Load on Trough Bellows
Following an Argon Spill

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INTRODUCTION

In the case of a gross argon spill from the D0 detector, the liquid argon is caught in three plenums. These plenums are to be connected by bellows to make a horizontal trough open at one end for removing the argon. The design of these bellows is dependent on the maximum argon load they must carry.

DISCUSSION-Rectangular Bellows

To approximate this load, first consider a horizontal open channel of uniform, rectangular cross section 2.2 feet wide and 1.1 feet high (the size of the openings in the plenums) and extending 30 feet in length. In the worst case, 168 gal/min or 0.374 cfs would spill into the plenum farthest from the open end and flow the full 30 feet to exit the trough. The profile of this flow sketched in Figure 1 shows a gradual flow beginning at d_o and continuing to d_c , the critical depth, after which the drop in depth is more pronounced to the overfall at d_f . This critical depth is independent of the channel slope and roughness and is

$$d_c = \sqrt[3]{\frac{Q^2}{b^2 g}}$$

where d_c = critical depth, ft

Q = quantity of flow, cfs

b = width of channel, ft

g = acceleration due to gravity, ft/s²

for rectangular channels.¹ For our case, d_c is about 0.1 ft, or 1.2 inches. Critical depth for horizontal channels occurs 11.6 d_c upstream from the overfall.² Here, this is 1.16 ft or about 14 inches.

The depth, d_f , at the overfall is defined³ as 0.715 d_c and is 0.0715 ft or about 0.86 inches.

To approximate the depth, d_o , at the beginning of the channel, a useful expression is the Manning equation⁴

$$Q = \frac{1.486}{n} A R^{2/3} S^{1/2}$$

where n = Manning's roughness coefficient

A = area of flow, ft^2

R = hydraulic radius, ft

S = loss of head/ linear foot.

The most appropriate value for n is .024, which corresponds to corrugated-metal storm drains. We define S upstream from the critical depth, where the slope is approximately constant, as

$$S = \frac{d_o - d_c}{28.8}.$$

Finally, for rectangular channels,⁵

$$A = bd \quad \text{and} \quad R = \frac{bd}{b + 2d}.$$

Difficulty arises in determining where d should be measured. For our purposes, the average between the initial and critical depths is taken, so

$$d = \frac{d_o + d_c}{2}.$$

With substitution, the Manning equation becomes

$$Q = \frac{1.486}{n} \left(\frac{b(d_o + d_c)}{2} \right) \left(\frac{b(d_o + d_c)}{2(b + d_o + d_c)} \right)^{2/3} \left(\frac{d_o - d_c}{28.8} \right)^{1/2}$$

Since all variables except d_o are known, trial-and-error solution yields $d_o = 0.22$ ft or about 2.6 inches.

For bellows with a closed length of 27 inches and an open length of 68 inches, the resulting argon load is

$$W = (\text{volume})(\text{density}).$$

For closed bellows $W = 92$ lbs, and for open bellows $W = 231$ lbs.

These weights correspond to a calculated d_o for smooth-walled, rectangular channel. Convolution loading is an addition. A bellows carries a volume in its convolutions

$$V = 0.5 L A_c$$

where L = length, in

A_c = convolution cross sectional area to depth of flow, in²

The factor of 0.5 is necessary because for every inner, filled convolution there is an outer, unfilled one.

As an example, a 2.2 feet wide (inside) rectangular bellows with 2 inch deep convolutions and a flow depth of 2.6 inches carries a volume of argon in its convolutions; $V = 950$ in³ and 2394 in³ for closed and open bellows, respectively. This corresponds to a load of 48 lbs (closed) and 121 lbs (open).

DISCUSSION-Circular Bellows

Another possibility for bellows design is two circular bellows positioned in parallel. Consider now a horizontal open channel consisting of 3 pieces of rectangular cross section 2.2 feet wide, 1.1 feet high, and 5.75 feet long connected to each other by pairs of circular bellows with inner diameters of 1.1 feet and 0.625 inch deep convolutions. Again, in the worst case, 0.374 cfs would spill into the plenum farthest from the open end and flow the full length to exit the trough.

The depth at the beginning of this new channel is comparable to that in the first example, so we use $d_o = 2.6$ inches. Flow in the first plenum is as before, but flow through the new bellows requires an increase in depth. Since the quantity of flow, Q , is constant, the new set of bellows must carry the same amount of argon as the rectangular bellows did in the same amount of time. Thus, the depth in the circular bellows is such that the new flow area is the same as the flow area for the rectangular bellows ($A = bd_o$, here 67.6 in²). The flow area⁶ of the 2 circles is

$$A_c = 2 \left\{ R^2 \left[\cos^{-1} \left(\frac{R-d_n}{R} \right) \right] - (R - d_n) \sqrt{2Rd_n - d_n^2} \right\}$$

where R = circle radius, in

d_n = necessary depth, in

Trial-and-error solution yields $d_n = 3.9$ inches. The load, of course, does not change.

Convolution loading is determined in a similar manner as before (except the geometry is tougher) and is 13.2 lbs and 33.2 lbs for the pair of bellows, closed and open, respectively.

CONCLUSIONS

Bellows to connect the three argon-catching plenums in the D0 detector must be able to carry at least 92 lbs of argon when closed and 231 lbs when open, plus the load due to argon in the convolutions. Examples of such loads and the method for their calculations are contained in the Discussion.

It should be noted that a set of assumptions was used in these calculations. First, we considered a uniform channel and uniform flow. Second, we used a value for Manning's n meant for a similar, but not exactly the same, case. Finally, we were forced to define an average depth, d , to be used to state the hydraulic radius, R , and area of flow, A . These facts may warrant consideration in future calculations.

Figure 1

CITINGS

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