MICE HYDROGEN SYSTEM

Requirements for Uninterruptable Power Supplies on the Hydrogen Delivery System

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1. Introduction

The MICE Hydrogen Delivery System must remain safe in the event of a mains failure in the MICE Hall. In addition, a central feature of the system's safety concept is that it be safe under two simultaneous failures. Therefore the system must not become unsafe should the mains failure coincide with another malfunction.

2. Implications of mains failure

In the event of a mains failure in the MICE Hall, the Hydrogen System would be affected in the following ways:

i. Loss of power to the absorber cryocooler.
ii. Loss of power to the hydride bed heater/chiller unit (it would therefore not be possible to maintain the hydride bed at the temperature required to absorb hydrogen - approx. -5°C).
iii. Ventilation fan stoppage.
iv. Vacuum pump stoppage.
v. Valves default to air-off state (air pressure maintained to up to solenoids, but they close).

Sequence of events following a mains failure without any UPS backup (assuming the absorber is filled with LH2):

1. Absorber vacuum space is no longer pumped.
2. PV20 shuts, isolating vacuum space. The insulating vacuum is therefore maintained subject to any leaks.
3. Cooling at 4K is no longer available, producing some net heat load on the absorber.
4. Temperature of absorber slowly starts to rise, boiling off some LH2.
5. With the valves in their "air-off" state, any boil-off gas will preferentially be returned to the hydride bed while the system pressure remains below 1.3bara.
6. As the temperature of the hydride bed begins to rise towards ambient it will no longer be capable of absorbing any hydrogen.
7. When the hydride bed can no longer absorb gas, the system pressure will rise above 1.5bara and the relief valves will open sending the gas to the high level vents.

If a mains failure were to occur during an absorber fill sequence, the following would take place:

1. Absorber vacuum space is no longer pumped.
2. PV20 shuts, isolating vacuum space. The insulating vacuum is therefore maintained subject to any leaks.
3. Cooling at 4K is no longer available, producing some net heat load on the absorber.
4. The heater/chiller for the hydride bed shuts off, leaving the bed at high temperature. Hydrogen would continue to be evolved until the bed naturally returned to ambient temperature.
5. If sufficient hydrogen was evolved to raise the pressure of the system above 1.5bara, the relief valves would open sending the gas to the high level vents.

If a mains failure were to occur during an absorber empty sequence, the following would take place:

1. Absorber vacuum space is no longer pumped.
2. PV20 shuts, isolating vacuum space. The insulating vacuum is therefore maintained subject to any leaks.
3. Power to the absorber heaters is lost, reducing the LH2 boil-off rate.
4. Boil-off gas will preferentially be returned to the hydride bed while the system pressure remains below 1.3bara.
5. As the temperature of the hydride bed begins to rise towards ambient it will no longer be capable of absorbing any hydrogen.
6. When the hydride bed can no longer absorb gas, the system pressure will rise above 1.5bara and the relief valves will open sending the gas to the high level vents.

3. Estimate of the LH2 boil-off rate during mains failure

Assumptions:

i. The insulating vacuum is maintained due to PV20 closing
ii. Net heat load on the absorber is 0.5W (must less than power of cryocooler – i.e. 1.5W) at 4K. This is almost certainly an overestimate, but the figure will increase slightly as the radiation shields warm.
iii. Absorber contains 22L of LH2.
iv. Latent heat of vapourisation of LH2 = 446kJ/kg
v. Density of LH2 = 70g/L

Mass of LH2

= 22 x 70
= 1540g
= 1.54kg

Heat input to boil-off entire absorber volume

= 1.54 x 446
= 686.8kJ

Boil-off time

= 686 800/0.5
= 13.736×10^6s
= 381.6hrs
= 15.9 days

It could therefore take over 2 weeks for the LH2 in a full absorber to entirely boil-off. This is much longer than any reasonably foreseeable mains outage.

4. Coincident failures

The following are the currently foreseeable failures/malfunctions that might coincide with a mains failure:

i. A small, undetected leak in the gas panel pipework.
ii. A small, undetected vacuum leak.

5. Possible UPS implementation

There are several ways a UPS could be utilised in the Hydrogen Delivery System:

i. Maintain power to one or both ventilation fans. This will keep the Gas Panel Enclosure ventilated and exhaust any small leaks that may be present when the mains goes off.

ii. Maintain power to the hydride bed heater/chiller (rated at 5.6kW) to prolong the period during which it can absorb boil-off gas during a mains failure.

iii. Maintain power to the hydrogen detection system. This means that any leaks in the gas panel are detected even if they cannot be exhausted rapidly and provides a warning that would alert anyone entering the hall.

iv. Maintain power to the cryostat heaters and hydride bed to return as much LH2 as possible to the bed[1].

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[1] The LH2 could be returned to the bed faster with the use of the cryostat heaters. The absorber pot in the R&D test cryostat is fitted with 3 x 75W heaters; similarly 2 x 100W heaters are available on the final absorber. With 200W heating power, the boil-off time would be:

Boil-off time

= 686 800/200
= 3434s
= 57.2 minutes

This would allow all the hydrogen to be returned to the bed in under 1 hour. However, the evidence from the bed characterisation conducted at Treibacher (AD2) is that the bed would not be able to absorb gas at this rate.
Furthermore, the heaters are not on an intrinsically safe circuit so the use of them would create a hazard if a hydrogen-air mixture had formed in the absorber vacuum space.

6. Conclusions and Recommendations

i. Given that the valves will revert to their air-off state in a mains failure, a reasonable insulating vacuum (limited only by the leak rate in the cryostat) will be maintained in the cryostat/AFC module after the pumps stop. As a result, the H2 boil-off rate will be relatively slow and providing a UPS that could maintain the fans for the entire time that H2 may be present in the gas panel pipework (several days) is not considered feasible.

ii. Although the heaters could be used to increase the H2 boil-off rate, they are not on an intrinsically safe circuit and may create a hazard if a hydrogen-oxygen mixture had formed undetected in the cryostat.

iii. Even if the fans stopped running whilst there was a small leak in the Gas Panel Enclosure, the natural buoyancy of the hydrogen would cause it to escape through the (sealed) ventilation ducting.

iv. If leaks are not being extracted from the Gas Panel Enclosure (i.e. the fans are off), it is considered essential to know whether any H2 is present inside the enclosure. **The hydrogen detection system should therefore be backed by a UPS.**

v. The control system should be backed by a UPS for the purposes of being able to monitor instrumentation and valve positions during a power failure, *although no active control is required.*

vi. The fans should auto re-start after a mains failure. This will exhaust any hydrogen that may have built up during the outage.

vii. To perform any operations the control system will require a manual re-start after a mains failure.

viii. The procedures to be followed during a mains failure should be fully documented and appropriate members of the MICE team trained accordingly.

It is therefore not considered necessary to maintain full system functionality during a mains outage. It is recommended that a UPS system be purchased that can supply power to operate all monitoring systems including the hydrogen detection system for a period of at least 1 hour (exact time period TBD depending on available units).

7. External References

No.	Title	Ref
AD1	Hydrogen System P&ID	TD-1085-100-D Rev.2
AD2	FME 728678 (WA 26-2063): MHS 20000 STORAGE TANK CHARACTERISATION	728678_060811_RepRutherford.pdf