T940070-v1

~~LIGO-T940070-00~~

Note on virtual leaks in the beam tube spiral welds

R. Weiss September 24, 1994

STAPFE
SIBLEY
SANDER
WORDE
LAZZAR
DCC
TYLER
MATHER
ALTHOUS
ASIRI

Introduction: The LIGO beam tubes are planned to be fabricated by spiral welding with an initial autogeneous weld on the surface facing the vacuum followed by a TIG weld with cleaned filler wire on the outside. The autogeneous weld is specified as having a 70% or greater penetration while the weld with filler wire is specified to have greater than 50% penetration. The overlap of the melted region is 20% of the weld or greater. The overlap will be measured at each end of a 20 meter tube by cutting off a section of the welded tube and inspecting the weld after polishing and etching. The tube wall is close to 3 mm and in this thin section the standard vacuum technique of single pass autogeneous weld on the vacuum side followed, if needed, by skip welding on the outside is not practical if one specifies both full penetration welding as well as no reduction in wall thickness at the weld.

A question raised both at the beamtube final design review and in the September 1994 cost review of the LIGO project is the probability of voids occuring between the two weld passes that would be missed by the weld inspection. Voids with channels to the vacuum face would constitute sources of gas that would not be detected by standard helium leak detection methods - virtual leaks.

The purpose of this note is to estimate the size of the voids that would be troublesome and establishes that they are unlikely to occur as well as be missed in the inspections.

Beam tube vacuum requirements: The individual beam tube components are specified to leak less than 10^{-10} standard atmosphere cc/sec while an entire 2 km beam tube module is specified to leak less than 10^{-9} standard atmosphere cc/sec. The beam tube will be baked at 140 C for a month (2.6×10^6 seconds) before final acceptance and operation. The gas load from virtual leaks should be smaller than the specified leak rate after the bake.

Gas flow dynamics: The initial pressure in the void is assumed to be atmospheric pressure P_0 in atmospheres . Let the volume of the void be V in cc and the pumping speed of the channel connecting the void with the vacuum space be F in cc/sec of nitrogen at 300K. The gas flow from the void in standard atmosphere cc/sec as a function of time is

$$Q(t) \; = \; F \, P_0 \, e^{-tF/V}$$

where t is the pumping time in seconds.

$$\frac{dQ}{dF} = P_0 e^{-tF/V} - \frac{tF}{V} P_0 e^{-tF/V} \equiv 0$$

At a fixed pumping time t_0 and for a given void volume V there is a maximum gas flow from the virtual leak when the pumping speed is

$$1 - \frac{tF}{V} = 0$$

$$F \; = \frac{V}{t_0} \quad ✓$$

$$F = \frac{V}{t}$$

For larger values of F the gas flow at t_0 will be smaller since the void will have evacuated while for smaller values of F the gas flow is smaller due to the small pumping speed. The interesting case is that for which

$$Q(t_0) \leq Q(\text{leak specification}) = 10^{-9} \text{ standard atmosphere cc /sec}$$

Void and channel model: A simple and reasonable model is to assume that the volume of the void and the channel are the same. Let the channel radius be a cm and the channel length be l cm. The thermal speed of nitrogen is $u = 4 \times 10^4$ cm/sec. The volume and pumping speed of the channel are

$$V = \pi a^2 l \qquad F = \frac{2 \pi a^3 u}{3 l}$$

The gas flow at time t_0 becomes

$$Q(t_0) = \frac{2 P_0 \pi a^3 u}{3 l} e^{\frac{-2 a u t_0}{3 l^2}}$$

The maximum gas flow at time t_0 occurs when the relation between the channel length and radius is

$$l = \sqrt{\frac{2 u a t_0}{3}}$$

Introducing this relation into the gas flow equation gives

$$Q(t_0) \leq \frac{\pi P_0}{e} \sqrt{\frac{2 a^5 u}{3 t_0}}$$

Table of worst cases

see corrected Table next page

$Q(t_0)$ atm cc/sec	a cm	l cm	t_0 seconds
10^{-9}	1.0×10^{-3}	3.0×10^3	10^6
10^{-9}	1.6×10^{-3}	1.2×10^4	10^7
10^{-10}	4.0×10^{-4}	1.9×10^3	10^6
10^{-10}	6.4×10^{-4}	7.6×10^3	10^7

The way to interpret the table is that if a is larger or l is shorter than that given, the virtual leak will pump out, while if a is smaller or l is longer, the leak is of less consequence in making a gas load. The long length of the channel required to be troublesome makes it extremely unlikely that such voids would occur as well as be missed in the inspections.

One can of course invent really pathological void/channel models with large volumes and small channels. An example is a spherical void with diameter equal to the weld overlap region. Such a void would have a volume of 10^{-4} cc and would be most troublesome if connected to the vacuum by a channel with pumping speed of 3×10^{-9} cc/sec. The channel would have to have

$$\frac{a^3}{l} \leq 3.6 \times 10^{-14} \text{ cm}^2$$

For example, if the channel radius is 1 μ then the worst channel length is around 28 cm, again a shorter channel pumps the void out in t_0 while a longer channel would not allow enough gas flow to influence the leak specification.

Q(to)	a	l	to	to
atm-cc/sec	cm	cm	sec	years
1.0E-09	4.9E-04	3.6E+03	1.0E+06	0.03
1.0E-09	7.8E-04	1.4E+04	1.0E+07	0.32
1.0E-10	2.0E-04	2.3E+03	1.0E+06	0.03
1.0E-10	3.1E-04	9.1E+03	1.0E+07	0.32

If we do not assume that the void volume, V, is equal to the channel volume (but neglect the channel volume):

$$F = \frac{V}{t_0} = \frac{2\pi a^3 u}{3l}$$

$$\boxed{l = \frac{2\pi a^3 u t_0}{3V}}$$

$$Q(t_0) = F P_0 e^{-t_0 F/V} = \frac{F P_0}{e}$$

$$\boxed{Q(t_0) = \frac{V P_0}{t_0 e}}$$