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A LONGITUDINAL KICKER CAVITY FOR THE BESSY II BOOSTER

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Abstract

As part of the global refurbishment of the injector at BESSY II, a new longitudinal kicker cavity and suitable feedback will be installed in the booster. Both a flexible bunch charge and spacing is essential for efficient injection. Such a cavity is needed to mitigate the unwanted coupled bunch instabilities associated with these elaborate filling patterns and the HOMs of additional accelerating structures. This paper covers the conceptual design, simulation strategy, manufacture and bench tests of the longitudinal kicker cavity before it is installed in the ring.

MOTIVATION

In a familiar fashion that characterized 3rd generation light sources across the world, injection into the BESSY II storage ring is from a low energy linac followed by a full energy booster synchrotron.

The present injection scheme is highly reliable [1], but a global upgrade is necessary for the BESSY VSR project [2]. The most prominent aspect with respect to the injector is the evidence that the bunch length on injection into the storage ring needs to be reduced from its present value, by at least a factor of two in order to keep the high injection efficiencies.

The preferred method to produce shorter bunches from the booster is an upgrade of the existing 500 MHz RF system. Two additional 5-cell PETRA cavities each driven by 80 kW transmitters have been purchased. In terms of beam commissioning, slowly increasing the total RF gradient each year by installing the additional cavities one after another, is a subtle way to actively control and diagnose the beam in all dimensions.

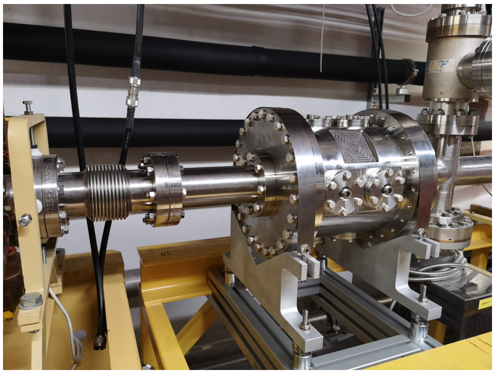

Figure 1: Longitudinal kicker cavity installed in the booster.

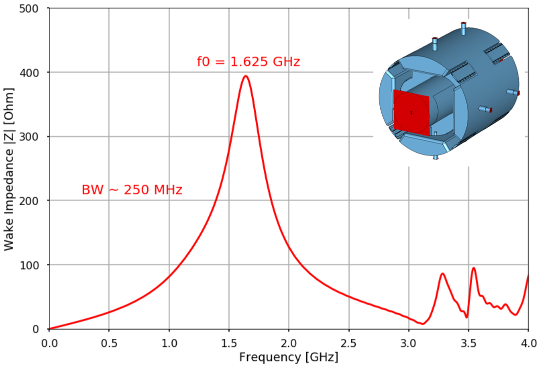

Figure 2: Longitudinal wake spectrum of the kicker cavity. Insert shows the vacuum model used for optimization.

The 5-cell PETRA cavities were developed without supplementary features to reduce unwanted HOMs. Installing such cavities will lead to higher ring impedance and enhance the longitudinal instabilities resulting in a larger effective emittance of the multi-bunch injection that we already witness in the booster [3]. A longitudinal kicker cavity, Fig. 1 was installed to mitigate these supplementary problems.

DEVELOPMENT OF DESIGN

The use of overloaded cavities and active feedbacks to compensate longitudinal instabilities at both the BESSY II and MLS storage rings is long established. [4] details the excellent performance at both storage rings and the additional bunch-by-bunch features the beam users could take advantage of. The cavity hardware presently installed at BESSY II was first commissioned almost two decades ago. Since the first design in 1995 at *DAΦNE* [5] the overloaded cavity has been modified and optimized to suit most light sources across the world. The base design for the longitudinal kicker to be installed in the booster was that used at Diamond Light Source (DLS) [6]. This design is an amalgamation over the years of high end computer simulations and multi-objective optimization to produce a low-Q, broadband device with little impedance at high frequencies suitable for modern storage rings.

The noticeable design modifications from the DLS baseline are that the beam pipe in the booster is round not tapered and the field enhancing nose stubs have been removed. The simulation strategy was based on optimizing each of the three main components consecutively. First the resonator is tuned to a fundamental frequency f_0 of 1.625 GHz, Fig. 2 (the upper band of the third RF harmonic). Next the feedthroughs and loaded waveguides were added to the model to optimize their positions with respect to each other and the resonator

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to obtain the required large bandwidth of 250 MHz. After fine tuning the final design was implemented into a CAD ready for manufacturing. This process was re-iterated to check for miss-matches in the models, and in addition a perturbation analysis was undertaken to estimate the machining tolerances to be used in the specification for the call for tender.

SITE ACCEPTANCE TESTS

The longitudinal kicker cavity was manufactured by the company FMB Feinwerk- und Meßtechnik GmbH in Berlin [7]. The electrical properties of the feedthroughs, bought from a third party, were tested using a Vector Network Analyzer (VNA) on delivery to FMB and after the extension of the inner coupler as a means of quality control. The complete cavity was vacuum tested and delivered on-time to HZB.

During the site acceptance tests, the S-parameters from all the ports were extensively investigated and compared to the CST [8] simulations. From the original eight feedthroughs two independent problems were found. One port showed the fundamental mode to be at an incorrect frequency, $f_0 - 100$ MHz. This was fixed by a slight adjustment of the RF finger separating the feedthrough and the cavity.

The second problem was the appearance of an unwanted resonance at ≈ 1 GHz. This notch at 1.040 GHz, blue curve in Fig. 7 shown later, could be seen in the matrix of all 8 × 8 S-parameters measurements involving two adjacent feedthroughs at one end of the cavity. Any unwanted field enhancement at 1 GHz; the second harmonic of the RF could be a source for heating problems.

In order to further diagnose the cavity a fully automated bead pull measurement was set up. In the usual manner, the metallic bead introduces a small perturbation of the cavity volume and media, resulting in a shift of the resonant frequency. This frequency shift is related to the relative field strengths in close proximity of the bead. Pulling the bead through the cavity allows for mapping the field distributions for a given mode. In this setup, high resolution is obtained by measuring the phase shift of the transmission S_{21} rather than the frequency shift. For small deviations in resonant frequency, there are large measurable linear changes in the phase at either side of the zero crossing. The relative phase shift values are given in the legends in Fig. 3 to 5. Each figure is a transverse slice in the longitudinal plane located in the middle of the cavity.

By mapping the field profile the source of the unwanted mode could be geometrically located. At this position, Fig. 3 in the upper region between the two troublesome feedthroughs there exists a RF spring on the inner side of the cavity.

Figure 4 shows that the field is not perfectly centered at 1.625 GHz. Although the bead itself was large and the tension of the wire was not optimal, a precision of 1 mm was achieved. The translation of the center (0,0) to (-3,-3) mm shows a slight cause for concern.

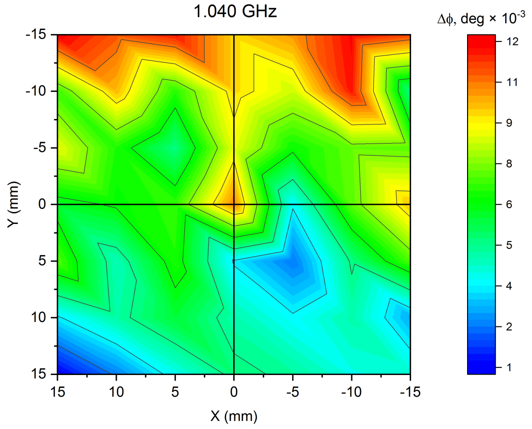

Figure 3: Bead pull, locating the high field region at 1 GHz.

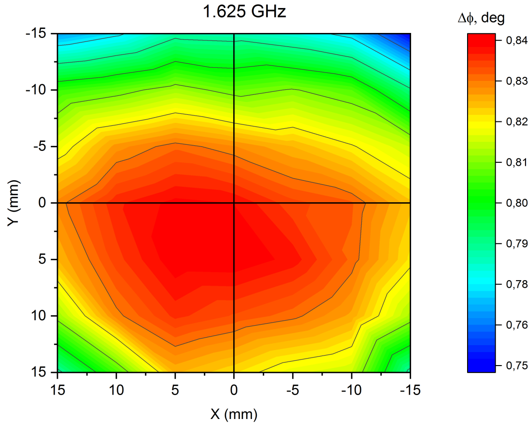

Figure 4: Bead pull, before modification the fundamental mode appears to be slightly off center.

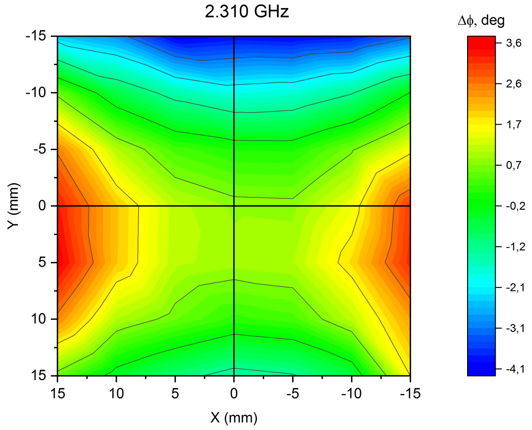

Figure 5: Bead pull, the dipole mode could be evaluated using this set-up.

For this setup with a metallic bead it is possible to measure a dipole mode. Taking the resonator as a simple LC circuit where $f \approx \sqrt{1/LC}$, the sign of the phase shift depicts the vector of the field: positive phase shifts for electric fields (increase in capacitance) and negative for magnetic fields. The third map, Fig. 5 shows such a dipole mode. This mode is also seen in simulations, and has no substantial longitudinal coupling to the beam.

The results of the VNA measurements and the bead-pull investigations led to the decision to take the cavity apart and inspect the inner RF springs. At the expected location, Fig. 6, the RF springs were found to be flat, rather than bent, and the RF contact between the loaded waveguide and the cavity was poor.

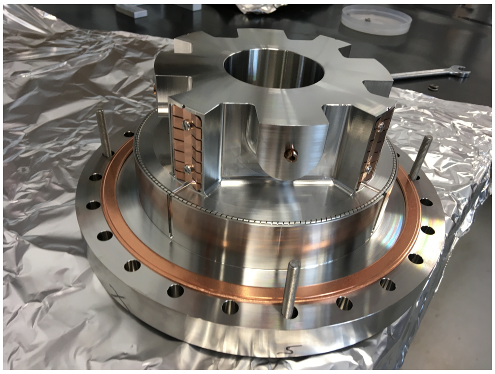

Figure 6: Loaded waveguide component, copper-beryllium RF springs are found on every second ridge.

All the RF springs were inspected and adjusted where necessary. The longitudinal kicker cavity was re-assembled, vacuum tested and remeasured using the VNA. Figure 7 shows the reflection properties of one of the troublesome feedthroughs before and after the RF spring modifications, blue and red curves respectively. The final state shows a good agreement to the simulation. The cut-off frequency of the circular beam pipe of radius $r = 30\,\text{mm}$ is $f_c = (1.8412c)/(2\pi r) \approx 3\,\text{GHz}$.

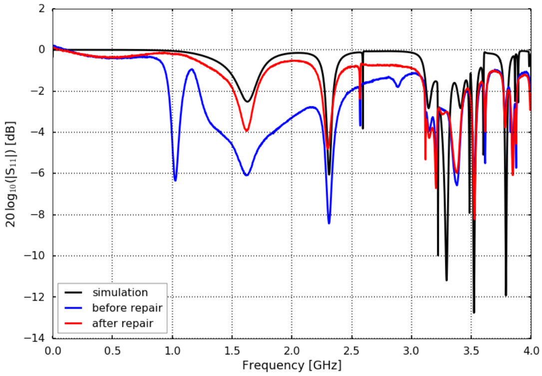

Figure 7: Reflection (S_{11}) measurements of port 4 before in blue and after modifications in red.

The reflection properties of all the feedthroughs are identical. The red curve in Fig. 7 can be used to estimate the maximum kick voltage $V_{\max}$ per feedthrough to the beam at 1.625 GHz. Using the value of the wake impedance $Z = R/Q$ shown in Fig. 2, $Q = f_0/\Delta f$, and the nominal power of the broadband amplifiers $P_{\text{amp}} \approx 50\,\text{W}$ the voltage is given by

$$V_{\max} = \sqrt{P_{\text{amp}}\left(1 - |S_{11}|^2\right)\frac{f_0}{\Delta f}Z} \approx 300\,\text{Volts}$$

Such a kick is comparable to the one produced by the existing cavity in the BESSY II storage ring where longitudinal damping rates of the bunch-by-bunch feedback system τ_{fb}^{-1} are actively measured. From these studies [9] one would estimate the damping time to be $\tau_{\text{fb}} \approx 0.3\,\text{ms}$.

FEEDBACK SYSTEMS

The mitigation of coupled-bunch-instabilities enhanced by the additional accelerating cavities is essential for reliable operation and high injection efficiencies. With the installation of the longitudinal kicker cavity and the already active stripline kickers, the booster will be equipped with 3D digital bunch-by-bunch feedback (BBFB) systems [10]. These systems are able to suppress transverse and longitudinal beam instabilities for a wide range of machine parameters, while offering excellent diagnostics opportunities.

OUTLOOK

A longitudinal cavity has been developed using a well established baseline design. The model was developed and systematically optimized to suit the demands of the booster upgrade. The cavity was manufactured and delivered on-time to be thoroughly bench tested before installation. Problems were diagnosed in a location of high sensitivity and slight modifications were necessary. The final S-parameter measurements compared beyond expectations to the simulations allowing the installation to be carried out in full confidence. The acquisition of the digital feedback systems is well advanced.

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