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PARTICLE MEASUREMENT ON ALL-METAL GATE VALVE FOR CEBAF BEAMLINE VIA LASER-BASED PARTICLE COUNTER*

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Abstract

The Viton gate valves installed in the CEBAF beamline degrade significantly after long-term operation in a radiation environment, generating numerous particles that cause heavy contamination and increased risk of field emission. All-metal gate valves have been proposed as a replacement for installation in the CEBAF beamline. In this paper, we present thorough comparison tests between the Viton gate valves and the all-metal gate valves, including evaluations of particle levels, aging tests of the gate valves, and analysis of the particle material.

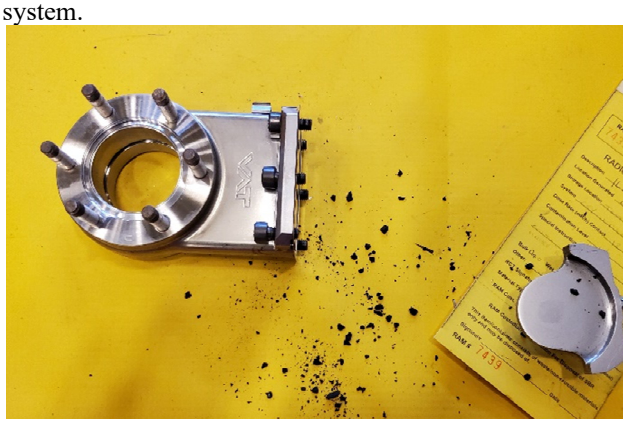
INTRODUCTION

During CEBAF operation, various beamline components, such as Viton gate valves, may generate microscopic particulates. Those that migrate onto SRF cavity surfaces can become field emitters, causing field emission (FE) and leading to performance degradation of the SRF cavities [1-3]. Frozen gases can also activate non-field-emitting particulates [4, 5].

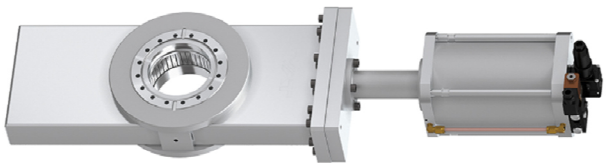
The Viton gate valves (VAT 01.0 Mini UHV Gate Valve [6]) have been widely used in the CEBAF beamline. Each CEBAF cryomodule has two Viton gate valves, one at each extremity, resulting in approximately 190 Viton gate valves installed in the CEBAF accelerator. Although the root cause of the field emitters has not been definitively identified, one of the primary suspicions is that the Viton seals become hardened and shattered into microparticles after long periods of accelerator operation under a high-level radiation environment.

Viton gate valve failures have occurred many times in the CEBAF beamline. In some cases, a small piece of the Viton seal was missing. There were two instances of complete Viton gate valve failure. In both cases, the Viton seals had hardened after over 12 years of use in cryomodules with excessive field emission. When the Viton seals shattered, adjacent cavities became inoperable due to gas discharges. Following the failure, the operational gradient of cryomodule 1L25 dropped from 79 MeV to 59 MeV, accompanied by a significant increase in radiation. Similarly, cryomodule 1L26, which operated at 82 MeV before the failure, dropped to 38-45 MeV afterward. Upon disassembly of the Viton gate valve, it was observed that the Viton seal had shattered into numerous dark particles, as shown in Fig. 1 (a).

To eliminate the potential risk of field emission from the Viton gate valve, the VAT 47.2 XHV RF All-Metal Gate Valve [6], as shown in Fig. 1 (b), is proposed to replace all the Viton gate valves on the CEBAF cryomodules. Unlike the Viton seals, the materials of this all-metal valve should not shatter after long periods of operation under high-level radiation. The critical metric for qualifying the all-metal valve is that the particle level generated during valve operation (i.e., opening and closing) should be equal to or less than that of a brand-new Viton gate valve. In this work, we present the setup and results of particle-level measurements comparing the all-metal valve and the Viton gate valve using a laser-based vacuum particle counter system.



(a)



(b)

Figure 1: (a) Numerous dark particles from the Viton gate valve after disassembly from CEBAF cryomodule 1L26; (b) Photograph of the VAT 47.2 XHV RF All-Metal Gate Valve.

LASER-BASED PARTICLE COUNTER SYSTEM

The particle counter system was first developed at Jefferson Lab around 2018-2020 [7]. This system utilizes a laser-based vacuum particle sensor [8], capable of measuring particle sizes up to 3.6 µm and counting particles in a 2.75-inch OD vacuum pipeline in real-time. In 2022-2023, the system was upgraded with new features, such as slow pumping. The diagram and photograph of the particle counter system are shown in Fig. 2 (a) and (b), respectively. During a measurement, a gate valve is mounted above the particle sensor. Slow pumping is performed before data collection to prevent particle movement and agitation.

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Once the isolation valve is opened, the gate valve operation is carried out. The particles generated from the gate valve will fall, and as they pass through the particle sensor, their number and size are captured.

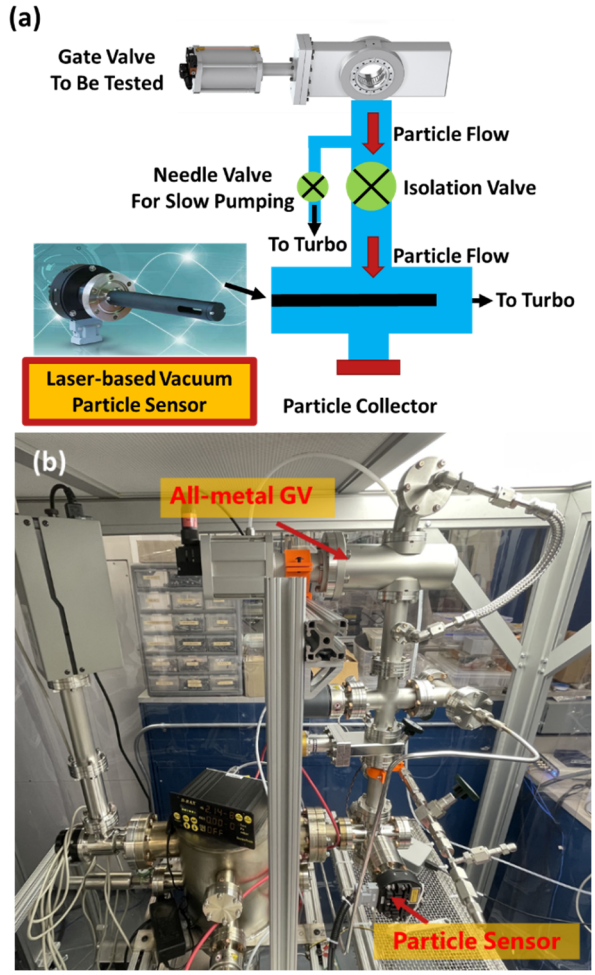

Figure 2: (a) Diagram of the particle counter system illustrating the system's working principle; (b) Photograph of the system.

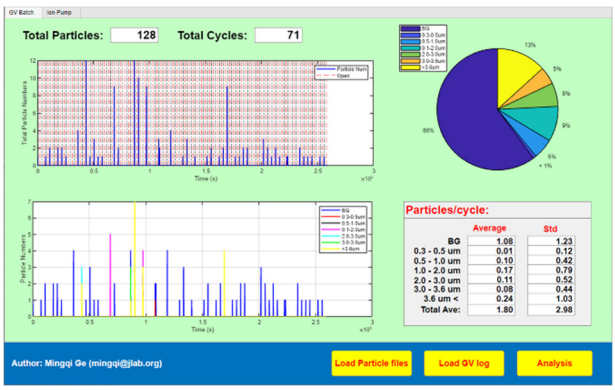

Figure 3: Data analysis program developed in MATLAB GUI, showing the particle numbers generated after each valve cycle.

A new data analysis software has been developed using a MATLAB GUI for particle measurement of gate valves, as shown in Fig. 3. The program can synchronize the valve operation with the particle sensor data collection rate, enabling it to track the number and size of particles generated after each valve cycle and provide statistical results. Particles with a size below 0.3 µm are regarded as background (BG). Since the particle size that causes field emission (FE) is unknown, we have counted the total number of particles across all sizes in this study.

PARTICLE-LEVEL MEASUREMENTS

Comparison Tests

Two brand new all-metal gate valves, designated as All-metal GV01 and All-metal GV02, along with a brand-new Viton gate valve (Viton GV02) and a used Viton gate valve (Viton GV01) disassembled from the upstream position of cryomodule 2L23 in the CEBAF tunnel, have been tested. While installed in CEBAF, Viton GV01 underwent approximately 12 actuation (Open/Close) and six half actuations (2 from Open to Half Open and four from Closed to Half Open) between April 2022 and June 2022. It was exposed to 160 kRad gamma and 23 kRem neutron radiation during the first period in the tunnel and 80 kRad gamma and 10 kRem neutron radiation during the second period.

We performed approximately 72 cycles (Open/Close) for each gate valve in the particle measurements. A 30-minute interval was maintained between each opening and closing operation. This interval was necessary because each actuation of the gate valve can cause the vacuum pressure perturbation and lead to particle movement. After 30 minutes, the vacuum system had sufficient time to recover, ensuring that the subsequent measurement would not be affected by the previous operation.

The key to accurate particle measurement is avoiding contamination during the pre-assembly and mounting the gate valves on the test stand. A rigorous cleaning procedure was implemented, which involved wiping each component with methanol and performing a blowdown to zero particles in a Class 100 cleanroom before assembly. This meticulous process is crucial for minimizing environmental contamination and ensuring the reliability of the measurements, as demonstrated by the significant reduction in particle numbers shown in Table 1: All-metal GV01 test (rows 1) and re-test (row 2).

The detailed comparison test results are summarized in Table 1. The brand-new all-metal valves, GV02 and GV01, showed total particle numbers of 21 and 128, respectively, leading to average particles per cycle of 0.3 and 1.8, respectively, much lower than the brand-new Viton GV02, which had 5.3 particles per cycle. The Viton GV01, retrieved from the CEBAF tunnel, showed a total particle count of 5,683, averaging 81 particles per cycle. This result indicates that the performance of the Viton gate valve significantly degraded after long-term accelerator operation, as compared with the brand-new Viton GV02 test results.

Life Cycling Tests

A life cycling test was conducted to assess whether the performance of the all-metal gate valve degrades over long-term operation due to mechanical wear. The average

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gate valve operation rate at CEBAF is approximately 4-5 cycles per month. To simulate about 20 years of operation, we measured the gate valve performance up to ~1000 cycles, as shown in Fig. 4. For the All-metal GV02, data was collected approximately every 100-200 cycles. The results indicate that the performance remains very stable, with the average number of particles generated per cycle remaining below 1, which is excellent. The test result for All-metal GV01 showed an average of about 2 particles per cycle, consistent with the performance of All-metal GV02. Both all-metal gate valve results perform better than the brand-new Viton GV02, as illustrated in Fig. 4, suggesting that the all-metal valves are a superior choice for long-term applications.

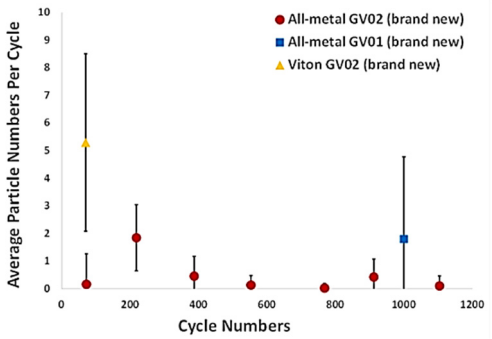

Figure 4: Life cycling test results of the all-metal gate valves simulating 20 years of operation.

PRELIMINARY MATERIAL ANALYSIS

The material analysis of the particles from Viton gate valves has been systematically carried out in Refs. [5, 7]. The particles are primarily composed of stainless steel and fluorine-bearing polymers/elastomers. To complement these previous studies, we performed SEM and EDS analyses on the particles collected from the All-metal GV02 by contacting the carbon tape stubs (known as gun-shot-residue (GSR) stubs) after aging tests (~1000 cycles). Figure 5 shows representative images of the sizes of particles ranging between maximum dimensions of 5-100 µm. Most particles detected had Fe-Ni-Cr and Al-Mg alloy chemistry. The total density of particles detected was 0.16 particles/mm^2. The results are preliminary, and further investigation is planned.

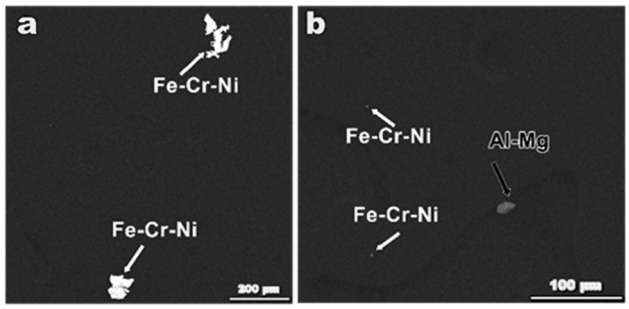

Figure 5: Backscatter electron images of particles on stubs sampled after tests show particles generated during the operation of the all-metal gate valve. The particles indicated by white arrows showed the presence of Fe, Ni, and Cr, and the black arrow showed the presence of Al and Mg by electron dispersive spectroscopy (EDS), interpreted as steel and Al-Mg alloy, respectively.

CONCLUSION

The comparison and life cycling test experiments conducted on the all-metal gate valve and Viton gate valve demonstrate that the all-metal gate valves outperform the Viton gate valves regarding particle generation and long-term operational stability. Even after extensive cycling, the all-metal valves showed minimal degradation, with significantly lower particle counts than the Viton gate valves. These results indicate that the all-metal gate valves are more reliable and durable for CEBAF beamline applications.

The performance of the all-metal gate valves will be further investigated after operation in the CEBAF beamline under high-radiation environments to confirm the absence of degradation.

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Table 1: Comparison Tests of the All-metal GVs and the Viton GV

	Clean Procedure Applied?	Cycles	Total Number of Particles	Particles/Cycle	Std
All-metal GV01	No	71	617	8.6	5.2
All-metal GV01 (re-test)	Yes	71	128	1.8	3.0
All-metal GV02	Yes	71	21	0.3	1.5
Viton GV01 (from tunnel)	Yes	70	5683	81.2	9.2
Viton GV02 (brand new)	Yes	70	371	5.3	3.2

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