SRF GUN AT BNL: FIRST BEAM AND OTHER COMMISSIONING RESULTS *

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Abstract

The BNL 704 MHz SRF gun for R&D Energy Recovery Linac (ERL) successfully generated the first photoemission beam in November of 2014, with a copper substrate cathode stalk. A new multipacting-free, Ta-substrate cathode stalk was designed, fabricated and demonstrated as truly multipacting free. With this new cathode stalk, the beam commissioning has been continued to bring the beam to dump, which is called Gun-to-dump commissioning. This paper discusses the first beam commissioning, design and commissioning of multipacting-free cathode stalk. ERL commissioning status will be addressed as well.

INTRODUCTION

The R&D ERL [1] at BNL is an electron accelerator designed for high average current, up to 350 mA. It serves as a test bed for future RHIC projects, such as eRHIC [2], Coherent-Electron-Cooling [3], and Low Energy RHIC Electron Cooler [4]. The 704 MHz half-cell SRF gun is designed to provide 0.5 A, 2 MeV electron beam. Commissioning of the SRF gun is being carried out in stages: (1) without a cathode stalk, (2) with a copper cathode stalk, (3) first beam commissioning and (4) gun to dump commissioning. Without a cathode stalk insertion, the SRF gun cavity reached the design voltage of 2 MV in CW mode. However, strong multipacting in the quarter-wavelength choke-joint occurred during commissioning with a copper-substrate cathode stalk. Multipacting in the choke-joint was later understood with simulations [5]. While the beam commissioning was carried out with Cu-substrate cathode stalk to successfully generate the first beam in November 2014 [6,7], a multipacting-free choke joint with Ta substrate has been designed, tested and showed that it is truly multipacting-free in March 2015. With the Ta-tip cathode stalk [8], the cathode lifetime is very long: from its first use June 1 and three days per week since then, QE is still good for beam commissioning. We are now in the Gun-to-Dump commissioning stage, where the electron beam is transported from SRF gun, through Zig-Zag, and 5-cell main linac (5-cell cavity is not powered) down to the beam dump. This paper discusses the latest commissioning results.

FIRST BEAM COMMISSIONING

Layout

The first beam commissioning of the SRF gun was done with a straight beam line ending up at a faraday cup. This beam line configuration is shown in Figure 1. The Cs_3Sb photocathode was deposited on the cathode stalk with copper substrate in the cathode deposition system located outside the ERL blockhouse. Then, the cathode stalk was moved to the ERL blockhouse inside a cathode transport cart and inserted into the SRF gun. A load-locked system is used for the connection between the SRF gun and the cathode transport cart. The beam path consists of the 704 MHz half-cell SRF gun cavity, a high temperature superconducting solenoid (HTSS), a room-temperature HOM absorber (Now, in the place of the absorber, a room temperature solenoid was installed there for better beam quality), a laser cross, an Integrated Current transformer (ICT), a Beam Position Monitor (BPM), a vertical and horizontal beam corrector, a beam halo monitor, a pepper pot for beam emittance measurement, a beam profile monitor and a Faraday cup. The dipole magnet for bending electron beams to the Zig-Zag is locked out for the first beam tests.

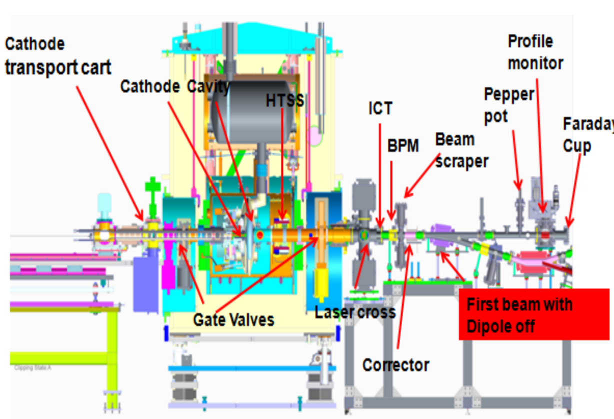

Figure 1: First beam commissioning configuration.

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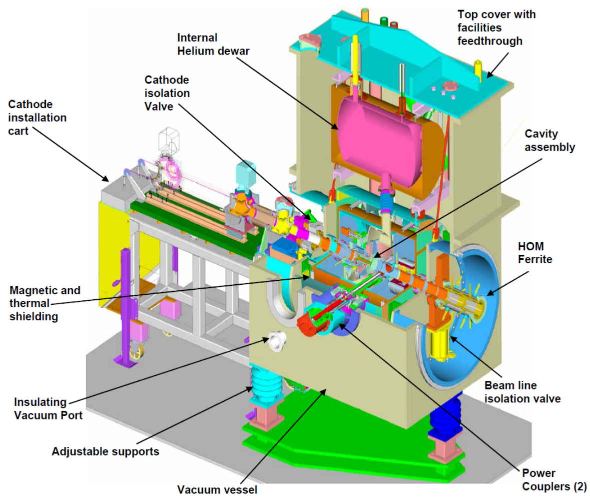

Figure 2: SRF gun cryomodule.

SRF Gun Cryomodule

The SRF gun cavity is the core component in the system. The cryomodule is built around the cavity, which shown in Figure 2. It includes a quarter-wavelength choke-joint cathode insert, a pair of opposing fundamental power couplers (FPC) to deliver 1 MW of RF power, a high temperature superconducting solenoid (HTSS) to compensate space charge and a room-temperature ferrite HOM damper with a ceramic break. The gun was successfully commissioned and it reached the design goal (2 MV in CW mode) without a cathode stalk insert. After spending some time on conditioning to suppress multipacting (to suppress it) with a Cu-substrate cathode stalk, we were able to operate the gun at 1.9 MV with 18% duty factor. The field stability was studied during cavity tests. The achieved amplitude stability is 2.3×10^{-4} (rms) and the phase stability was 0.035° (rms). While a new multipacting-free cathode stalk was been designed, we tried to use this cathode stalk to generate first electron beams.

Cs_3Sb Cathode for First Beam

Because the substrate of the cathode stalk is copper, the QE of Cs_3Sb was relatively low, 0.25% as measured in the cathode preparation chamber. However, after the cathode stalk was moved into the ERL block house and connected to the gun with a load-lock connector and the load-lock was baked out, the QE dropped to 3.5×10^{-4} (at room temperature) before it was inserted into the cavity. After the cathode was inserted into the cavity, the QE was measured as 1.2×10^{-5} with the cathode cooled by LN2. This drop was understood to be due to an increase in the work function of the cathode at LN2 temperature [9].

First Beam Test Results

The First beam test was carried out with approval of DOE for a beam power lower than 70 W. In November 2014, we successfully generated the first photoemission beam in the SRF gun and measured some of the beam parameters. Figure 3 shows the beam current measured by a Faraday cup with laser on and off. The beam current was 1.09 µA with only 38 nA dark current (laser off), and the bunch charge was 7.7 pC. The rms beam size was measured on the beam profile monitor as 1.4 mm, shown in Figure 4. A beam energy of 1.25 MeV was measured through steering and dipole magnets, consistent with the RF voltage.

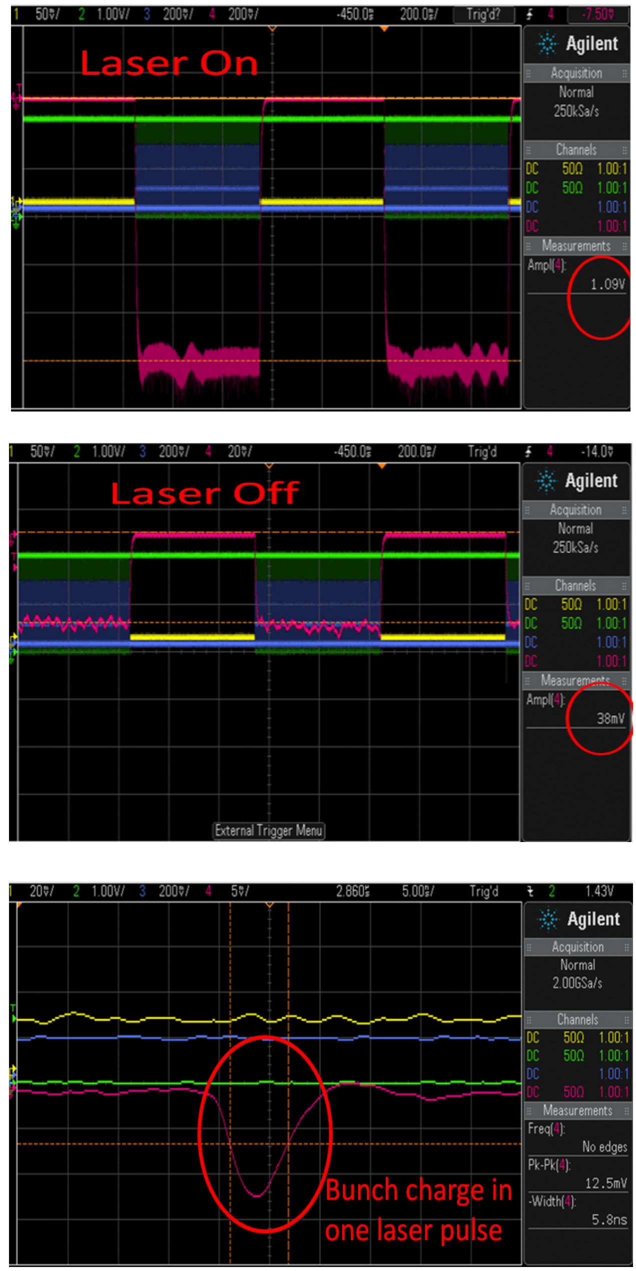

Figure 3: Beam current (top), dark current (middle) and bunch charge (bottom) measured by Faraday Cup.

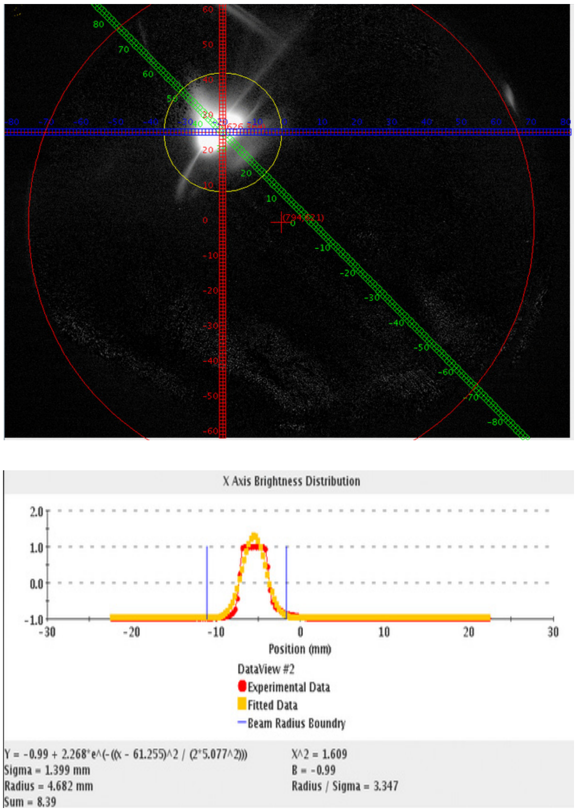

Figure 4: Beam size measured by beam profile monitor.

MULTIPACTING-FREE CATHODE STALK

Multipacting in the Old Cu Substrate Cathode Stalk

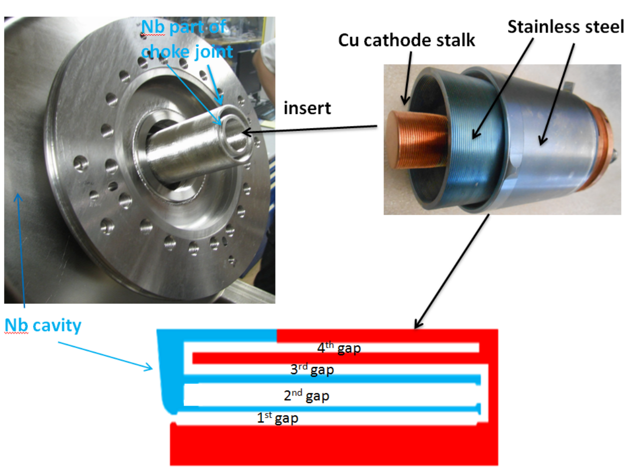

Figure 5: Quarter-wavelength cathode stalk insertion. In the choke-joint, the red part is the cathode stalk and the blue part is Nb cavity.

Figure 5 shows the combination of SRF gun cavity (top left) and a cathode stalk (top right) and a schematic of how the two mate. There are two folded half-wavelength chokes with four gaps. The copper cathode substrate and an inner Nb cylinder compose the first gap. The second gap (end of the first choke) is formed by two Nb cylinders. The third gap is composed of the outer Nb cylinder and an inner stainless steel cylinder. Two stainless steel cylinders constitute the forth gap. The Nb cylinders are part of the Nb cavity, which stays inside the cryomodule. The copper substrate and stainless steel cylinders form the cathode stalk, which stays with a cathode transport cart.

Without a cathode stalk insert, the gun cavity was successfully commissioned and reached the design goal of 2 MV in CW mode. However, multipacting occurred during commissioning with the copper cathode stalk. The main reason for multipacting was distortion of anti-multipacting grooves during Buffered Chemical Polish (BCP) and high Second Emission Yield (SEY) in the stainless steel area of the choke joint. Figure 6 shows signals during the cathode stalk conditioning when strong multipacting was observed. The reflected power could be as low as 50% of the forward power when multipacting is active. The main reason for multipacting was distortion of grooves due to BCP and high SEY in the stainless steel area.

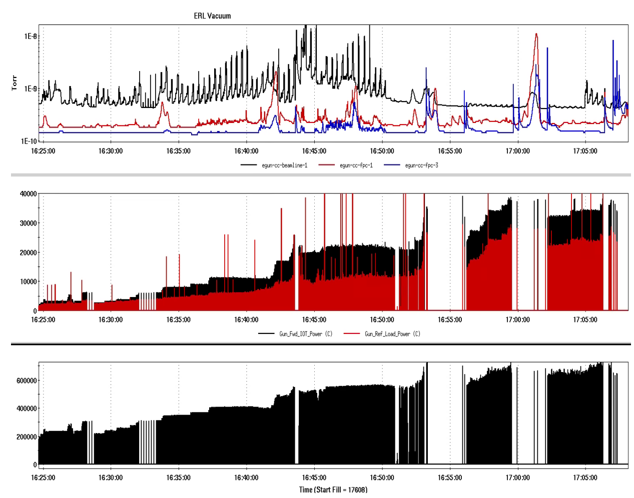

Figure 6: Signature of strong multipacting in the cathode stalk: vacuum behavior (top); reflected and forward power difference due to multipacting (middle); cavity voltage (bottom).

Design of a Multipacting-Free Cathode Stalk

To run the gun in CW mode, a new multipacting-free photocathode choke joint has been designed, as shown in Figure 7. The main features of the new design are: 1) To suppress multipacting in the 1st gap, the ratio of the groove's depth over period is increased from 1 to 2; 2) To suppress multipacting in the 3rd and 4th gaps, the ratio of the groove's depth over period is increased from 1 to 1.2; 3) To suppress multipacting in the 2nd gap (Nb part), the cathode radius is reduced from 1.25 to 0.9 cm, which pushes the field higher, as shown in Figure 8. The results of multipacting simulations in the choke joint are shown in the Figure 9.

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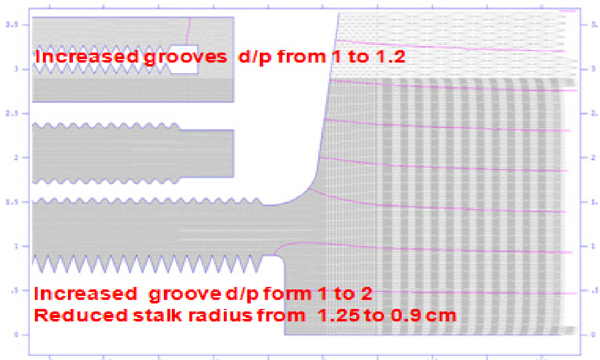

Figure 7: New design of a multipacting-free cathode stalk.

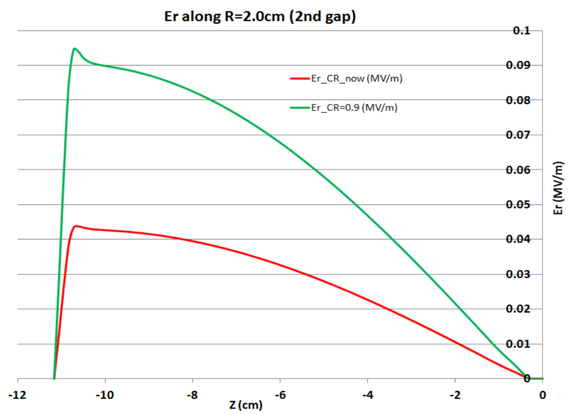

Figure 8: Electric field in the 2nd gap.

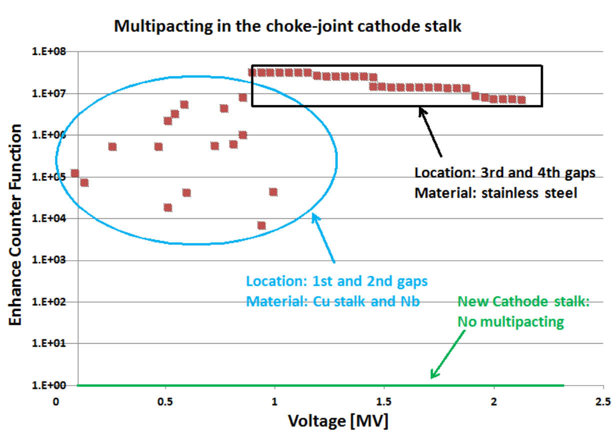

Figure 9: Multipacting simulation results in the quater-wavelength choke joint.

Figure 10 shows thermal analysis of the new photocathode stalk. One important concern is RF heating of the choke-joint as the new design has higher fields for the same gun voltage. A LN2 cooling was re-designed using fin-style channel to improve its efficiency. The cooling capacity is now 736 W, which is bigger than the heat load of 656 W. RF heat load to 2 K is only 5.22 W, as compared to 7 W in the old cooling channel design. The maximum temperature on the cathode stalk is 83.1 K. In addition to multipacting suppression, the tip of the cathode stalk is brazed with tantalum to minimize the interaction between Sb and the substrate metal, thereby to increase quantum efficiency (QE) of the photocathode.

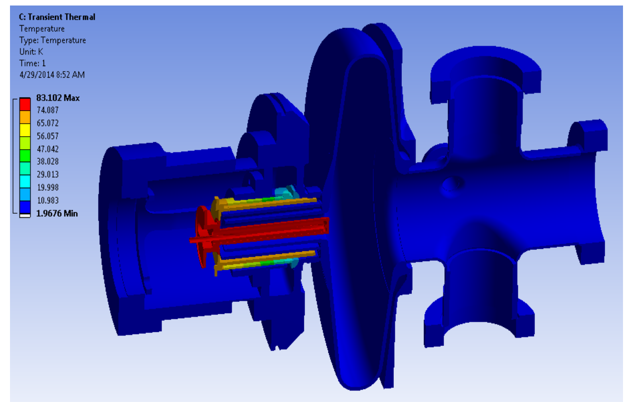

Figure 10: Thermal analysis of the new cathode stalk.

Commissioning Results of New Cathode Stalk

Figure 11 shows the new cathode stalk, which has a Ta-tip brazed on the copper stalk as a substrate of photocathode for high QE. The cathode stalk was performed ultrasonically cleaned, leak checked and baked out in a vacuum chamber at 350 °C for 48 hours. It was stored in a N2 filled bag to minimize the oxidation on the copper surfaces, while waiting for assembly.

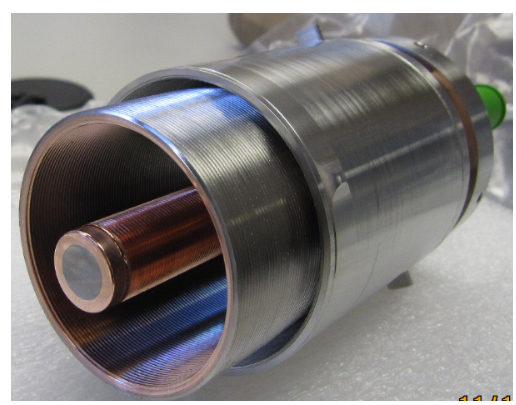

Figure 11: New cathode stalk.

The cathode stalk was inserted into the gun and tested with high power RF in mid March, 2015. Within the first 1.5 hours, the cavity voltage went up to 2 MV in pulsed mode without multipacting, which is illustrated in Figure 12. To reach the same level, it took tens of hours for the old cathode stalk. For the voltage levels above 1.4 MV in CW mode, field emission was observed but we didn't spend time on conditioning because the field was high/good enough for generating electron beam. Figure 13 shows CW operation level for the beam tests after less than 10 hours conditioning time. The previous cathode stalk never reached such CW operational mode at all.

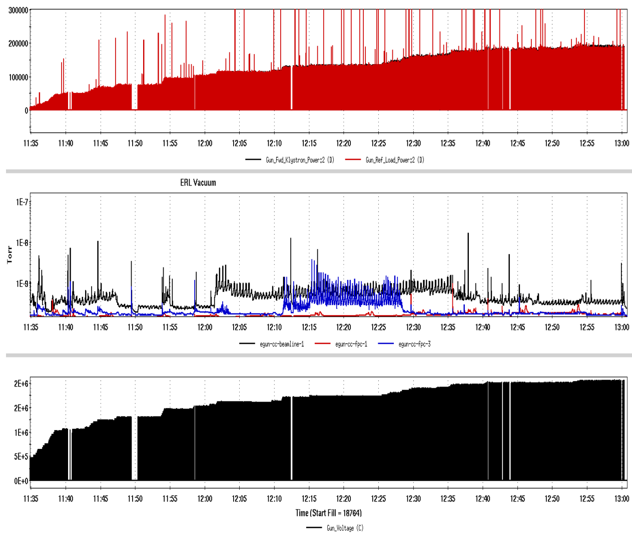

Figure 12: Multipacting-free cathode stalk tests result.

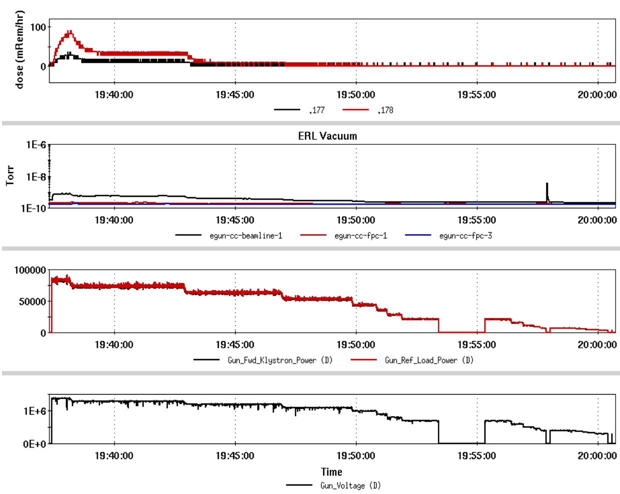

Figure 13: CW operational voltages.

ERL COMMISSIONING STATUS AND PLAN

K_2CsSb Cathode

After the cathode stalk was conditioned, K_2CsSb cathode was deposited on the Ta tip, which got 4.2 % of QE in the deposition area. The QE was constantly monitored during the baking out of load lock and in cathode retracted position when there is no beam test. The QE was above 2.8 % for about 40 days, then it dropped and stayed at below 0.1 % for months.

Commissioning Plan

R&D ERL is now at Gun-to-Dump commissioning stage. The beam path is shown in the Figure 14. The next stage will be the ERL loop commissioning. As most of ERL components will be used for LEReC, the commissioning goal is to study potential issues in LEReC, including beam dynamics issues and critical components commissioning.

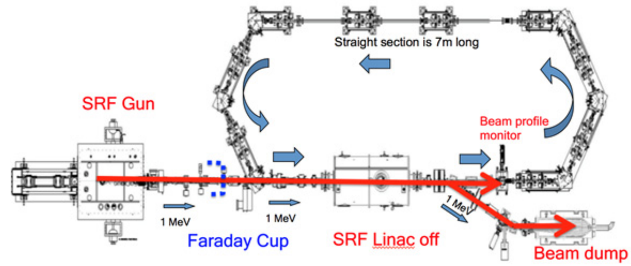

Figure 14: ERL commissioning status.

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