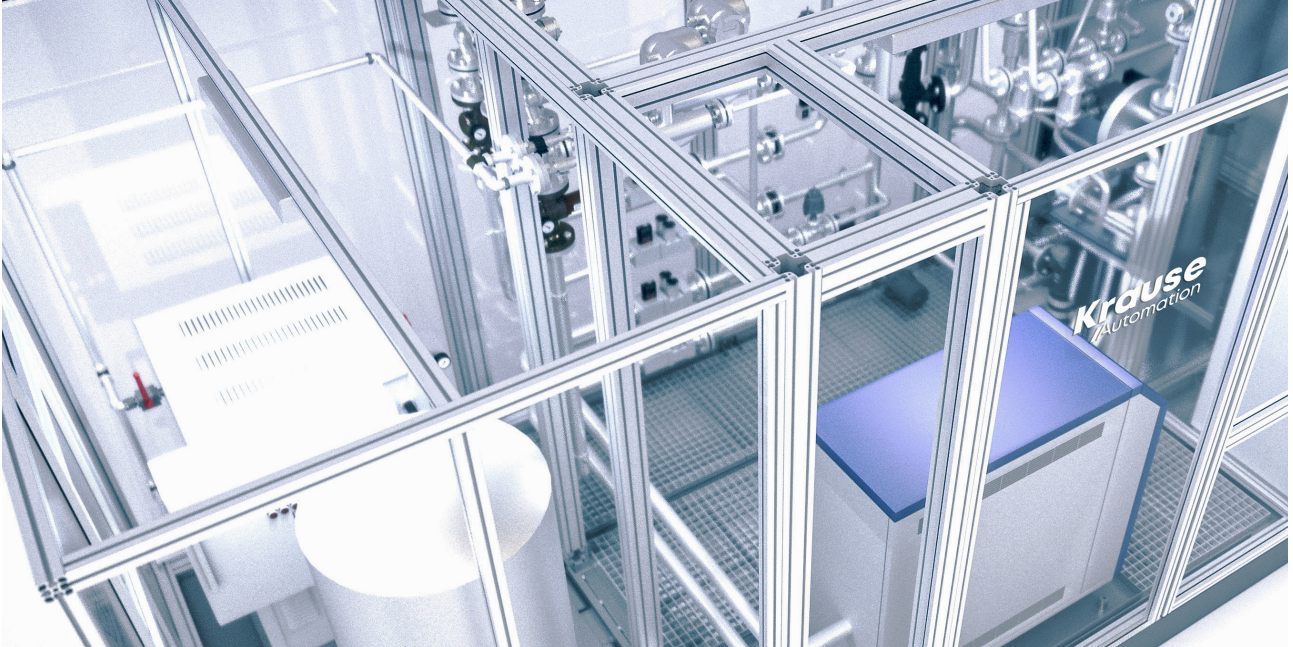


Test technology



Stack- and System Test of Fuel Cells and Electrolyzers in Production

From Laboratory Function Testing to Industrial Manufacturing and Reducing Costs

A laboratory test bench can verify whether a fuel cell or electrolyzer stack works. Industrial manufacturing, however, requires repeatable, automated, and highly efficient testing processes.

In serial production, every stack must be tested quickly and reliably and testing equipment must have a maximum availability. Downtime and manual interventions directly impact productivity and costs.

Every minute saved during testing increases factory output. Optimized automated processes and parallel operations significantly reduce cycle time. The result is higher throughput compared to conventional laboratory test benches.

The true cost of testing is measured per stack produced, not per test bench purchased. Higher throughput means less stations are required for the same production volume. This reduces overall investment costs and improves profitability.

This is the advantage of our production test benches: We transform testing into a scalable manufacturing operation. Our automated benches are designed specifically for continuous,

round-the-clock manufacturing environments, high throughput because of reduced cycle time with easy maintenance access and industrial-grade components to reduce your production costs.

Stack Test and Conditioning (on Fuel Cells) Test Bench

Our stack test stand follows the stacking line and includes all the systems required to operate a stack and record measurement data, such as media conditioning, cell voltage monitoring (CVM), etc. and the sink (power) modules. This allows the heart of a fuel cell or electrolyzer system to be tested for all quality-relevant parameters before integration. On a fuel cell, at the same time, the stack is conditioned to run in here in order to achieve full performance when delivered.

End of Line (EoL) Test Bench

The EoL (system) test bench is located at the end of the production line and simulates the real operation of the fuel cell or electrolyzer system by means of a test run. It includes not only the stack operation but also checks of all balance-of-plant components (pumps, sensors, etc.). Depending on the requirements, a test run can take from a few minutes to several hours. Focusing on optimizing the cycle time we implement feature like fast filling and emptying of the media-supply or customer-specific adaptation solutions.

Innovative Solutions for Production-Stack & System



Features of Production Stack-Test Bench

- **PROCESS CONTROL:** Automated- and PLC-controlled, incl. safety- and function-monitoring of any Valve and Sensor for mal-function to assure reliable testing
- **FLOW-CONTROL:** Advanced flow control technology combines fast response time with outstanding accuracy across the entire operating range
- **GAS CONDITIONING:** Thermal management systems provide precisely conditioned gas streams across the entire operating range
- **STEAM DOSING:** On fuel cells our intelligent "advanced steam dosing technology" creates realistic conditions across wide operating ranges
- **HYDROGEN RECIRCULATION:** On fuel cells our hydrogen recirculation solution returns unused hydrogen to reduce production costs
- **MODULAR SYSTEM ARCHITECTURE:** Our modular architecture allows your solution to be configured for your specific stack types, production capacities and automation levels

Features of Production System-Test Bench

- **TIGHTNESS & FUNCTION TESTING:** Automated verification of all auxiliary media circuits ensures leak free, reliable operation and maximum system integrity
- **GAS CONSUMPTION OR PRODUCTION ANALYSIS:** High-precision gas measurement delivers accurate consumption or production data for performance check
- **SENSOR & ACTUATOR VALIDATION:** Automated diagnostics verify sensors, valves and actuators for maximum functional reliability
- **DRIVING CYCLE & LOAD SIMULATION:** Realistic load profiles to reproduce real-world operating conditions for reliable system validation
- **POWER MEASUREMENT:** Precise power analysis delivers trustworthy performance and efficiency data across the entire operating range
- **MODULAR SYSTEM ARCHITECTURE:** Flexible modular and scalable platform design adapts to different systems, power classes and future product generations

www.krause-automation.com

Features of Test-Bench Software, Data Acquisition and Line

Control

- **TEST BENCH SOFTWARE:** Combines object-driven test-run programming, Process visualization and latest statistical and AI-supported data analyses to reduce errors and accelerates analysis for improvement of your processes
- **DATA ACQUISITION AND LINE CONTROL:** The Advanced Data Management system (ADM) is a mixture of a Manufacturing Execution System (MES), Supervisory Control and Data Acquisition (SCADA) tool, which controls your production and evaluates your manufacturing and quality data
- It can be connected with additional production lines like MEA-/ BPP-manufacturing, Stack-Assembly, etc. for a holistic production control

What we stand for...

- Experience and expertise in the field of hydrogen technology for over 10 years
- Delivery of professional pre-project consulting services
- Experiences in investment cost and support in complete factory planning
- Serving the entire production value chain alongside our partners and supplier network
- Innovative products and design concepts for customized requirements
- Reliable turnkey solution provider for manual or mass production systems

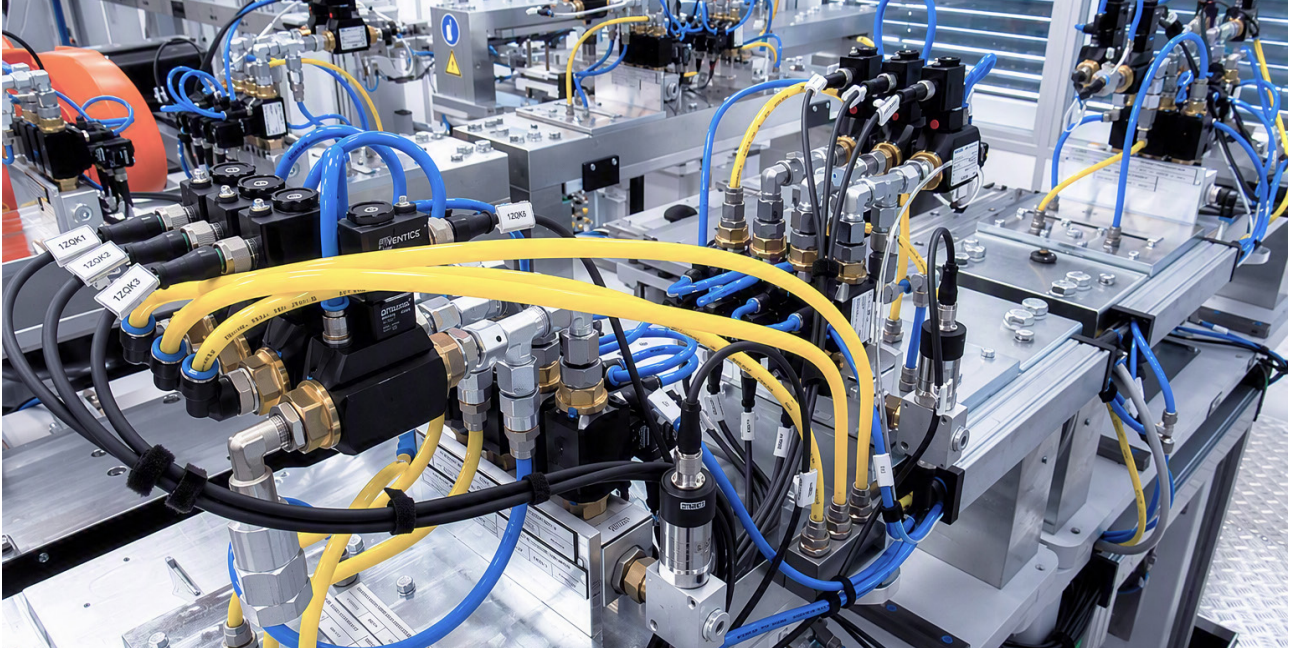
We are the **H** of Hydrogen

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Leak testing



Leak Testing in Hydrogen Applications

Safety Through Precision

As hydrogen gains momentum in mobility and energy storage, leak detection has become a critical factor in ensuring safety and efficiency. Due to its low density and very small size, hydrogen is significantly more prone to leakage than other gasses. Even small leaks pose serious risks: With a lower explosion limit of 4 %, even small amounts of hydrogen can be flammable when mixed with atmospheric air. Beyond safety, undetected hydrogen losses impact system performance and reduce the environmental benefits of hydrogen technology.

Industry standards like DIN EN IEC 62282-2 and ISO 22734 define certain leak rate limits and test procedures, but often they leave key parameters vague or open to manufacturer interpretation. This ambiguity leads to varying practices, especially in the definition of permissible leakage and the methods used to detect it. At Krause Automation, we bring clarity to this challenge.

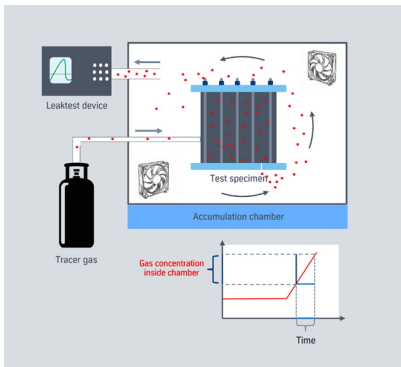
With many years of experience in leak testing fuel cell stacks, electrolyzers and components such as bipolar plates or membrane electrode assemblies, we offer tailored solutions that match specific product designs and customer requirements. We can draw on a wide range of measurement methods with different test times, accuracies and investment costs. Depending on the application, we use atmospheric tracer gas methods for relatively low leakage rates, or advanced technologies like vacuum mass spectroscopy for high-precision and high-speed testing. For complete stacks and large volume electrolysis cell air or a combination of air and tracer gas is used to cover comprehensive leakage specifications. Our experience does not only include test solutions, but also the integration of the processes into a scalable production environment.

By aligning test strategies with component geometry, production speed and investment targets, we help our customers to secure safety, compliance and competitiveness – every step of the way.

Innovative Leak Test Solutions

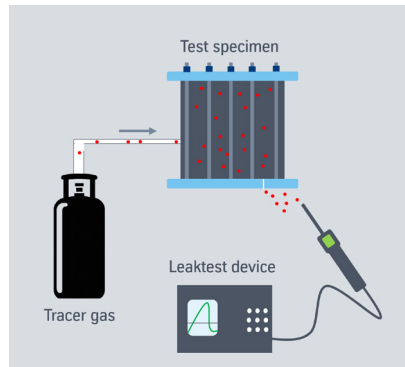
Accumulation method

- Detects extremely small leak rates
- Suitable for both small and large test objects
- Detectable leak rates down to $1\text{e-}5$ mbar l/s



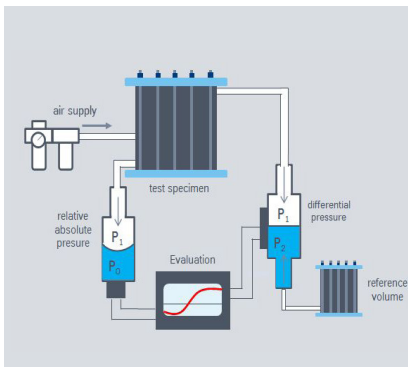
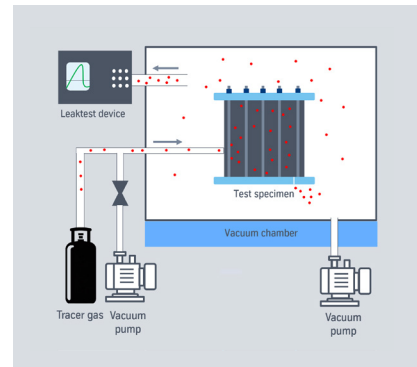
Sniffer leak test

- Cost-effective equipment set up
- Flexible use for components of various sizes and shapes
- Detectable leak rates down to $2\text{e-}4$ mbar l/s



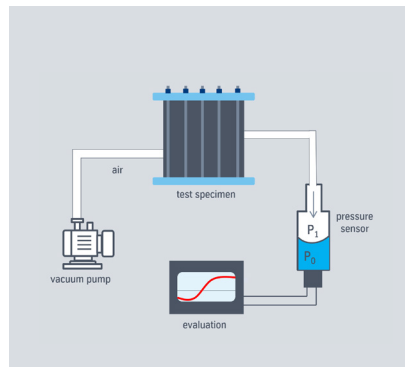
Vacuum leak test with tracer gases

- Very short cycle time
- Often used with helium as tracer gas
- Detectable leak rates down to $1\text{e-}6$ mbar l/s



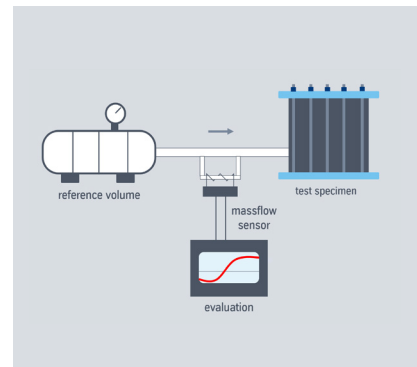
Pressure decay (relative differential pressure)

- Simple implementation without complex equipment
- Ideal for high-throughput serial production
- Detectable leak rates down to $1,6\text{e-}2$ mbar l/s (1 ml/min)



Pressure increase method

- Enables faster testing compared
- Detectable leak rates down from $1,6\text{e-}3$ to $1,6\text{e-}2$ mbar l/s (0,1-1 ml/min)



Mass flow measurement

- Direct leak test measurement for high accuracy
- Suitable for large or volumetrically unstable parts
- Detectable leak rates down to $1,6\text{e-}2$ mbar l/s (1 ml/min)

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