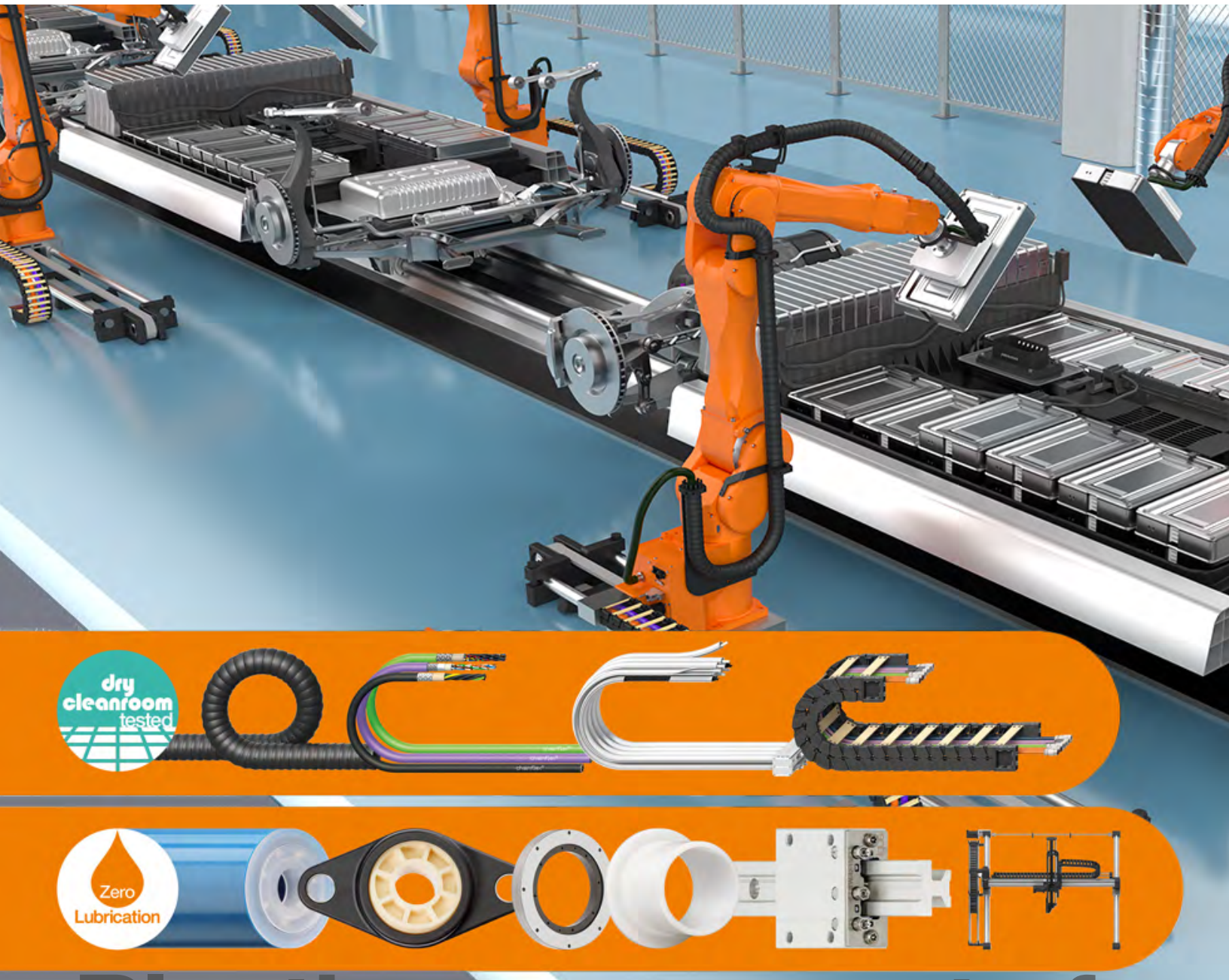


Plastic components for dry cleanrooms

Charging battery manufacturing with 100% dry operating systems

Introduction & background

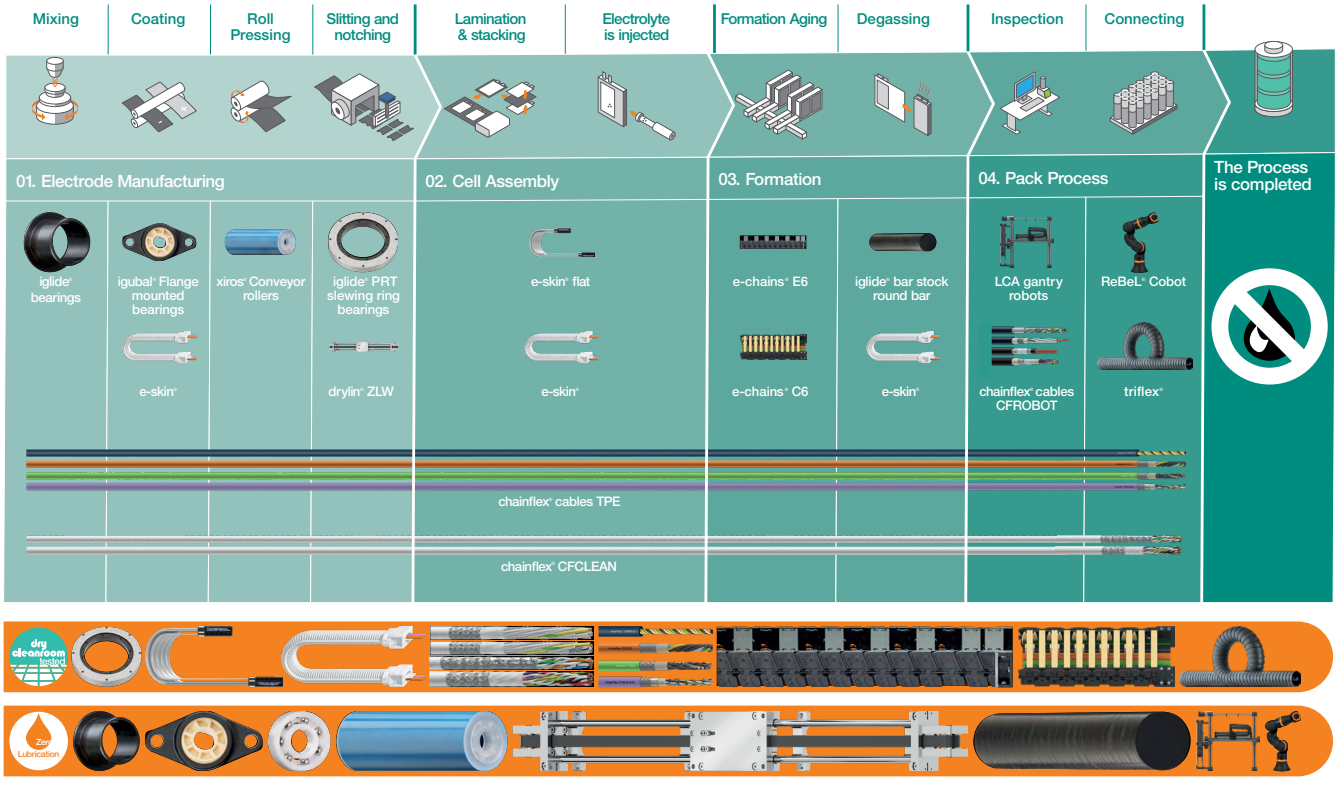
The production of batteries for electromobility requires the highest level of cleanliness and process reliability. Many production steps take place in dry cleanrooms, where not only the number of particles, but also parameters such as temperature and humidity must be precisely controlled. Only in this way can the strict quality requirements be achieved.

To minimize waste, the systems in these environments are highly automated. Moving components such as linear and transfer units or robots require reliable energy and signal supply systems that fulfill the cleanliness requirements. This is precisely where cleanroom-certified energy chain systems and linear actuators from igus® display their strengths.

Find out in our white paper how motion plastics® not only makes your production cleaner, but also more efficient and economical.

igus® motion plastics® for battery manufacturing

Charging battery manufacturing by 100 % dry running systems



Production of batteries for electromobility **a challenge**

High volume production of batteries for electromobility (in cylindrical and prismatic form as well as pouch cells) has already become established in Asia, Europe and America, and the number of "gigafactories" is being further expanded.

The entire production process of an electric car battery system — from the raw materials to cell and module production and the ready-to-install battery pack — comprises more than one hundred processing and assembly steps. Some of them are very complex as dozens of parameters have to be precisely adhered to and harmonized.

This complexity increases the number of possible errors that can occur. Errors need to be kept to a minimum in order to achieve cost targets per cell or pack. This applies to today's most widely used cell chemistry (lithium-ion/LiIo) and to alternative battery technologies (lithium iron phosphate/LiFeP), as well as to future solid-state batteries.

Even in various individual processes, the requirements are high and varied:

Material quality

The purity and quality of the materials used directly influence the performance and service life of the battery.

Production environment

Clean production conditions are essential to avoid contamination. Dryness is also a key requirement in some important process steps.

Degree of automation

Highly efficient and scalable manufacturing processes with high throughput require a high degree of automation.

Special requirements cell production

With regard to the production environment, especially in the manufacture of lithium-ion batteries, there are strict requirements for certain production steps, which include, among other things, the ambient air.

Humidity, temperature, dew point

A low moisture content is crucial, as lithium reacts strongly with water and can release heat and hazardous gases in the process. Constant monitoring and regulation of humidity is therefore essential. The temperature must be kept stable in order to preserve material properties and ensure consistent production conditions. The dew point is an important parameter here, as it indicates the point at which water vapor condenses in the air.

Particle control and pressure regulation

Particles in the ambient air during battery production are regarded as contaminants that can cause short circuits or power losses in the battery cells and thus increase the failure rate. High-grade air filter systems are used to eliminate particles of all sizes. To prevent contaminated outside air from entering, the production environment is often slightly pressurized.

Safety measures

Due to the chemical reactivity of the materials, strict safety requirements apply, which include special protective clothing for personnel, and suitable fire protection measures.

The dry cleanroom a suitable production environment

Battery production requirements can be met in a dry cleanroom. It provides a special environment for the production and processing of products that are sensitive to moisture and foreign particles.

In a dry cleanroom, the humidity is often reduced to below 1% relative humidity, which corresponds to a dew point of -40°C. This ensures that no condensation takes place and no moisture gets into the materials. This is of great importance in some process steps of battery production because even small amounts of water can lead to battery fires.

Depending on the process and requirements, the dew points can range from -30°C to -70°C or even -80°C, such as in electrode production. In this white paper we refer to normal production conditions with a -40°C dew point.

In detail, battery production in a dry cleanroom offers the following advantages:

Higher product quality

Reduced contamination leads to higher quality and reliability of the battery cells.

Longer service life

Minimization of chemical reactions extends the service life of the batteries.

Safer working environment

Strict control of hazardous materials increases safety for staff.

Process steps
of battery production in dry cleanrooms

To summarize, it can be said that dry cleanrooms are indispensable for modern battery production. They offer a controlled environment in which the high quality requirements of this industry are met and the highest safety standards are guaranteed at the same time.

For these reasons, they are used in the following process:

1. Material preparation

Mixing and grinding: The active materials (cathode and anode materials) are mixed and ground into fine powders to ensure a homogeneous mixture.

Prepare solutions: Electrolytes are prepared by mixing solvents and lithium salts.

2. Electrode generation

Coating: The prepared powder is coated onto metal foils (copper for anodes, aluminium for cathodes).

Drying: The coated films are dried to remove solvent residues.

Calendering: The dried electrodes are rolled to control the thickness and increase the density.

3. Cell assembly

Stacking or winding: The electrodes and separators are either stacked or wound to form a cell arrangement.

Electrolyte filling: The liquid electrolyte is filled into the cell.

Sealing: The cells are sealed to prevent the ingress of moisture.

4. Forming and aging

Initial charge: The battery is charged for the first time, which is known as the forming process. This enables the formation of a strong solid electrolyte interface (SEI) at the anode.

Aging: After forming, the battery undergoes an aging process in which it is stored under certain conditions to test its stability and performance.

5. Final assembly & testing

Final assembly: The finished cells are assembled into modules or packs.

Quality check: Each battery undergoes a series of tests to check its capacity, performance and safety.

This overview shows that dry cleanrooms are — for good reason — widely used in battery production, from the initial process steps to final assembly and inspection.

ISO classes
for cleanrooms & dry cleanrooms

ISO 14644-1 defines cleanroom classes for “non-dry” cleanrooms. Manufacturers and users of cleanrooms worldwide are guided by them, as are the manufacturers of cleanroom equipment.

The standard defines nine classes (ISO 1 to ISO 9), which specify the maximum permissible quantities of particles in individual size classes per cubic meter of space. While one cubic meter of “normal” ambient air in a city contains between 15 and 100 million particles, in ISO Class 6 cleanrooms it may only be around 1.38 million (spread over six size classes from 0.1 to 5.0µm). A maximum of 134 particles in three size classes are permitted in ISO Class 2.

Cleanroom classes according to DIN EN ISO 14644-1

	Particles per m³					
Class	0.1 µm	0.2 µm	0.3 µm	0.5 µm	1.0 µm	5.0 µm
ISO 1	10					
ISO 2	100	24	10			
ISO 3	1,000	237	102	35		
ISO 4	10,000	2,370	1,020	352	83	
ISO 5	100,000	23,700	10,200	3,520	832	
ISO 6	1,000,000	237,000	102,000	35,200	8,320	293
ISO 7				352,000	83,200	2,930
ISO 8				3,520,000	832,000	29,300
ISO 9				35,200,000	8,320,000	293,000

Controlled environmental conditions preferably certified

Monitoring the central production parameters in dry cleanrooms is not usually one of the battery manufacturer's core competences. Fraunhofer IPA has been offering recognized testing and certification services for over 30 years and has customers and project partners in over 30 countries.

The institute offers certifications for dry cleanrooms, which ensure that the production environment fulfills the strict requirements of battery production. The certifications include regular checks of humidity, particle concentration and other important parameters.

The IPA also offers consulting services to help manufacturers optimize their production environment. The institute's research work also contributes to the further development of technologies for controlling humidity and particles.

IPA

© Fraunhofer IPA

CAPE® - The mobile & flexible cleanroom - developed by Fraunhofer IPA

Fraunhofer IPA offers the CAPE® system, a tent-like cleanroom system with which a cleanroom environment can be created quickly, flexibly and cost-effectively. The DryClean-CAPE also enables the provision of a dry cleanroom environment reliably and flexibly.

More information under:

▶ DryClean-CAPE®

Automation
for dry cleanrooms

Production of identical products in large numbers with the highest quality requirements: this profile fits perfectly with a high degree of automation. Consequently, many process steps in battery production are highly automated. Automation offers the additional and very significant advantage of minimizing contamination or moisture ingress from personnel entering the production environment, as there are little to no personnel present.

There are numerous critical process steps in the dry cleanrooms of battery production that can be optimized through automation:

1. Material handling

The automatic **feeding** of raw materials such as cathode and anode powder and electrolytes into the process reduces the risk of contamination.

Automatic conveyor systems **transport** materials and semi-finished products between the various production stations within the dry cleanroom.

2. Electrode generation

High-precision **coating systems** apply the active material to the metal foils under controlled conditions, which ensures consistent quality.

Automated **drying ovens and calendering systems** remove solvent residues and ensure a uniform thickness of the electrodes.

Electrode cutting machines cut the electrodes to the desired width.

3. Cell assembly

Robots take over the **stacking or winding** of electrodes and separators to ensure consistent cell structures.

Welding machines weld the current collectors to the tabs of the electrodes.

For pouch cells, the cell housings must be shaped accordingly.

The cells **are filled** with electrolytes using automated systems. The ingress of moisture must be prevented.

4. Sealing & further processing

Sealing machines seal the cells airtight (often in a protective atmosphere) to prevent the ingress of moisture.

The finished cells are automatically combined into modules and then into complete packs, taking safety-related aspects into account.

5. Control & inspection

Automated, camera- and sensor-based inspection systems are used to **test and inspect** the cells, modules and packs that have just been produced.

Certified energy chains for cleanrooms since 1997

Wherever there is automation, moving cables and with them energy chains are used. igus® developed energy chains for cleanroom applications (especially for semiconductor production) which are characterized, among other things, by minimized abrasion.

The E6 series of e-chain®, along with the specialized e-skin flat pod-style cable carriers, are the two most popular cleanroom cable carriers from igus®. In addition, the very large chainflex® line of cables for mobile applications also includes the cleanroom-compatible CFCLEAN product range.

The energy chains of the E6 series have been certified by the Fraunhofer IPA — a frequent and close collaborator of igus® — for use in cleanrooms up to ISO Class 1 in accordance with DIN ISO 14644-1

In addition to many other solutions, the following white paper describes the comprehensive expertise of igus® in the field of energy chains for cleanroom applications.

More information under:

- **White paper: Overcoming challenges in cleanroom equipment design**

IPA-certified
energy chains for cleanrooms

Due to the demand for energy chains for dry cleanrooms, igus® commissioned the Fraunhofer IPA to certify the E6 series for this area of application following extensive in-house testing. In order to fulfill this task, the institute first had to develop a new type of certificate for the combination of ISO cleanroom classification under dry room conditions before testing the energy chain under these special conditions.

The result: The e-chains® of the E6 series passed the tests and is the first cable guide to be certified by the IPA under dry room conditions. Installation size E6.29.060.100.0 achieved the best possible result at the time: ISO Class 4.

The e-chain was tested® in an ISO Class 3 dry cleanroom with a dew point of -40°C, which corresponds to a relative humidity of <1 % at 22°C room temperature.

Under these conditions, the three-dimensional triflex® energy chain TRC.40.058.0.ESD, in combination with the associated fiber-rod system, was also certified under these conditions. This system was developed specifically for use on industrial robots to ensure a production process that is literally frictionless, abrasion-free, and as contact-free as possible. The triflex version made of ESD-compliant material was certified here.

e-chain®	E6.29.060.100.0	TRC.40.ESD + fibre rod
Report number	2303 - 1408	IG 2309 -1461
Test parameter	Cleanroom class (according to ISO 14644-1)	Cleanroom class (according to ISO 14644-1)
v_1 = 0.5 m/s a_1 = 1 m/s²	4	4
v_1 = 1 m/s a_1 = 2 m/s²	4	4
v_1 = 2 m/s a_1 = 4 m/s²	4	5
Overall result	4	5

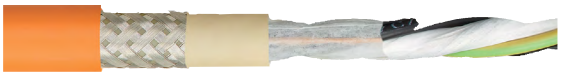
CF9
Control cable shielded

CF10 control cable

CF11 data cable

CF11.D measuring system cable

CF12 data cable



CF29.D servo cable

CF38 motor cable

CF98.PLUS control cable

CF99.PLUS control cable shielded

CF330.D motor cable

CF340 motor cable shielded

CFBUS.LB bus cable

CFLG.LB FOC

Other components
for the cleanrooms

Manufacturers of both batteries and battery production machinery will be interested to know that, in addition to the dry cleanroom-compatible energy chains described and certified here, igus® has also developed other heavy-duty materials and machine components for battery production.

Durable energy and signal cables

This applies, among other things, to the contents of the energy chains: cables for energy and signals that have been developed from the ground up for mobile applications and have achieved a service life in the high double-digit millions of strokes in tests under practical conditions (again in cooperation with the Fraunhofer IPA). The chainflex® product range is characterized by a long service life even with small bend radii. As the series suitable for battery production are manufactured from high-quality TPE, they are resistant to the cleaning agents and acids used in battery production. As the material absorbs little moisture, there is also very little outgassing, and because the plasticizers are firmly embedded in the TPE, there is no risk of the cable jacket breaking and causing contamination.

Grease-free drive components made from motion plastics®

The grease-free plain bearing technology also developed by igus® made from motion plastics® offers clear advantages for use in battery production and other sensitive areas of application. The plain bearings (iglide®), linear technology modules (drylin®), ball bearings and knife edge rollers (xiros®) and bar stock do not release any lubricants into the environment, which is ideal for dry rooms and cleanrooms. This is because lubricants are a real disruptive factor in dry rooms: they dry out very quickly, which leads to corrosion and material failure. Materials that do not require external lubricants are therefore a much better alternative.

In addition, the motion plastics® components from igus® are maintenance-free, abrasion-resistant and cost-effective, and they achieve a very long service life even under high loads.

With the exception of the linear technology, they are also completely metal-free, which is another major advantage in battery production. This means that magnetic or chemical reactions with the battery material can be ruled out. Another positive factor is the open design of the igus® drive elements. They can be cleaned easily and thoroughly.

IPA valid until: March 28, 2030
Fraunhofer TESTED® DEVICE
igus GmbH
chainflex CF9
Report No. IG 2405-1526

New!

dry cleanroom certification after long-term tests

In April 2025, Fraunhofer IPA issued two modified certificates confirming the dry cleanroom suitability of igus® e-chains® in long-term tests.

The certificates examine and take into account the aging behavior of energy chains under dry cleanroom conditions. This is of great importance as many plastic components only achieve a very short service life in dry cleanrooms because the materials become brittle at a relative humidity of less than one per cent. This not only reduces their service life, which in some cases is only two to three months, but also increases particle emission and thus impairs the cleanroom specifications. A long-term test investigation of the behavior of the e-chains® in motion in a dry environment therefore makes sense.

IPA Dry-Cleanroom valid until: February 3, 2030
Fraunhofer TESTED® DEVICE
igus GmbH
E14.4.100.0
Report No. IG 2411-1575

IPA Dry-Cleanroom valid until: March 28, 2030
Fraunhofer TESTED® DEVICE
igus GmbH
e-skin flat System
Report No. IG 2402-1498

IPA Dry-Cleanroom valid until: February 3, 2030
Fraunhofer TESTED® DEVICE
igus GmbH
SKS28.068.02.1
Report No. IG 2411-1575

IPA Dry-Cleanroom valid until: October 9, 2028
Fraunhofer TESTED® DEVICE
igus GmbH
TRC.40.ESD + fiber rod
Report No. IG 2309-1461

IPA Dry-Cleanroom valid until: March 28, 2030
Fraunhofer TESTED® DEVICE
igus GmbH
E6.29.060J.100.0
Report No. IG 2402-1498

IPA Dry-Cleanroom valid until: March 31, 2028
Fraunhofer TESTED® DEVICE
igus GmbH
E6.29.060.100.0
Report No. IG 2303-1408

Particle measurements

in the “pre-aging” & “aging behavior” states

The new Fraunhofer TESTED DEVICE® certifications record the behavior and particle emission of the tested energy supply systems in the “pre-aging” and “aging behavior” states, in which the aging behavior of components in an extremely dry environment is investigated.

Source: Roman Hickel, Fraunhofer IPA

The SKS28, e-skin flat and E6 cleanroom energy chains mentioned have ISO Class 1 cleanroom certification at normal room humidity levels

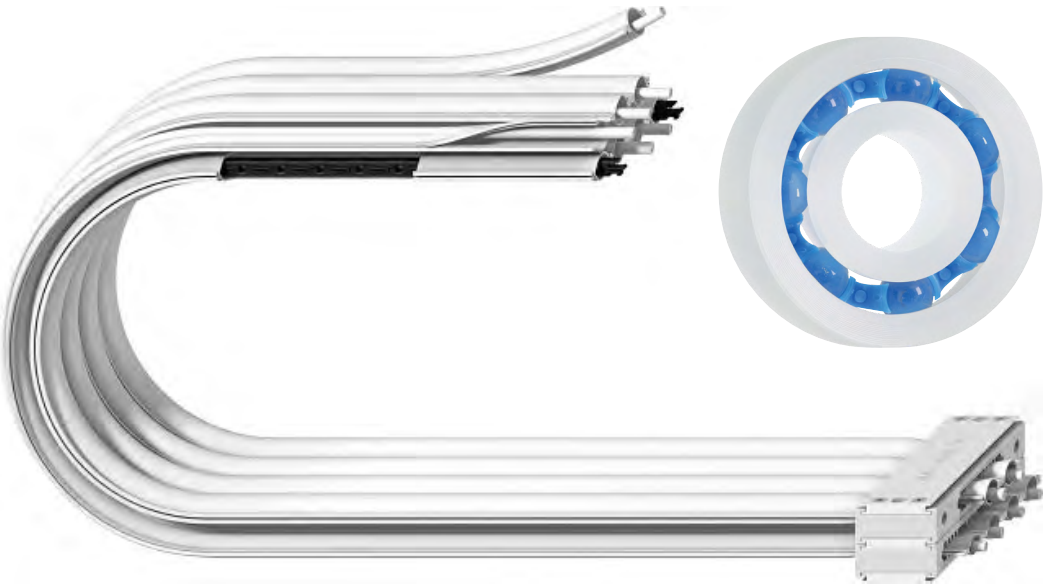
© Fraunhofer IPA

In pre-aging tests, the IPA operates the products under practical conditions for several months and then analyzes them. In the aging behavior tests, the test object is operated permanently and examined regularly. This provides insights into the aging behavior over a longer period of time.

In this case, two energy supply systems, E6.J and the e-skin® flat system, were tested in the aging behavior test over a period of ten months in the dry room. They completed over 15 million double strokes. The systems were tested and certified for their ISO class every two months.

The result: The e-skin® flat survived the double strokes without any problems and received the best possible certification of ISO Class 4. A higher certification is not possible as the test environment (ISO Class 3 dry cleanroom with a relative humidity of <1%, corresponding to a dew point of -40°C) does not allow this. The E6.J was also able to maintain this result for four months and ultimately achieved ISO Class 5, which is a very good result for battery production.

The pre-aging certificate, which is available for the energy supply systems e-skin® soft and easy chain® E14 energy supply systems, certifies the systems after 15 million double strokes and 10 months in the dry room. Here too, the igus® e-chains® received the best possible ISO Class 4 certification. Thanks to these long-term tests and certifications by the Fraunhofer IPA, igus® was able to confirm that the energy supply systems have very low particle emissions and are therefore very well suited for automation in dry cleanrooms — for example, in automated battery production.



GO ZERO Lubrication!

dry cleanroom tested

Conclusion

customized solution for energy supply on automated systems in dry cleanrooms

The tests conducted in accordance with the new certifications developed by the Fraunhofer IPA clearly show that igus® provides plant manufacturers and users of battery production systems with customized and certified solutions for energy supply on automated systems in dry cleanrooms.

The appropriate energy chains were developed and certified on the basis of extensive expertise in related areas of application, in particular semiconductor production. The igus® industry management for this area application is based in Korea in order to be able to provide intensive support to the main battery and semiconductor manufacturing markets in China, Japan, Korea and the USA with short response times. The proximity of igus® is close to both plant engineering and production facilities in the microchip and electronics industry.

This proximity also results in a wide variety of applications of the currently certified energy chain series E6 and triflex® in battery production facilities. A few examples:

- A German premium car manufacturer uses the triflex® ESD in battery cell assembly
- A battery manufacturer in Ohio/USA uses not only the e-skin® flat, but also uses CFCLEAN cables suitable for dry cleanrooms.
- In a battery plant in Wuxi/China, complete production lines are equipped with the E6 and e-skin® series as well as with CF9 TPE cables.

Other applications, including cell handling, battery assembly, cathode production and electrode processing, involve not only energy chains, but also xiros® ball bearings and knife edge rollers as well as drylin® R linear drives.

igus® and Fraunhofer IPA: a decades-long co-operation

The Fraunhofer Institute for Manufacturing Engineering and Automation IPA is - among other things - a globally recognized research and development partner for issues relating to production in cleanrooms and dry cleanrooms. For 15 years, igus® and the IPA have been working together. The Fraunhofer IPA has developed a cleanroom test laboratory for igus®.

The topic of “production in dry cleanrooms” is even more difficult. Dr Frank Bürger, Business Unit Manager of Testing & Certifications at the Fraunhofer IPA (Institute for Manufacturing Engineering and Automation):

“The behavior of components, especially those made of plastic, in dry cleanrooms has not yet been researched very much. Dryness significantly changes the material properties, which can result in embrittlement and shrinkage. Tribological systems are also subjected to high stresses. We are investigating this and supporting companies like igus® in developing customized materials and components that achieve a long service life in the automated systems in the dry cleanroom.” This also includes the development of standard-compliance certifications and participation in standardization committees: “This is where we contribute our decades of experience.”