White Paper
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Rupture Disc Sizing for Micro Motion Coriolis Sensors

Rupture Disc Sizing

1 Introduction

Emerson's Micro Motion Coriolis flow meters are widely used in many industries that require high accuracy flow and density measurements.
Micro Motion Coriolis meters are designed to the ASME B31.3 standard, and are classified as part of the Process Pressure Piping, which is used in most customer installations worldwide. The process fluid is contained within a pressure boundary formed by two process connections, two manifolds and two tubes, all welded together. The flow tubes, which make the mass flow measurement, are contained inside an outer housing (case) which protects them from the environment. Please refer to Figure 1 for a visual representation of the components described above. The sensor's electronics are contained within an outer enclosure. The feedthrough is a glass-to-metal seal that provides a means for the electrical circuits to pass to the electronics and serves as a secondary seal.

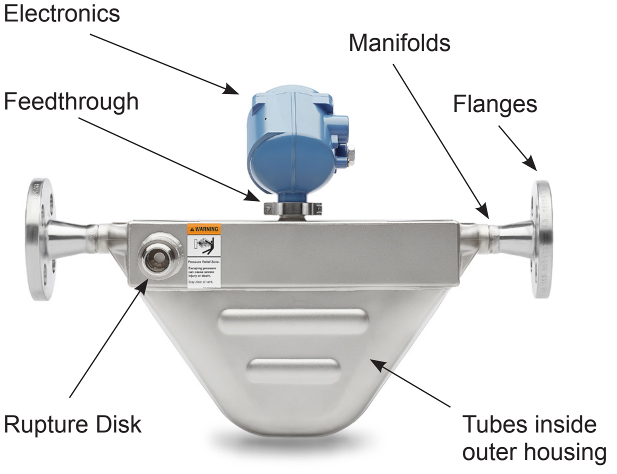


Figure 1: Depiction of Coriolis meter

Micro Motion Coriolis flow meters are used in a wide variety of applications that cover many different pressure ranges. Many Micro Motion Coriolis meters have, at least, a primary containment pressure rating of 1450 psig. There are also Micro Motion Coriolis meters that have an even higher primary containment pressure rating that goes up to 15,000 psig. In certain applications, the case that protects the tubes has a burst pressure below the primary containment pressure of the tubes. Some customers want to add an extra measure of safety to their piping system by having a rupture disk installed in the Coriolis meter case. Furthermore, a few standards exist in the industry that provide guidance on the use of Rupture Disk in applications, please see Table 1 below. This white paper deals with how Micro Motion sizes rupture disks for our Coriolis meters.

Table 1: Industry Standards

API MPMS 5.6 (Manual of Petroleum Measurement Standards Chapter 5 – Metering, Section 6 – Measurement of Liquid Hydrocarbons by Coriolis Meters)
ISO 10790 (Measurement of Fluid Flow in Closed Conduits – Guidance to the Selection, Installation and Use of Coriolis Meters)
ISA 12.27.01 (Requirements for Process Sealing Between Electrical Systems and Flammable or Combustible Process Fluids)

2 Rupture Disk Sizing Methodology

The primary design goal for a rupture disk is to size the disk orifice large enough to allow for any pressurized fluid to exit the case before the pressure within the case can exceed its safe working pressure. A methodology has been put in place to size the rupture disk using compressed gas theory. Compressed gas that enters the case, due to a breach in the flow tube, is the worst-case condition because the pressurized gas expands as it enters the case. Fluids that are incompressible do not expand as it exits the flow tube and is therefore a much less catastrophic condition. Sizing a rupture disk for compressed gas will also encompass the needs of liquid applications. Cryogenic applications are not considered in this analysis and further calculations should be performed before selecting a rupture disk for cryogenic applications.

The model used for sizing the rupture disk is taken from an article published in *Hydrocarbon Processing*, February 1992. Important references in this article are Crane Technical Bulletin 410, API RP 520 and API RP 521. Although the *Hydrocarbon Processing* article is directed at shell and tube heat exchangers, it has direct applicability to the sensor's pressure containment design.

Figure 2 shows a cross-section of a Coriolis meter's pressure boundary which will be used as the model to develop the sizing methodology. Three distinct areas are shown in the diagram, inside the flow tube (line pressure), inside the case, outside of case (atmospheric pressure).

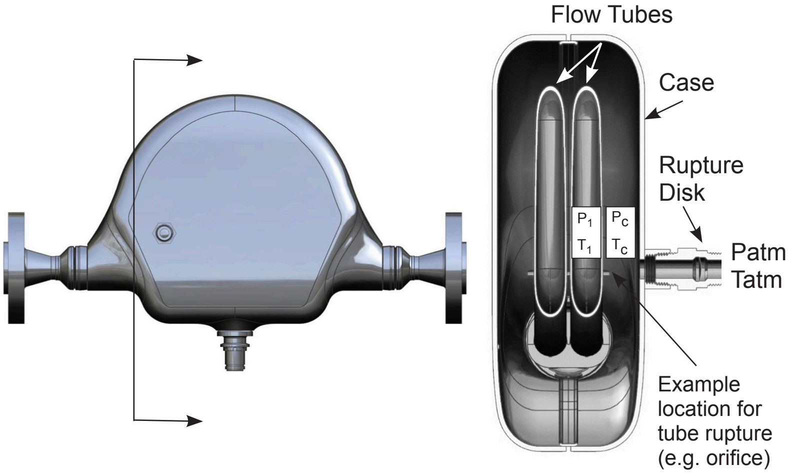


Figure 2: Cross section of flow meter pressure boundaries

The model can be considered as three different volumes, each with a thermodynamic state defined by pressure and temperature. The three volumes are: Volume 1 inside flow tube (system pressure), Volume 2 inside the case, Volume 3 outside the case (atmospheric conditions). The process conditions of the primary containment are known. The atmospheric conditions outside the vent are assumed to be standard conditions. The state of the fluid in the case volume is dependent upon the state of the fluid in the other two volumes and the flow rate of process fluid through the tube rupture.

In the event the sensor's primary containment fails due to a breach in the flow tube, the process fluid will flow into the case and then from the case to the atmosphere. A detailed discussion of how the crack size is determined is discussed in Appendix A. The breach opening for all sensors is assumed to be 40% of the wall thickness in width and 180° around one tube. Assuming the process pipeline has a limitless supply of fluid, the maximum flow exiting the cracked tube is then limited by the sonic velocity of the expanding gas (the crack is acting as an orifice).

The flow is sonic (Mach 1) at the throat of the tube crack, and cannot exit any faster due it being choked flow. This is an important fluid dynamics principle that governs the analysis in this paper. The flow rate cannot increase even if the downstream atmospheric conditions change, because the sonic condition at the throat still exists.

Assuming two concepts from fluid dynamics, continuity of flow and the choked fluid flow is limited by the sonic velocity across the tube breach, it is then possible to determine the mass flow rate exiting the rupture disk and the fluid pressure inside the case. The rupture disk area is sized to maintain a pressure within the safe pressure containment region of the case.

In this analysis, the worst-case condition is assumed, the flow through the tube rupture is assumed to be steady state choked flow. Assuming ideal gas behavior, steady-state choked flow occurs when the downstream pressure falls below a critical pressure. The critical pressure at the throat of the orifice is given by Equation 1, where k is the ratio of specific heats for the gas.

$$P_{critical} = P_1 \left(\frac{2}{k+1} \right)^{\frac{k}{k-1}}$$

Equation 1: Critical pressure for choked flow

The mass flow rate (lb/hr) through the rupture disk is given by Equation 2, and is a function of: the area of the breach, A (in2); the process pressure P_1 (psi); the upstream fluid density, ρ (lb/ft3); and the pressure drop, dP (psi). The pressure drop used in Equation 2 is the lesser of the two values as calculated by Equation 3.

$$MassFlow = 1445A \left(1 - 0.317 \frac{dP}{P_1} \right) (dP \cdot \rho)^{1/2}$$

Equation 2: Mass flow through the tube rupture

$$\begin{gathered} dP = P_1 - P_{critical} \\ \text{or} \\ dP = P_1 - P_c \end{gathered}$$

Equation 3: Pressure drop across tube rupture

Using Equations 1, 2, and 3 it is possible to determine the size of the rupture disk opening necessary to prevent the pressure within the case from exceeding a safe pressure.

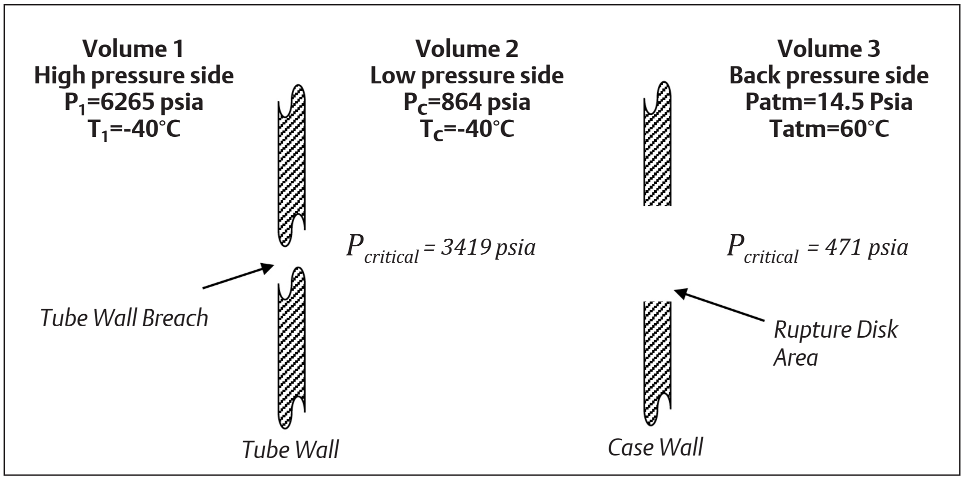
3 Example Calculation

The F100P will be used as an example for calculating the required size of the rupture disk. The scenario used to determine the size of the rupture disk is the tube ruptures and pressurizes the case, at the same time the rupture disk is venting enough fluid out of the case to ensure a safe pressure is always maintained inside the case. All the rupture disk sizes are calculated in the same manner. Cryogenic applications are not considered in this analysis. The input values for this example calculation are shown in Table 2. The flow conditions are also shown graphically in Figure 3.

Table 2: Input values for F100P Calculation

Fluid	Natural Gas
k	1.3
ID	0.547 in
Wall thickness	0.086 in
Crack size	0.034” in width 180° around one tube (half-moon shape)
A	0.0171 in
P_1	6265 psia
T_1	-40°C
P_C	864 psia
T_C	-40°C
Patm	14.7 psia
Tatm	60°C
Rupture disk size	1.0 in
Rupture disk relief pressure	64 psig
Process line density	22.3 lb/ft3

Figure 3: Simplified diagram of Coriolis pressure boundary with flow conditions



The first step is to start with Equation 1 and determine the critical pressure of the tube rupture, which is found to be 3419 psia. Steady state choked flow happens when the downstream pressure is lower than the critical pressure. The max pressure in the case can only be 865 psia which is lower than the critical pressure causing the choked flow through the tube rupture. The choked flow condition governs the mass flow rate that can exit the rupture.

$$P_{critical} = 6265\left(\frac{2}{1.3+1}\right)^{\frac{1.3}{1.3-1}} = 3419\ psia$$

The second step is to check the critical pressure at the throat of the rupture disk. The ambient pressure (14.7 psia) is below the critical pressure of 471 psia, thus the rupture disk is also choked.

$$P_{critical\ rupture\ disc} = 864\left(\frac{2}{1.3+1}\right)^{\frac{1.3}{1.3-1}} = 471\ psia$$

The third step is to determine the pressure drop value to be used in Equation 2, which is calculated using Equation 3. The pressure drop across the tube rupture has the lower pressure drop and is the value to be used to determine the mass flow rate.

$$dP = P_1 - P_{critical} = 6265 - 3419 = 2846\, psia$$

or

$$dP = P_1 - P_c = 6265 - 471 = 5793\, psia$$

The fourth step is to calculate the mass flow rate exiting the tube rupture using Equation 2.

$$MassFlow = 1445(0.0171)\left(1 - 0.317\frac{6265 - 3419}{6265}\right)\left([6265 - 3419]\cdot 22.3\right)^{1/2} = 5330\, lb/hr$$

The fifth step is to calculate the required rupture disk area. The mass flow exiting the case must be equal or greater than the mass flow exiting the tube breach. Therefore, rupture disk must flow 5443 lb/hr out of the case to maintain a safe pressure of 865 psia in the case. Rearranging Equation 2 and solving for the area gives the required rupture disk area and diameter.

$$A = \frac{5330}{1445 * \left(1 - 0.317\frac{864 - 471}{864}\right)\left([864 - 471]\cdot 3.1\right)^{1/2}} = 0.124 in^2$$

$$A = 0.124 \text{in}^2$$

$$Rupture\ disc\ diameter = \left(\frac{0.124 \cdot 4}{\pi}\right)^{1/2} = 0.40''$$

The F100P requires a rupture disk diameter of 0.40 in. The F100P sensor has a rupture disk of 1.0 inch installed which exceeds the minimum requirement.

4 Summary

A methodology is discussed that calculates the rupture disk size based on the theories laid out in steady state choked flow. The example discussed above shows the methodology used to calculate rupture disk installed on Coriolis sensors at Micro Motion. The rupture disk sizes for Micro Motion sensors are listed in Table 3.

Table 3: Sensor Case Rupture Disk Diameters

Sensor	Rupture Disk Diameter (in)
CMF010H	0.5
CMF010L	0.5
CMF010M	0.5
CMF010P	0.5
CMF025H	0.5
CMF025L	0.5
CMF025M	0.5
CMF050H	0.5
CMF050L	0.5
CMF050M	0.5
CMF100H	0.5
CMF100L	0.5
CMF100M	0.5
CMF200A	1.0
CMF200B	1.0
CMF200H	0.5
CMF200L	0.5
CMF200M	0.5
CMF300A	1.0
CMF300B	1.0
CMF300H	0.5
CMF300L	0.5
CMF300M	0.5
CMF350A	1.0
CMF350M	1.0
CMF350P	1.0
CMF400A	1.0
CMF400B	1.0
CMF400H	1.0
CMF400M	1.0
CMF400P	1.0
CMFHC2A	1.5
CMFHC2M	1.5
CMFHC3A	1.5
CMFHC3M	1.5
CMFHC4M	1.5
CMFS007M	0.5
CMFS010H	0.5
CMFS010M	0.5
CMFS010P	0.5
CMFS015H	0.5
CMFS015M	0.5
CMFS015P	0.5
CMFS025H	0.5
CMFS025M	0.5
CMFS025P	0.5
CMFS040M	0.5
CMFS050H	0.5
CMFS050M	0.5
CMFS050P	0.5
CMFS075M	0.5
CMFS100H	0.5
CMFS100M	0.5
CMFS100P	0.5
CMFS150H	0.5
CMFS150M	0.5
CMFS150P	0.5
F025A	0.5
F025B	0.5
F025H	0.5
F025P	0.5
F025S	0.5
F050A	0.5
F050B	0.5
F050H	0.5
F050P	0.5
F050S	0.5
F100A	0.5
F100B	0.5
F100H	0.5
F100S	0.5
F100P	1.0
F200H	0.5
F200S	0.5
F300H	0.5
F300S	0.5
HPC010P	0.5

Appendix A: Determination of Tube Crack Size

The primary containment breach dimension and size are the most important assumptions made in this analysis. Micro Motion experience has shown that if there is a relief path between the high-pressure gas (e.g. a rupture disc) and atmosphere, catastrophic case failure does not occur. When a crack forms in the tube, gas simply escapes into the secondary case and "pops" the relief feature at low pressure (64 psi). When the relief feature pops, gas flows in a controlled manner to atmospheric conditions. Micro Motion has studied a number of tube failures over the years and has used that data to develop an understanding of a typical tube crack size.

A typical failed tube is shown in Figure 4. The tube crack is on a ½" diameter tube with a wall thickness of 0.062 inches. Process fluid was natural gas at approximately 3500 psi. As noted in the figure the crack is less than 0.01 inches in width, or 16% of the wall thickness. Figure 5 shows the cross section of the crack, which is approximately 90° around the circumference of the tube. Compiling historical primary containment breaches, the conservative assumption Micro Motion uses in this model is that the crack width is 40% of the wall thickness and length of the crack goes 180° around the circumference of the tube.

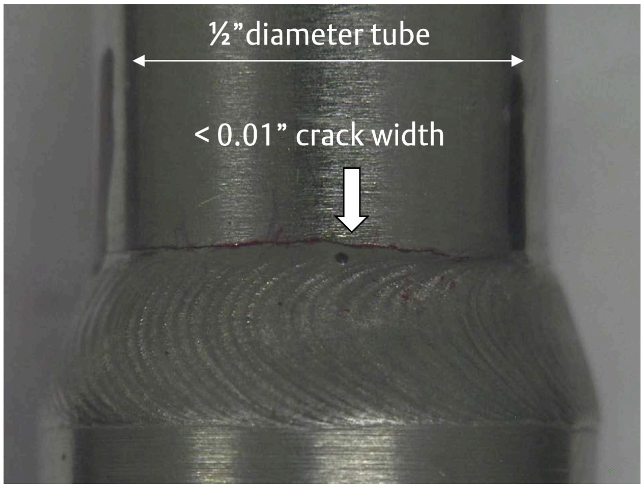


Figure 4: Tube crack

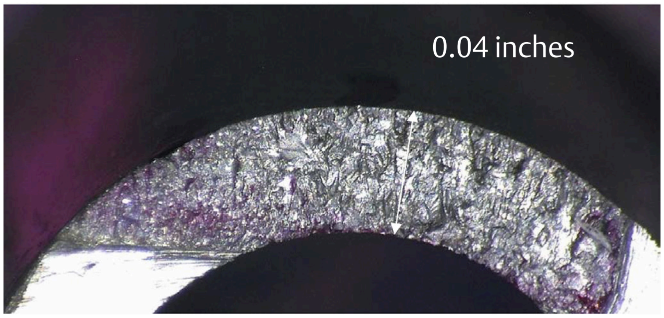


Figure 5: Crack cross section

Appendix B: Reference Documents

Crane Technical Bulletin 410
API RP 520
API RP 521

Written by Tony Pankratz
Director, Sensor Technology

Emerson Automation Solutions
7070 Winchester Circle
Boulder, CO USA 80301
T +1 303 527 6277
F +1 303 530 8459
www.Emerson.com