FAST DETUNING EXPERIMENT ON AN SRF CAVITY*

G. Wu[#], D. Horan, J. Holzbauer, N. Arnold, A. Cours, J. Fuerst, T. Berenc, Y. Yang, J. Carwardine, A. Nassiri, Argonne National Laboratory, 9700 S. Cass Avenue, Argonne, IL 60439, USA
J. Matalevich, Jefferson Lab, 12000 Jefferson Avenue, Newport News, VA 23606, USA

Abstract

A deflecting cavity cryomodule concept was developed for the APS Upgrade. The beamline experiments that will use the deflected beam will occupy a limited number of sectors after the APS Upgrade. The majority of APS users will not use the deflected beam for their experiments. As user operation requires the best beam availability, it is important that any cryomodule-related trip that requires the extinguishment of rf power should not affect overall beam availability. As such, it is necessary to decouple the superconducting rf cavities from beam when such an rf fault happens.

An example of such a fault is rf window arcing, which has to be stopped as soon as possible before serious damage occurs to the window ceramic. As the rf amplifier shuts down the rf output, beam-driven cavity power has to be reduced, too. If the cavity can be detuned fast enough and far enough away from its resonance, the beam does not have to be aborted.

The mechanical tuner is equipped with a fast response piezo actuator in the cavity tuner stack. This piezo may be able to give a quick jolt to the cavity to provide detuning capability for the purpose of maintaining the beam in the event of an rf fault.

In this paper, we describe the experimental setup and results obtained, and discuss its effectiveness for beam operation.

INTRODUCTION

An earlier planned APS Upgrade [1] called for one superconducting deflecting cavity cryomodule to deflect the storage beam and a second cryomodule to restore the storage beam [2]. While a small number of the beamline experiments would use this deflected beam, a majority of APS users would not. The users have been enjoying the high beam availability of the APS. The inclusion of the superconducting cavities should not reduce the overall reliability of the storage ring. Although superconducting cavities in many accelerators have demonstrated high reliability, it is highly beneficial to design a superconducting cryomodule with the capability to decouple any superconducting-cavity-related rf faults and the beam passing through the superconducting cavities. Such a capability will allow a negligible beam loss for the users' experiments while the superconducting cavity rf system recovers from the fault.

An example of such an rf fault is when rf window arcing has to be stopped as fast as possible before serious damage occurs to the ceramic. As the rf amplifier shuts down the rf output, beam-driven cavity power has to be reduced, too. If the cavity can be detuned fast enough and far enough away from its resonance, the beam does not have to be aborted.

As the deflecting cavity operates at 2815 MHz, which has an external power coupling of 1×10^6, a five half width at half maximum (HWHM) resonance detuning will sufficiently drop the beam-induced voltage inside the deflecting cavity.

The cryomodule has a mechanical tuner to adjust the cavity frequency at an operational speed of 1 kHz per second. The slow adjustment is dictated by the tuner mechanical motor's optimal response time. Although the motor is capable of a higher speed, it is set to lower speed to minimize the motor-related vibration; its lower speed is also needed to preserve the motor lifetime.

To achieve a much faster cavity tuning, a fast-response piezo actuator is added in the cavity tuner stack [3]. Such a piezo may be able to give a quick jolt to the cavity to provide detuning capability for the purpose of maintaining the beam in the event of rf faults. A magneto-strictive tuner [4] would not be possible for the scissor jack tuner due to very limited space in the deflecting cavity cryomodule.

EXPERIMENTAL SETUP

Figure 1 shows a tuner assembly that has a fast-response piezo actuator stacked next to the slow stepping motor. Both are located outside of the cryostat. Any motion of the piezo has to travel through the tuner stack, scissor jack, and fulcrum bar before reaching a cavity through the helium vessel.

A high-resolution piezo actuator was used for the tuner stack, which operates with the cavity in tension. It provides 3500 N (787 lbs) at full voltage of 130 V with maximum displacement of 60 μm in the tuner driver axis.

A fast-switching DC power supply was built into a piezo driver chassis to provide a fast voltage step for the piezo [5]. A fast oscilloscope was connected to a cavity field probe, and a function generator provided trigger signals to both the oscilloscope and the piezo driver. A fast detuning experiment was conducted with a fully dressed cavity at 2 K [6].

MEASUREMENT RESULTS

The piezo tuning frequency was measured up to 20 V. Figure 2 shows a cavity frequency response to various piezo driving voltage. If a linear response is assumed, the maximum piezo voltage of 130 V can tune cavity frequency by 16.4 kHz. To avoid high stress and extend the lifetime of the piezo actuator, 100 V will be the upper

*Work supported by the U.S. Department of Energy, Office of Science, under Contract No. DE-AC02-06CH11357.
#genfa@aps.anl.gov

limit for the piezo driver. The piezo tuning range is set at 12.6 kHz.

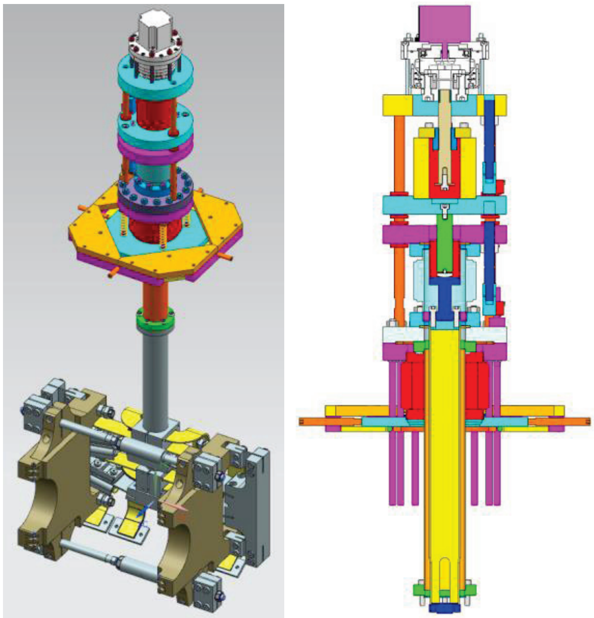

Figure 1: Scissor-jack style tuner assembly has slow stepping motor and fast response piezo (green cylinder in the right figure) stacked together.

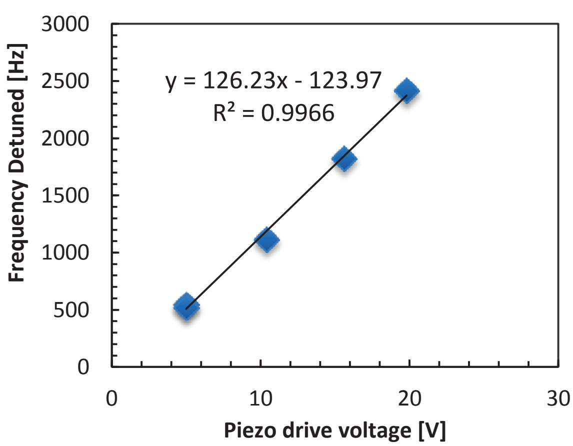

Figure 2: Piezo tuning is seen at 126 Hz per driving volt.

For the fast detuning test, piezo driver voltage was limited to below 75 V. Cavity field was maintained at ~35 mT. Cavity low-level rf was set to one of the three modes: (1) Open loop with the rf tripped off at the same time as the piezo driver was triggered, (2) open loop with the rf staying on after the piezo driver was triggered, and (3) self-excited loop with the rf staying on after the piezo driver was triggered. The cavity field signal was then captured together with the trigger signal as the piezo drive voltage was set at 25 V, 50 V, and 75 V. Digital LLRF also captured the cavity field signal.

Figure 3 shows a cavity field probe signal when LLRF was configured with open loop while rf stayed on when the piezo driver voltage was set at 75 V.

The cavity field probe voltage was reduced to ~5% of the voltage before the piezo was activated. The total field decay time from full voltage to 5% of the voltage was 1.5 milliseconds. Cavity voltage remained low for another 1.0 millisecond before it oscillated back to a slight off-resonating high field again as the cavity vibrated due to the piezo "knock." As the cavity power stabilized after 50 ms, the field probe voltage was reduced to 13% of the voltage before the piezo was activated.

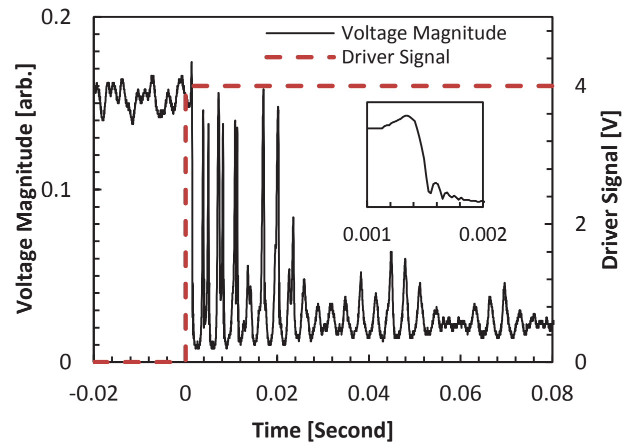

Figure 3: Voltage magnitude of the field probe signal from an oscilloscope when the cavity rf stayed on without phase control while the piezo driver voltage was at 75 V corresponding to a $\Delta f \sim 7.5$ kHz. Zoomed window shows the voltage drop in 1.5 ms.

DISCUSSION

As mentioned earlier, the storage ring beam has the potential to couple significant rf power into the rf cavities and associated devices, such as windows, the amplifier output isolators, and loads. It can also instigate rf arcing in these components. A machine equipment interlock system must detect any over-dissipation, over-temperature, or arcing conditions in the deflecting cavity rf systems caused by beam-generated rf power and take action to prevent hardware damage. Fast detuning of the superconducting rf cavities to decouple them from the stored beam in response to these conditions will be useful in order to avoid interruptions in beam for the end users.

The big mass of the cold tuner is very inert, and its long distance from the piezo actuator to the cavity will result in a physical limit to the mechanical response time. A simple estimate showed the mechanical limit for the cavity to move 7.5 kHz is around 50 µs, which is faster than the cavity's power decay time.

Based on a cavity fill time of 500 µs, a response time in the millisecond range is targeted as the nominal specification for effective fast cavity detuning in an equipment interlock application. In comparison, it takes approximately 200 µs for the storage ring beam to dissipate when the Machine Protection System is utilized to dump the beam.

ISBN 978-3-95450-143-4

The cavity frequency change of 7.5 kHz in 1.5 milliseconds would be sufficient and may be fast enough for the needs of a fast detuning application. The cavity tuner system showed a mechanical vibration after the piezo was activated. The main vibration was seen at 160 Hz as shown in Figure 4, which provided the needed 1-ms power void for fast detuning purposes.

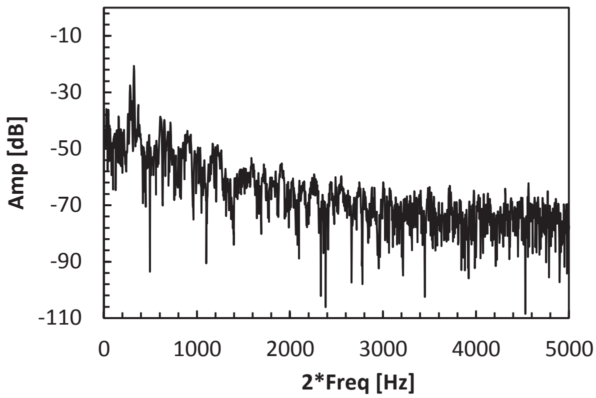

Figure 4: Fourier transformation of the cavity voltage signal amplitude.

The cavity and tuner system vibration caused the power coupling to the cavity to revert back to high field in an extended 20-ms period. During that period the residual field in the cavity after piezo activation would continue its action on the beam. A careful adjustment of the piezo voltage could be employed to proactively reduce the cavity resonance similar to a Lorentz force detuning in pulsed accelerator applications.

During the measurement, the rf power source was used to power the cavity as the cavity was detuned. A passing electron bunch will have a wakefield that is different from the monochrome input power. Further tests should be conducted to obtain repeatability of the detuning effectiveness.

CONCLUSION

A fast detuning system for a superconducting rf cavity has been designed, prototyped, and tested with a dressed niobium cavity at 2 K.

The test demonstrated that fast detuning is feasible for millisecond response time. A beam test with actual storage beam could further confirm the detuner's effectiveness.

ACKNOWLEDGMENT

We would like to thank Argonne National Laboratory's Physics Division for their support of the test and colleagues from Jefferson Lab for the design, fabrication, and preparation of the cavity test system.

REFERENCES

[1] K. Harkay, M. Borland, Y-C. Chae, G. Decker, R. Dejus, L. Emery, W. Guo et al., "Generation of Short X-ray Pulses Using Crab Cavities at the Advanced Photon Source," Proc. of PAC2005, TOAB009, p. 668 (2005); www.JACoW.org

[2] A. Nassiri, N. D. Arnold, T. Berenc, M. Borland, B. Brajuskovic, D. Bromberek, J. Carwardine et al., "Status of the Short-Pulse X-Ray Project at the Advanced Photon Source," Proc. of IPAC2012, WEPPC038, p. 2292 (2012); www.JACoW.org

[3] G. Davis, J. Delayen, M. Drury, and E. Feldl, "Development and Testing of a Prototype Tuner for the CEBAF Upgrade Cryomodule," Proc. of PAC2001, MPPH156, p. 1149 (2001); www.JACoW.org

[4] G. Cavallari et al., "The Tuner System for the S.C. 352MHz LEP 4-Cell Cavities," Proc. of the 3rd Workshop on RF Superconductivity, Argonne, USA, 1988.

[5] A. Cours, private communication.

[6] J. Holzbauer et al., "Horizontal Testing of a Dressed Deflecting Mode Cavity for APS Upgrade Short Pulse X-ray Project," these proceedings.