MICE HYDROGEN SYSTEM

Safety window failure note

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1 Introduction

In the event of an absorber window breach, liquid hydrogen will enter the insulating vacuum space and vapourise rapidly, causing a pressure rise. The safety windows which separate this space from the adjacent upstream and downstream spectrometer solenoid bores have been analysed with FEA, verified by physical testing, to endure 8.5 bar gauge of pressure before rupturing. The relief system for the insulating vacuum is designed to limit the pressure rise in the aforementioned failure mode to below 4.25 bar gauge, thus meeting the design factor of safety of 2.

This note explores the scenario where unforseen circumstances cause the safety windows to fail.

It is important to emphasise that the conditions described are unquantified and largely speculative, and thus tend to fall outside the formal safety case for the Liquid Hydrogen system. However, this does not prohibit critical safety actions being generated from these scenarios.

2 Window failure causes

2.1 Material flaw

At their thinnest point, the safety windows are 0.21 mm thick. This increases the potential effect of material inclusions and hydrogen / nitrogen porosity on the local strength of the window. If a significant defect was located in the thinnest and most highly stressed area of the window, it could potentially reduce the effective burst pressure of that window.

Material quality certification has not been provided by the US manufacturers.

2.2 Damage during installation

Although extreme care has been taken throughout installation (at the time of writing, the absorber is installed in the beamline and has been leak tested to 3×10^{-9} mbar.l/s), there remains a possibility that shock or impact damage was sustained to a window unknowingly and has compromised its integrity.

2.3 Unforeseen thermal shock

In the event of an absorber fracture, it could be conceived that liquid hydrogen would spray in a very localised jet against the safety window and reduce its simultaneous pressure bearing capacity. A thermal analysis to this effect is presented in MICE Note 100 (*http://mice.iit.edu/micenotes/public/pdf/MICE0100/MICE0100.pdf*) but does not account for simultaneous pressure loading.

2.4 Weakening due to plastic deformation

Although both window designs will endure in excess of 8 bar before rupturing, they will plastically deform a long way prior to this point. Permanent deformation begins between 2 and 2.5 bar forward pressure, so it is conceivable that a simultaneous nitrogen purge and evacuated downstream volume could result in a gauge pressure across the window high enough to cause minor plastic deformation. This would change the geometry of the window and possibly reduce its subsequent burst pressure.

2.5 Excessive pressure rise due to blockage in relief pipework

With the previous relief circuit design, the restricted and convoluted nature of the pipework made it conceivable that a blockage could arise due to a failed valve, mechanical damage or some other unforeseen phenomena. However, with the revised method of using the vacuum pumping line as a relief route, blockage of the 100mm diameter pipe is less likely.

The line does incorporate a turbo pump and backing pump, both subject to potential failure. To mitigate against this, the turbo is bypassed with a welded burst-disk assembly and the backing pump has two relief valves situated upstream of it. The only remaining component in the line is the gate valve. This is a dual-acting pneumatic valve used to isolate the cryostat for testing. It is proposed that the valve is only actuated manually from herein and, by default, left in the open position. Control of the valve then becomes a procedural issue and will be dealt with in the system's Operating Instructions.

2.6 Window buckling due to reverse pressure

The safety window is design to accommodate a reverse pressure of approximately 1.2 bar. This allows for the inner space to be evacuated for testing without the need for the outer space encapsulated by the FC-SS bellows to be simultaneously evacuated. The window has never been subject to a reverse pressure beyond 1 atmosphere though, so the scenario whereby a nitrogen purge of the bellow space, or some other pressure excursion, could cause a sufficient reverse pressure differential to cause buckling is conceivable.

3 Window failure consequences

3.1 Failure outside hydrogen operation

In the event of a window rupture due to buckling or mechanical damage during installation, there is no safety consequence until liquid hydrogen is present inside the absorber. The key requirement is thus to detect a window failure before hydrogen is admitted to the system.

3.2 Failure during hydrogen pressure excursion

In the event of a window rupture due to a hydrogen pressure excursion inside the insulating vacuum, hydrogen gas will escape into the vacuum space between the Focus Coil and Spectrometer Solenoid magnets and onwards into the Spectrometer Solenoid bore – see Fig 1. This volume is significantly larger than the absorber insulating vacuum, so will act as a buffer on the pressure rise.

The tracker window has been designed to the same thickness profile as the safety window but is reversed, as the tracker is housed in low pressure helium gas. This means that it can only be expected to tolerate a pressure rise of around 2 bar before buckling. At this point, hydrogen would enter the tracker space. This, as already mentioned, is filled with low pressure helium, so can be considered an inert atmosphere. However, the downstream seals are not designed to accommodate high pressure, so should not be expected to provide any significant containment of hydrogen. If this downstream seals did fail, hydrogen would then exit into the main Hall, where ignition could reasonably be expected.

A mitigating factor is that the various windows and seals would inhibit the quantity of hydrogen released into the Hall as the relief line would remain the preferential path. As such, ignition of significant quantities of hydrogen inside the Hall is extremely unlikely, even in the worst case scenario.

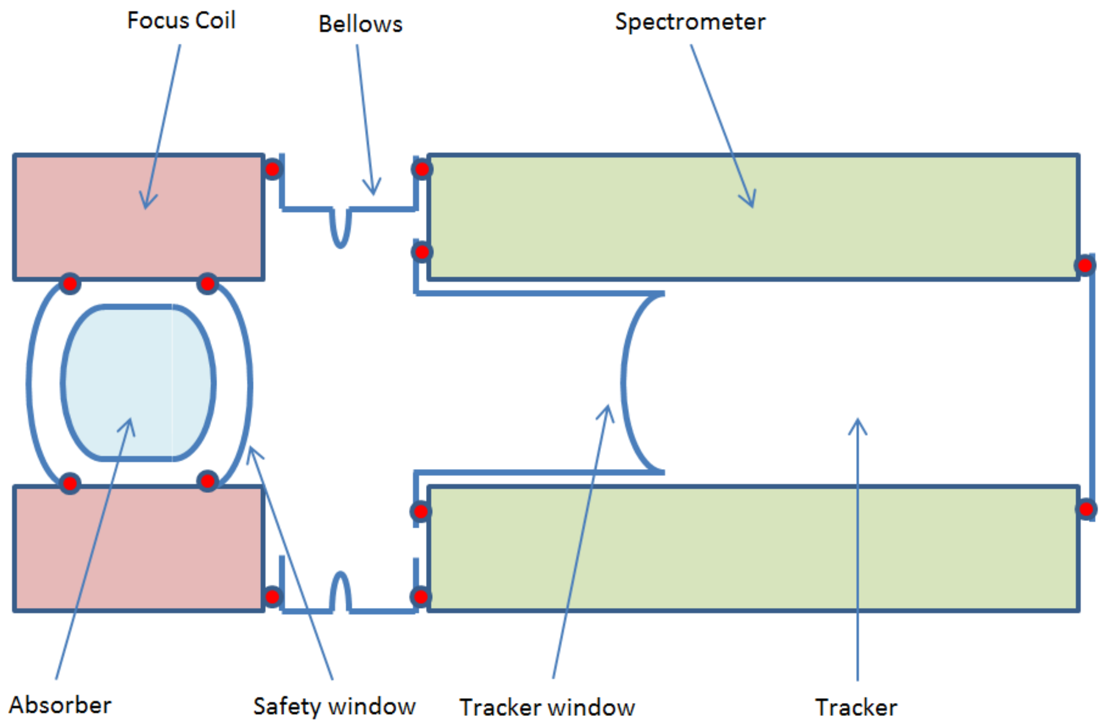

Figure 1: FC - SSD schematic

4 Actions

4.1 Failure detection

The ability to detect a window breach prior to hydrogen operations is critical. No dedicated instrumentation exists however, so diagnosis will rely on the existing vacuum gauges.

- If an absorber window fails prior to hydrogen operations, the insulating vacuum will go soft and the turbomolecular pump will likely begin to overheat, particularly if purge gases are present in the buffer tank. Even if the internal system is under vacuum when the window somehow fails, it will still be obvious as the insulating vacuum would be expected to be in the 10^{-5} mbar and would see a rise to a significantly rougher vacuum in a short space of time.
- If a safety window fails prior to hydrogen operations, the insulating vacuum will equalise with the interspace vacuum. This may be a less obvious change than an absorber window failure.
- **A pre-operation test should thus be devised to test for safety window integrity prior to hydrogen operation, possibly along the lines of admitting a small amount of nitrogen into the insulating space and checking that the subsequent pressure differential across the window is maintained for a period of time.**

4.2 Gate valve control

The gate valve was previously interlocked to slam shut during vacuum failure to ensure that gas flow was directed up the separate relief line. With the system change to using the vacuum line as a relief route, this must be reversed.

A method for ensuring that the valve remains open during both air pressure and power failure must be developed.