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Air-Crew Radiation Exposure

Measurements of the dose rates in civil aircraft at aviation altitudes allow to estimate and to minimise the air-crew exposure to ionising radiation.

At flight altitudes air crews are occupationally exposed for about 800 hours per year to cosmic radiation with an intensity which is up to two orders of magnitude greater than the intensity of natural ionising radiation at ground level. A European directive commits airlines to treat air-crew exposure as an occupational risk from the year 2000 on and to monitor and minimize the exposure.

The radiation field at aviation altitudes is produced by reactions of extraterrestrial charged particles with the atmosphere and is strongly influenced by the magnetic field of the earth. The main radiation component (more than 80 %) consists of secondary high-energy neutrons and electrons. The composition of the radiation field differs significantly from that in conventional radiation-protection dosimetry. In order to obtain reliable data and to test new experimental methods for the dose assessment, PTB took part in the ACREM (Air Crew Radiation Exposure Monitoring) EU project together with the Deutsche Lufthansa and the Austrian Research Centre Seibersdorf. Measurements were performed during 195 hours at cruising altitudes ranging from 7,9 km to 11,9 km.

Special investigations were devoted to neutron dosimetry. A modified neutron detector was tested which also takes properly into account the high-energy neutron dose fractions. The measurements confirmed the expected increase of the dose rate moving from the equator to the poles as well as to increasing altitudes. The measured data for the neutron spectrum can be approximated by a shape which is independent of position and altitude and an intensity which scales with the magnetic latitude and the altitude. On the basis of the measured

Air-crew members are exposed to enhanced cosmic radiation at aviation altitudes. It is possible, though, to keep the exposure low with an optimised roster.
Photo: Ingrid Friedl/Lufthansa

global dose rate distributions, the annual air-crew exposure can be estimated. By optimisation of the route roster it is possible to keep the annual dose equivalent below 6 mSv for all air-crew members. For comparison, the natural exposure on ground varies between 1 mSv and 4 mSv per year.

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NMR Magnetometer for Magnetic Fields Down to 2 mT

Nuclear magnetic resonance (NMR) magnetometers are the most accurate instruments for measuring medium-strength magnetic fields. So far, the lower limit of the measuring range was about 100 mT. With a newly developed «marginal» oscillator, this limit has now been reduced to 2 mT.

NMR magnetometers take advantage of the precisely known gyromagnetic coefficients of atomic nuclei, the quotients of magnetic moment and angular momentum. The gyromagnetic coefficient of protons in water molecules, for example, is known as a fundamental constant with a very small relative uncertainty of $3 \cdot 10^{-7}$. Presently, the most accurate values for magnetic field strengths are obtained by measuring the precession frequency of nuclei in dc magnetic fields. However, the magnitude of nuclear resonance signals is roughly proportional to the square of the magnetic field strength. This set a lower limit of about 100mT for precise measurements with the NMR method so far. Using a newly developed highly sensitive oscillator, PTB has now succeeded to extend the measurement range down to 2mT.

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Traceable Standards for Coating Thickness

The economic importance of surface and coating technologies has been steadily increasing for years. As a new service of PTB, coated substrates and foils of widely used material combinations can now be calibrated in a traceable way as standards in the thickness range from about 10 nm to 50 µm.

Coatings determine the properties of products (e. g., the durability of tools) or enable their functions (microelectronic devices being a well-known example). In general, the function to be tailored by the coating and the coating thickness *h* are directly correlated. Hence, the establishment of reference standards and of appropriate calibration procedures is a major topic in the field.

This coating thickness standard (40 mm × 24 mm × 10 mm) for X-ray measuring devices is made of a 4,93 µm ± 0,1 µm thick nickel coating on a diamond-turned copper substrate. The surface of the coating is exposed and accessible for measurement inside a circle with a diameter of 8 mm.

The following equipment for calibration of coating thickness is presently available at PTB:

- a scanning electron microscope for measuring cross sections prepared with the ion-beam technique (measuring range 200 nm to 50 µm, measuring uncertainty $25\text{ nm} + 5 \cdot 10^{-3} h$)
- a scanning force microscope for standards where the coating thickness is accessible as step height (measuring range 5 nm to 10 µm, measuring uncertainty $1{,}1\text{ nm} + 2 \cdot 10^{-4} h$).

Both measuring devices were modified for metrological use and equipped with laser interferometers for traceable measurements.

In addition to this equipment, coating thickness transfer standards are now available. The standards were developed in cooperation with small and medium-sized enterprises. They differ from commercial standards by their traceability and a distinctly lower uncertainty. These advantages result from a combination of relative measurements and a direct length measuring procedure in conjunction with the highly accurate manufacturing method of the substrate surface (roughness less than 20 nm).

With the measuring facilities and transfer standards, PTB is in the position of offering calibration services and coating thickness standards for industrial quality assurance according to DIN ISO 9000 and DIN EN 45000.

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Unified Quality Characterisation of Electrical Sheet Steel

Measurements of the quality characteristics of electrical sheet steel according to two different IEC standards yield significantly deviating results. Recent investigations by PTB demonstrate how to transform the results into each other.

Electrical sheet steel is the material for the magnetic cores of almost all electrical and electromechanical devices. Electrical energy is transformed at least five times on its way from the power plant to the customer. The efficiency of transformation depends crucially on the quality of sheet steel materials and is therefore of high economic significance. For the measurement of the quality parameters, the most important of which is the magnetic power loss, one of the two relevant IEC standards requires the use of so-called Epstein strip samples whereas the other standard is based on single sheet samples. Electrical steel producers prefer the single sheet tester (SST) method because it is less expensive and more generally applicable. In opposition to this, users of electrical steel, in particular transformer designers, insist on adhering to the traditional Epstein method because their calculation procedures are based on Epstein values. The two methods lead to results showing considerable systematic differences.

In order to overcome this dilemma and to support the acceptance of the more economical SST method, PTB has carried out a thorough investigation of the relationship between the Epstein and the SST results. For this purpose, comprehensive experimental studies were performed on 760 samples of the most significant material grades produced by nine of the largest manufacturers world-wide.

The measurements revealed that the magnetic power loss values determined by the two methods can differ by as much as 10 %. On the basis of the

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Optical Measurement of Partial Pressure

Absorption spectroscopy with tuneable diode lasers allows the measurement of partial pressures with a relative uncertainty of 3 % and the detection of one absorbing molecule among 10^8 other particles.

A variety of industrial processes, for example in semiconductor fabrication, are performed in low pressure environments and require the control and monitoring of low partial pressures in order to maintain a high production yield and a low defect rate. Currently used residual gas analysers based on quadrupole mass spectrometers in general give readings which depend on the total pressure and the composition of the process gas. Furthermore, their hot cathodes may influence the composition of the gas to be measured.

Multiple path absorption cell for optical partial pressure measurement in the vacuum region, operated in air with a He-Ne laser here

In order to explore other methods of vacuum pressure measurement and residual gas analysis free of these limitations, PTB has investigated the possibility of exploiting the molecular absorption of infrared radiation from a tuneable diode laser for this purpose. A multiple-reflection absorption cell (Herriott cell) in an ultra-high vacuum chamber was used to vary the absorption path length between 6 m and 100 m. Experiments were performed to measure absolute partial pressures of the technically relevant carbon monoxide gas in the range from 10^{-5} Pa to 1 kPa. At first, the line strengths of several IR transitions of CO, which were not available with sufficient accuracy, were measured with a relative uncertainty of 2 % at wavelengths between 4,4 µm and 5 µm. Then, these data were used to determine partial pressures of CO with a total relative uncertainty of 3 %. The minimum resolvable partial pressure of 10^{-5} Pa allows the detection of impurity gases at the 10^{-8} level for a total pressure of 1 kPa.

The novel method of partial pressure measurement is not limited to CO, but can be extended to other applications in analytical metrology if required.

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Unified Quality Characterisation of Electrical Sheet Steel *(continued)*

extensive set of measured data it was also possible to show, however, that the SST method can be modified such as to agree with the Epstein method: If one parameter of the SST evaluation, namely the effective magnetic path length, is properly adapted, the results of the SST method coincide with the Epstein results. This modification of the SST method will be proposed to the IEC in order to amend the existing standard.

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PTB single sheet tester for the determination of the magnetic properties of electrical sheet steel

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Helmholtz Prizes Awarded

The 1999 Helmholtz research prizes have been awarded to two research groups of PTB for precision measurements with atom interferometers and for a novel technique to unveil the effects of ionising particles in matter.

The prize for «Precision Measurement of Physical Quantities» has been awarded to Fritz Riehle, Tilmann Trebst, Harald Schnatz and Jürgen Helmcke of PTB's length and time department for their work on time-domain atom interferometry for precision measurements. Microscopically, atoms have to be described as wave packets which can be split, deflected and recombined by pulses of laser light with high frequency stability. The number of recombined particles, which can be measured with a detector, oscillates depending on the phase difference between the partial waves, which itself depends on the laser frequency. As a result of experiments with calcium atomic waves at PTB, the frequency of a laser stabilised by means of these interference oscillations has been determined with a relative uncertainty of $2{,}5 \cdot 10^{-13}$. This has led to the most accurate realisation of the length unit to date. The novel atom-interferometric techniques allow also the development of most precise level meters and acceleration sensors of hitherto unprecedented low uncertainty.

Uwe Titt, Volker Dangendorf and Helmut Schuhmacher won the award in the field of «Measurement Techniques for Medicine and Environmental Protection» for their novel measuring device for ionising radiation. The detector was developed in the neutron dosimetry section of PTB and allows to monitor the path of charged particles in a triethylamine gas cell by detecting the light emitted by the gas molecules excited by the radiation. A three dimensional picture of the traces is recovered by an electronic camera system and fast photo multipliers. The system achieves a position sensitivity in the micro- to nanometre region. This represents a large improvement for investigations of the energy deposition by ionising radiation in biological structures. Such investigations are prerequisite to unveil the mechanisms of radiation hazards and to optimise radiation protection.

The winners of the Helmholtz awards together with Ernst O. Göbel (president of PTB; at the centre) and Ruprecht von Siemens (treasurer of the Helmholtz-Fonds; at the right): J. Helmcke, T. Trebst, H. Schnatz, F. Riehle, V. Dangendorf, H. Schuhmacher, and U. Titt (from the left)

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NMR Magnetometer for Magnetic Fields Down to 2 mT

(continued from page 1)

The absorption of energy by the precessing nuclei results in a damping of the amplitude of a «marginal» oscillator, an oscillator which is only slightly oscillating. This damping serves to detect the magnetic nuclear resonance of the NMR probe in the resonance circuit coil of the oscillator: Absorption of energy occurs if the oscillator frequency coincides with the precession frequency of the nuclei determined by the magnetic field and the gyromagnetic coefficient. Fields down to 2 mT can now be measured with a signal-to-noise ratio of 10 by detecting the proton resonance in slightly paramagnetic water solutions. With a sample volume of about 1 cm^3, a sample absorption line width of about 2 µT, and a measuring time of about 2 s, the instrument allows to make quasi-continuous measurements with a resolution of 5 nT.

The NMR magnetometer is used for the calibration of magnetometers based on other physical effects, e. g., Hall-effect sensors. Field coils intended to be used for supervision of the production of magnetic field sensors can also be calibrated with a relative uncertainty of the order of 10^{-4} or less in the range from 2 mT to 100 mT.

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Sample holder with NMR probe and Hall sensor to be calibrated (red dot, 4 mm in diameter) Industry uses sensors of this kind in the fabrication of ferromagnetic materials and in car production (ignition devices, antilock brake systems), for example.