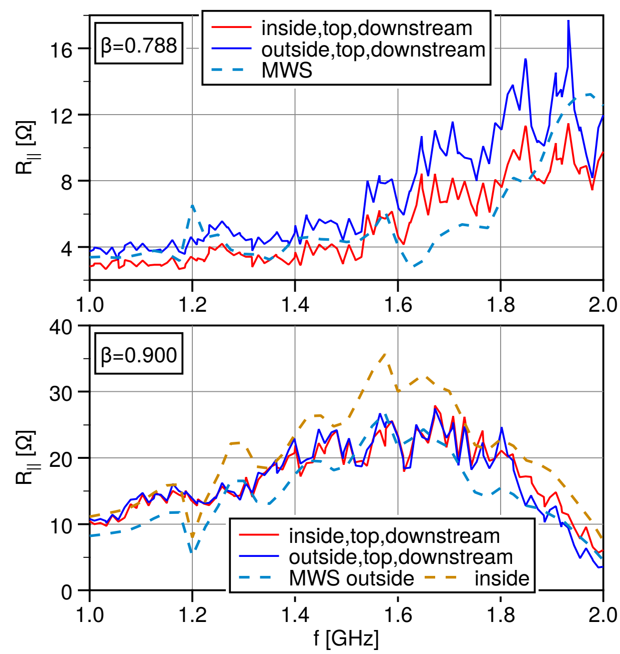

Figure 7: Shunt impedance with β variation.

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