Author	Department	Date
Michael A. Green	**Mechanical Engineering**	**2/10/06**

MICE Vacuum Leak Check Procedure

Authored by: ______________________________ **MICE Magnet Engineer**
Michael A. Green, LBNL

Reviewed by: ______________________________ **MICE Mechanical Engineer**
Steve Virostek, LBNL

Approved by: ______________________________ **LBNL MICE Program Manager**
Michael Zisman, LBNL

Author: **Michael A. Green**
Department: **Mechanical Engineering**
Date: **2/10/06**

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1. Purpose

This note identifies the vacuum leak check requirements and procedure for checking the MICE cryogenic piping, the MICE magnet assemblies, the MICE absorbers, and the finished vacuum vessel with all of the equipment installed within it.

2. MICE Vacuum Leak Requirements

The The MICE leak tightness standards given here are based on standards that have been adopted by CERN for the LHC [1]. Table 1 below shows the maximum acceptable leak rates for various components of the MICE cryogenic system. Table 1 gives the maximum allowable MICE helium leak detector leak rates in three commonly used sets of units ($Pa \cdot m^3 \cdot s^{-1}$), ($atm \cdot cc \cdot s^{-1}$), and ($torr \cdot liter \cdot s^{-1}$).

Table 1. MICE Maximum Allowable Leak Rate for Various Components

Component or Assembly	Leak Rate ($Pa \cdot m^3 \cdot s^{-1}$)	Leak Rate ($atm \cdot cc \cdot s^{-1}$)	Leak Rate ($torr \cdot liter \cdot s^{-1}$)
Absorber Window Seals	10^{-10}	10^{-9}	$7.5x10^{-10}$
Absorber Assembly	10^{-10}	10^{-9}	$7.5x10^{-10}$
Pipe Assemblies	10^{-10}	10^{-9}	$7.5x10^{-10}$
Cold Mass Assembly	10^{-10}	10^{-9}	$7.5x10^{-10}$
Magnet and Absorber Vacuum Vessel with MLI	10^{-8}	10^{-7}	$7.5x10^{-8}$
RF Vacuum Vessel without MLI	$3x10^{-9}$	$3x10^{-8}$	$2.3x10^{-8}$

Note: 1.00 $Pa \cdot m^3 \cdot s^{-1}$ = 9.87 $atm \cdot cc \cdot s^{-1}$ = 7.50 $torr \cdot liter \cdot s^{-1}$. In all cases: T = 20 ºC = 68 ºF

3. Equipment Needed for Vacuum Leak Checking

3.1. Principle Pumping Group

The pumping group shall normally consist of a turbo-molecular pump in series with an oil sealed rotary backing pump. Diffusion pumps may be used in series with a oil sealed rotary backing pump. To avoid oil back streaming via the turbo pump in the event of an electrical failure, the connecting manifold between the pumps shall have a normally closed valve. If a diffusion pump is used this valve must be located between the diffusion pump and the load being pumped. When a cryostat vacuum vessel is being pumped there must be a liquid nitrogen trap between the pump group and the load being pumped. The backing side of the turbomolecular pump should be equipped with a manifold to enable a leak detector to be connected. It is recommended that the backing pump should not exhaust into the room where leak checking will take place.

3.2. Auxiliary Pumping Group

The auxiliary pumping group shall be suitable for repeated pumping of enclosures containing gaseous helium. The pump will be required to operate in the range from 0.13 Pa to 13 Pa (10^{-3} torr to 10^{-1} torr). A dedicated oil sealed rotary pump with a liquid nitrogen trap is suitable for this use. To avoid parasitic helium signals, the auxiliary pump shall not exhaust into the ambient air of the test area.

3.3. Vacuum Pressure Gauges

Vacuum pressure gauges shall cover the range from 13 Pa to 1.3×10^{-5} Pa (10^{-1} torr to 10^{-7} torr). Suitable gauges would be thermal conductivity gauges (a Pirani guage) and cold cathode ionization gauges (a Penning gauge) in combination. The vacuum gauges should be located on the manifold between the pump trap and the load to be pumped.

3.4. Helium Leak Detector

The sensitivity of the mass spectrometer helium leak detector shall be in accordance with the specified leak detection value. Through the assembly of most of the components in the DFBX boxes (the piping, the cold mass assembly and the vacuum vessel assembly) will require a helium leak detector that is sensitive to at least 5×10^{-11} $Pa{\cdot}m^3{\cdot}s^{-1}$ (5×10^{-10} $atm{\cdot}cc{\cdot}s^{-1}$).

3.5. Calibrated Helium Leak

The calibrated helium leaks shall be in the range from 10^{-8} to 10^{-10} $Pa{\cdot}m^3{\cdot}s^{-1}$ (from 10^{-7} to 10^{-9} $atm{\cdot}cc{\cdot}s^{-1}$). Each calibrated helium leak shall have a valid test date. For most of the leak checks the calibrated leak shall be connected to the load being leak checked at a point at the opposite end of the load from the vacuum pump and leak detector.

3.6. Data Recorder

CERN recommends that a data recorder (usually a paper strip chart recorder) be used. It is recommended that a two input channel recorder be used. One channel records the leak detector signal; the second channel records the pressure in the evacuated enclosure. The strip from the chart recorder can become part of the traveler record.

4. Preparation before Leak Check

The cryogenic circuits to be leaked checked should be cleaned in accordance with the manufacturing specification. All components used for closing the vacuum envelope must be cleaned and leaked checked (if possible) to a sensitivity suitable for the subsequent vacuum leak check.

The assembly and leak checking must take place in a clean dust free enclosed area. No machining operations may take place in or close to the assembly and leak check area. Area used for cryogenic operations with abnormal concentrations of helium in the ambient air shall be avoided.

Prior to assembly, all vacuum sealing surfaces should be visually inspected for damage and contamination. Oil or grease should not be used on any seals or vacuum surfaces of the cryogenic circuit.

The seals of the vacuum vessel or connections of the principle pumping group and leak detector may be elastomer O-rings. If the required leak testing sensitivity can not be achieved, it may be necessary to use metal seals.

The cryogenic systems should be of all metal construction in order to achieve the required sensitivity and avoid helium permeation. If not already specified, the vendor may chose to seal the extremities of cryogenic circuit or the vacuum vessel with welded or demountable flanges. Pre-testing of demountable metal sealed joints at the cryogenic circuit extremities is strongly advised.

The vacuum leak tests shall be performed in accordance with US and international leak testing standards by properly trained personnel. References [2] through [8] are recommended for information on correct vacuum leak checking procedure.

5. Leak Check Procedure

There are two methods of doing vacuum leak checks. The first method, the method recommended by CERN, is to put the component to be checked into a vacuum vessel and pressurize that component with gaseous helium and do the vacuum leak check. The second method, which is widely used by various laboratories including CERN, is to pump out the component being tested and bag it with a plastic shroud containing gaseous helium at 1 atmosphere. The second method can be used to determine the leak rate and it can also be used to determine the location of the leak by putting helium gas at various locations on the outside of the part being leak checked. The first method is at least an order of magnitude more sensitive to vacuum leaks than the second. In general, the first method is used for small components such as pipe assemblies. The second method is used for larger helium vessels and the vacuum vessel of a cryostat. With both methods, the measured leak rate is compared with a standard leak.

5.1. Vacuum Leak Checking in a Vacuum Vessel with Vacuum outside of the Part

The set up of the leak check equipment for a system where the leak checking is done inside a vacuum vessel is shown in Figure 1. The most important thing illustrated in

Figure 1 is the location of the standard leak. The standard leak should be located on the vacuum vessel at a point as far away from the vacuum pumping system as possible. The typical vacuum leak check sequence for a part that is in a vacuum vessel goes as follows:

- Clean the part that is being vacuum leak checked. Oil, grease, and crud will interfere with the leak checking process. Clean all of the parts that make up the leak checking system.
- Close the cryogenic circuit at the extremities. Connect one end to a source of helium gas. The pressure of the helium in the part may be as high as the working pressure of the part.
- Install the cryogenic circuit (with its extremities closed and one end connected to a source of helium gas) into a vacuum vessel.
- Connect the vacuum pump and the vacuum leak mass spectrometer to the vacuum vessel. The mass spectrometer should be connected to the pipe between the high vacuum pump and the roughing pump.
- Connect a calibrated helium gas source to the vacuum vessel at the opposite end of the vacuum vessel from the pump and leak check mass spectrometer.
- Evacuate the vacuum vessel, and evacuate the cryogenic circuit being tested. The vacuum vessel should be pumped down to as low a pressure as possible. The part being tested should be pumped down to a pressure of at least 1 Pa (about 0.0075 torr)
- Verify that one can measure the desired leak rate by measuring a calibrated leak into the vacuum vessel.
- Pressurize the cryogenic circuits and measure the vacuum and the vacuum leak rate into the vacuum enclosure.
- Vent the gas in the cryogenic circuit and evacuate the part to a pressure of at least 1 Pa (about 0.0075 torr).
- Fill the cryogenic circuit and the vacuum vessel with dry nitrogen.
- If the part has a leak, find the location of the leak, and repair the part. The leak check method outlined in Section 5.2 can be used to locate the vacuum leak.
- Repeat the vacuum leak check until the leak rate from the part is less than the specified value.

5.2. Vacuum Leak Checking with the Vacuum inside the Part

The set up of the leak check equipment for a system where the leak checking is done inside a vacuum vessel is shown in Figure 2. The most important thing illustrated in Figure 2 is the location of the standard leak. The standard leak should be located on the vacuum vessel at a point as far away from the vacuum pumping system as possible. The typical vacuum leak check sequence for a part that is in a vacuum vessel goes as follows:

- Clean the part that is being checked. Oil, grease and crud will interfere with the leak checking process. Clean all of the parts that make up the leak checking system.
- Close the cryogenic circuit at the extremities, and connect one end of the cryogenic circuit to a valve and standard leak. The other end is connected to the vacuum pump and vacuum leak helium mass spectrometer system. The mass spectrometer leak detection system is connected to the pipe between the high vacuum pump and the roughing backup pump.
- Evacuate the cryogenic part to the lowest pressure possible (a pressure of at least 0.133 Pa (10^{-3} torr)). The leak check is more accurate if the pressure in the cryogenic part being tested is lower.
- First bath the part and the joints in the vacuum system with gaseous helium to check for gross leaks. Selectively bath the cryogenic part being leaked checked with helium gas to see if there are gross vacuum leaks in the part.
- Repair any leaks that are found in the cryogenic part. Repeat bathing selected portions of the part with gaseous helium looking for gross vacuum leaks. Repeat the leak checking and repair until no vacuum leaks can be found by casual sniffing of the cryogenic part with gaseous helium. One can now do a serious measurement of the leak rate of the leaks that remain.
- Bag the cryogenic part with plastic bagging. Squeeze the bag around the part to remove as much air from the bag as possible. Fill the bag with gaseous helium and repeat the leak check.
- If the part shows a leak when there is a helium atmosphere around the part. Selectively bag various places around the part to pin point the source of the vacuum leak.
- If one can find the location of the leak, repair the part. Repeat the leak check by filling the bags around the part. Continue repairing the part until no leak is detected. If the repaired part has to be thermal shocked, make sure that the part is properly thermal shocked to liquid nitrogen temperature before the final leak check is done.
- Fill the cryogenic part with dry nitrogen before doing the final leak check. This is to get rid of any residual helium that might be in the part. Pump the part down to the lowest pressure possible below 0.133 Pa (10^{-3} torr). Once the part has been evacuated to the lowest possible pressure, the final leak check can begin.
- Bag the part and remove as much air as possible from the bag around the part. Fill the bag with gaseous helium and measure the pressure in the part and the leak rate. The measured leak rate must be lower than required maximum leak rate for the part. (See Table 1)

- To check to see that the leak has been correctly measured, remove the bag around the part. Open valve to the standard calibrated leak source corresponding to the maximum allowable leak. If the leak check is being done correctly, the standard leak should be clearly visible when the valve is opened.

5.3. Vacuum Leak Check Procedure for Magnet Cryostat Vacuum Vessels

The vacuum leak check procedure for cryostat vacuum vessel is essentially the same as the procedure given in Section 5.2. The differences lie in a couple of areas. These differences are as follows:

- One must put a liquid nitrogen trap between the pumps and the vacuum vessel.
- During the initial pump down of the vacuum vessel, where water is being removed from the multi-layer insulation, this trap must be emptied periodically. It is suggested that the high vacuum pump be by-passed during the phase where water is being removed from the MLI.
- The vacuum vessel should be back filled with warm dry nitrogen periodically to speed up the process of water removal from the MLI. Powering the magnet coils with a small current will heat the magnet assembly to drive off the water.
- In order to get the pressure down in the vacuum vessel below 10^{-3} torr to do the vacuum vessel leak check, it is recommended that one should put a small amount of liquid nitrogen in the magnet cooling tubes. The pressure in the vacuum vessel should drop quickly to the 10^{-5} torr range, if there are no leaks in the vacuum vessel or the magnet cooling tube.

Once there is liquid nitrogen in the helium tank one can follow the helium leak check steps given in Section 5.2. One should be able to measure the leak rate into the DFBX vacuum vessel to the $3\text{x}10^{-9}$ atm·cc·s^{-1} range (an order of magnitude and a half lower than required).

6. References

[1] "LHC Standards Annex J3: Final Pressure and Leak Tests," IT-2593/LHC/LHC, EDMS No. 107609
[2] N. G. Wilson and L. C. Beavis, "Handbook on Leak Detection," American Vacuum Society Publication M-2 (1979). See http://www.avs.org.
[3] "AVS Recommended Practices on Vacuum Measurements and Techniques," American Vacuum Society publication S-2. See http://www.avs.org.
[4] "Standard Test Methods for Leaks Using the Mass Spectrometer Leak Detector or Residual Gas Analyzer in the Tracer Probe Mode," ASTM International publication E498-95, ASTM International, West Conshohocken PA (2000) See http://www.astm.org.

[5] “Testing for Leaks Using the Mass Spectrometer Leak Detector or Residual Gas Analyzer,” ISO/AWI 12724
[6] “Mass Spectrometer Type Leak Detector Calibration,” ISO 3530
[7] “Non-Destructive Testing (NDT) - Testing for Leak Tightness – Recommended Practices for the Specification and Testing of Gas Tightness,” NFA 09-490
[8] “Non-Destructive Testing (NDT) – Tightness Testing – Method under Vacuum with Tracer Gas,” NFA 09-492

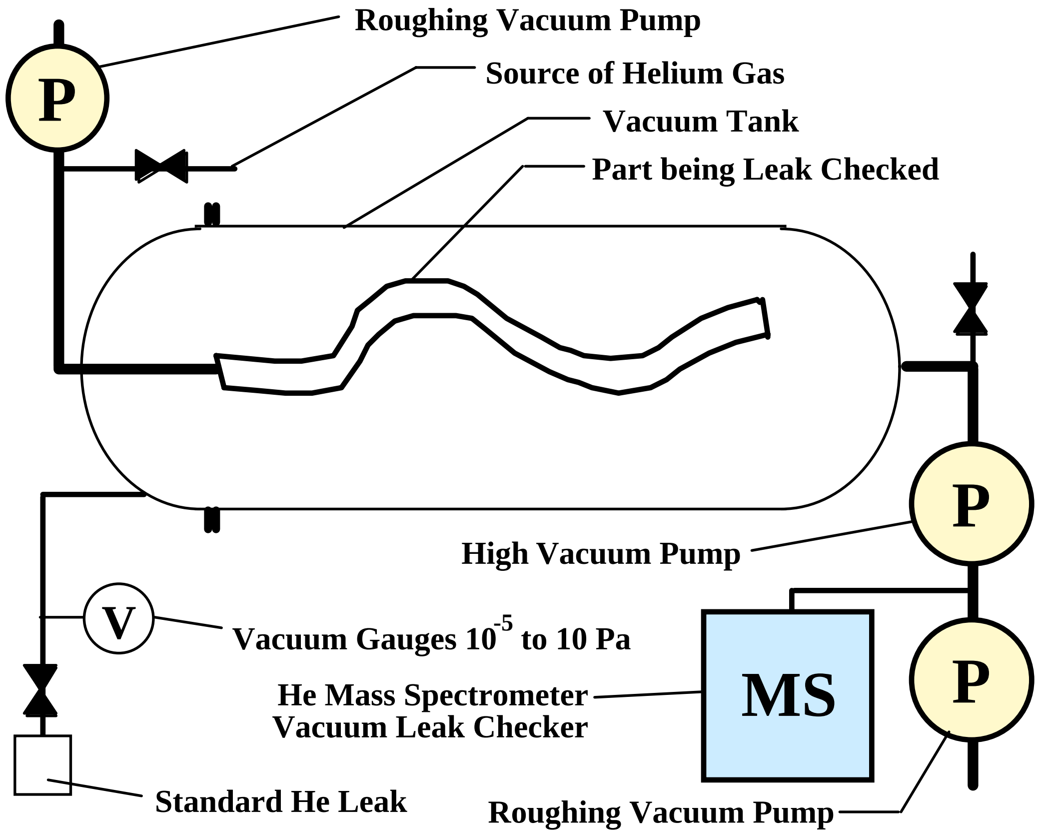

Figure 1. A schematic representation of the vacuum leak check procedure when the part being checked is inside a vacuum vessel

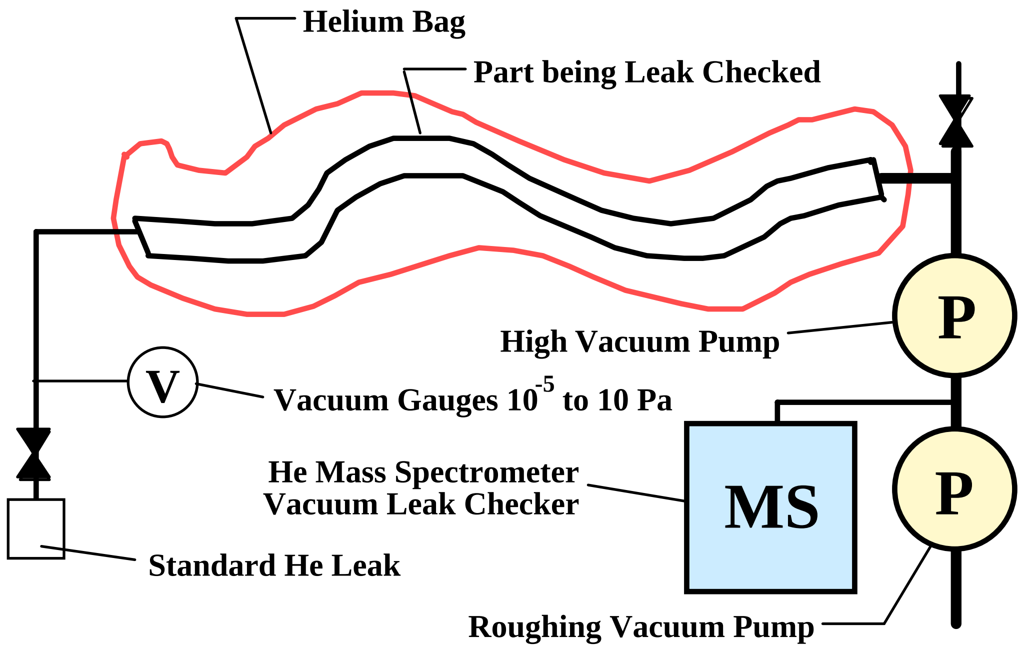

Figure 2. A schematic representation of the vacuum leak check procedure when the part being leak checked has vacuum within it

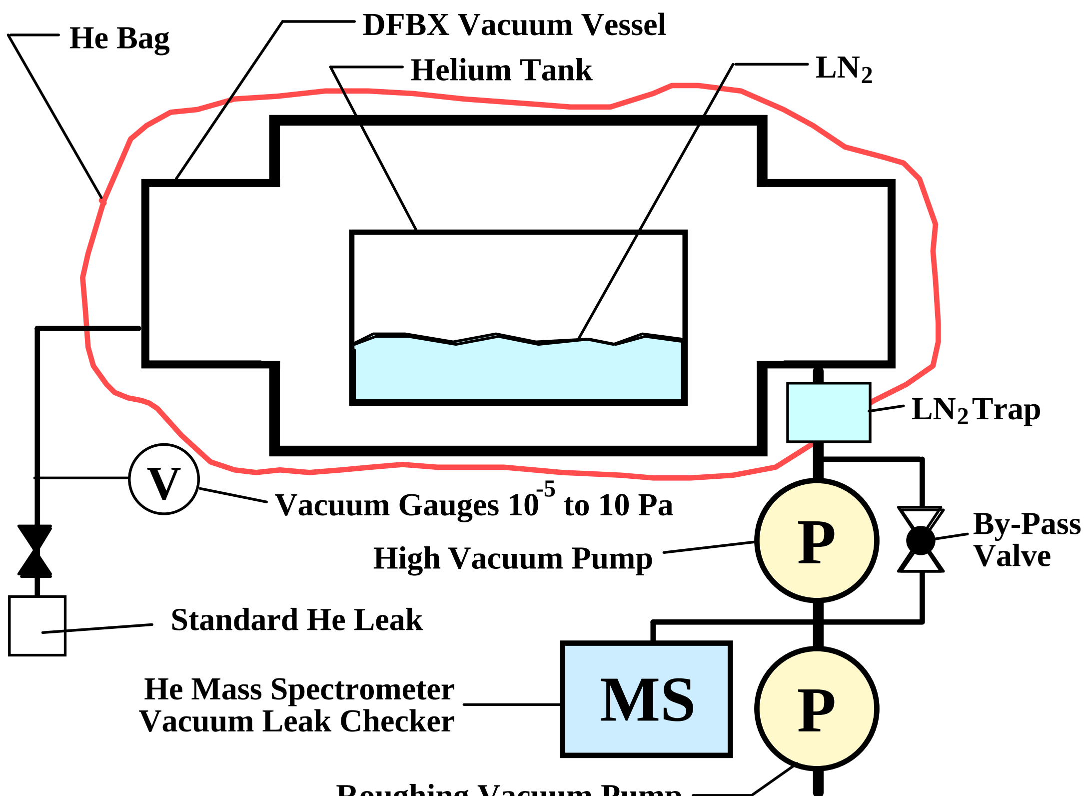

Figure 3. Vacuum leak check of the magnet cryostat vacuum vessel