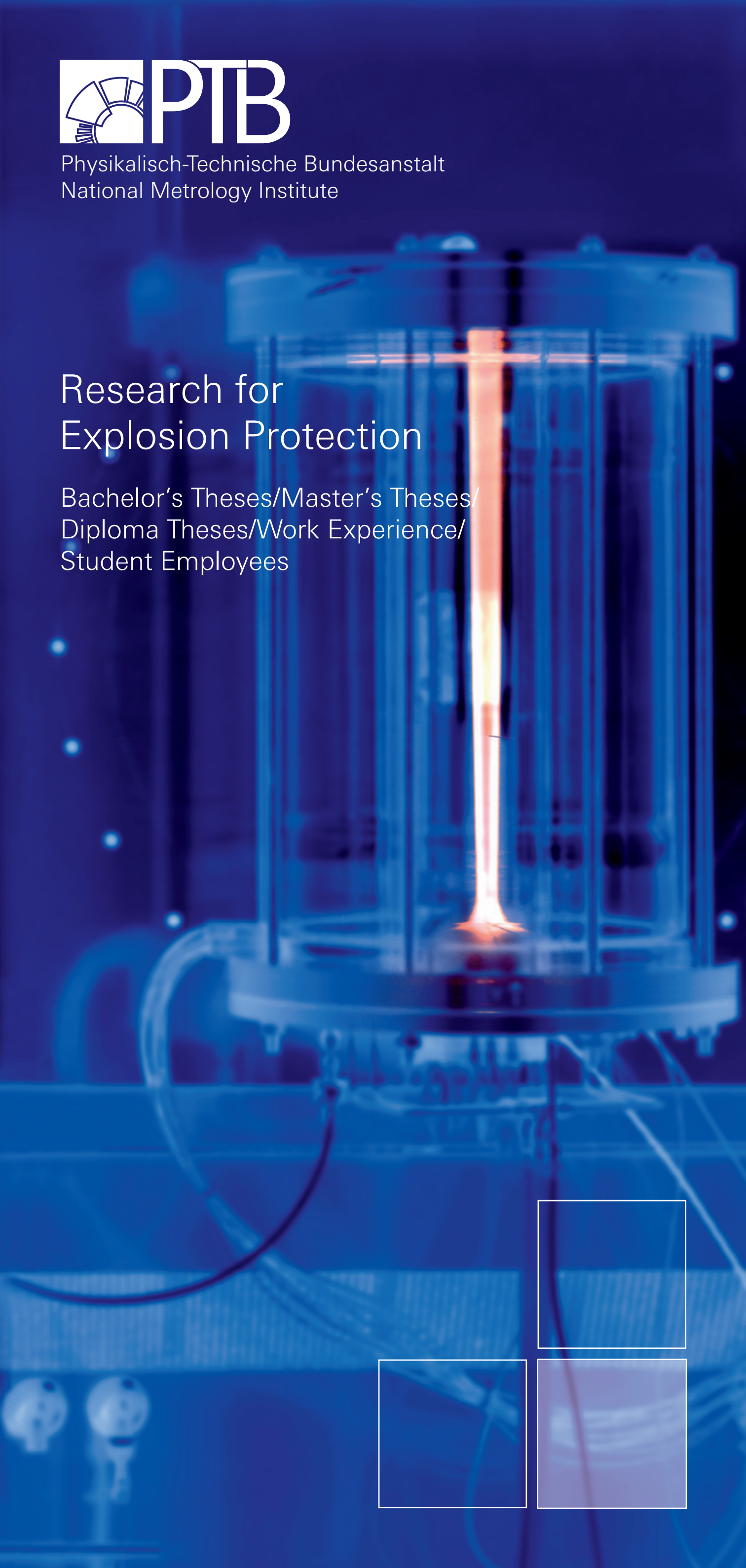


PTB
Physikalisch-Technische Bundesanstalt
National Metrology Institute

Research for Explosion Protection

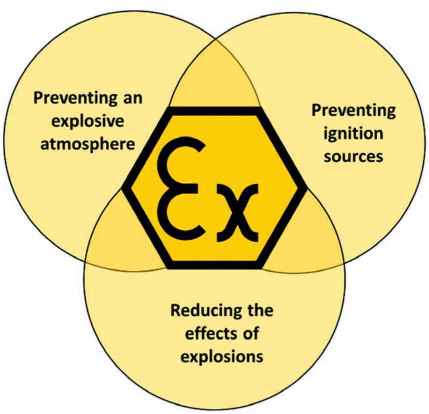
Bachelor's Theses/Master's Theses/
Diploma Theses/Work Experience/
Student Employees

Explosion Protection at PTB

In many branches of industry, there is a risk of explosion when processing or producing combustible substances. This traditionally applies to the chemical and petrochemical industry, the paint and coatings industry, and mining. New fields such as hydrogen technology as well as regenerative energy carriers and storage pose new challenges for explosion protection.

With the oxygen in air, combustible substances may form an explosive mixture which, if ignited, is a hazard for people and the environment. Apart from characterizing explosive gas mixtures, explosion protection deals with understanding the diverse effects which arise after ignition has occurred and with preventing explosions.

One way of avoiding explosions is to prevent the formation of explosive gas mixtures. If this cannot be assured, technical measures are used to prevent potential ignition sources (e.g. sparks, hot surfaces) in that environment. If it is not possible to reduce the risk of an explosion to an acceptable level with these particular measures, the effects of incipient explosions have to be minimized by constructive means. This makes the work in the field of explosion protection interdisciplinary and provides a broad range of activities for physicists, chemists, and engineers.



Basic principles of explosion protection

As Germany's National Metrology Institute, the Physikalisch-Technische Bundesanstalt (PTB) is Germany's highest authority when it comes to correct and reliable measurements. PTB is among the top names in metrology and safety technology worldwide. It contributes significantly to the development of internationally valid regulations. Research and development work amounts to about two thirds of all of PTB's activities. The spectrum of tasks in the field of explosion protection stretches from investigating ignition sources via characterizing explosive gas mixtures to modelling combustion processes. Explosion protection concepts that are application-oriented are developed closely with industry. Our partners often use these concepts immediately.

Students can participate in ongoing research at PTB. This might be as part of a bachelor's or master's thesis, during an internship, or as a student employee. PTB's current research in the field of explosion protection is presented below. It encompasses the fundamentals, applied research, and the technical realization of novel explosion protection concepts.

Are you interested in working on one of our research projects?

The contact details for the scientists responsible for the various fields can be found at the end of the individual sections.

Hydrogen Technology

Description

Hydrogen is a versatile energy carrier and it is indispensable for achieving global climate goals. Germany's national hydrogen strategy demands and promotes a rapid expansion of the hydrogen economy. One of the main tasks of PTB is to guarantee the measurement and safety requirements for hydrogen technologies. PTB supports diverse technological innovations and contributes to the safety of the use of hydrogen as well as to a reliable quality infrastructure. Many new types of large-scale energy systems are emerging. This implies new safety-related issues that cannot be comprehensively solved with the available resources and experience. The special characteristics of hydrogen cause special challenges:

- Leak tightness – hydrogen diffuses through materials very easily.
- Joule-Thomson coefficient – hydrogen heats up as it expands.
- Explosion limits – hydrogen can explode when mixed with air (between 4 % and 77 %).
- Ignition sources – hydrogen can be ignited by extremely low ignition energies.
- Reaction rate – hydrogen explosions are very fast and difficult to stop.

Research and development projects in cooperation with industry address these and other challenges and develop safety-related solutions for equipment and protective systems. An important point is the transfer of knowledge gained into standards and the legal framework.

Prerequisites

The various projects require you to be particularly interested in interdisciplinary issues and experimental work. Knowledge from your science or engineering degree course forms the foundation for developing the necessary basic understanding of other subjects.

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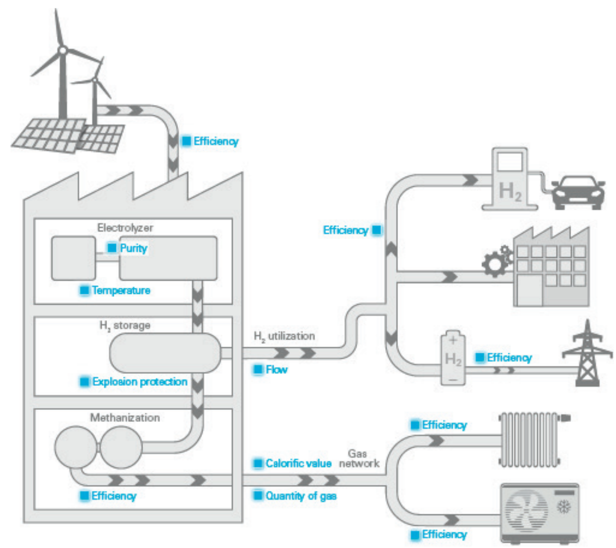


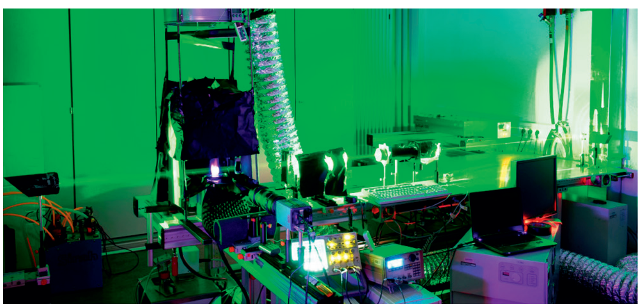
Power-to-gas system

Laser-based Temperature and Concentration Measurements of Gases

Description

When investigating explosions and combustion, knowledge of the spatial and time-dependent distribution of the concentration and temperature of the gases involved is crucial. Concentration can be measured using laser-induced fluorescence (LIF). This is done by exciting a suitable gas (e.g. NO, acetone, 3-pentanone) with a short UV laser pulse and making the gas glow. With appropriate filters, objectives, and cameras, the fluorescent light is then depicted and evaluated.

Temperature measurements in gases can be performed by using Rayleigh light scattering. In accordance with the ideal gas law, the number of molecules per unit volume is inversely proportional to the temperature of the gas. Analogously, the laser light scattered off the molecules decreases with temperature.



Experimental setup to measure flame temperatures two-dimensionally with high resolution using 532 nm Rayleigh scattering

Prerequisites

This field is particularly suited to students of physics, chemistry, or engineering sciences with a focus on the natural sciences. Doing practical work on improving measurement technology and electronics is also possible. What is important here is having an interest in independent lab work, being curious about science, enjoying experiments, and being reliable. We work with laser radiation of the highest danger classification.

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Safety of Lithium-ion Batteries

Description

Lithium-ion batteries are being used more and more widely for a variety of applications such as e-mobility. The design of such batteries means that they harbor a potential risk if there should be any mechanical damage, an electrical overload, or if the thermal limit load is reached. Our research team in WG 3.55 focuses on strategies to avoid accidents as well as characterizing the effect of such incidents.

- Characterizing Li-ion battery modules for second-life applications: evaluating the condition of battery modules, integrating metrology into battery management systems
- Studying the influence of temperature distribution on the life span of the batteries in electric cars: aging tests, evaluating thermal management, developing mathematical models to predict temperature distribution
- Conducting experimental investigations into the safety of cells and modules: characterization by means of electrochemical impedance spectroscopy, cyclization, destructive tests

Cell that has caught fire while being overloaded (Source: BaSS Project, elenia Institute for High Voltage Technology and Power Systems, Technische Universität Braunschweig)

Prerequisites

Students of electrical engineering, physics, or engineering sciences are especially suited to this field. A basic knowledge of electrical engineering, fluid flow mechanics and thermodynamics is therefore desirable but not mandatory. What is more important is your interest in working in a scientific lab and being committed to your work. Prior knowledge of LabView, Python, or Diadem as well as of PXI systems would be an advantage for working on battery management systems.

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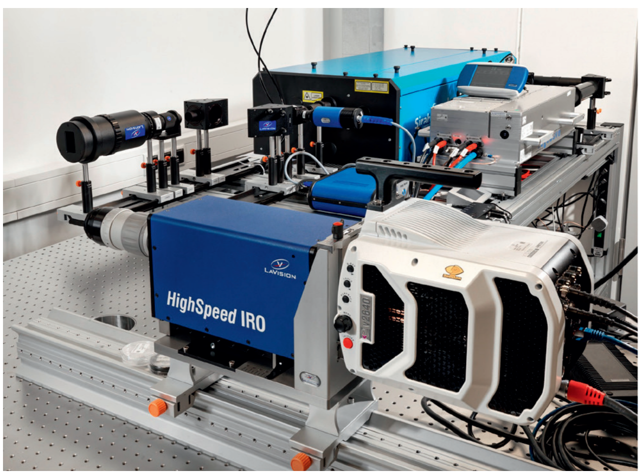
Ignition by Electrical Discharges

Description

Electrical discharges are among the most frequently occurring ignition sources in both explosion-protected equipment and industrial plants. Our current project is concerned with short duration high voltage discharges (50 ns, >1 kV). Ignition by electrical discharges is determined by various physical and chemical processes. These take place on different time scales stretching from the nanosecond to the millisecond range and include: the production of electrical discharges, energy transfer in the gas, flow dynamics, heat transfer, and chemical reactions. These processes are investigated at PTB by using time-resolved optical diagnostics.

- Background-oriented schlieren method (BOS method): measuring the temperature distribution in gas following an electrical discharge
- Laser-induced fluorescence of OH (OH-LIF): measuring the reaction zone
- Schlieren method: flame propagation, influence of the composition of the mixture on ignition behavior



High-speed LIF system to determine the reaction zone of a flame's inner kernel with a time resolution of 50 kHz

Prerequisites

Students of physics, chemistry, or engineering sciences are especially suited to this field. A basic knowledge of electrical engineering, fluid flow mechanics, and thermodynamics is also desirable but not mandatory. What is more important is your interest in working in a scientific lab and being committed to your work. Experience with optical, spectroscopic, or laser-based measurement methods is of advantage.

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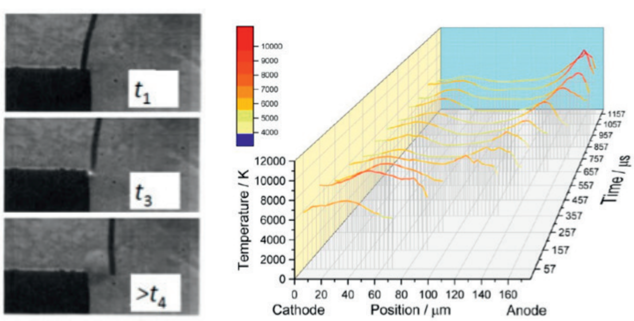
Ignition by Electrical Contact Discharges

Description

Electrical contact discharges may occur when a plug is disconnected or at the contacts inside relays. These discharges occur at low voltage ranges (typically 30 V) and last up to 1 ms. Such discharges are growing more important as components become progressively miniature in size. One of our research projects focuses on determining the multi-physical fundamentals of electrical discharges in electrical contacts and their safety implications in mixtures of gases that are explosive. The goal is to establish the safety critical limits which are used in international standardization. The results are additionally used for modelling.

The project will investigate the various processes from electrical discharges to the thermo-chemical ignition of gas mixtures by a hot inner gas core. High-speed cameras, schlieren optics, spectroscopy, etc. will be used for this.

Our investigations will comprise experimental work such as the preparation (calibration etc.) and performance of measurements, along with modelling, as well as the simulation of these processes and scientific methods for the analysis of the results.



Schlieren photographs of contact discharge (left) and the evolution of the temperature field of such a contact discharge (right)

Prerequisites

Constructive cooperation within our research team is of primary importance in this project focusing on very different fields such as electrical engineering, physics, metrology, and comparable areas ...

... and what is more, enjoying scientific lab work and being committed to your own work are just as important!

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Characterization of Magnetic Materials for Use in Synchronous Machines

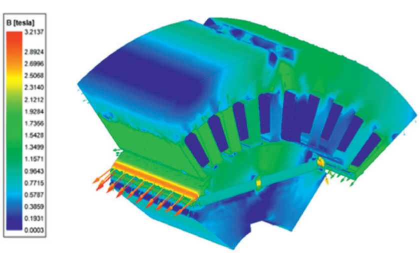
Description

Knowledge of the distribution of losses occurring in permanent magnet synchronous machines (PMSMs) is of decisive interest for evaluating whether they are suitable for use in hazardous locations. This also applies to the assessment of the total power losses in the machines and evaluating their efficiency. In particular, the metrological determination of eddy current losses occurring in the permanent magnets (PMs) poses a special challenge when determining the total losses in PMSMs during normal rotational operation.

In addition, the eddy current losses of the PMs that are used in PMSMs can be determined in a separate measuring device (a closed magnetic circuit) for a higher B-field and frequency. The external alternating (AC) field for the energization of the PM sample to be investigated is supplied by separate excitation coils. These coils can be fed via a power amplifier system or a frequency converter (inverter).

However, it is essential to apply the same boundary conditions as in the machine for the metrological verification of the results. These results have been derived from calculations of the harmonic power losses occurring in the rotor magnets using the finite element method.

Therefore, a test bench measuring eddy current losses is currently being set up and optimized as part of a research project. This test bench will later measure the harmonic power loss converted in the rotor magnets during the operation of the machine. The results are then to be used to optimize the model for the FEM calculation of the rotor losses.



Magnetic field distribution in a motor as the basis for calculating the eddy current losses in rotor magnets, FEM simulation

Prerequisites

This topic is especially suitable for students of electrical engineering. Experience in the field of electrical drives, as well as basic knowledge in programming with LabVIEW and MATLAB are advantageous.

Basic knowledge in the field of frequency converters/power electronics and FEM simulation software is desirable but not a mandatory requirement. Being interested in scientific issues along with having initiative and being committed to your work are more important.

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Motor Protection for Converter-fed Drives

Description

Today, frequency-converter-fed drives are used to an ever increasing extent in the industrial environment. Through this, the energy efficiency of the processes is clearly increased and both the installation and the product are protected through the prevention of torque surges. It is, therefore, also of interest to refit already existing facilities with frequency converters. If these drives are used in hazardous locations, one requirement for instrument category 2 is that the motor will not reach inadmissibly high temperatures even in the event of a fault and that it will not become an ignition source for the surrounding explosive atmosphere.

One fault to be considered here is an overload of the motor. Such an occurrence must be recognized via a function-tested protection device before the motor becomes an effective ignition source or before the winding, for example, reaches inadmissible temperatures, which considerably shorten a motor's service life. At present, the temperature of converter-fed drives is monitored by temperature sensors in the winding, together with a separate and certified tripping device. All of these devices comply in addition with the required aspects of functional safety. A disadvantage – in particular when existing drives are refitted – is the cable required between the motor and the tripping device in the switch cabinet outside the potentially explosive atmosphere. It is, therefore, the objective of a planned research project, which will be performed in cooperation with industrial partners, to develop a novel motor protection device for frequency-converter-fed drives. This will allow direct temperature monitoring (which has been required so far) to be dispensed with in future.

Research projects studying the safe operation of explosion-protected electrical drive systems are ongoing at PTB. In addition to explosion protection, our work focuses on determining the efficiency of electrical drives as well as analyzing and optimizing measurement methods with regard to measurement uncertainty.

Prerequisites

This subject is particularly suited to students specializing in electrical engineering. Experience in the field of electrical drive technology is of an advantage. Basic knowledge in the field of frequency inverters/power electronics is desirable but is not an absolute prerequisite. What is more important is an interest in scientific questions, as well as your personal initiative and commitment.

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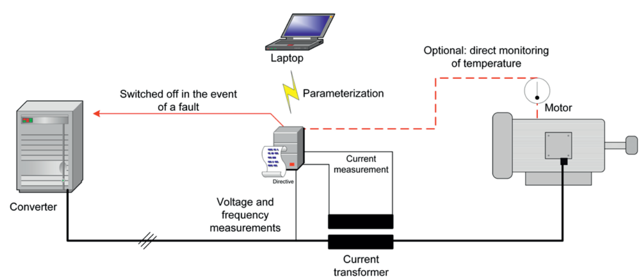

Block diagram of the protection concept for converter-fed drives

Safety Characteristics in Explosion Protection

Description

Ignition experiments are used to test flammable substances regarding the parameters that quantify their explosion behavior. The measured quantities are the basis of all explosion protection measures.

The conditions under which explosive mixtures are formed are characterized by the flash point, the lower and upper explosion limits, and the corresponding explosion points. Ignition temperature, minimum ignition energy, minimum ignition current, and voltage, on the other hand, describe the conditions under which explosive mixtures can be ignited. The maximum experimental safe gap, the maximum explosion pressure rise rate, and the maximum explosion pressure ultimately permit statements on the effects of an explosion. The characteristics of explosion protection depend to varying degrees on the determination procedure. For this reason, determination procedures are generally laid down in national or international standards, which are, however, continuously adapted to scientific and technical advances. In addition, there are dependencies on pressure, temperature, and the oxidizing agent. The determination methods used to date cover an upstream pressure range from 30 mbar to 30 bar and a temperature range from -20 °C to 200 °C. Current research is mainly concerned with conditions outside these intervals. Research projects are continuously carried out at PTB on these issues, which are also worked on in the form of student theses.

Prerequisites

This field is suitable for students of natural sciences or engineering. A basic knowledge of chemistry or safety engineering is an advantage but is not an absolute requirement.

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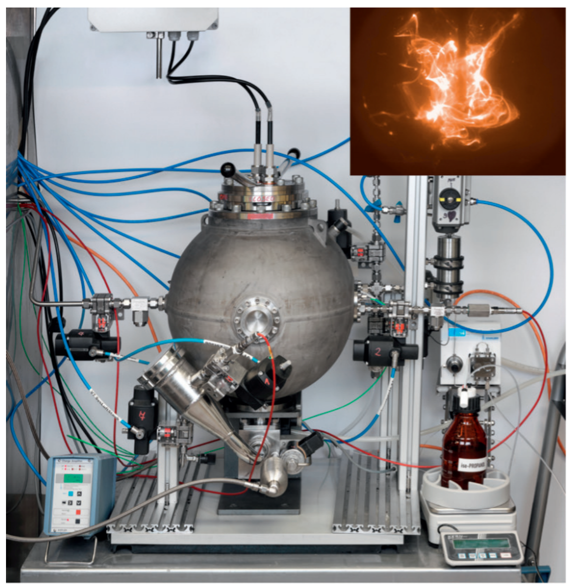

Apparatus for determining safety characteristics and photo of an explosion within the sphere

Flame Arresters and Explosion Processes

Description

The blast wave generated by an explosion (and thus the impact of an explosion) considerably depends on how fast the flame propagates. Explosions whose propagation speed is below the local speed of sound are called deflagrations. Under certain conditions, due to the positive superposition of acoustic oscillations and due to turbulence generation in front of the flame front, the flame may be accelerated to such an extent that this leads to a detonation. In the event of a detonation, the flame front, together with the shock wave resulting from the process, propagates at supersonic speed (approx. 2000 m/s). During the further propagation of the detonation, the preceding shock wave acts as an ignition source (ignition by adiabatic compression). Contrary to a simple blast wave, this shock wave is a directed variable. Extremely strong mechanical impulse stress occurs in the direction of propagation of the detonation

Designing safe facilities and protecting facilities by means of flame arresters (as in the chemical industry or at gas stations) presupposes knowledge and a basic understanding of the explosion processes mentioned above.

This is why various influencing parameters are studied:

- The energy input through an ignition source
- The material the pipe is made of and the piping geometries
- The gas mixture and the fuel structure
- Non-atmospheric conditions: pressure, temperature, oxidant

While doing this, various diagnostic procedures such as schlieren measurements and molecular beam mass spectrometry are applied and continually adapted for their use in these extreme processes.

At PTB, research projects on this subject area are continuously being carried out. Certain aspects of these investigations can be dealt with within the scope of student work.

Prerequisites

This field of work is suitable for students specializing in natural or engineering sciences, who enjoy experimental work. Having a good command of German is important so that all the members of the team can work safely together.

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Experimental testing of a flame arrester

Electrostatics as an Ignition Source

Description

An important ignition source which is often not taken into account in everyday explosion protection is electrostatics. Static electricity occurs, for example, in situations where bulk goods are poured or mixed or where liquids flow or discharge. This causes charge carriers to be divided; these charge carriers gather on insulating surfaces – sometimes over a longer period of time – and remain there. Only in the event of earth contact can these charge carriers discharge. Several discharge types are distinguished (e.g. brush discharge, sparks, propagating brush discharge); they depend on the type of material concerned (whether conductive, dissipative, or insulating) and on the manner in which the charge carriers were gained (e.g. friction, division, induction).

Even a discharge such as one we can feel in our fingertips when getting out of a car and then touching it can cause an explosive mixture consisting of a flammable substance and air to ignite. Electrostatics is used in processes such as painting to obtain an equal distribution of the paint particles over the object being painted. When using solvent-based paints, we have not only the ignition source (in the form of the spraying equipment), but we are also supplied with the explosive mixture!

The materials used are characterized based on their size, the surface resistivity, and the transmitted charge. There are some parameters which have an influence on the electrostatic properties and have to be investigated. Apart from the ambient conditions (such as temperature and humidity), these parameters include the surface texture, the aging of the material, chemical or other types of external influence (such as UV light), and the materials used themselves. At PTB, research projects on this subject area are continuously being carried out and are also dealt with within the scope of student work.

Prerequisites

University-level skills in physics, electrical engineering or mechanical engineering.

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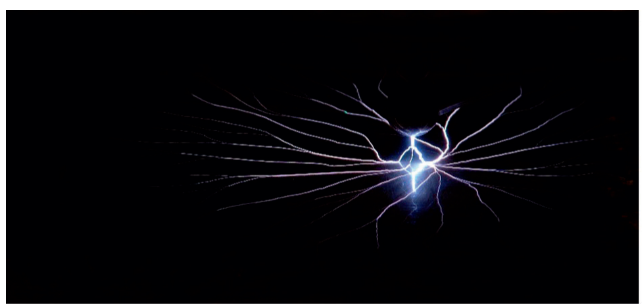

Propagating brush discharge

Physical Ignition Sources

Description

In addition to electrical and electrostatic ignition sources, there are several other types of ignition sources that must be avoided in potentially explosive atmospheres. These include hot surfaces, mechanical sparks, optical radiation, high-frequency radiation, and ultrasound. Our research projects on these topics clarify fundamental questions about the transfer of energy into the explosive gas mixture, the ignition mechanisms, and the influencing factors. This is used to better understand how all this works. The results are implemented in standards and test requirements for explosion-proof equipment.

Ignition by high frequency radiation is an important field that is currently being investigated. To be able to use radiation sources in the GHz range in potentially explosive atmospheres (e.g. WLAN, 5G, microwaves), basic principles must be established that enable an adequate safety assessment of electromagnetic fields. For this purpose, the relevant ignition mechanisms are examined, corresponding limit values are determined, and requirements for equipment are developed. Fault conditions have to be considered, as well as sources that are operated outside but radiate into the hazardous area.

Very small hot surfaces require much higher temperatures for ignition than the auto ignition temperature of the gas mixture. Real ignition temperatures are determined in ignition tests. Another focal point is the investigation into the dependency on the position and shape of the hot surface. In the PTB's friction apparatus, the ignition properties of mechanically generated sparks and the simultaneously occurring transient hot surfaces at the friction point are investigated. These processes are closely related to the dry friction in rotating machinery after the loss of lubricant as well as to the material properties.

Prerequisites

The various projects require you to have an interest in interdisciplinary issues and experimental work. Knowledge from your science or engineering degree course forms the foundation for developing the necessary basic understanding of other subjects.

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The formation of sparks in PTB's apparatus

Interlaboratory Comparisons in the Field of Explosion Protection

Description

For testing laboratories in the field of explosion protection (Ex laboratories), there is a need to perform interlaboratory comparisons to demonstrate competence. The implementation of such interlaboratory comparison programs provides an objective performance evaluation with regard to specific tests or measurements and helps to identify differences between Ex laboratories. Furthermore, it is an effective tool to investigate the comparability of test and measurement procedures.

The main task of Working Group 3.54 is the development, performance, and evaluation of interlaboratory comparisons for the safety-related testing of explosion-protected equipment. If the outcomes reveal weaknesses in the measurement and test methods used, these are further developed with a focus on achieving greater accuracy and simplifying the knowledge transfer to other laboratories.

More detailed questions such as the fundamental applicability of certain measurement and test methods (e.g. explosion pressure measurement as a basis for the safety-related evaluation of flameproof enclosures) are scientifically investigated in research work.

Depending on the program, investigations of the respective test methods are to be performed with regard to factors influencing the test result. The topics cover all the main areas in the field of explosion protection, from electrostatics and temperature measurement to the determination of explosion pressures. The investigations include experimental work as well as theoretical analyses of the measurement uncertainty.

Prerequisites

This field of work is suitable for students with a natural science or engineering background (electrical engineering, mechanical engineering, or similar). Having an interest in experimental work as well as being able to work independently and responsibly would be an advantage.

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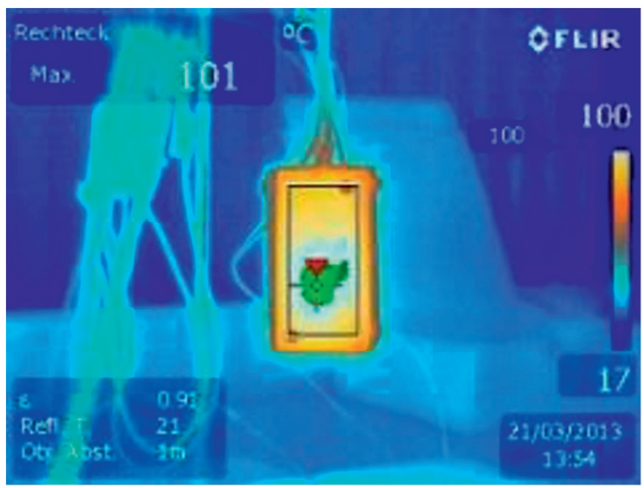

Determination of the thermal hotspot for the proficiency testing program entitled "Temperature Classification"

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