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A ConFlat iris diaphragm device for direct beam control and alignment inside a vacuum chamber

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ABSTRACT
We describe an easy-to-assemble and robust design of a ConFlat (CF) iris diaphragm device installed in a vacuum environment with its aperture size directly adjustable by users outside the vacuum. This design involves commercially available vacuum equipment, 3D-printed but vacuum-compatible components and a minimal need of professional machining to be straightforwardly taken advantage by a wide range of research groups. The iris diaphragm is centered in a 4.5 in. o.d. double-sided CF flange with user-customizable mounting orientation to allow a maximum range of aperture opening from 0.5 mm to 15 mm in diameter. Installation of this device does not require an additional pump for differential pumping across the iris diaphragm. The functionality of this device is examined at a pressure of \( \sim 7 \times 10^{-9} \) Torr to provide continuous control on the cross section of a light beam passed through the aperture.

I. INTRODUCTION
Iris diaphragms are commonly used on optical tables for precisely aligning laser beams in a user-defined path. Placing it directly in front of a sensor can limit the amount of detected photons in order to prevent damage by oversaturation. These properties of an iris diaphragm come from the smooth adjustment of a circular aperture via controlled movements of a set of well-positioned thin metal leaves. However, many research groups around the globe perform experiments using laser and/or molecular beams in vacuum (with examples of recent publications given here\(^{1-17}\)), and the alignment of the laser beam path inside a vacuum space is usually achieved via placing two iris diaphragms outside the optical windows on both ends of the vacuum chamber. If one of the windows is replaced by a detector, precise re-alignment would inevitably involve vacuum breaking. In cases where the laser beam has a long traveling path inside the vacuum chamber, a small angle of deviation at the optical window could result in a completely off alignment at the target.

It would thus be preferable if an iris diaphragm can be installed in vacuo along the beam traveling path or directly in front of a highly sensitive detector, and it is imperative that its aperture size (the movement of the iris leaves) can be finely controlled outside the vacuum chamber. Such device can also be used for atomic or molecular beam experiments in terms of controlling the amount of atoms/molecules entering the interaction region. Major features of this device would necessarily include 1 an easy-to-construct design; 2 vacuum compatibility for all the constituent materials; and 3 a completely vented architecture that precludes dead volume within the device and facilitates the original vacuum condition prior to installation.

No such device is currently available from major vacuum equipment manufacturers. As part of an effort to directly align a laser beam towards, as well as to control the amount of molecules arriving at, a UHV cryogenic scanning tunneling microscope, we have designed and built a CF iris diaphragm device with the above-mentioned key properties. Design consideration for this device centers around maximum usage of commercially available parts and minimization of professional machine shop work so that fellow researchers can easily adopt this design into their own instrument. 3D-printed but vacuum-compatible materials are used as a straightforward method to make small but intricate components for this device, but these components can also be easily made by a professional machine shop. Diagrams of the key components are provided
in the supplementary material document. The functionality of this device has been tested below 10⁻⁸ Torr.

II. INSTRUMENT DESIGN

The primary design philosophy for this device is the ease of integration into existing vacuum systems. We chose a double-sided 4.5 in. o.d. CF flange as the base of this device. As a result, it can be coupled with other CF flanges of different sizes via commonly available CF reducers. Part A of Figure 1 provides an overview of the entire device, while its key components are individually presented in parts B to H. Its foundation, a double-sided 4.5 in. o.d. CF flange welded with a 1.33 in. mini top port, is a part of a readily available 4.5 in. UHV viewport shutter from MDC Vacuum Products (part number 454001) and is illustrated in part B of Figure 1 with unused components drawn in blank. This flange can also be individually ordered from MDC (without the shutter blade and the manual rotator) with the part number of 945411. The advantages of using this specific flange include: it is commercially available and can be directly adopted into our design with minimal amount of modification; it has a 1.33 in. port welded on the side to be connected to an operating mechanism for out-of-vacuum control; it offers complete venting on both sides of the aperture while providing sufficient coverage of a stainless steel (SS) plate with 0.1 in. thickness inside the flange to securely install the iris diaphragm; and since the inner SS plate is parallel to the cross-section of the 4.5 in. o.d. CF flange, it automatically secures the movements of the aperture leaves on the same plane when the iris diaphragm is mounted parallel to this SS plate.

Part C is a stand-alone, vacuum compatible iris diaphragm made of bare SS case and leafs without black anodization (OptoSigma Corporation part number VIII-15) and is used in our design without any modification. This iris diaphragm is mounted inside the 4.5 in. flange using a tightly-fit holder (part D) that is designed by us and 3D printed using sterling silver (93% silver, 3% tin and 4% copper from Shapeways, www.shapeways.com). This silver material has been previously demonstrated to be UHV compatible.18,19 The iris diaphragm is secured on the holder using a SS NF 6−40×1/4 in. allen cap set screw at the bottom of its case (position (a) in Figure 1) with a vent hole that is already drilled by the manufacturer on the iris body (position (b)). With the assistance of the professional machine shop here at Washington State University, we tapped two threaded holes of size NF 1-72 in. on the inside plate of the 4.5 in. flange to securely mount the holder and the iris diaphragm (positions (d)). The positions of these two threaded holes can be user-modified based on the purpose of individual experiment: As shown in part A of Figure 1, the 3D-printed base is installed at an angle vs. the vertical neck (position (e)) connecting the 1.33 in. o.d. port. This particular orientation provides a maximum opening of the aperture of ~9.5 mm in diameter, which is more than sufficient for our purpose of study. It is however straightforward to install this holding base parallel to the flange neck in order to take advantage of the entire opening range of the aperture from 0.5 mm to 15 mm in diameter. This feature has been embraced in the original design in a way that the length of the 3D-printed base is calculated so that once both of its corners (labeled in red in Figure 1) touch the inner wall of the flange, the center of the aperture is aligned with the center of the flange regardless of the installation angle between the base and the flange neck. Most importantly, the shape of this holder ensures that the motion of the iris leaves is perpendicular to the traveling path of the molecular or laser beam.

Parts E and F in Figure 1 illustrate two small 3D printed silver adapters that are designed to tightly hug the turning knob of the iris diaphragm using two pairs of SS NF 1-72 in. socket cap screws with hex nuts to clamp down at their “wings”. The shapes of the inner cavity of these adapters are designed to exactly match the geometry of the iris diaphragm turning knob together for tight fitting. There is also a hole on each adapter (positions (f)) made for venting. Due to the friction of motion for the iris leaves (in opening and closing the aperture) is adjusted via rotating the turning knob (similar to
This rod is 4.881 in. long and made by MDC Vacuum part number L-2111-2 and a customized aluminum rod professionally fabricated in-house at WSU’s machine shop (part H). This rod is 4.881 in. × 0.037 in. × 0.176 in. and connected to the linear feedthrough via two slotted round head NF 6-32 × 1/4 in. set screws (positions (h)). There is a 0.200 in. × 0.090 in. rectangular hole on the other end of the rod (position (i)) through which the rod, or equivalently the angle between the adapter protrusion and the rod, is constantly changing while the device is in operation. We have purposely designed the length of the rectangular hole on the rod (0.200 in.; position (i)) larger than the size of the rectangular hole on the other end of the rod (0.090 in. diameter) in order to prevent clamping between the two parts. Since the region of contact between these parts is not visible once this device is installed in vacuum, forced operation of the linear feedthrough without knowing the parts were clamped could easily damage the iris leaves. Unnecessary friction and silver–aluminum grinding is also effectively avoided by this size difference.

This “loose” fitting at the region of contact nevertheless introduces inactive linear motion for the rod. This inactive motion, however, does not affect the functionality of this device, and the relationship between readings of the linear feedthrough vs. the actual aperture size in diameter is plotted in panel (A) of Figure 2. The physical contact of the rectangular hole and the adapter protrusion at the turn-around positions are shown in panels (B) to (E) as indicated by the red circles, and each panel contains images taken on the feedthrough scale as well as on the iris diaphragm at the same stage of operation. Panels (B) and (C) both correspond to the minimum opening state of the aperture with a diameter of ~0.5 mm;
while panels (D) and (E) correspond to the maximum opening state (in our particular case) of ~9.5 mm in diameter. Going from panels (B) → (C) → (D) → (E) and back to (B) represents a full cycle of opening and closing for the iris diaphragm. As indicated by the red circles in panels (B) and (C), operating the linear feedthrough from its scale reading of ~16 mm to ~19 mm does not open the aperture. The aperture is gradually opened as the linear feedthrough extends from ~19 mm to ~50 mm on its scale. Similarly for the closing process, operating the linear feedthrough from its scale reading of ~50 mm (panel D) to ~47 mm (panel E) does not move the iris leaves. The aperture is gradually closed as the linear feedthrough retracts from ~47 mm to ~16 mm (back to panel B) on its scale. The overall relationship of aperture diameter vs. the feedthrough scale reading is illustrated in panel (A) for our particular set-up, in which (◯) represents the opening process while (●) represents the closing process. This relationship will vary if one customizes the installing orientation of the base (part D in Figure 1) or the length of the aluminum rod. The two arrows in Figure 2(A) indicate the above-mentioned inactive linear motions at the fully closed and opened stages. The (◯) and (●) trends can be used to determine the aperture diameter from the feedthrough scale readings when this device is in operation inside a vacuum chamber. Note that as shown in the plot, similar inactive motions are also expected when the operational direction is reversed at any other stages of aperture openings.

IV. FUNCTIONALITY

To examine the functionality of this iris diaphragm device in a vacuum environment, a compact system is assembled and shown in panel (A) of Figure 3, which consists of (a) the device of study in this work; (b) a turbomolecular pump (Pfeiffer HIPACE 80); (d) an UHV pressure gauge (Inficon BPG400); (e) a foreline pressure gauge (Inficon TV90) and a dry scroll pump (Edwards nDXS10i, not shown in the photo). This system is pumped down to ~7 × 10⁻³ Torr within 24 hrs using a turbomolecular pump (with a foreline pressure of ~2 × 10⁻³ Torr), which demonstrates effective pumping across this device without the need of differential pumping.

In order to demonstrate complete opening and closing of the aperture in operation, a simple LED flashlight (which has much larger beam cross-section than a laser) is used as the light source. The LED light source is place in front of the 2.75 in. CF window (part g) (with the end of the flashlight touches the window and at most 0.5 cm from the window to the led bulb), and this window is ~34.5 cm away from the iris diaphragm device. A piece of paper containing a series of concentric circles with 0.05 in. difference in diameter is placed and centered in front of the exit window (part f) that is ~4 cm away from the aperture. Four stages representing the passages of different amount of light through the aperture (and further through the piece of paper) is recorded using a camera aiming at the "bull's-eye" and shown in panels (B) → (E) in Figure 3. This closing process from panel (B) to panel (E) corresponds to the feedthrough readings of 47 cm → 37 cm → 27 cm → 17 cm, which is exactly the (●) progress plotted in Figure 2(A).

SUPPLEMENTARY MATERIAL

See supplementary material for dimensions of parts (D), (E), (F) and (H) in Figure 1.

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