CHARACTERIZATION OF THE FIRST SRF ELECTRON BEAM SOURCE AT THE NAVAL POSTGRADUATE SCHOOL

A.D. Holmes, A.B. Baxter, C.W. Bennett, J.R. Harris, J.W. Lewellen, R.L. Swent, Naval Postgraduate School, Monterey, CA 93943, USA
CDR J. Didoszak, CDR J.M. Utschig Navy Reserve Science and Technology Program, Office of Naval Research, Alexandria, VA 22203, USA

Abstract

In June 2011, the Naval Postgraduate school (NPS) received the 500 MHz Mark I quarter-wave superconducting RF (SRF) electron beam source and, among other firsts, completed the first cool down and characterization of an SRF beam source at a US Naval facility. The Mark I has a photocathode with adjustable position and uses a unique cascaded RF coupler design. As part of an on-going advanced electron source development project, the NPS Beam Physics Laboratory (BPL) team continues characterization of the Mark I cavity at various cathode stalk, coupler, and probe positions. Methods and experimentation used to measure the cavity Q and β, as well as characteristic results, with respect to coupler, cathode stalk, and probe positions are presented.

INTRODUCTION

As part of on-going research into free electron lasers (FELs) and advanced electron sources at the Naval Postgraduate School (NPS), the Beam Physics Laboratory (BPL) has received a 500MHz Mark I (see Fig. 1), the first superconducting radio-frequency (SRF) quarter-wave electron beam source in the United States (US) [1]. This electron beam source, or gun, fabricated by Niowave, Inc, of Lansing, MI [2] was delivered to NPS in June 2011, which is also the first industrial delivery and acceptance of an SRF beam source at a US Naval facility. As part of initial acceptance at NPS and characterization of the Mark I, the BPL conducted the first cool-down of an SRF beam source at a US Naval facility.

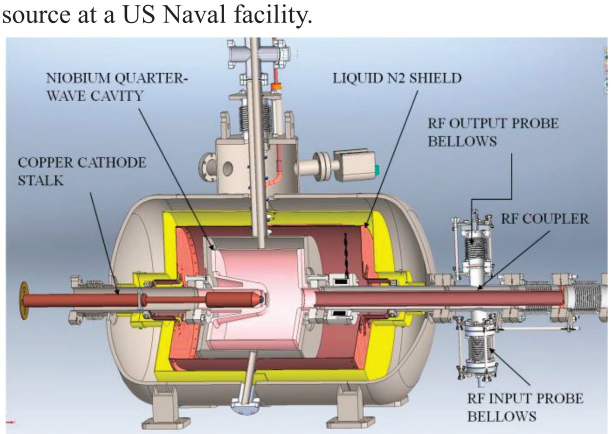

Figure 1: 500MHz Mark I SRF Quarter-Wave Electron Gun fabricated at Niowave, Inc. The cathode stalk is to the left and the RF coupler and probes are to the right. Note the quarter-wave cavity and liquid N_2 shield.

Since delivery in June 2011, the BPL has continued research into electron beam sources and characterization of the Mark I. As shown in Fig. 1 and Fig. 2, the niobium cathode plug is on the end of a copper stalk that can be moved in or out of the cavity. The stalk contains steps designed to minimize the flow of RF down the stalk, but still the cavity losses are very sensitive to the position of this warm assembly. The cathode and stalk are presently un-cooled. The RF power coupler uses a cascaded design that consists of a coaxial tube and radial probes (see Fig. 2 and Fig. 3).

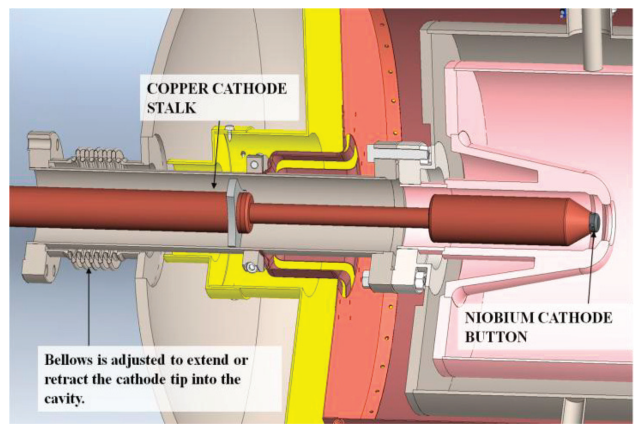

Figure 2: The cathode stalk has a range of 1.51 mm extended and 14.23 mm retracted into the nose cone [1].

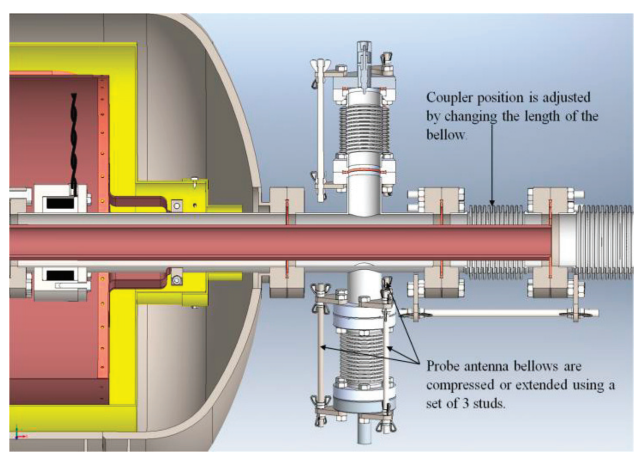

Figure 3: RF power coupler with antenna probes. The flange bolts or the probe connections to the coupler are not shown in this view.

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The coaxial tube couples power into the cavity while allowing the electron beam to pass through its center. The tube is mounted between two bellows, allowing the position to be adjusted. The two radial probes, inside the tubes and bellows, shown in Fig. 3, are capacitively coupled to the coax and the gaps can be adjusted independently. That allows the overall coupling for forward power (lower probe) and transmitted power (upper probe) to be adjusted independently.

Upon delivery of the Mark I to NPS, the first goal was to characterize this system by measuring quality factor Q, coupling factor β, and resonant frequency ω_o based on the cathode, coupler, and probe positions. Experimental methods and results are presented here, as well as planned improvements to the cathode stalk and coupler probe positioning system.

CHARACTERIZATION OF THE MARK I

Cavity Cool-Down

The cavity cool-down process begins with cooling down of the "bulk" of the gun by flowing liquid nitrogen through tubing of the copper liquid nitrogen shield. This allows conductive cooling from the shield to the rest of the system. Liquid nitrogen continues to flow at 77K through the nitrogen shield throughout the cool-down process to help maintain temperature stability.

Next, liquid nitrogen is poured directly into the helium vessel (which surrounds the niobium cavity) at approximately 30 minute intervals, see Fig 1. This helps the cavity transition quickly through the Q-disease temperature region, approximately 150K to 66K [1], while preserving liquid helium. The liquid nitrogen is allowed to boil off, and then liquid helium is transferred into the helium vessel. Using this method, the system cools to about 4.5K in approximately 2.5 – 3 hrs after initial cool-down begins. A 100 liter dewar gives a full day of operation at low power after cool-down.

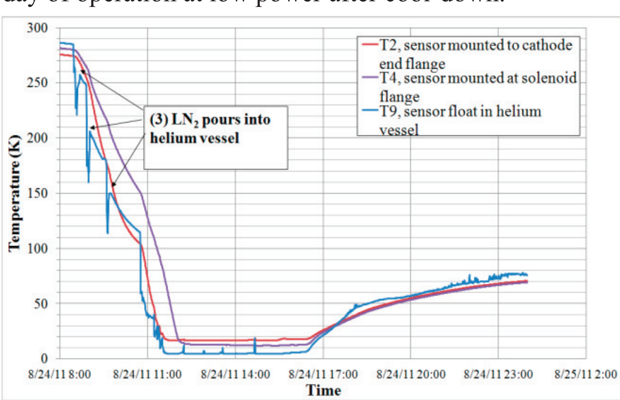

Figure 4: Cool-down of Mark I cavity on 8/24/2011 showing only 2-3hrs before reaching temperatures approaching 4K

There are nine temperature sensors fabricated into the cryogenic assembly. During cool-down these sensors are monitored and readings are logged on a computer system that allows personnel to actively observe temperature changes as well as analyze them afterwards. Two sensors give the best indication of a superconducting niobium cavity, known as T2 and T9, see Fig 4.

Measuring Q, β and ω_o

As well as verifying that the cavity was not subject to damage during shipment from Niowave to NPS, BPL is interested in characterizing coupling factor β, and resonant frequency ω_o of this SRF quarter-wave cavity. This is done using methods discussed in Padamsee, Knoblock, and Hays [3]. The cavity is tested at a low input power of 10mW. A typical RF circuit diagram used to make low power measurements on the Mark I cavity having one power coupler with two associated probes and a cathode stalk, see Fig 5.

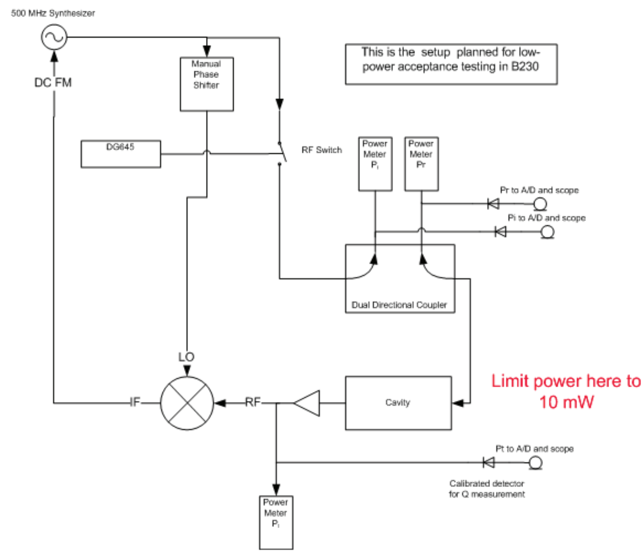

Figure 5: Circuit diagram for low power testing , includes a 500MHz signal generator, power meters for forward, transmitted, and reverse power, a dual directional coupler, a manual phase shifter, and other circuit components.

During cool-down, we watch for the cavity to go superconducting, and then adjust the power coupler for β~1. A network analyser is used to show reverse power vs. resonant frequency, ω_o. Then the circuit shown in Fig. 4 is used with the RF pulsed at 10 Hz. Using several codes written in LabVIEW, a ring down curve is fit in order to take measurements of Q_L, (see example ring down in Fig 6). The intrinsic quality factor, Q_o is then calculated using Eq. 1.

$$Q_0 = (1+\beta)Q_L \tag{1}$$

$$\beta = \frac{1 \pm \sqrt{P_r/P_f}}{1 \mp \sqrt{P_r/P_f}} \tag{2}$$

β is the coupling factor, P_r is reflected power and P_f is forward power, and Q_L is the loaded Q.

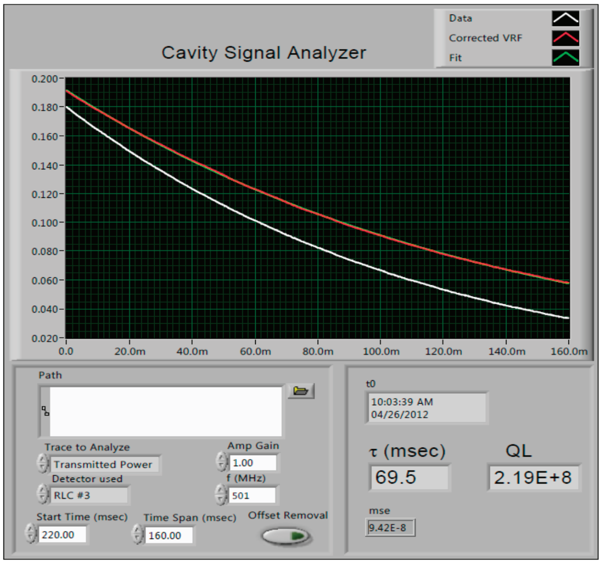

Figure 6: Ring down curve fit using LabVIEW. Once this is done, a value for Q_L can be used to calculate Q_o.

The waveform from the diode detectors at the start of the pulse tells us whether the cavity is over-coupled or under-coupled, i.e. whether β is less than or greater than unity. This tells us which sign to use in Eq. 2. The pulser is then turned off and the forward and reverse powers are used to calculate β. The directivity of the directional coupler limits the accuracy of this measurement near β=1.

We are also interested in how Q, β, and ω_o change as we move the coupler, cathode, and probes to different positions. Figure 7 and Figure 8 show the results of these measurements.

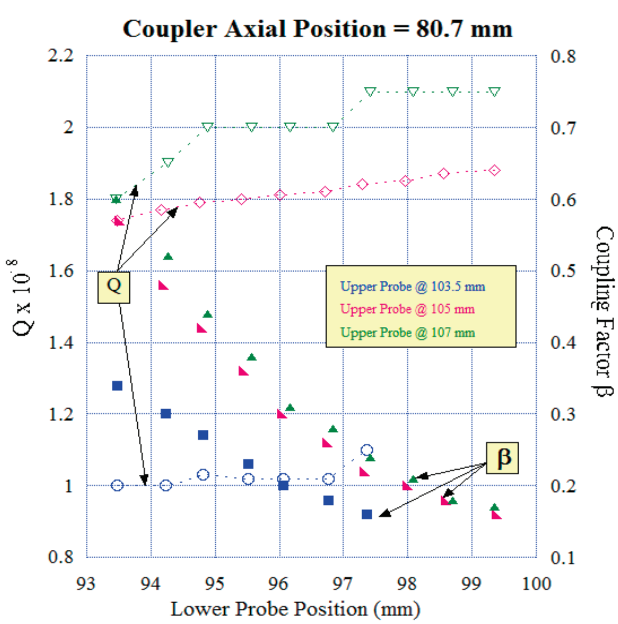

Figure 7: Q and β changes due to lower probe positioning, as coupler position is set to 80.7mm and probe antenna is moved from 103.5mm, 105mm, and 107mm.

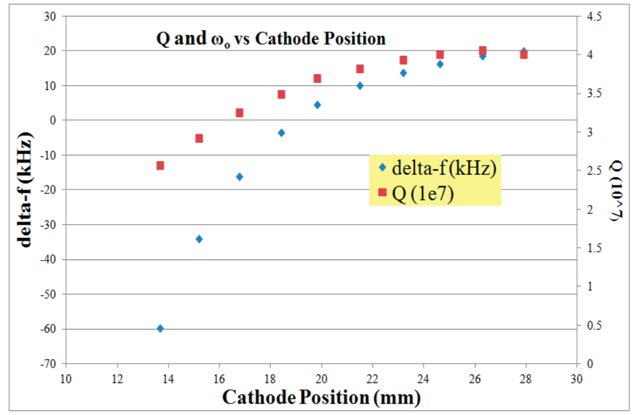

Figure 8: ω_o and Q as a function of cathode position

OUTLOOK

Characterization of the Mark I is on-going at NPS. The next step is to characterize the cavity at higher gradients. As part of on-going upgrades to the Mark I, investigation into active cathode stalk cooling [4] will be integrated to study its effects on Q, β, and ω_o. Also, a new antenna probe positioning system will be investigated. Currently, the power coupler settings are adjusted manually. For added ease of operation, we are pursuing an upgrade of this system which will include servomotor-driven linear actuators to remotely set the antenna and axial coupler positions using a LabVIEW control interface. Sample components provided by vendors are now being tested to ensure they meet our mechanical and magnetic requirements.

ACKNOWLEDGEMENTS

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