A High-Pressure Rinse System for use at Brookhaven National Laboratory

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Introduction

Superconducting radio-frequency (SRF) cavities are used to both accelerate and focus charged particle beams in many accelerators, such as RHIC and the future EIC at BNL. The performance of such cavities is depreciated by surface particulates causing field emissions of electrons as accelerating fields are excited in the cavity [5]. This motivates a method for removing small, strongly adhering surface particles from SRF cavities. Many methods have been considered, including but not limited: to ultrasonic (US) cleaning, HPR, wiping, high-velocity gas cleaning and electrolytic polishing. In practice, several of these methods are used in combination and alternatives are under constant investigation [2].

BNL already has an accelerator with SRF cavities, RHIC, and will be making another, the future EIC. The accelerators combine for a set of cavities with diverse geometry and dimensions. This necessitates the creation of cleaning equipment flexible enough to accommodate these cavities. My project has been to design an appropriate HPR station.

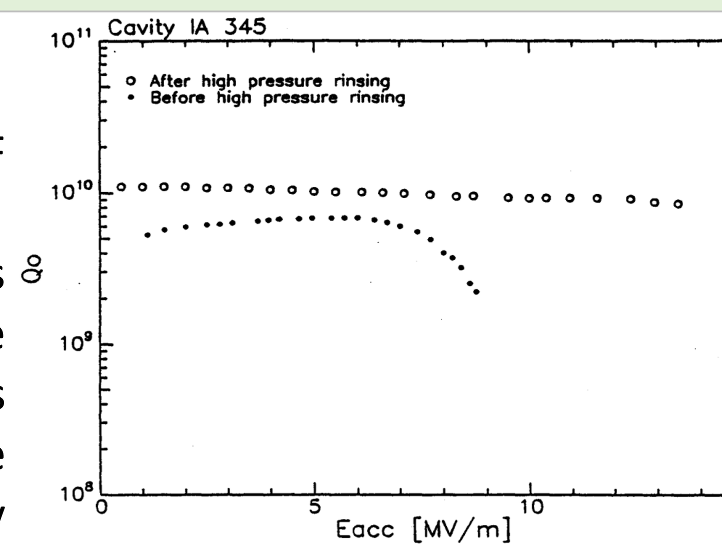

FIGURE 1. Plot of quality factor with respect to accelerating field before and after HPR for a JLAB 1.5 GHz ECR [3].

Design Requirements

1. To be able to serve the diverse set of cavities, the rinse wand must
   a) Be able to be positioned in a 36-inch radius
   b) Have a vertical stroke of 6 feet
2. The rinse tip can deform a maximum of 1 millimeter in non-vertical directions
3. The system must be corrosion resistant for use with ultra-high purity water
4. The system must generate as few particulates as possible during use

Requirement 1 was met by mounting a two-hinged arm with the rinse hardware attached to a linear actuator, like a system at use at Argonne National Laboratory [4]. Requirement 2 was met by carefully designing the arm and adding support structures to the frame. Requirement 3 was met by designing the system almost entirely from aluminum and 304 or 316 series stainless steel. Requirement 4 was met by designing for as few moving parts as possible and careful selection of bearings and actuator.

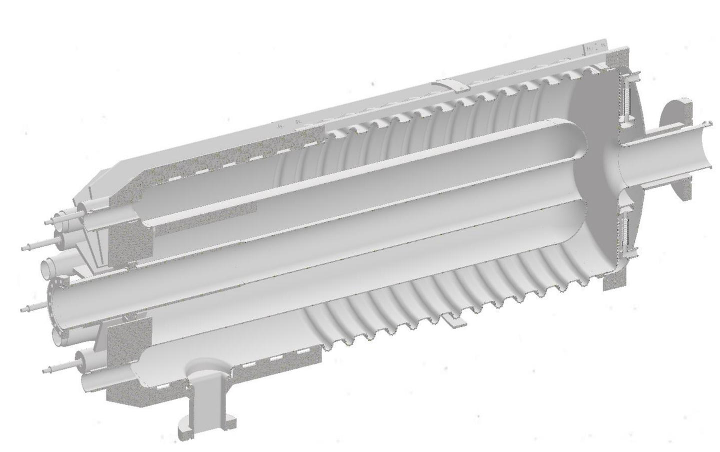

FIGURE 2. CAD model of a cross section of a BNL 56 MHz quarter wave resonator. Its dimensions, internal geometry, and port placement motivate requirement 1.

Design and Analytical Analysis of Arm

The part of the HPR system that we can control the deflection characteristics of most readily is the arm, shown in Fig. 2. The support structure it resembles most strongly is a cantilever beam. Under the loads of self weight and the rinse hardware, which is being modeled as a point load, a cantilever beam deflects according to

$$\delta_s = \frac{wl^3}{8EI} \quad \text{and} \quad \delta_p = \frac{Wl^3}{3EI} \; [1]$$

Since the arm will be machined from aluminum plate, its cross section will be rectangular, so its area moment of inertia $I = \frac{bh^3}{12}$. Its weight $\mathrm{w} = \rho bhl$. For small deflections, the two equations can be superimposed; doing this and substituting for I and w results in

$$\delta_t = h^{-2}\frac{3\rho l^4}{2E} + h^{-3}\frac{4Wl^3}{Eb}$$

If we allow the arm to cause half the allowable deformation, then decrease this further by a factor of two for safety, we can solve numerically δ_t for h. Doing so results in a height of 5.02 inches, which we increased to 8 inches in the design to account for manufacturing tolerances and the differences between an ideal beam and the arm design.

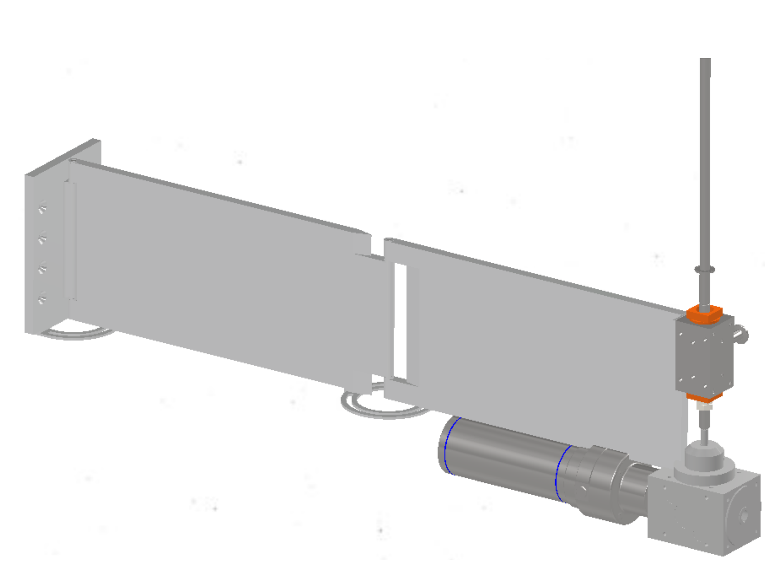

FIGURE 3. CAD model of the rinse station arm. The 6-foot wand was cut short in the photo so the rest of the arm could be seen with greater detail.

Finite Element Analysis of the entire HPR station

There reaches a point where the boundary conditions make the differential equations governing the equations of the support structures result in a situation that can only be solved with numerical methods. Finite element analysis is the numerical method we used to continue our evaluation of the design. FEA simulations were run at 8 evenly spaced points along the actuator plus 2 points of interest (¼ and ¾ stroke).

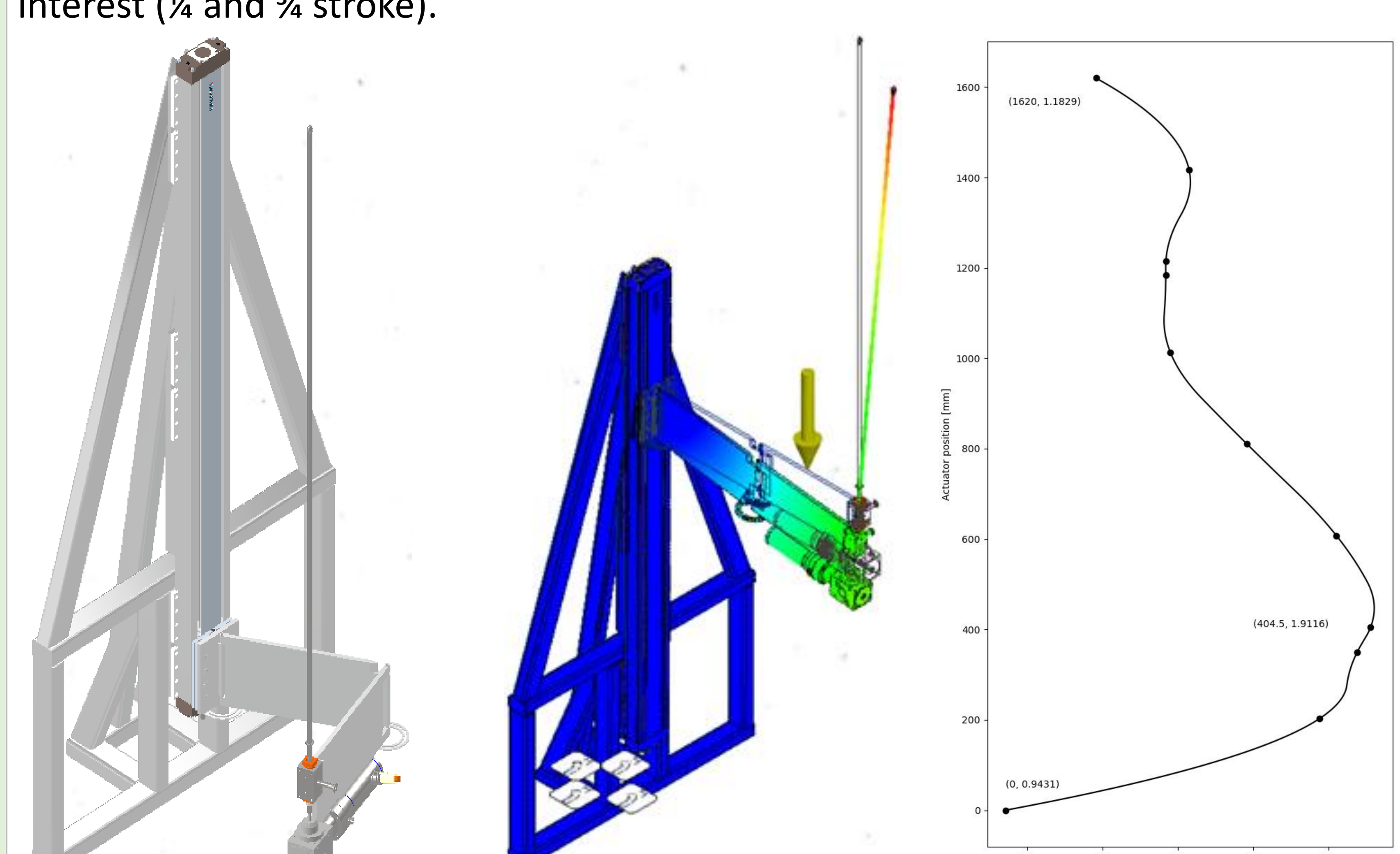

FIGURE 4. From left to right: CAD model of the complete HPR station, sample FEA result of the entire assembly (color map represents deflection), and plot of x-direction deflection with respect to slide position for 10 simulations.

The set of simulations revealed that the deflection would exceed the maximum nearly by a factor of 2, so an upwards tilt of 0.4347° was added to the arm. This was chosen by approximating the average deflection according to $\frac{1}{l}\int_0^l \delta(y)\,dy$ and finding the angle that would bring the average deflection to zero.

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