DESIGN AND OPERATION OF A FERRITE LOADED KICKER CAVITY FOR THE LONGITUDINAL COUPLED BUNCH FEEDBACK FOR HERA-p

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Abstract

A longitudinal broadband damper system to control coupled bunch instabilities has recently been constructed and installed in the 920 GeV proton accelereator HERA–p at the Deutsches Elektronen-Synchrotron (DESY). The goal of this system is to reduce the bunch length and thus increase specific luminosity at HERA–p. Within the control system a kicker cavity is used as an actuator. The original aspect of this cavity lies in the simple geometry with no need for vacuum inside the cavity and high shunt impedance despite an internal ferrite load. The ferrite load is successfully used to dampen higher order modes down to Q $<$50 while the fundamental mode is damped by less than 2 dB. While nominal input power is rated at 1 kW the cavity is prepared to handle beam loading. In spite of power requirements and ferrite load the cavity needs no active cooling. It can be tuned in resonance frequency and bandwidth over a range of 96…105 MHz and 7.8…12 MHz respectively and in consequence provides an optimal actuator for the particle beam control system.

INTRODUCTION

This paper is part 2 of a series of 3 papers [3][4] describing the recently successfully installed Longitudinal Multi-Bunch Feedback system (LMBF) at HERA-p.

The kicker cavity is an essential part of the LMBF, serving as actuator on the beam. The cavity is designed to the necessities of the damping principle described in [3]. It has to provide the desired fundamental mode at ~104 MHz with a bandwidth of about 10 MHz. While keeping construction simple, higher order modes (HOMs) have to be suppressed in the cavity and the fundamental mode (FM) still coupled well to the beam.

CAVITY STRUCTURE

The kicker cavity is designed as a single cell quarter wavelength coaxial line cavity as shown in Fig. 1. Its most important property is the bandwidth of 5 MHz minimum. To ease processing and mechanical stability the cavity is made of steel.

The cylindrical hull of the cavity is made of two halves screwed together. This kept the construction extremely simple and allows easy access to the cavity for further installations.

Other criteria for a simple design were the cooling and the ability to easily calculate or even estimate the resulting electrical parameters. To keep the cavity as matched as possible to the transmitter is has been designed with two ports. The first port is connected to the transmitter, the second port to a load. Load and transmitter each damp the cavity down to $2Q_L$ resulting in Q_L for the whole structure.

Using an external load instead of one inside the cavity keeps the requirements for cooling the cavity low. Thus active cooling and complicated passive cooling elements are avoided. The load is able to handle up to 4 kW, which gives plenty overhead room for the transmitter power of 1 kW. The two ports are placed symmetrically at an angle of 120 deg to one another.

The cavity hull can be unscrewed and moved along the beam pipe. This effectively enables the repositioning of the gap over a range of 220 mm inside the cavity. By moving the gap resonance frequency and bandwidth of the cavity can be adjusted. A mechanical sketch of the cavity is shown in Fig. 1.

To be able to retrofit the cavity into the existing HERA-p ring it had to adhere to size restrictions. For this reason and the fact of a readily available ceramic gap the coaxial shape was chosen for the cavity. With a fundamental mode at 104.1 MHz the cavity length was set to 600 mm and the outer diameter to 400 mm. The inner diameter was retained from the beam pipe diameter of 100 mm. As the cavity can be moved relative to the gap a more accurate frequency tuning can be done after construction.

Determining electrical parameters is eased by the symmetrical cavity design. Having the gap not directly at one wall makes this cavity actually a set of two coupled quarter-wave cavities. Since they are of coaxial structure they can be easily described analytically. This setup of two cavities allows for fine tuning the resonance frequency, but will also cause HOMs.

Calculation showed that because of the roughly quarter-wave cavity size the occurring HOMs should have an am-

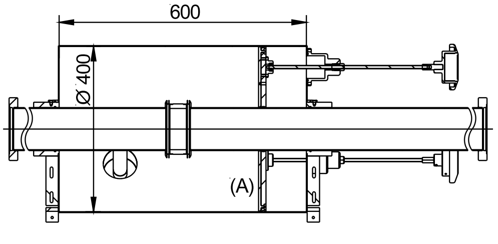

Figure 1: Simplified cross section of the kicker cavity.

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plitude maximum directly at the wall near the gap. By using this wall to place high–μ ferrites HOMs will be reduced in amplitude and Q as well as the bandwidth of the cavity is increased as desired. The ferrites are millimeter wave ferrites with $\mu = 317$ (Trans Tech, TT2-111, 60×60×6 mm^3) bolted flat as a ring against the wall as seen in Fig. 2.

Figure 2: Inside view of the kicker cavity – direct look at the ferrite loaded moveable wall.

Loading the cavity with the ferrites detuned the cavity resonance frequency by -3 MHz, which was not possible to compensate by shifting the gap. For this reason a circular moveable wall was introduced to the cavity. It effectively decreases the cavity length, which results into a change of resonance frequency, bandwidth and HOMs. The wall is fastened by three rods that extend to the outside of the cavity, as can be seen at the right hand side of Fig. 1. Via these 3 rods it is possible to move the wall while the cavity is fully sealed. Because of the input couplers the moveable wall has to be located at the far end (Fig. 1A) where the ferrites are located as well. Thus the moveable wall carries the ferrites.

ELECTRICAL PROPERTIES

As indicated above not all parameters are fixed by the cavity design. Steps taken to adjust the cavity were damping the HOMs, tuning the resonance frequency and bandwidth and determining the shunt impedance.

Damping HOMs

The occurring HOMs are damped by ferrites. To determine the effectiveness of the damping the spectrum seen by the beam was measured offline using antennas introduced into the beam pipe.[2] To change the field distribution as little as possible the antennas were placed at the edge of the gap not directly at its center and closely matched to 50 Ω. Because of the influence of the antenna on the field and the antenna characteristic results can only be an indicator.

Fig. 3 shows the cavity spectrum before and after placing the ferrites. It can be clearly seen that all HOMs are damped while the fundamental mode is hardly affected. At their most effective position – at the moveable wall – the ferrites damp all HOMs to a Q less than 50 (estimated was a maximum of Q <100). The minimal distance between fundamental mode and higher order modes is more than 7 dB.

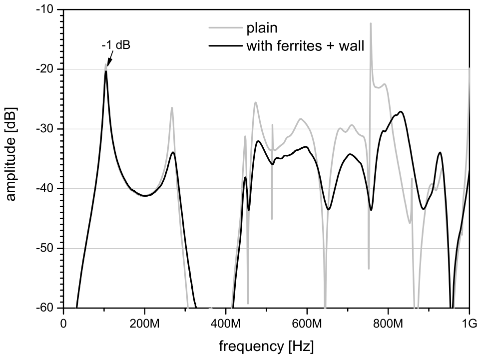

Figure 3: Influence of wall and ferrites to HOMs in cavity.

Tuning the Cavity

The position of the gap and the moveable wall form the two degrees of freedom to tune this cavity in its three main parameters – resonance frequency, bandwidth and HOMs.

While scanning the whole parameter field was expected to be too time consuming an estimation was made to find a suitable configuration.

To tune the cavity an initial scan of resonance frequency and bandwidth as a function of the gap position was made (Fig. 4). Then the tuning range of the moveable wall was roughly measured. With this information the gap position was set to keep the desired resonance frequency well within the tuning range of the moveable wall.

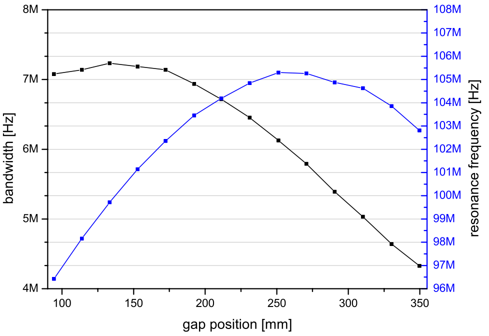

Figure 4: Center frequency and bandwidth as a function of gap position without ferrites.

For more sensitive applications the design of the cavity allows for very fine tuning of HOMs, resonance frequency and bandwidth by elaborating the whole parameter field. This would include scanning resonance frequency, bandwidth and HOM suppression as a function of gap and wall position.

Shunt Impedance

The shunt impedance was measured by the perturbation technique [2]. Because of the high bandwidth a large PE–ball (diameter 30 mm, ϵ_r = 3.4) was used to obtain a measurable frequency deviation. A low step width of 0.8 µm and correction for temperature drift over the measurement time allowed for a fair accuracy. From the frequency deviation (Fig. 5) and the relative dielectric constant ϵ_S and Volume V$_S$ of the PE–ball the longitudinal shunt impedance was calculated according to:

$$R_S = \frac{U_C^2}{2 \cdot P_C} = \left(\int_0^L \sqrt{\frac{(\omega_0^2 - \omega^2)\, Q}{\alpha \omega^3}} \mathrm{d}s \right)^2 \qquad (1)$$

$$\alpha = \frac{\epsilon_0 \epsilon_S - \epsilon_0}{2} V_S \quad . \qquad (2)$$

This was done before and after loading the cavity with ferrites. After loading the shunt impedance was only insignificantly lower than before with a value of R$_S$ = (2360 ±200) Ω. At a power level of P = 1 kW this will result in a maximum accelerating voltage of U = (2360 ±90) V.

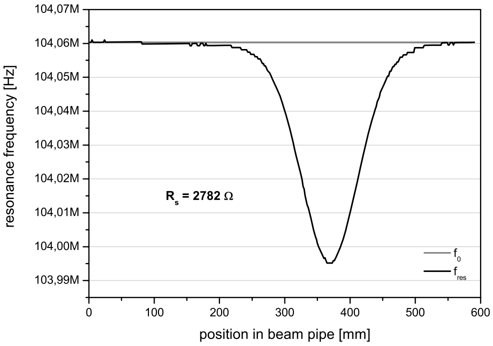

Figure 5: Measurement of longitudinal shunt impedance.

Table 1: Electrical properties.

res. frequency	104.1 ±0.05 MHz
bandwidth	7.9 ±0.05 MHz
Q$_L$ factor	13.2 ±0.05
long. Shuntimp.	2782 ±200 Ω
R/Q	105.3 ±10 Ω
power rating	1 kW
frequency tuning	96 – 117 MHz
bandwidth tuning	4 – 12 MHz
frequency drift	7 kHz/K
strongest HOM	f = 830 MHz, Q = 17, G$_{\mathrm{FM}}$ = -7.1
highest Q HOM	f = 448 MHz, Q = 44, G$_{\mathrm{FM}}$ = -18

OPERATION EXPERIENCE

The cavity was installed at HERA-p in Nov. 2005. Commissioning went without major problems as the cavity was tuned very easily by the available tuning mechanisms.

During operation the cavity design proved to be a success. The thermal concept proved to be correct. In the lab under full power (1 kW) the ferrites reached temperatures of up to 70°C resulting in a hull temperature of max. 42°C. During operation temperatures of 40°C were not exceeded.

The tuning mechanism works very reliable and has not shown deviations in frequency after three months of operation.

Within the feedback loop the cavity behaves as required. No cavity imposed higher order modes could be found on the beam response.

CONCLUSION

The design of the kicker cavity for the LMBF is simple and leaves much room for tuning to the needs. This allowed for fast and timely construction, which was a major factor to success of the short term project Longitudinal MultiBunch Feedback system for HERA-p.

The design is not only based on minimum technical effort, while fulfilling all requirements - it also demonstrated very good HOM damping behavior, while leaving the fundamental mode nearly untouched, damping it only by 1 dB. This behavior is achieved by discriminating the fundamental mode by use of mode amplitude dependency of position of ferrites, rather than by use of tuned circuits or additional damping cavities.

Successful operation validated the design concept and its implementation.

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