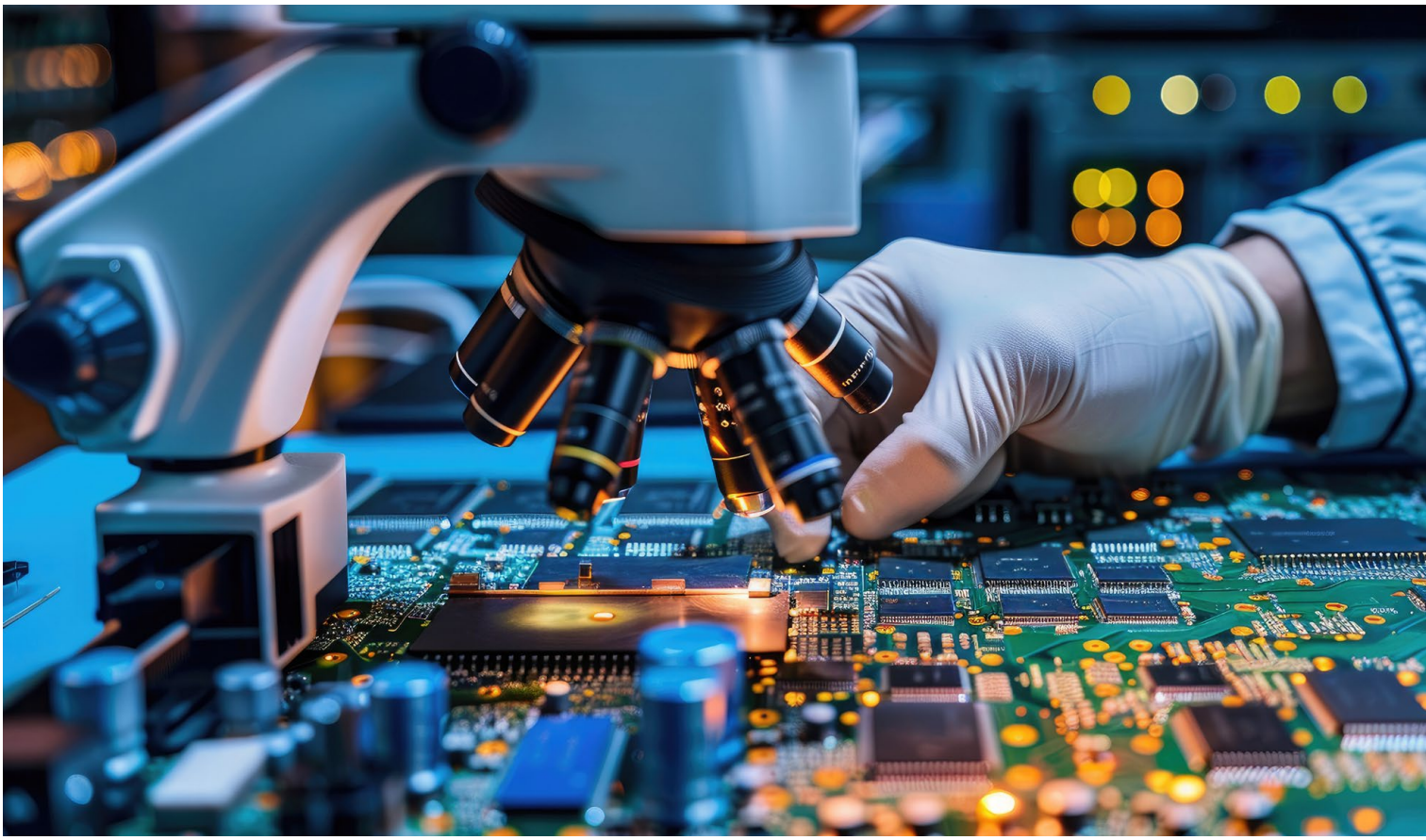
WHITE PAPER

The physics of failure

Drive quality and reliability at ABB



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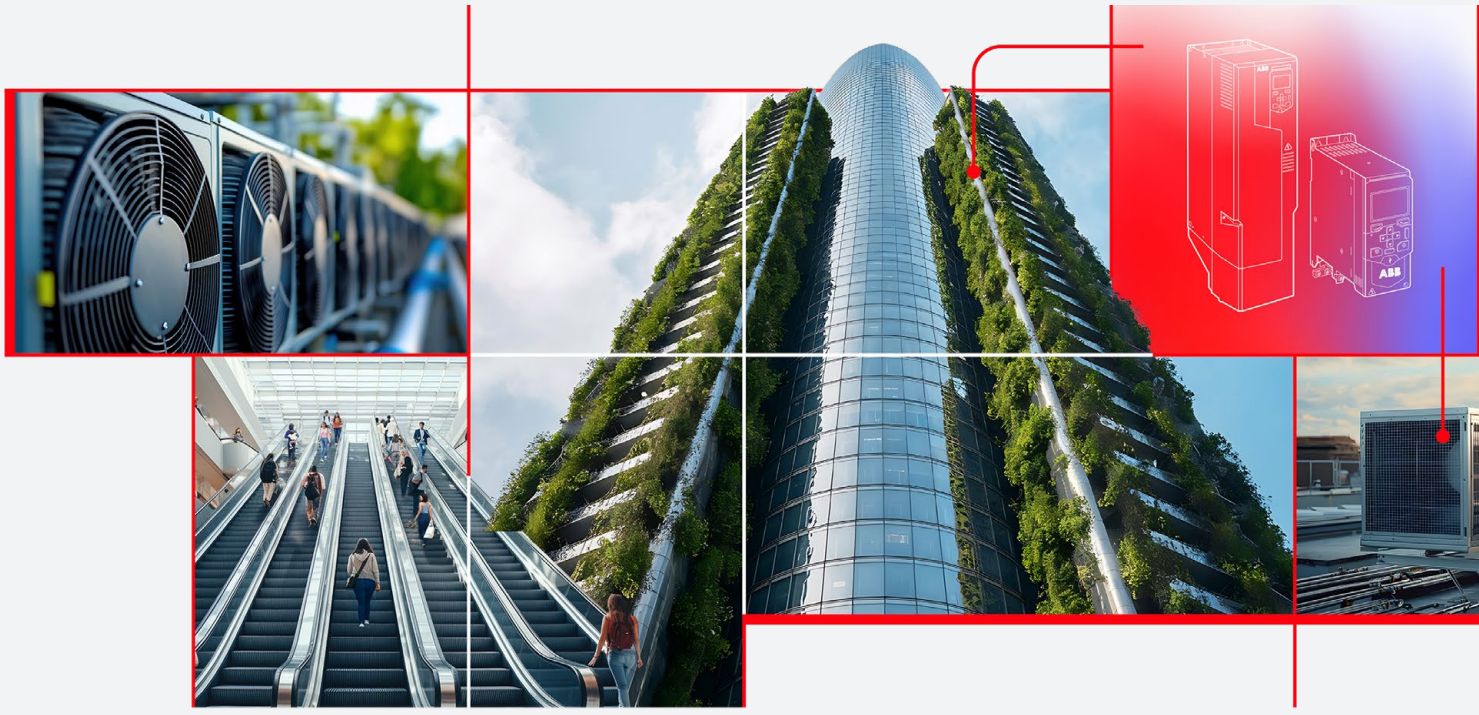

Introduction

For most of history, human innovation at its core has been about a mastery over motion. From mills, locomotives and the combustion engine, to submarines, aeroplanes and space rockets, technological progress has been measured in our ability to make things move faster and more efficiently.

Even in the information age, the electric motor and its closest accomplice, the variable speed drive, are at the heart of almost everything that moves. Precise and consistent control of motion is foundational to our ability to keep the lights on, both figuratively and literally.

But when the lights do go out, the consequences can be dire. If a motor or drive fails, it can result in blackouts in hospitals, life support on a space station failing, or a ship full of people being stranded in the middle of the ocean.

None understand the stakes better than ABB, the global leader in motors and drives. Our products are responsible for mission-critical motion in steel mills, hospital HVAC systems, and even theme parks.

As such, we have developed a uniquely robust approach to quality and reliability. This whitepaper aims to give you an insight into our approach to drive quality and reliability, so you can see how we ensure our products will perform as expected, in any environment.

Quality and reliability at ABB

Think of ‘quality’ as a photo that captures a product’s immediate performance. ‘Reliability’, meanwhile, is like a video – it is quality unfolding over time. Together, they determine true product value for customers, ensuring moment-to-moment operation, long-term durability, and minimal downtime throughout a drive’s lifespan.

ABB’s approach to quality and reliability is one of the most sophisticated and rigorous in the world. At our cutting-edge 6,000 square metre testing facilities in Helsinki, Finland, we test components so we know which are the best to use, and we test our finished products to their breaking points to learn the limits. This way we can assess their quality and reliability at customer conditions. To help in this study is ABB’s own CSI lab. No, not “Crime Scene Investigation”, but rather “Customer Supplier Investigation”.

Component-level testing
At ABB we believe that a drive is only as good as its weakest component. Every detail matters, from high-power semiconductors to the smallest resistors on a circuit board. We therefore conduct extensive component-level testing, especially the components of power semiconductors but also on different types of capacitors, current transducers, optocouplers, memory units, and fans. We do this to verify that critical components meet the claims of our suppliers, and we repeat tests until we see failures.

These tests include:
- Electrical stress tests – pushing voltage and current limits to verify endurance under extreme conditions
- Environmental stress testing – subjecting components to extreme heat, cold, humidity, and corrosive gases and salt mist to identify weaknesses.
- Mechanical durability testing – vibration, thermal cycling, and mechanical stress to simulate years of operation within months.

We have learnt that it is unavoidable that, occasionally, we will get bad batches of components, and so we stockpile high-quality components when we identify them. This has had the added benefit of buffering us against major supply chain disruption, like we saw over the COVID-19 pandemic. Being selective has paid off: over the years, our approach to component-level testing has given us a reputation for uncompromising stringency among our suppliers. A reputation we are proud of.

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Equipment-level testing
With more than 1.3 million ABB drives are delivered yearly, our customers depend on their performance across vastly different environments. Like with the individual components, we put our finished products to the test in some of the harshest possible real-world conditions, simulated in our main testing hub in Helsinki, as well as our testing facilities in Estonia, China, India and the USA.

Our testing environments include, but are not limited to: The Sahara Room, Finland's largest controlled humidity and temperature testing facility, capable of exposing drives to extreme heat and moisture conditions over extended periods.

- Electromagnetic compatibility (EMC) laboratories, where we assess the drive's performance in the presence of large electromagnetic fields – crucial for applications in industrial plants and data centres
- Weather chambers and heat chambers, simulating extreme environmental fluctuations for drives used in skyscraper elevators, offshore drilling platforms, and desert mining operations.
- Corrosion testing facilities that expose drives to various corrosive gases and salt mist fog to simulate industrial and agricultural conditions as well as coastal regions and marine vessels.

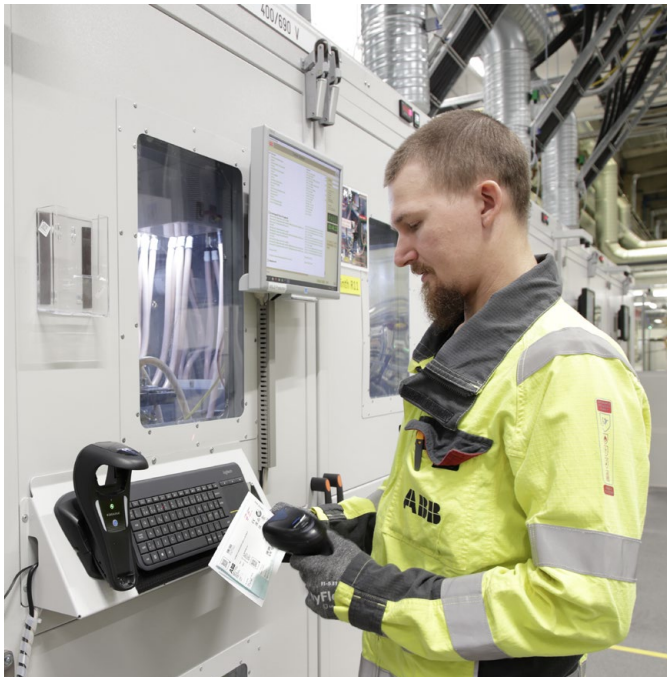
As with our component-level testing, we conduct lifetime tests on completed drives that project how they will perform over 10+ years of real-world usage. We do this by accelerating conditions over just 3-4 months through heat, electrical load, and moisture cycling. Through this, we can accurately predict component failure rates and inform customers when maintenance or replacements should be performed, giving them maximum control over operational uptime.

A real-life example of stress-induced failure dynamics comes from studying elevator operations in skyscrapers. A frequently running elevator maintains a regular, predictable temperature, while a VIP elevator, used sporadically, experiences irregular and intense thermal cycling. These stressors can accelerate wear on certain components, like power semiconductors and capacitors, if not properly accounted for in design. It's not intuitive, but the elevator that is used less frequently may fail faster. Our testing ensures that even under such unpredictable conditions, ABB drives remain reliable for decades.

Random testing

During mass production, ongoing testing is vital to maintaining product quality. At ABB, we randomly test three drives of varying sizes each week, totalling around 150 drives per year. This helps us detect anomalies that could become significant if left unchecked, offering a preventative approach to quality assurance.

Even after products have been deployed, their quality and reliability are still on our minds. Our maintenance-phase testing involves ongoing reliability assessments to identify and fix potential faults before they impact customers. This proactive stance allows ABB to quickly address issues and ensure that products continue to meet performance benchmarks over time.



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Product testing at ABB Drives factory in Helsinki, Finland.

Fault analysis and root cause investigation

Our detailed knowledge of our own products, combined with our knowledge of our customer's use cases, allows us to predict faults with a high degree of accuracy. Our preventative maintenance plans extend the life of our products significantly, and save our customers money. If we know when and how the drive is likely to fail, the failure can be predicted, prevented and mitigated by well-timed and focused maintenance activities.

Fault analysis
While our drives are unrivalled in their reliability, they are ultimately complex systems that can fail in myriad ways due to a variety of factors. One of the most common contributing factors to a drive's failure is overstress. This can be summarized as when the strain on a product exceeds its durability. This could be from torque, temperature, force, bending, etc.

More commonly, it's the drive's durability that is compromised over time due to environmental stressors, such as an excessively high ambient temperature, or temperature that wildly fluctuates. Whenever a product is exposed to stress, it takes on a small amount of damage. This cumulates over time as what we might call "wear-and-tear".

	Overstress	Wearout
Mechanical	Yield Fracture Interfacial de-adhesion	Fatigue Creep Wear
Thermal	Glass transition (Tg) Phase transition	Stress driven diffusion voiding (SDDV)
Electrical	Dielectric breakdown Electrical overstress Electrostatic discharge Second breakdown	TDDB Electromigration Surface charge spreading Hot electrons
Radiaton	Single event upset	Radiation embrittlement Charge trapping in oxidies
Chemical		Corrosion, EMC Dendrites & whiskers Depolymerization Intermetallic growth

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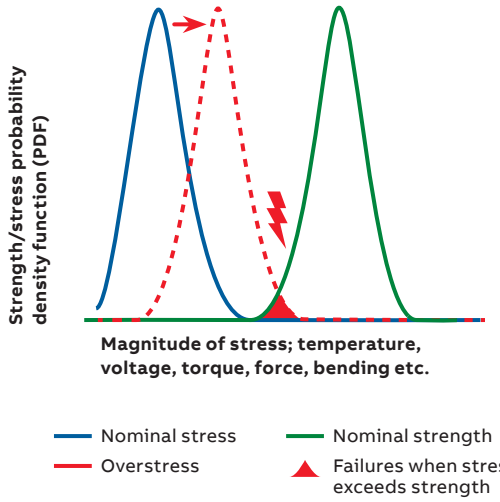
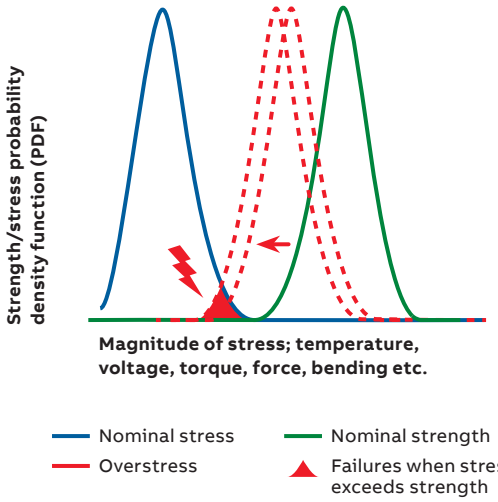
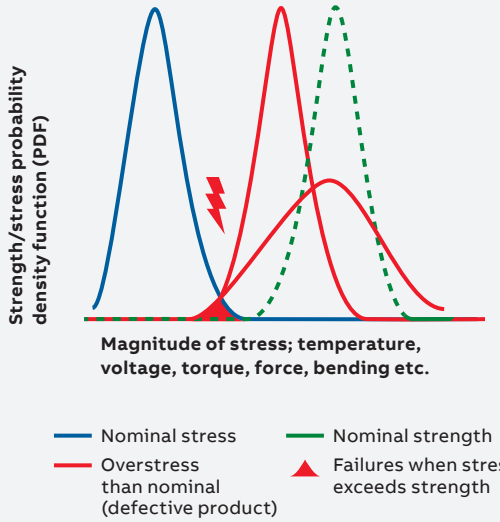
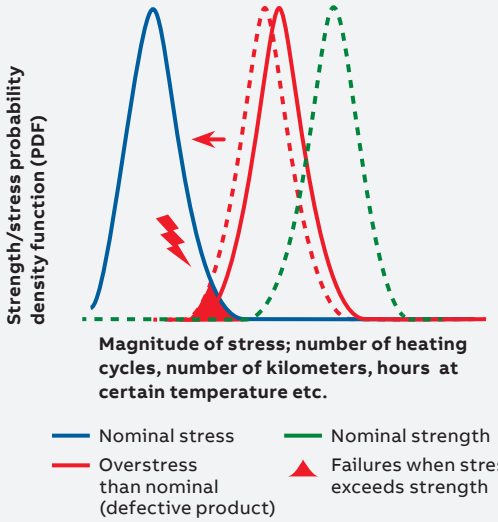
Typical failure mechanisms for electronic equipment.

	Overstress	Wearout
Nominal	 An overstress failure will occur if a product is subjected to stress that exceeds its strength.	 The cumulative damage caused by stress over time reduces the strength and eventually causes the product to fail.
Defective	 Defective products will fail when nominal stress is applied to the defect site.	 A defective product cannot last its expected lifetime and thus wears out faster and fails earlier.

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There are only two reasons why products fail: overstress and wear-out. If the stress exceeds its strength the product will fail and the result is an overstress failure. Wear-out failure happens when the cumulative stress exceeds the product's durability. There are two kinds of products: nominal and defective. A nominal product doesn't fail at nominal stress and it will last the useful life it was designed for when exposed to the specified stresses. A defective product fails when nominal stress is applied to the defect site.

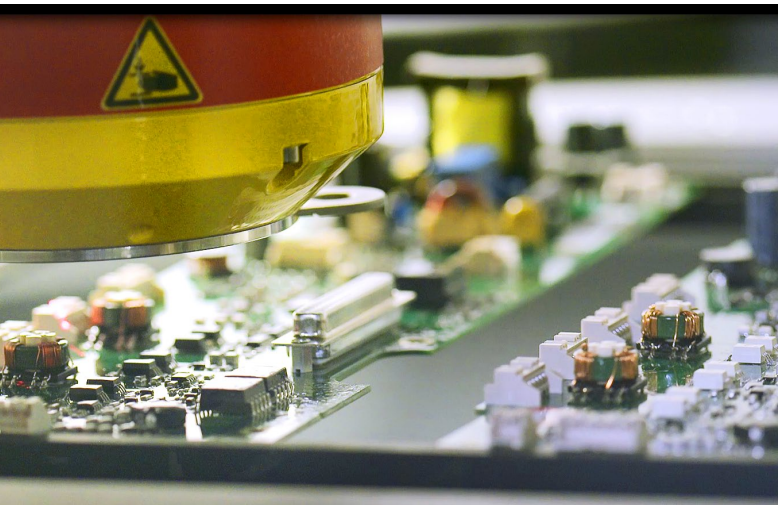
Root-cause investigations

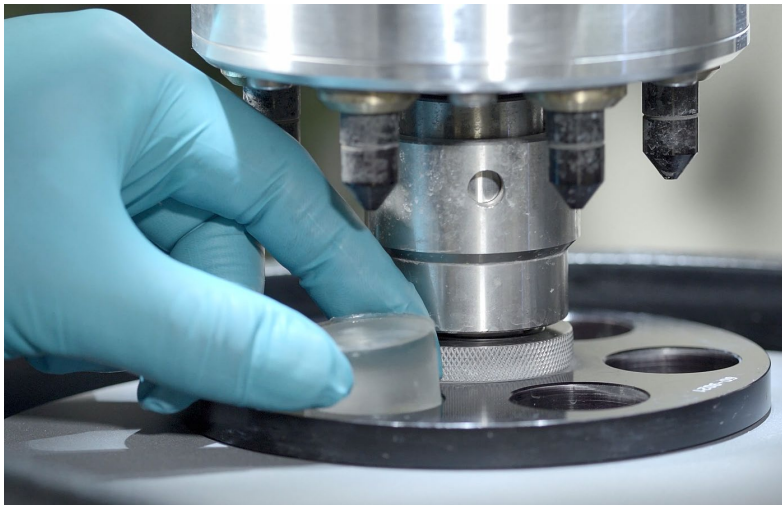
When drives fail in our reliability test, or on the rare occasion that we receive a failed drive from a customer, our technicians literally take a scalpel to them. They perform a forensic-level post-mortem analysis to determine the exact sequence leading to failure, which involves:

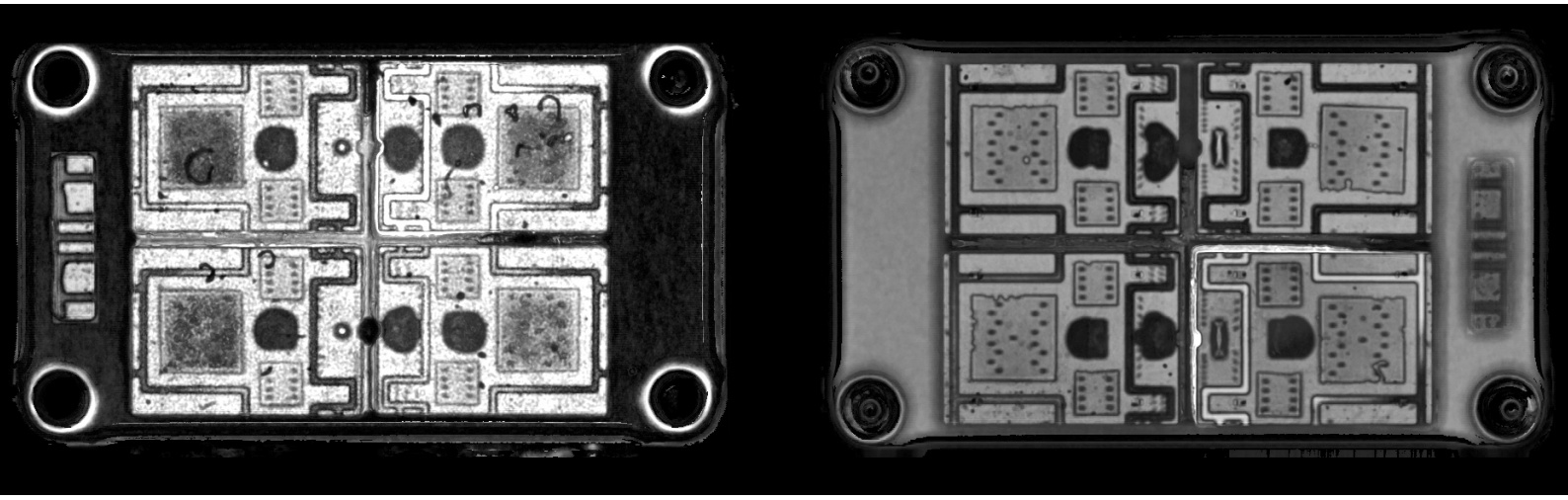
- High-magnification imaging using X-ray machines, acoustic testing, and other advanced sensing equipment.
- Cross-section analysis, where drives are sliced open using diamond-cutting blades for microscopic structural examination.
- Plasma grinding, which removes material one atomic layer at a time to reveal imperfections deep within a component's structure.

Through this process, we not only identify failures, but trace them back to their root cause, whether a mechanical stress point, a chemical reaction, or an unexpected thermal expansion issue. Understanding the root-cause and chain of events leading to final failure helps us better understand the failure mechanisms and further improve our drive's reliability.

A notable success story from our root-cause investigations was when our engineers identified sulphurous gas exposure as a frequent failure mechanism in industrial environments. By modifying protective silicon coatings, we were able to develop a solution together with a component supplier that increased component lifespan in these environments well beyond competitor alternatives.







Collaboration with suppliers
Through years of research, iterative tests, and collaborations with universities, ABB has accumulated one of the most comprehensive failure analysis libraries in the world. This knowledge enables us to work with our suppliers toward the highest industry standards.

Our data shows that 90% of notable failures in testing originate from component-related issues. That means we need to rigorously qualify supplier components before we choose to adopt them.

When we do identify failed components and the cause of the failure, we sometimes need the expertise and knowledge of the component supplier regarding their specific component, so in this way ABB's quality and reliability is a team effort. Our ability to assure the quality and reliability of our products depends on our excellent relationships with suppliers, universities and with different departments within ABB.

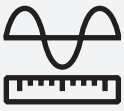
Commonly, the steps in the process are as follows:

1. We observe a failure in customer conditions

2. We investigate the route cause

3. We simulate the failure conditions in the lab as precisely as possible

4. We learn everything we can about what happened and why



5. We adjust our product design to prevent the same fault happening again

ABB's motors and drives have a very long market lifetime but, in this way, our products are undergoing a continuous evolution, improving with every iteration.

Conclusion

Our drives are deployed in a multitude of environments, from dirty mines and farms to high-end clean rooms in factories, and for a multitude of purposes from monotonous pump and fan applications to demanding cyclic uses with high variance and accuracy. Malfunctions in these contexts can mean significant financial losses, operational downtimes, and even grave risks to human safety.

ABB's approach to reliability effectively gives our clients and customers an advantage over their competitors. In every industry, equipment uptime and operational efficiency are critical to maximising profit margins. Our rigorous testing and predictive maintenance mean our products continuously perform – and when they fail, we've planned for every possibility. This lack of disruption therefore gives our customers the headspace to focus on improving other areas of their businesses.

It's no wonder, then, each year more than 1.3 million ABB drives are delivered out into the world, making things move – year after year, second after second.

Ultimately, our motto of identifying and resolving issues before they impact the customer embodies our dedication to quality and innovation. In choosing ABB, customers not only gain access to reliable products, but also a partner committed to supporting their operational success over the long term.

What now?
Discover more about the Drive Quality and Reliability at ABB

Visit our Reliability web pages

Watch our Reliability videos

For more information, please contact
your local ABB representative or visit

new.abb.com/drives

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