Liquid Cooling Reliability: Assessment of Barbed Sealing Interfaces

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High-performance computing. AI data centers. Electric vehicle charging. Industrial robotics. Grid-scale electric battery storage.

Energy-dense, heat-intensive applications are multiplying across a diverse array of industries. Meanwhile, liquid cooling is surpassing air cooling as the most effective and efficient thermal management solution for many applications.

Given these trends, growing numbers of system designers face the challenge of ensuring leak-free cooling. Because damage and downtime caused by leaks could be costly to business operations and even company reputation, today's designers are seeking advanced robustness as they approach cooling system planning, components, and integration.

CONSIDERATIONS FOR DESIGNING ROBUST LIQUID COOLING SYSTEMS

Why robustness? Even if each supplier makes components that meet spec and perform reliably for their functional lifetime, potential for overall system variability still can be significant. That variability can result in greater risk of fluid leaks.

Given the supply chain complexity involved when integrating multiple components, subsystems and vendor services into a high-performing cooling system, factors that might contribute to variability include:

- Improper assembly of components by integrators and contract manufacturers.
- "Tolerance stack" (i.e., the cumulative effect of individual part tolerances when multiple components come together in an assembled system).
- Inadequate testing and validation at key steps along a system implementation.
- Damage to components during transit, handling and system assembly.
- Environmental factors that might contaminate the system and its components.
- Incompatibility among system and subsystem components.
- Excursion conditions, such as pressure spikes, temperature spikes, or surge flow.

This variability potential puts added onus on working with component manufacturers and integration partners who are:

- Experienced at supporting high-performance liquid cooling in heat-intensive applications.
- Proven at delivering consistently on-spec, high-reliability products.
- Committed to doing their part to help customers minimize system variability.

PROACTIVE TESTING FOR CRITICAL SUBSYSTEM ROBUSTNESS

CPC has nearly 50 years of experience designing and manufacturing quick disconnects (QDs), including non-spill (i.e., "dry break") QDs, for critical applications. That includes a decade of experience supplying QDs to the high-performance computing (HPC) and AI data center sector.

The company also embraces an industry leadership role in advancing liquid cooling science and innovation. For example, as a UQD v2 workstream leader in the Open Compute Project, CPC's principal thermal technologist led development of next-generation universal QD specifications for the most advanced HPC and artificial intelligence systems and data centers.

As part of CPC's focus on expanding and sharing thermal management knowledge, it conducted a first-of-its-kind reliability analysis. The analysis looked at the potential for variability within a critical and extremely common cooling subsystem: a hose-barbed QD terminating into tubing.

More specifically, it examined how a supply chain anomaly — damage to a QD's hose barb — might affect robustness of the termination's seal. Connections of tubing onto hose-barbed QDs are found by the hundreds, even thousands, in large HPC installations. Analyzing the potential impacts of damage within this common subsystem held the promise of producing useful insights for designers across many cooling applications.

To conduct the analysis, CPC used its own, strategically evolved approach to Failure Mode and Effects Analysis (FMEA). FMEA is a widely used, time-tested methodology to anticipate potential failures in a design or manufacturing process. CPC's approach overlays a systematic way of conducting and documenting FMEA (see Five Questions Drive Systematic FMEA). It has the advantage of efficiently isolating critical system functions, failure modes and potential causes of failure. Doing so sets the stage for highly targeted, purposeful design of experiments (DOE) to identify potential failure effects and possible solutions.

Ultimately, the analysis led CPC engineers to "sensitivity test" these termination variables:

- Whether damage occurred to hose barb 1 or 2 (see Figure 1)
- Size of the damage (an indentation, or "ding," ranging from 0.2 mm^2 to 0.4 mm^2)
- Position of damage on the barb – inside, middle, or outside of barb (see Figure 2)
- Hose characteristics (i.e., internal diameter, wall thickness, material)
- Applied pressure

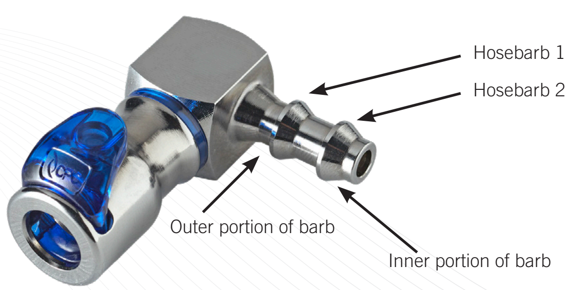


Figure 1

FIVE QUESTIONS DRIVE SYSTEMATIC FMEA

CPC has evolved an approach to FMEA analysis that calls for answering five questions, then documenting/diagramming the answers in ways that make revisiting the analysis highly traceable.

A summary of CPC's FMEA for this tubing and hose-barbed QD termination study included:

- What is it? Isolate the subsystem to be analyzed and understand its elements.

  (Tubing and hose-barbed QD termination was the subsystem).

Artifact: Block Diagram

- What does it do? Identify required subsystem functions.

  (In this case, hose installs onto a QD's barbs, barbs hold the hose in position under load, and barbs seal against the hose.)

Artifact: Boundary Diagram

- How could it fail? Identify subsystem failure modes (i.e., Undesired Output). Apply 7 Modes of Failure to each Output to identify Undesired Outputs.

  (For this analysis, lack of a seal sufficient to prevent leaking was the focus.)

Artifact: Parameter Diagram

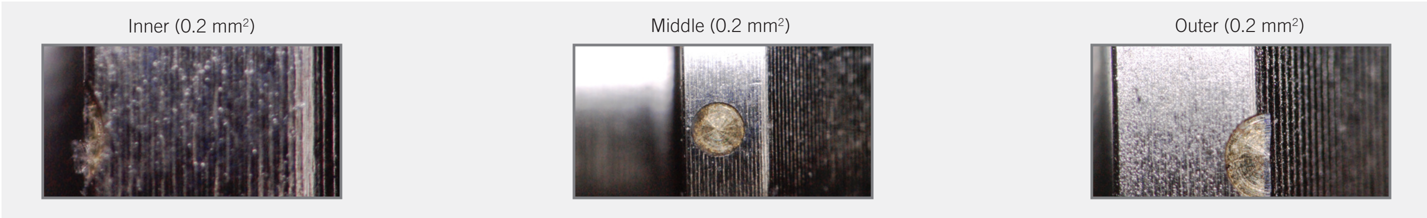
- What could cause that failure? Ideate potential failure causes based on acquired technical and application knowledge (i.e., "Noise Factors").

  (Hose barb damage was the predetermined failure cause.)

- How sensitive is it to that cause? Based on key variables identified for testing, develop a design of experiments (DOE) to test the sensitivity of each.

  (Variables tested included damage to the first or second hose barb; position of damage, size of damage, hose internal diameter, thickness and material, and applied pressure.)

Figure 2



CPC's Everis® LQ2 latched liquid cooling connector was used in the analysis. Variables were tested using a bubble leak test. This test submerges a termination in water, then applies air pressure to see whether bubbles signal leakage.

As the QD's two barbs each play a role in preventing leakage, the test was designed to assess each hose barb's role in prevention individually.

Terminations were evaluated using three common hose types: multiple internal diameters (IDs) of PTFE hose (polytetrafluoroethylene), as well as a single internal diameter each of EPDM (synthetic rubber, an ethylene, propylene, and diene monomer) and so-called "locking" EPDM (a two-layer reinforced rubber hose). (See Figure 3.)

TUBING EMERGES AS PRIMARY ROBUSTNESS FACTOR

Test results and analysis found that hose characteristics, not damage to a connector's hose barb, had the greatest impact on termination variability and probability of leakage. Specific findings included:

- Hose wall thickness had the strongest effect on leakage probability (see Figure 4). The thickest PTFE hose wall showed a significant performance improvement over thinner PTFE. "Locking" EPDM and the thickest PTFE tubing with a 0.25" ID proved most leak resistant among the tubing types tested. The standard EDPM also resisted leakage. The thinner the PTFE hose wall, the more susceptible it was to leaks.
- Of the two hose barbs, the first barb (i.e., the first barb to enter the hose) was shown to be most responsible for sealing. The second barb was most responsible for locking the hose in place.
- Barb damage alone, regardless of size or location on either barb, was not enough to allow a leak. Damage to a barb's innermost edge contributed to leaks, but only when paired with a hose prone to leakage. Damage in other areas of either barb that were tested did not contribute to leaks.

Figure 3

MATERIAL	QTY STUDIED	INNER DIAMETER RANGE (INCH)	OUTER DIAMETER RANGE (INCH)	THICKNESS RANGE (INCH)
PTFE	5	0.225–0.275	0.313–0.375	0.031–0.063
EPDM	2 (generic vs locking)	0.250	0.500	0.125

Variables not tested or controlled in this study included tubing surface finish, tubing hardness, tubing additives, tubing installation method, tube installation depth

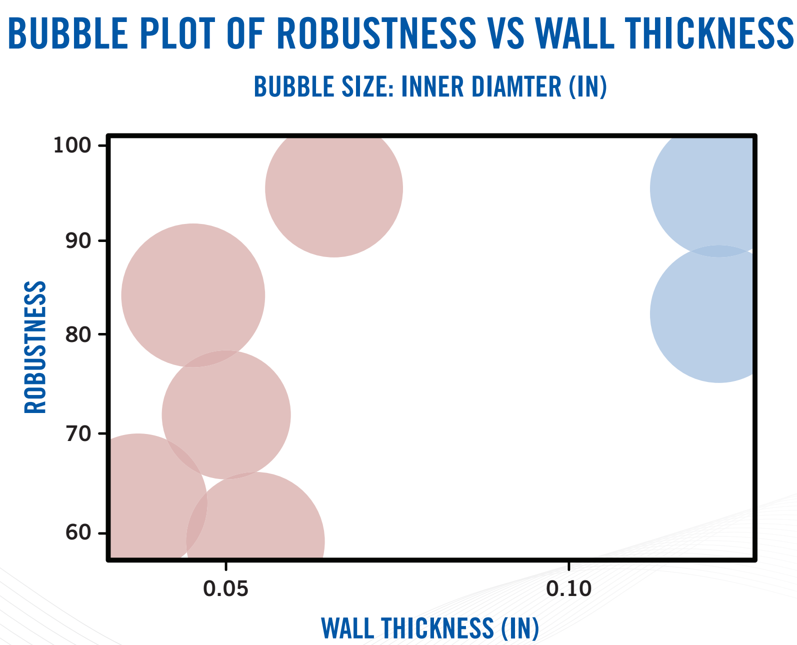


Figure 4

WORKING TOWARD LEAK-FREE LIQUID COOLING

The more business-critical the application to be liquid cooled, and the more costly damage and downtime can be, the more important it is to aim for leak-free operation. For cooling system designers, this analysis is an important reminder that simply connecting high-quality, on-spec components does not automatically result in robust performance.

The analysis found that tubing characteristics can help make leak-free terminations achievable, even when potential for variability arises via damage to a connector occurring somewhere downstream in the supply chain. The findings also suggest limitations to choosing pre-connected QD and hose combinations, where the quality and performance characteristics of both components are fixed. Instead, choosing the right QD for your application, then pairing it with the most leak-resistant tubing, could be a more robust approach.

Ultimately, leak prevention starts with blending your design with high-quality and purpose-built components. Within that, system designers are steps ahead working with partners that offer technical experience and expertise to help anticipate and research the challenges that can arise when merging products and services from a complex supply chain.

The more collaboration and insight you can gain from partners on your system's design, components, and operating dynamics, the more likely you'll have a system that performs to a level of robustness your organization and its customers need.

To learn more about this Tech Guide topic, or to discuss your application for QDs with a CPC engineer, please reach out to CPC.

ADDITIONAL RESOURCES

Scan the QR code for additional Liquid Cooling resources: