# FESHM 5033.1: VACUUM WINDOW SAFETY

**Revision History**

| Author | Description of Change | Revision Date |
|---|---|---|
| Christine Ader | Initial release Chapter 5033.1 with current FESHM template. | April 2015 |

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## 1.0 INTRODUCTION

Vacuum windows pose a potential hazard to equipment and personnel from rupture or implosion. This chapter specifies the procedure to be followed in designing, fabricating, testing, and using vacuum windows in order to reduce hazards. This chapter applies to any vacuum window used at Fermilab except:

a) Portions of vacuum vessel through which beam may pass which are designed in accordance with the ASME Boiler and Pressure vessel code. Such 'windows' shall be documented in the engineering note prepared per Fermilab Environment, Safety and Health Manual 5033, Vacuum Vessel Safety.

b) Optical windows (should be properly designed to meet operating pressures).

## 2.0 DEFINITIONS

Vacuum Window – Any relatively thin separation between a volume under vacuum and a volume at atmospheric pressure or vacuum through which primary or secondary beam passes. ***This definition does not include optical windows***.

Engineering Note - A written analysis demonstrating that a given vacuum window satisfies the requirements of this chapter.

Qualified Person - A qualified person is "a person who, by possession of a recognized degree or certificate of professional standing, or who, by extensive knowledge, training and experience, has successfully demonstrated the ability to solve or resolve problems relating to the subject matter and work."

An Exceptional Vacuum Window - An exceptional vacuum window is defined as one which cannot meet the tenets of this chapter and therefore requires a Director's Exception.

Vacuum Window Failure – Failure of a vacuum window is defined as the onset of any condition which renders the window inadequate for its intended use. This includes not only catastrophic burst, but any failure in the window or its mounting system that prevents sealing against vacuum.

Similar Windows – Windows are deemed similar if they share one or more of several characteristics with a window for which an Engineering Note has been approved. These characteristics include, but are not limited to: material, thickness, differential pressure, fabrication techniques, mounting system, beam exposure, and hazard analysis.

Identical Windows – Windows are deemed identical if they differ in no way from a representative window for which an Engineering Note has been approved.

## 3.0 RESPONSIBILITIES

The division/section head, or designee, who controls the area of operation of the vacuum window is responsible for carrying out the requirements of this chapter. That person shall:

a) Arrange for the review of the Engineering Note by a qualified person.

b) Place the Engineering Notes into Teamcenter.

c) Assign a number to each vacuum window, and assure that this number is applied by some legible and durable means to the window or its mounting hardware (permanent marker, scribed on flange, adhesive sticker, etc.). If the window is one-of-a-kind, the assigned number must be unique. If the window is one of a group of identical windows for which a single Engineering Note has been approved, the assigned number need not be unique, but may be the same for all windows in the group.

d) For beryllium windows ensure that the beryllium handling, labeling and inventory requirements per FESHM Chapter 4190 are followed.

The Environment, Safety, Health and Quality Section (ESH&Q) Section shall audit the divisions and sections on their compliance to this chapter.

The Mechanical Safety Subcommittee shall serve the division/section heads and ESH&Q Section in a consulting capacity on all vacuum window matters. This committee may propose appropriate modifications to this chapter as necessary. Changes in policy and responsibility shall be recommended by the Laboratory Safety Committee after consulting with the division/section heads. Changes in procedure shall be recommended by the Mechanical Safety Subcommittee.

## 4.0 DESIGN CRITERIA

Thin vacuum windows shall be designed according to the requirements of 5033.1 TA, "Technical Appendix to Vacuum Window Safety: Requirements for Vacuum Window Design, Fabrication, Inspection, Testing, and Documentation."

## 5.0 IMPLEMENTATION

5.1 Preparation of Engineering Note: An Engineering Note shall be prepared by a qualified person for all vacuum windows at Fermilab. The format of the Engineering Note is shown in Exhibit A. The Engineering Note allows a reviewer to check the design and installation and to inform future users of the window parameters. The Engineering Note shall include design calculations for the vacuum window and shall also include precautions and operating procedures necessary for the safe use of the vacuum window. See Appendix 5033.1 TA for additional information.

5.2 Review of Engineering Note: All vacuum window Engineering Notes shall be reviewed by an independent, qualified reviewer, other than the preparer, for compliance with this chapter. The reviewer shall be from a group not reporting to the preparer or his supervisor. The note shall be deposited in Teamcenter as noted in "Special Responsibilities" using the procedure outlined below.

a. A New Item shall be created in Teamcenter with the type chosen as Engineering Note
    i. The New Item Name shall use the Vacuum Window prefix followed by a meaningful Name which briefly describes the contents of the note
    ii. A full Description shall be entered for the New Item
b. If applicable the Division Legacy Number shall be entered
c. The appropriate Engineering Note category of Vacuum Window shall be chosen
d. The Revision Author, Revision Comments, Lab Location Code, Exceptional Status, and Division\Section\Center shall be entered
e. The Engineering Note and supporting files shall be added as Data Sets. All documentation required for independent review of the Engineering Note must be included.
f. Approval
    i. The Teamcenter Workflow may be used to electronically obtain the required approvals and release the Engineering Note.
    ii. Approvals may also be obtained by physical signature, scanned, and included with the Engineering Note. A Teamcenter Workflow must still be completed so that the Engineering Note is released. This workflow need not involve the required approvers in the case of physical signature.

5.3 Amendment of Engineering Note: Any subsequent changes in the fabrication, assembly or operation of the vacuum window which could affect the performance of the window require an

amendment to the original Engineering Note. This amendment shall be reviewed in the same manner as the original Engineering Note.

5.4 Similar Windows: Similar windows need not have the full Engineering Note repeated. Adequate documentation can be provided by referencing an approved Engineering Note and noting differences.

5.5 Identical Windows: Identical windows do not require any documentation beyond the approved Engineering Note representative of the design.

5.6 Director's Exception: Exceptions to the provisions of this chapter shall be allowed only with the signature of the Laboratory Director or his designee, documented in the Engineering Note. The need for such exceptions is to be minimized by adhering to the provisions of this chapter. Exceptions shall be identified and submitted to the Director for review in a timely manner, and shall only be allowed after the Director is assured that sound engineering practice will be followed during design, fabrication and testing of the vacuum window. The ESH&Q Section shall maintain copies of exceptions for the Director.

If the Engineering Note cannot be approved, operation shall not be permitted until modifications are made which result in the Engineering Note being approved, or until a Director's Exception is granted. Should a Director's Exception be sought, the division/section head shall provide a brief statement justifying the application for a Director's Exception.

# TECHNICAL APPENDIX TO 5033.1 VACUUM WINDOW SAFETY

## REQUIREMENTS FOR VACUUM WINDOW DESIGN, FABRICATION, INSPECTION, TESTING, AND DOCUMENTATION

### 1.0 Design

Thin metal vacuum windows can be designed following the "Mechanical Safety Subcommittee Guidelines for the Design of Thin Windows for Vacuum Vessels" (TM-1380) by Jeffrey L. Western or "Roark's Formulas for Stress and Strain" by Warren C. Young. Please use the TM-1380 Revision dated November 2014 since previous versions have a typo in equations 5.1b and 5.2b on page 5.

This type of flat window design does not allow for dished windows. Alternate design analysis methods such as Finite Element Analysis should be used for dished windows.

### 1.1 Loads

a) In addition to vacuum loading, window design shall take into account any other load which may affect window function. These loads include, but are not limited to, those resulting from variation of pressure on the window (due to normal operation or possible faulty procedure), as well as all relevant effects of beam deposition such as thermal loading, cyclic mechanical shock due to very brief, high intensity beam pulsing, the number of cycles that the window experiences, corrosion which may be due to high ionizing radiation, and materials degradation from long-term beam exposure. Considering these effects may lead to additional analyses or tests related to creep or fatigue failure of the window.

b) Vacuum windows constructed of materials subject to creep rupture, such as Kevlar, shall have a calculation of the stress in the window and an evaluation of the expected lifetime before a creep rupture failure can be expected at that stress. Calculate and document the maximum design lifetime permissible to ensure to a 95% confidence level that the vacuum window will not fail.

1.2 Safety Factor – Manned Areas

Vacuum windows used in manned areas shall be designed with a minimum safety factor of 2.0 on failure.

1.3 Safety Factor – Unmanned Areas

Vacuum windows used in unmanned areas shall be allowed to have minimum failure pressures approach the external differential pressure (see Table TA-1) as long as the following additional criteria are met:

a) Sufficient means and methods shall be developed to either relieve the differential pressure or protect the area from the effects of a vacuum window failure when people enter the area. A hazard analysis shall be performed and attached to the engineering note to show the means and methods implemented to remove the hazard during personnel access.

b) Property losses resulting from the effects of a vacuum window failure shall be determined, documented, and acknowledged by the appropriate Division Head and Experiment Spokesperson (if applicable).

1.4 Failure Testing

a) Vacuum window safety factors shall be verified by testing a window or windows. Deflection and pressure shall be measured during the test.

b) For manned areas, it is not necessary to burst the window if stable deflections at a pressure differential corresponding to a Safety Factor ≥ 2 is demonstrated.

c) For unmanned areas, where Safety Factor < 2, the window(s) must be burst to verify the safety factor.

d) For the tested windows, all details of fabrication and assembly such as flanges, bolts, welds, etc., shall be identical to those of the window intended for service.

e) Whether multiple failure tests are necessary is determined by a qualified person based on the repeatability of fabrication, integrity of materials, and experience with similar window designs.

f) A hazard analysis shall be written for the failure tests, describing hazards to personnel and equipment associated with the test, and documenting the safeguards provided.

1.5 Compliance with Additional Design Load Requirements

a) Failure testing as required by this Appendix cannot demonstrate safe window operation under any loading but static vacuum. The designer shall demonstrate compliance with the additional loads of (1.1)(a) of this Appendix through analysis, or testing, or both.

2.0 Fabrication

a) The qualified person shall provide a written fabrication and assembly procedure, a list of planned and completed inspections, and any other quality control procedures taken for vacuum windows built in house. Use of a 'Traveler' to document the fabrication and assembly is recommended, but not mandatory.

b) Vendor material certifications shall be included in the window documentation.

c) Windows purchased from a manufacturer do not require a fabrication procedure to be included in the engineering note.

3.0 Inspection

a) The vacuum window shall be inspected during fabrication by the qualified person for compliance to this chapter, conformance to the design calculations, conformance to the design drawings, and conformance to the assembly procedure for windows built in house.

b) Windows purchased from a manufacturer can be inspected after delivery.

4.0 Acceptance Testing

a) Acceptance testing is required, and shall occur after the Engineering Note has been prepared and approved.

b) The acceptance test shall consist of successfully achieving the full differential pressure across the vacuum window and demonstrating that the deflections are stable, i.e., that the window does not creep.

c) For manned areas, the initial operation of the system may be considered to fulfill the acceptance test requirement. For unmanned areas where SF < 2 and the resulting risk to system components higher, a separate test is required.

d) A hazard analysis shall be written for the acceptance test, describing hazards to personnel and equipment associated with the test, and documenting the safeguards provided.

5.0 Venting of Positive System Pressure

a) If a vacuum system may experience an excursion to positive pressure under any circumstance, a calculation shall be provided to show that venting is sufficient to keep the maximum pressure at or below one fourth of the pressure which would cause failure of the thin vacuum window.

6.0 Operating Procedures

a) Provide cautions and operating procedures necessary for the safe use of the vacuum window.

7.0 Hazard Analysis

a) A hazard analysis shall be written for operation, describing hazards to personnel and equipment associated with vacuum window operation, and documenting the safeguards provided.

8.0 Documentation

a) All documents generated in compliance with paragraphs 1-7 of this Appendix shall be assembled into a technical appendix to the Engineering Note to document the design, fabrication, inspection, testing, assembly, operating procedures, and hazard analysis for the vacuum window.

The design and testing requirements for vacuum windows are summarized in Table TA-1 below.

**Table TA-1. Summary of Design and Testing Requirements for Vacuum Windows**

| | | Manned Areas | Unmanned Areas |
|---|---|---|---|
| **Safety Factor** | | **≥ 2.0** | **> 1.0** |
| **Failure Testing** | | | |
| | **Measured quantities?** | **Pressure and Deflection** | **Pressure and Deflection** |
| | **Is burst necessary?** | **No, if stable deflection at Safety Factor ≥ 2 is demonstrated** | **Yes, if Safety Factor < 2** |
| | **How many windows are tested?** | **Discretion of Qualified Person** | **Discretion of Qualified Person** |
| | **HA required for failure test?** | **Yes** | **Yes** |
| **Acceptance Test** | | | |
| | **Test Pressure** | **Operating differential** | **Operating differential** |
| | **Test same as operation?** | **Optional** | **Separate test required if SF < 2** |
| | **HA required for acceptance test?** | **Yes** | **Yes** |
| **Operation** | | | |
| | **HA required?** | **Yes** | **Yes** |