FIRST EXPERIENCES WITH THE LONGITUDINAL FEEDBACK SYSTEM AT DIAMOND LIGHT SOURCE

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Abstract

In order to avoid longitudinal multibunch instabilities potentially caused by the addition of normal conducting radio frequency (RF) cavities into the Diamond storage ring, a longitudinal feedback (LMBF) was designed and installed. The main components are newly developed feedback electronics, in-house built modulator and amplifier RF chains, and an in house designed low Q kicker cavity. This paper describes the performance of the cavity as well as the full longitudinal feedback system as it is installed on the machine and tested before the installation of the normal conducting RF cavities.

SYSTEM OVERVIEW

The system comprises a set of button pickups (shared with the transverse feedback systems) into bunch by bunch frontend electronics which generate an I and Q signal for each bunch. This information passes into our digital system which calculates the required correction for each bunch. These corrections are sent to a set of RF amplifier chains which feed the cavity thus applying the corrections to the beam.

KICKER CAVITY

The cavity is a low quality factor overloaded type with four input ports and four extraction ports. The main resonance is designed to cover 1.75 GHz to 2 GHz. The 250 MHz bandwidth is needed in order to allow all possible modes of coupled beam motion to be corrected. Tapers are included in the design in order to reduce the wake impedance of the structure. However the angle of the tapers had to be carefully tuned so as not to detrimentally impact on the performance of the kicker. More detail on the design of the cavity can be found in previous papers [1] [2].

The assembly of the cavity was done in house. Figure 1 shows the inside of the cavity with one end assembled. From this one can see four of the eight ridged waveguide structures used to couple power into and out of the cavity. One feature of the design was a deliberate separation of the RF continuity from the vacuum sealing. This allowed us to better optimise both cases. Figures 2 and 3 both show this, whereby the gold components are for RF continuity and are separated from features like the knife edges used for vacuum sealing. Figure 2 shows the recess before one of the feedthroughs was installed. The copper beryllium spring is to ensure RF continuity along the transmission line formed by the hole and the feedthrough pin. Figure 3 shows the helical RF spring used to seal the end of the cavity, and the set of linear fingers used to achieve isolation between adjacent ridged waveguides. Also visible at the curved end of the waveguide ridge is the hole with bushing that the end of the feedthrough pin will push fit into when assembled.

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Cavity Bench Tests

Before installation, the kicker cavity was tested using a vector network analyser in order to compare the predicted S-parameters with the real device. A representative sample of the results is shown in Fig. 4. The measurements are in reasonable agreement with the simulation. Baking out improved the match between measurements and simulation, particularly below 1.75 GHz. It also reduced the variations between the ports. This was put down to a relaxation of the material of the coaxial pin of the feedthroughs, which are push fit into bushings in the main structure. Figure 5 shows the cavity in its final installed location. In order to make room for the cavity the downstream pumping vessel had to be redesigned to be shorter.

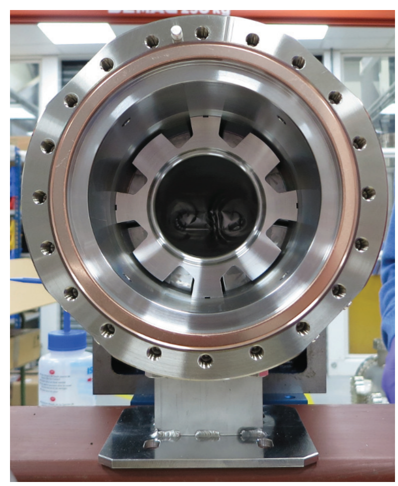

Figure 1: An inside view of the partially completed cavity assembly. The waveguide structures of the port couplers are clearly seen.

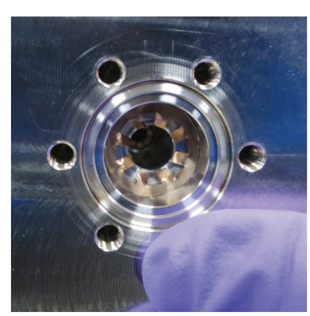

Figure 2: The recess with beryllium copper spring prior to the feedthrough installation.

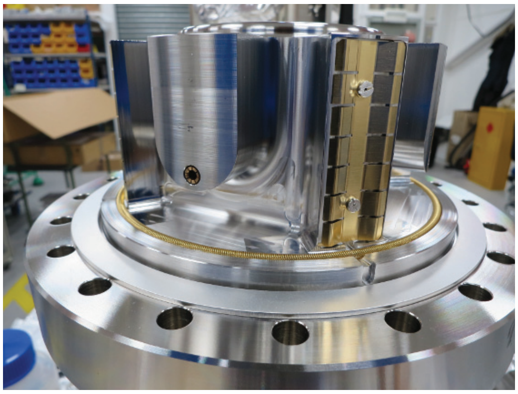

Figure 3: View of the internal structure of the cavity. The gold coloured components are for ensuring good RF continuity, while the silver ring is for the vacuum seal.

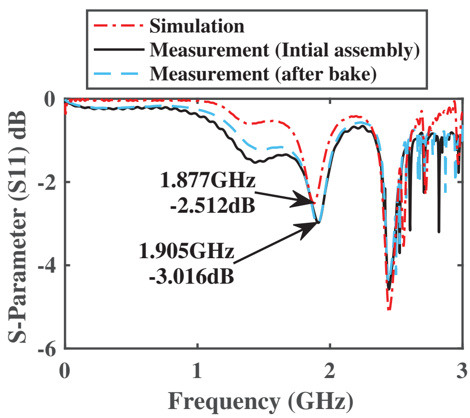

Figure 4: Representative bench measurements. There is broad agreement between simulation and measurements. The change due to bake out implies that the lower frequency discrepancy is due to fine detail in the waveguide coupler.

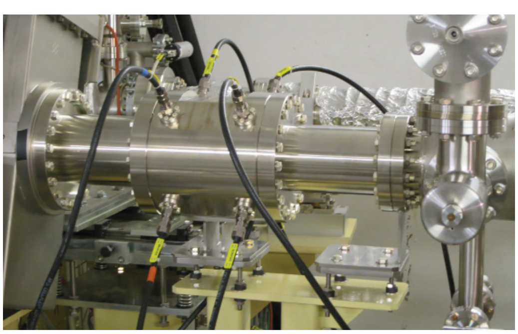

Figure 5: The kicker cavity installed in the storage ring. Upstream is left, downstream is right.

AMPLIFIER CHAINS

Figure 6 shows a schematic of the amplifier chains of the feedback system. This serves to both deliver power to the cavity as well as to protect the amplifier from power returned from the beam. The amplifier in each chain can drive up to 30 W of power into the cavity. Most of this power is removed from the cavity via the extraction ports which are connected to 30 m of cable and then terminated with high power loads. Due to imperfect matching, a fraction of the input power returns and is redirected to a high power load using the circulator. Additionally, power is injected into the chains due to the electron beam in the cavity. The in band component is treated as the returned power, while the out of band power is send to a separate high power load using the diplexer.

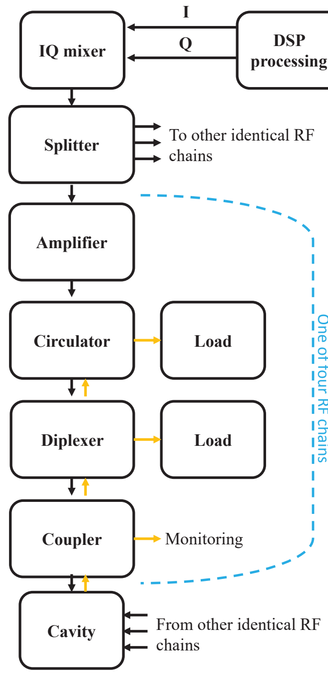

Figure 6: System diagram for the amplifier chains in the final configuration. Currently only I is driven.

Having the couplers in the system allow us to monitor both outward and return power. This has proved a useful diagnostic as it has allowed the identification of component failures in a single chain.

DSP PROCESSING

The digital signal processing is based on the same approach as the existing transverse multibunch feedback systems [3] [4] [5]. Thus the longitudinal movement of each bunch is tracked over a series of turns, and the amplitude of oscillation at the synchrotron frequency for each bunch is calculated. A fraction of this signal is applied with inverted phase to reduce the amplitude and so stabilise the bunch motion. Compared to the transverse systems additional decimation steps were needed to operate at the much lower frequencies seen in the longitudinal plane (see Fig. 7).

INITIAL PERFORMANCE

During final system tests, two of the four diplexers failed. In order to protect the remaining two we limited the power

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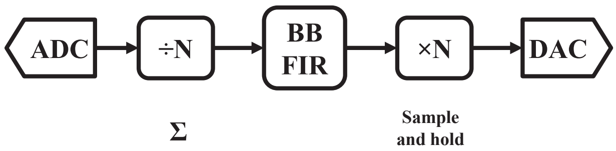

Figure 7: High level schematic of the LMBF DSP processing chain. After the signals are digitised the data for each individual bunch is decimated using a sum function. The data is put through bunch specific FIR filters. Then a sample and hold function increases the data rate to that which the DAC is expecting.

of the system and disconnected the broken chains. All the results are using this degraded setup.

In order to measure system performance we used the grow-damp methodology. For each mode, we excite all bunches at the mode frequency, then either allow them to damp naturally, or apply active damping using the feedback system. The gradient of these decay curves give the damping times and from there, the growth rates. Once all modes have been measured the growth rate versus mode curves can be used to identify any changes in behaviour.

Using the already installed stripline based test system [1] [6], we took a series of baseline measurements of the machine before the installation of the longitudinal feedback cavity. By comparing this data with equivalent measurements after the cavity installation we have validated that the unpowered cavity does not have any detrimental effects on machine performance.

The open loop behaviour using the cavity to excite the beam was shown to match the behaviour when exciting with the test system. Both of these results can be seen in Fig. 8.

After closing the feedback loop we were able to demonstrate significantly reduced growth rates as shown in Fig. 9.

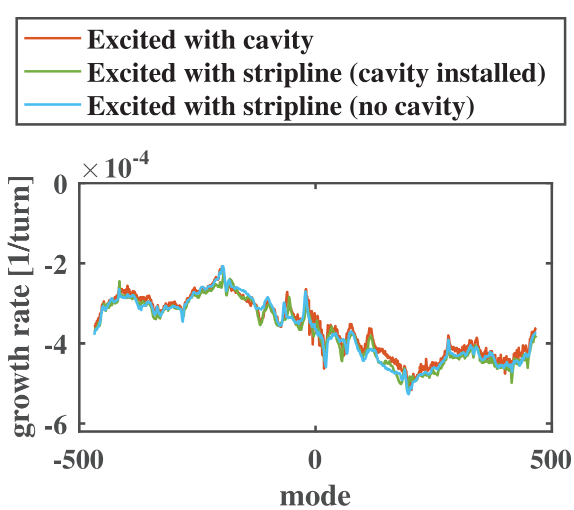

Figure 8: Comparing new cavity to stripline based test system, and assessing impact of the unpowered cavity on the synchrotron.

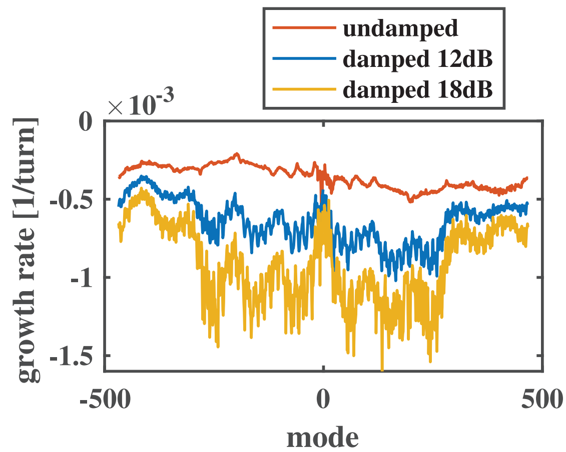

Figure 9: Feedback performance at different gains.

Currently the system is much more effective at suppressing the low frequency modes. We think this can be improved with better system tuning.

FUTURE WORK

The system as it is, is performing well, however the required corrective power is still unknown as that is dependent on the behaviour of the normal conducting RF cavities which have yet to be installed. With this in mind we have plans to upgrade the feedback system to allow for stronger corrections.

The system is currently only using two of the four possible feeds to the cavity, due to component failure. Repairing these will double the available power available for correction.

The current LMBF FPGA code is running on the same type of hardware as the transverse systems which shows unwanted signals on the ADC due to standing waves generated in the input analogue section. Moving to new uTCA based hardware should allow better use of the ADC range due to better input matching. Upgrading the hardware will also allow driving in a single sideband manner as it will be able to provide true IQ signals. This will give us an additional factor of two in correction, as we will be able to selectively output power only into those sidebands for which the LMBF system can control.

These upgrades, along with further system tuning in order to improve the effectiveness for higher frequency modes is expected to give us an improved level of correction compared to that which we have so far demonstrated.

CONCLUSION

We have shown that the new longitudinal feedback system designed and installed for the Diamond light source is functioning and is ready to act in suppressing longitudinal instabilities. Further improvements have been identified, which will improve the performance of the overall system. When the cavity is unpowered we have shown that it has no detrimental effects on the synchrotron.

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