Emerging Best Practices in Fuel Rail Leak Testing

Leak testing has been a manufacturing requirement for as long as companies produced parts with its humble beginnings utilizing a water bubble tank. This morphed the use of air, then tracer gasses, and then variations of the leak testing using Helium, culminating in the hard vac leak test machine.

The concept of a hard vac leak tester has been around for two or more decades that is still 20 or more years with the premise that a part(s) to be leak tested could be placed in a chamber, have that chamber evacuated or air (put under an extreme vacuum) while charging the part with Helium under pressure. This combination would produce a leak test with the shortest cycle time.

The concept of evacuating a chamber under extreme vacuum is neither new nor unique. What is unique is the intersection of reducing cycle time while achieving a high vacuum. This is where we look to the Semiconductor industry where the majority of the manufacturing is performed under high vacuum and the impact of any residual particles or even the presence of water moisture can mean a scrapped product or reduced yield.

Yield is typically measured by the number of produced vs the number of good products available for sale.

Several examples of contaminations and mechanisms responsible for yield loss follows:

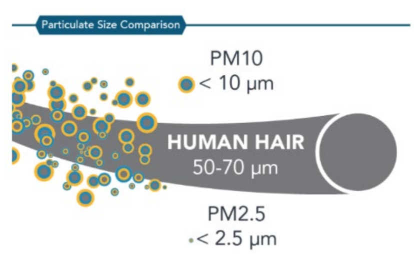
- *airborne molecular contamination (AMC) or particles of organic or inorganic matter caused by the environment or by the tools.*
- *process-induced defects as scratches, cracks, and particles, overlay faults, and stress.*[i]

The lessons learned from Semiconductors can be applied to leak testing to improve the overall quality of the process with an eye to also reducing cycle time.

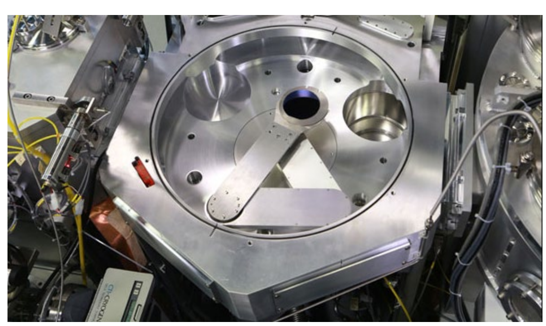
The correlation is simple:

- Particles = lower yield = less good product produced
- Slower Process time = lower cycle time = less good product produced

The chart to the right shows the relative size of particles that are present in any automobile manufacturing plant. A particle size of 10 or more microns can result from airborne dust or as emissions from the manufacturing processes. This particle size is large enough to cover a hole where there could be a leak. Some fuel rail manufacturers have adopted cleanroom designs to help manage the impact of particles and airborne contaminants yet do not address the most critical factor, the design of the tools themselves.



The image shown here is that of a semiconductor process chamber that would be subjected to high vacuum. The chamber is designed to have the least amount of volume and have as smooth a surface as possible, with the least number of areas for particles to get trapped. While this is a chamber from a semiconductor tool, best practices in the design of a vacuum chamber carry over to other industries such as automotive leak testing with hard vacuums.



The design of vacuum chambers had to evolve where surfaces were as smooth as possible to:

i) restrict areas where particles or molecules could be trapped and

ii) allow for proper airflow to clean up any lingering particles or molecules.

In the Semiconductor industry, the impact of particles on yield is such an issue that manufacturers were forced to recognize early on areas where particle buildup could become a problem in their factory. This recognition produced its own vernacular.

Artifacts: This a catch-all term for particles or molecules that are not removed during the chamber purge cycle and could negatively impact yield.

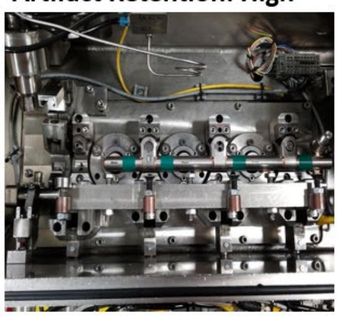
Flow Resistance or Conductance: Air/gas/liquid resistance caused due to turbulence resulting from obstructions or nonsmoothed surfaces.

Torturous Design/Topography: A semiconductor industry engineering designation for a design or form factor that significantly deviates (in a bad way) from any industry-standard operating best practice or design.

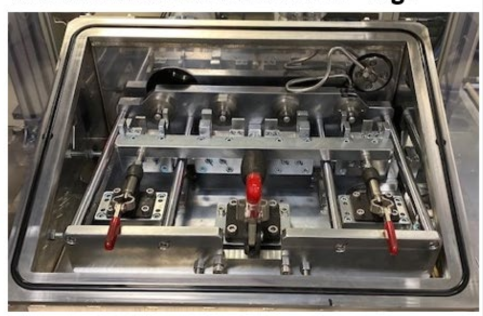
These concepts can be directly applied to Fuel Rail leak testing. The internal chamber designs vary greatly between the three different manufacturers. What is also clear is that the majority of these chamber designs were not considering flow resistance nor artifact retention. In the case of fuel rail leak testing, artifacts would include particles (that could cover a potential leak), water vapor (that could freeze under high vacuum), or residual helium that could produce false fails. Artifacts can also cling to surfaces. The greater the total surface area in a chamber, the more surface there is for artifacts to cling to.

Flow Resistance: Low
Artifact Retention: Low - Medium

Flow Resistance: High
Artifact Retention: High



Flow Resistance: High
Artifact Retention: Medium - High



"I was asked to weigh in on lessons learned from semiconductor process tool design as it relates to other industries and in particular leak detection equipment for the automotive industry. I was surprised the see internal chamber designs with torturous topologies that retain particles or other molecules that are difficult to purge. These artifacts ultimately contribute to lower yield and quality.

Moreover, these torturous topographies contribute the loss of vacuum efficiency due to conductance (to airflow resistance) which means longer pump downtime which equates to longer cycle time. There will also be more strain on the vacuum pumps requiring more frequent service. It seems that only a few companies have taken and adopted the lessons learned long ago from the Semiconductor industry about best design practices and applied it to other industries like automotive leak testing."

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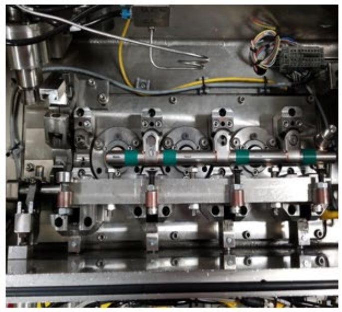
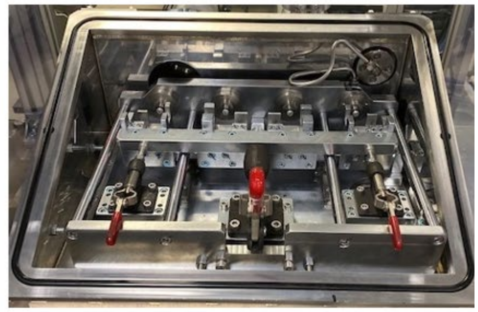
A major lesson learned from the semiconductor industry is to develop an internal chamber design that is more resistant to particle buildup and retention in large part because one of the design intents was to minimize the total surface area in the chamber. Artifact buildup can come from exposed O-Rings or polymer tubes, but also just through clinging to surfaces. Retention of particles becomes aggravated with rough or textured surfaces creating areas for particles to be trapped and released later. Residual helium can also be trapped and released during leak testing creating false “fails” for the leak test.

Chamber with Particle Resistant Design

Non-Particle Resistant Design Alternative



Non-Particle Resistant Design Alternative



Fuel Rail Internal Chamber Design Comparison Table

VIC Smooth Surface Particle Resistant Chamber Design	Particle Trapping Chamber Design
Simplified tooling with minimal chamber penetrations	Complicated tooling requiring numerous chamber penetrations and potential leak points.
Smooth internal chamber surface creates better purging and less opportunity for residual helium after a large leak.	Rough or textured surfaces create more turbulent purging and result in particle and helium trap locations that can negatively impact follow on leak testing.
Simplified chamber design to reduce chamber pockets, lower flow resistance and decrease pump down times	Busy chambers can lead to a much larger pocket to pump out.
Minimal surface area for artifact retention.	Large total surface area due to the inclusion of components inside the vacuum chamber.
Wires and charge lines located outside of chamber to prevent testing issues	Rubber and plastics can retain helium and other outgassing materials which result in pump down issues and false failures.
Chambers designed with safety in mind with minimal pinch points.	Numerous pinch points increase risk of operator injury
Chamber tooling designed to prevent damage to customer parts	Impact sites not protected with software materials to prevent part damage

The chamber design and the supporting machine design should make replacing chambers fast and easy. Also the design should be simple where there are minimal exposed componenst that could be damaged while in production or exchanging a chamber. VIC has designed their removable chambers with common elements moved to the back of the machine and utilizinf only those components required for the cart. This view shows the leak tester incorporated with the chamber cart as this is a dual independent 5,000 psi fuel rail leak test machine. The VIC machine has a common backplane where controls modules can be addded or replaced with minimal programing or wiring.

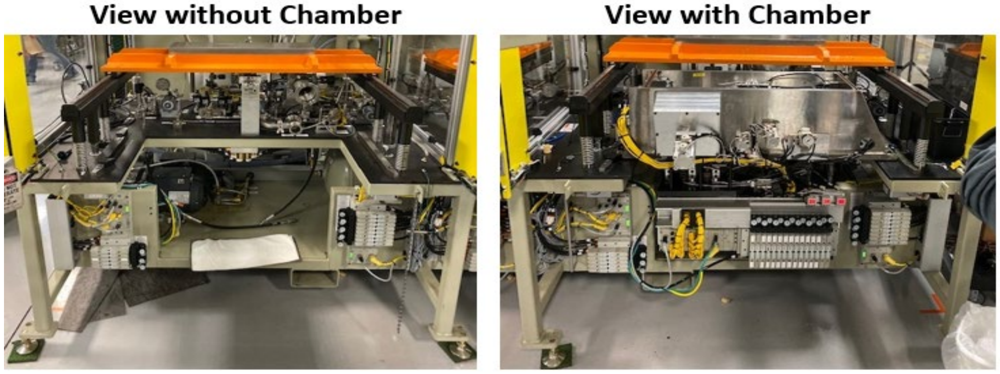
Alternate designs either do not allow for the removal of a chamber. Other designs are such that it exposes components that could be damaged during production The picture on the left is of a fuel rail leak test machine where the chamber is incorporated directly into the machine. No exchange of the chamber is possible. The alternate design below shows a design where chambers can be exchanged, but this design exposes the various components making them suseptible to damage from production. The more complex design makes service also more difficult. Resulting in higher maintenance costs, and longer down time.

VIC Design for Replaceable Chambers

View without Chamber **View with Chamber**

Design Alternative for Replaceable Chambers

View without Chamber **View with Chamber**



Fuel Rail

Chamber Design Comparison Table

VIC Modular Exchangeable Chamber Design	**Alternate Exchangeable Chamber Design**
Simplified tooling components for easier maintenance and manufacturing of replacement parts	Complex components and many different materials used
Tooling designed for longevity in an industrial setting	Intricate components result in early failure and frequent down-time
Compact system designed to minimize facility footprint and to meet height specs	Larger machine footprint design
Easily upgraded, to use new rail designs	System design and programming difficult and expensive to change for new components or hardware

If we follow these best practices and lessons learned, the vacuum test chambers used for Fuel Rail leak testing would be fabricated with an internal chamber design to minimize the potential for retaining artifacts. A less tortuous topography would also help with faster pump down time.

VIC has utilized lessons learned from the semiconductor industry to develop an internal chamber design that is more resistant to particle buildup and retention in large part because one of the design intents was to minimize the total surface area in the chamber.

VIC fuel rail leak testing machines have been engineered for minimized mechanical footprint with efficient tracer gas handling management and high pressure tracer gas versatility. In addition, all new machines have embedded reject control, require minimal changeover times due to compartmentalized interchangeable tooling and offer part traceability.

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[i] https://www.semiconductors.org/wp-content/uploads/2018/06/5_2015-ITRS-2.0-Yield-Enhancement.pdf