DFM
Danish National Metrology Institute

# ANNUAL REPORT
# 2022

## METROLOGY: THE SCIENCE OF MEASUREMENT

Metrology is the science of measurements and is the backbone of our high-tech society. Most aspects of daily life are influenced by metrology, and increasingly accurate and reliable measurements are essential to drive innovation and economic growth.

## DFM PROFILE

DFM is appointed as the Danish National Metrology Institute and contributes to the integrity, efficiency and impartiality of the world metrology system. DFM is also responsible for coordinating the Danish metrology infrastructure. DFM is a fully owned subsidiary of DTU, the Technical University of Denmark.

## DFM ACTIVITIES

DFM' s scientific research results in new knowledge, measurement techniques and standards, which support the needs of Danish industry and authorities for accurate measurements.

The services offered are high-level calibrations and reference materials traceable to national primary or reference standards, training courses related to metrology and consultancy services.

DFM has a special role in developing measurement capabilities needed by small and medium sized high-tech companies in order for them to evolve and prosper.

DFM works to ensure global confidence in Danish metrology services, which are critical for competing in the global marketplace.

## DIVERSITY AND SUSTAINABILITY

Diversity, inclusion and a global outlook are important to DFM in order to expand its strongholds in research. It is DFMs view that diverse teams perform better than homogeneous teams.

DFM aims to ensure that metrology supports sustainability through new standards and regulations that guide the sustainable development of products, services and processes, via reliable and widely accepted measurements.

ANNUAL REPORT 2022
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FaenoDesign.dk 5579 - 0720
Photo: Finn Brøndum and DFM

April 2023

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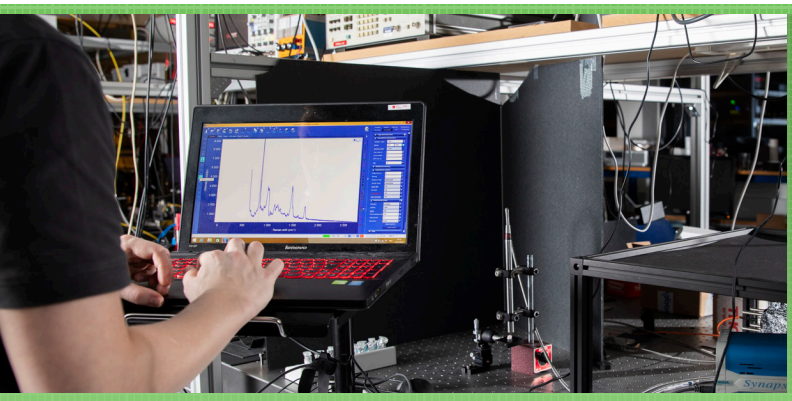
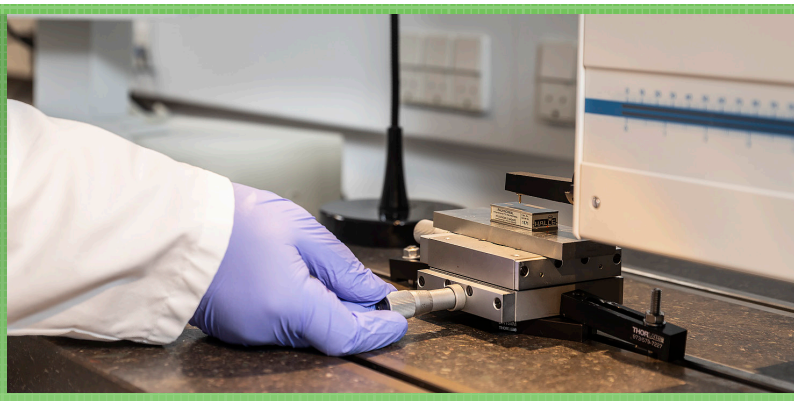


Optical investigation of nanostructures on a plastic foil produced by Roll-to-Roll printing



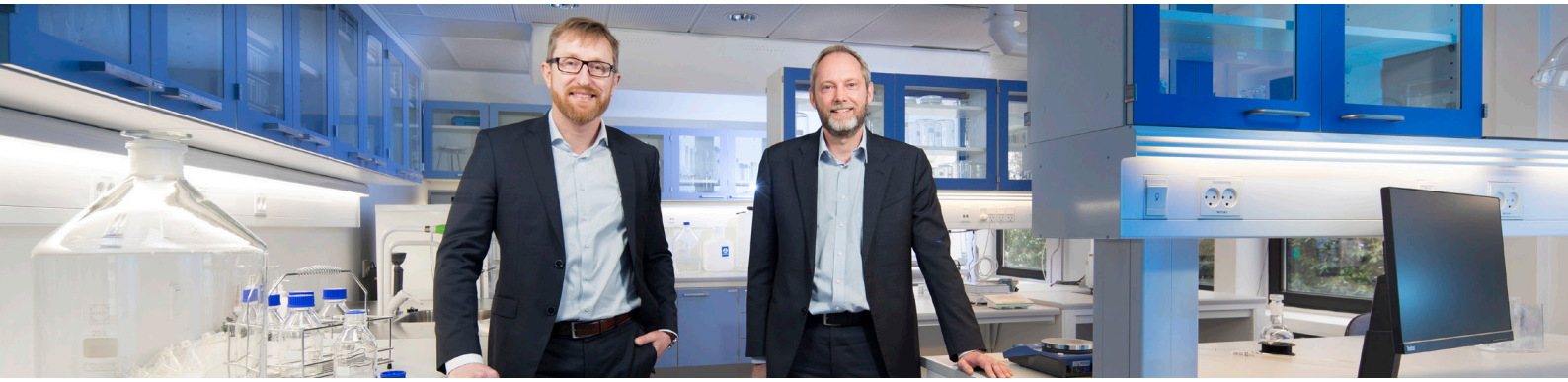
Calibration of roughfness standard - an essential link in the traceability chain for roughfness measurements

**Imagine a society in which there are no common measurement standards. Consumers would not be able to trust that they paid the right amount for food, gas, electricity, petrol, water and other consumables. Manufacturers would not be able to trust that parts bought from several suppliers could actually be assembled, and we would not be able to monitor the change in pollution of our environment and evaluate their effects on global warming.**

Metrology has played an important role in all civilisations. In the earliest civilisations, metrology was used to regulate trade by establishing local standards for weights and measures, but as the world trade expanded, the demand for international standards for weights and measures increased. In parallel, the technological revolution created a demand for other standards than just mass and length: The steam engines required standards for temperature and pressure, the electrical machines required measurement standard for voltage, current and resistance, and other technological inventions spurred the demand for further measurement standards.

Today we live in a global and high technology society. This demands a wide range of international measurement standards of high quality and a system to make sure that all measurements performed in society are traceable to those standards. DFM is part of an international network of national metrology institutes, which work closely together to ensure that the necessary measurement standards are available to the local society and that the measurements performed in different parts of the world are equivalent. These include measurements of physical and chemical quantities, measurements that industries rely on to foster innovation and to develop efficient manufacturing methods, measurements that secure fair trade, consumer protection, health and safety, law and order, and environment monitoring. Measurement are of increasing importance in connection with financial transactions, particularly to secure accurate time stamp of such transactions.

The situation is not static. New technologies continues to appear and the demand for addressing new fields, such as quantum technologies and life sciences, only increases. If the national metrology institutes were not able to meet these demands, the technological development would fade out. So not only do we need metrology in order to run a society, we also need to improve continuously our metrological capabilities!



Bjarne Fjeldsted, Chairman of the Board and Michael Kjær, CEO.

**The commercial revenue was 9.7 mio.kr. which was higher than expected. Growth was especially high in Q4 and included most of the metrology areas.**
**The project revenue grew 14 % to 8.9 mio.kr. - also higher than expected.**

**Total revenue was 46.7 mio.kr. which is similar to 2022 and profit before tax was 991 tkr vs. 1549 tkr in 2021. The profit was reduced due to high energy costs to run the laboratories in the second half of 2022.**

**The management views both revenue and profit as being satisfactory.**

In 2022, DFM was awarded a new government contract for a quantum test center. In a consortium with KU-NBI, DTU and Aarhus University, DFM was also awarded the new NATO DIANA center. The center will begin operations in 2023 and includes most quantum test center activities and a quantum start up incubator.

The development efforts in the time and frequency area began early 2021. By the end of 2022 it resulted in DFM beginning to contribute to the UTC timescale along with many other NMI's.
DFM is pleased with the results and will continue to develop the national time and frequency infrastructure.

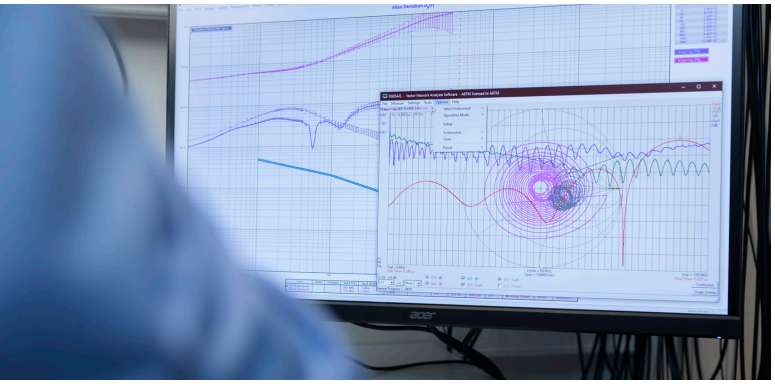
The company financial situation continues to be strong, and in Q1-2023 energy costs have declined significantly. The number of companies using DFM services continues to grow every year.
We are committed to continue to develop new advanced metrology services required by Danish industry and continue to provide high quality services with a short turn around time.

**Bjarne Fjeldsted**
Chairman of the Board

**Michael Kjær**
CEO

# ESTABLISHMENT OF DANISH UTC





In-depth analysis of phenomena in the time/frequency domain.

Checking meteorological data in the time/frequency laboratory

**Precise definition of time is extremely critical in many industries such as telecommunications and finance. A typical application could be, for example, precise time-stamping of financial transactions. In Denmark, we have so far not had our own calibrated atomic clock, and we have therefore been dependent on other countries' time references. In everyday life, this is not necessarily a problem, since with a satellite receiver you can extract an accurate time from satellite navigation systems such as GPS, which are based on precise atomic clocks.**

The problem arises in the event of a failure of the global navigation satellite systems (GNSS), which will be critical for the sectors that depend on accurate time stamping. This was pointed out in a report prepared by the consultancy London Economics for the Interministerial Space Committee in 2019.

At the beginning of 2021, DFM therefore received a grant from the Ministry of Education and Research to establish a national time reference and link it directly to UTC time. UTC stands for Coordinated Universal Time and is used everywhere in the world.

In February 2021, DFM received an atomic clock from the Swiss company T4 Science. The atomic clock is a Maser (Microwave amplification by stimulated emission of radiation), which is based on the frequency of the electromagnetic radiation emitted when a Hydrogen atom changes state between two very specific energy levels. In one energy level, the spins of proton and electron are in the same direction, and in the other energy level, spins are in opposite directions. Specifically, it is radiation at 1,420,405,751.768 Hz corresponding to a wavelength of around 21 cm that is emitted at the transition between these two energy levels.
The Danish UTC representation has been included in the Bureau International des Poids et Mesures (BIPM) list of time references and DFM reports monthly to BIPM, so that the Danish time measurement is included in the global definition of time.

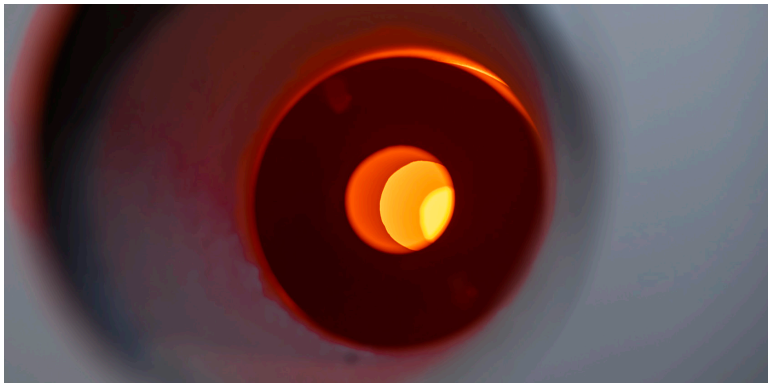
Although with UTC(DFM) there is now a real-time approximation of UTC time available in Denmark and in the future can be used by anyone who needs a very precise time reference, it is not actually the official time in Denmark. According to the current legislation from 1893, it is the "Middle Solstice for the 15th Longitude East of Greenwich" that officially defines time in Denmark. A legislative amendment is therefore needed for UTC+1 to become the official time in Denmark.

In the beginning of next year , the government is putting forward a bill that sets Danish standard time to follow Coordinated Universal Time (UTC), which is in line with the common practice in Denmark for several decades. If the amendment to the law is approved, it is planned to enter into force on March 26, 2023.

# ULTRA-PRECISE ABSOLUTE TEMPERATURE WITH NEW SILVER FIXED POINT




Thermal camera pointed at a calibration furnace.



Glowing hot opening of a fix point heating furnace..

**Temperature calibration of thermometers is performed using the International Temperature Scale of 1990 (ITS-90) specified by the International Committee of Weights and Measures (CIPM). The ITS-90 defines 14 calibration points in the range from -272.50 °C to 1084.62 °C based on various thermodynamic properties of 13 pure chemical elements as well as water, and are commonly referred to as fixed points.**

These defining fixed points utilize the property that a substance undergoing a phase-transition will remain stable at a fixed temperature. A well-known example of such a transition is boiling water which remains at exactly 100 °C under normal conditions such as standard atmospheric pressure in a laboratory. Fixed points are selected to be as stable and reproducible as possible.

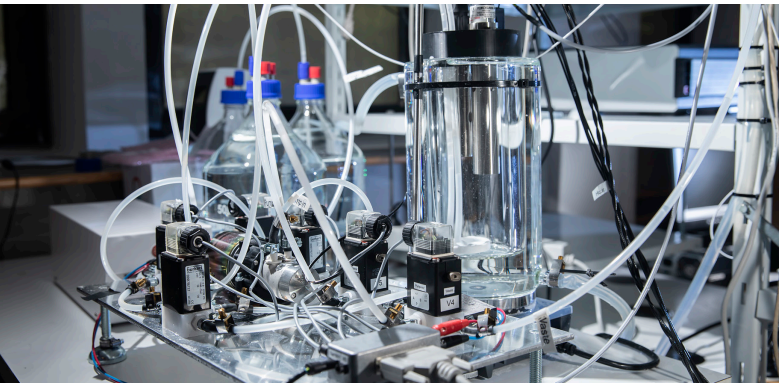
DFM is the leading laboratory for non-contact accredited temperature calibration in Denmark with more than 50 years of experience. In order to enhance temperature calibrations at temperatures above 660 °C, DFM has acquired a new fixed point made of ultra-pure silver that defines 961.78 °C.

The metal is encapsulated in a graphite cup allowing heating to temperatures above the melting point of the metal. The fixed point is placed in a custom-built furnace which is specifically optimized to ensure homogeneous heating. Using fine control of the furnace the fixed point is heated above the melting temperature until the metal is completely melted. The temperature of the oven is then lowered and the metal starts freezing at the freezing temperature, and maintains this temperature for a long time. The freezing temperature can then be measured and used for calibration of equipment. Measurements can be done using non-contact thermometry with for example a thermal camera or a so-called pyrometer.

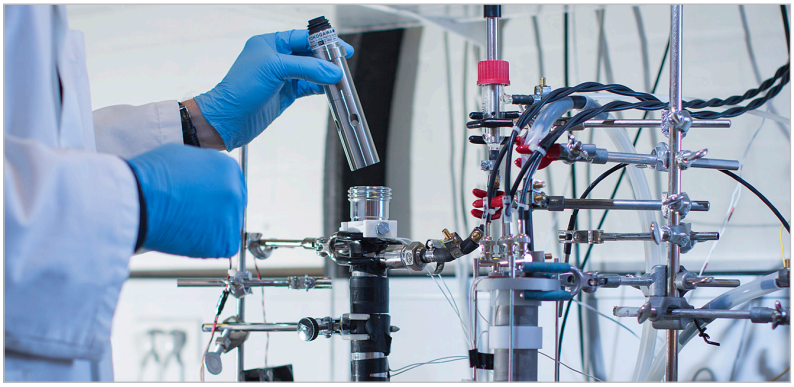
To ensure utmost performance of the new DFM fixed point in Denmark, it is necessary to verify performance by comparing with standards of other countries. To obtain this goal the DFM equipment was moved to Sweden for a measurement campaign at the thermometry laboratory of the metrological institute of Sweden, RISE. With the gracious help of the experts at RISE, the DFM silver fixed point was verified to be within 25 mK of the Swedish silver fixed point with only a few mK uncertainty. This impressive performance of the Danish silver fixed point confirms that we are able to define 961.78 °C with the lowest possible uncertainty of the transfer to measurement equipment.

# NEW ELECTROLYTIC CONDUCTIVITY CALIBRATION SYSTEM AT DFM





DFM's new kappaT system for calibration of electrolytic conductivity sensors.



DFM's UPW system for calibration of electrolytic conductivity sensors at very low conductivity levels.

**Electrolytical conductivity sensors are used extensively in controlling water quality, because they are sensitive, simple and robust. In order to provide measurement confidence and ensure compliance, it is required that the calibration is performed reliably and accurately and usually over a large range of conductivity (κ). In addition, the sensor calibration must be traced to a primary standard.**

DFM is maintaining two primary standards, a coaxial type cell in the low conductivity range; for aqueous solutions with κ from 0.05 µS/cm to 1.4 mS/cm, and a differential type cell for higher conductivities covering the range of aqueous solutions with κ from 100 µS/cm to 300 mS/cm.

In the low conductivity range, DFM offers conductivity sensor calibration in a closed-flow-loop. Until now, DFM has offered calibration for higher conductivities using reference materials produced at DFM and certified via the differential type cell at DFM. Fabrication of reference materials is laborious, and calibration points are therefore limited to a selected number of conductivity values, typically in steps by a factor of 10 from 100 µS/cm to 100 mS/cm. However, several of our customers have requested calibration at particular conductivities within this range.

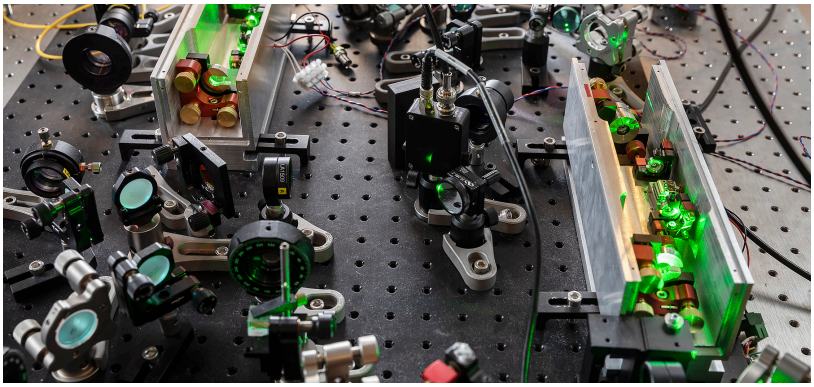
In response to this, DFM has now developed a conductivity calibration system, which offers conductivity sensor calibration covering any value at higher conductivities (κ from 100 µS/cm to 300 mS/cm) and with a best measurement capability within this range of 0.3 % (expanded uncertainty). The system is based on a comparison measurement in a temperature stabilized glass container, where the customer's sensor is immersed in the same electrolytic conductivity solution as DFM's reference cell with traceability to the differential type primary cell at DFM.

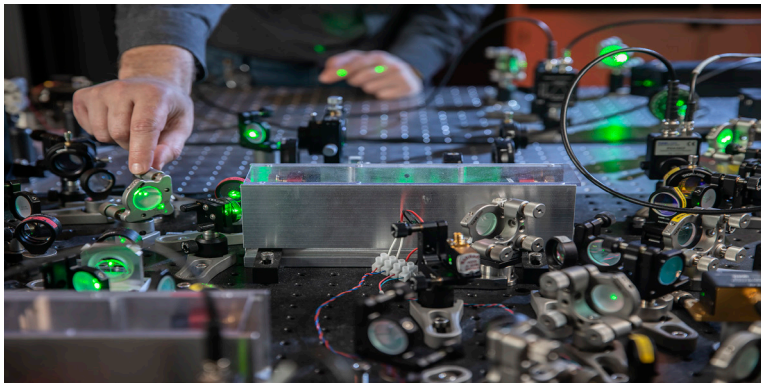
A combination of electrolytic conductivity solutions, a pump, and a number of valves enables the glass container to be filled with a solution of any conductivity within the higher conductivity range. The calibrations are performed automatically with control from a PC. Via tubings, the solution is pumped through a debubbler, which by means of vacuum degassing removes dissolved gas molecules from the solution. The calibrations are therefore free of visible air bubbles, but more important also free of microscopic air bubbles, which are not visible and not possible to remove manually. The new electrolytic conductivity calibration system therefore exhibits reliable and reproducible calibrations.

As a result, DFM now offers conductivity sensor calibration in electrolytic conductivity solutions at any conductivity value covering the whole range from 0.05 µS/cm to 300 mS/cm.

# NEW DFM QUANTUM TEST CENTER







Experimental setup for the quatum project Q-GWD.

**Quantum technology is expected to have a major impact on our society in the future and massive investments are being made in the fields of quantum computing, quantum sensing and quantum security.**

By taking advantage of the properties of quantum particles new quantum computers are expected to simulate complex chemical and biological processes that classical computers cannot solve. This can drastically reduce the time and cost of new drug developments as well as the development of more efficient batteries for the benefit of the climate, to name a few important examples of applications.

Quantum computers can however also be used to break current encryption methods making exchange of secret information vulnerable to attacks. Fortunately, the quantum technology can be used to generate unbreakable encryption methods for secure communication lines utilizing the true randomness of the quantum state of a particle.

Naturally, the new quantum technologies call for new test, validation, and calibration methods and to address these needs, DFM has established a national Quantum Test Center at our facilities in Hørsholm. The Test center is funded by the "Danish Agency for Higher Education and Science" for the period from 2022 through 2024. The Test center is furthermore part of NATO's new DIANA Center for Quantum Technology.

With the new center, DFM will strengthen and further develop our current quantum activities as well as contribute to the establishment of a strong Danish eco-system within quantum technology. It is DFM's vision that the Quantum Test Center shall become one of Europe's leading centers for test and validation of quantum materials, components, and systems.

Together with FORCE Technology DFM is planning several activities to disseminate knowledge about quantum technology.

# INCOME STATEMENT AND BALANCE SHEET



| INCOME STATEMENT (1000 DKK) | 2022 | 2021 |
|---|---|---|
| Commercial revenue | 9 746 | 11 067 |
| Project revenue | 8 925 | 7 818 |
| Government funding | 28 020 | 27 888 |
| **Total revenue** | **46 691** | **46 773** |
| Travel and out-of-pocket expenses | 17 885 | 17 889 |
| **Total out-of-pocket expenses** | 17 885 | 17 889 |
| **Gross profit** | **28 806** | **38 884** |
| Staff costs | 24 458 | 23 622 |
| **Total costs** | **24 458** | **23 622** |
| **Operating profit before depreciation and impairment losses** | **4 348** | **5 262** |
| Depreciation and impairment losses on property, plant and equipment | 3 119 | 3 457 |
| **Operating profit before financial income and expenses** | **1 229** | **1 805** |
| Financial income | 5 | 13 |
| Financial expenses | 244 | 269 |
| **Profit before tax** | **990** | **1 549** |
| Tax on profit for the year | 218 | 340 |
| | | |
| **Profit for the year** | **772** | **1 209** |
| Profit for the year to be carried forward | | |

## BALANCE SHEET AT 31 DECEMBER (1000 DKK)

| ASSETS | 2022 | 2021 |
|---|---|---|
| Deposits | 1 042 | 1 016 |
| **Total investments** | **1 042** | **1 016** |
| Equipment | 9 393 | 8 599 |
| Leasehold improvements | 12 429 | 13 612 |
| **Total property, plant and equipment** | **21 822** | **22 211** |
| **Total non-current assets** | **22 864** | **23 227** |
| **Contract work in progress** | **6 309** | **9 277** |
| Trade receivables | 2 356 | 1 259 |
| Prepayments | 114 | 14 |
| Other receivables | 388 | 666 |
| **Total receivables** | **2 858** | **1 939** |
| **Cash at bank and in hand** | **26 248** | **30 356** |
| **Total current assets** | **35 415** | **41 572** |
| **Total assets** | **58 279** | **64 799** |

| EQUITY AND LIABILITIES | 2022 | 2021 |
|---|---|---|
| Share capital | 1 000 | 1 000 |
| Retained earnings | 20 779 | 20 027 |
| **Total equity** | **21 779** | **21 027** |
| Prepayments from customers and of funding | 23 653 | 30 012 |
| Trade payables | 1 718 | 1 767 |
| Other payables | 11 109 | 11 993 |
| **Total current liabilities** | **36 480** | **43 772** |
| **Total equity and liabilities** | **58 279** | **64 799** |

# KEY FIGURES



| KEY FIGURES IN MILLION DKK | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| Net sales | 37.1 | 42.8 | 42.9 | 46.8 | 46.7 |
| Gross balance | 42.1 | 42.3 | 63.2 | 64.8 | 58.3 |
| Profit or loss for the financial year [1]) | 0.7 | 0.9 | 0.7 | 1.2 | 1.0 |
| Net capital | 18.2 | 19.1 | 19.8 | 21.0 | 19.3 |
| Commercial sale | 7.1 | 10.2 | 10.0 | 11.1 | 9.7 |
| - to small enterprises (less than 50 employees) | 0.9 | 1.0 | 1.0 | 1.1 | 1.6 |
| - to medium size enterprises (50-250 employees) | 1.5 | 1.9 | 1.9 | 1.9 | 1.7 |
| - to large enterprises (more than 250 employees) | 2.0 | 2.5 | 1.9 | 2.3 | 2.0 |
| - to Danish public institutions | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| - to foreign enterprises and institutions | 2.4 | 4.3 | 4.9 | 5.5 | 4.1 |
| Foreign net sales | 4.3 | 7.7 | 4.8 | 5.1 | 4.0 |
| **RESEARCH AND DEVELOPMENT** | | | | | |
| Number of collaborative projects | 23 | 24 | 29 | 28 | 31 |
| - thereof innovation consortia | 1 | 0 | 0 | 0 | 0 |
| - thereof international projects | 20 | 20 | 27 | 25 | 28 |
| R&D activities (million DKK) | 29.6 | 32.8 | 35.0 | 34.7 | 36.0 |
| - thereof self-funded | 2.6 | 2.8 | 3.2 | 3.3 | 2.0 |
| R&D work (man-year) | 19.7 | 21.1 | 31.2 | 27.7 | 27.2 |
| **NUMBER OF CUSTOMERS** | | | | | |
| Danish private enterprises | 146 | 168 | 142 | 154 | 159 |
| - thereof small enterprises (less than 50 employees) | 67 | 59 | 55 | 56 | 66 |
| - thereof medium size enterprises (50-250 employees) | 32 | 51 | 37 | 45 | 42 |
| - thereof large enterprises (more than 250 employees) | 47 | 43 | 34 | 39 | 33 |
| Danish public institutions | 20 | 15 | 16 | 14 | 18 |
| Foreign enterprises and institutions | 44 | 52 | 43 | 41 | 51 |
| Total customer base | 210 | 220 | 185 | 195 | 210 |
| **NUMBER OF STAFF CATEGORIZED BY EDUCATION (MAN-YEAR)** | | | | | |
| Dr & PhD | 26 | 27 | 31 | 27 | 26 |
| MSc | 1 | 1 | 1 | 1 | 1 |
| Other technical staff | 2 | 3 | 3 | 3 | 3 |
| Administrative staff | 4 | 5 | 5 | 5 | 5 |
| Average number of staff | 33 | 36 | 39 | 36 | 35 |
| **NUMBER OF PUBLICATIONS** | | | | | |
| Refereed publications | 19 | 10 | 19 | 16 | 17 |
| PhD and Master theses | 0 | 1 | 0 | 0 | 0 |
| Other reports | 2 | 0 | 0 | 0 | 5 |
| Conference papers | 17 | 24 | 10 | 12 | 9 |
| Calibration certificates and measurement reports | 1543 | 1 645 | 1 622 | 2 140 | 2 894 |
| **EDUCATION** | | | | | |
| DFM courses (number of days) | 4 | 2 | 0 | 0 | 1 |
| DFM courses (number of participants) | 28 | 21 | 0 | 0 | 7 |
| Supervision/teaching at universities (number of students/courses) | 3 | 4 | 4 | 5 | 4 |
| Co-supervision of master thesis students (number of theses) | 0 | 1 | 1 | 1 | 1 |
| Contribution to teaching at universities (number of days) | 3 | 4 | 4 | 5 | 4 |
| Committee work (number of committees) | 29 | 28 | 27 | 27 | 27 |
| - thereof international committee work | 25 | 24 | 23 | 23 | 23 |
| **EFFICIENCY** | | | | | |
| Turnover per employee (1000 DKK) | 1 126 | 1 147 | 1 102 | 1 308 | 1 334 |
| Profit per employee (1000 DKK) | 17 | 24 | 19 | 34 | 22 |
| Commercial turnover per DKK of governmental funding | 0.3 | 0.4 | 0.4 | 0.5 | 0.4 |
| R&D turnover per DKK of governmental funding | 1.4 | 1.3 | 1.4 | 1.5 | 1.6 |

1) Excluding extraordinary items

# DANISH METROLOGY INSTITUTES



**According to the CIPM Mutual Recognition Arrangement, a country can have one national metrology institute (NMI) and a number of designated institutes (DI). In Denmark, these metrology institutes are appointed by the Danish Safety Technology Authority (www.sik.dk). In the list below, each appointed metrology institute is identified by the acronym used in the BIPM database for Calibration and Measurement Capabilities. The fields covered by the appointments are indicated in the table on the next page.**

## DFM

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Phone: +45 7730 5800
dbh@dfm.dk

## HBK-DPLA

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Contact: Erling Sandermann Olsen
Phone: +45 7741 2000
erlingsandermann.olsen@hbkworld.com

## FORCE

FORCE Technology
Park Allé 345, DK-2605 Brøndbyvester
Contact: Michael Møller Nielsen
Phone: +45 4325 0108
mmn@force.dk

## DTI

Danish Technological Institute
Kongsvang Allé 29, DK 8000 Århus C
Contact: Jan Nielsen
Phone: +45 7220 2000
jnn@teknologisk.dk

## TRESCAL

Trescal A/S
Mads Clausens Vej 12, DK 8600 Silkeborg
Contact: Torsten Lippert
Phone: +45 8720 6969
torsten.lippert@trescal.com

## DTU

Technical University of Denmark
Frederiksborgvej 399, Building 201, room S41,
DK-4000 Roskilde
Contact: Jørgen Schøller
Phone: +45 2043 7665
jorsch@dtu.dk

# THE 12 SUBJECT FIELDS OF METROLOGY



**Fundamental metrology in Denmark follows the EURAMET division into 12 subject fields, while the subfields reflect a Danish subdivision of metrological activities.**

| SUBJECT FIELD | CONTACT PERSON | SUBFIELDS | METROLOGY INSTITUTE |
|---|---|---|---|
| MASS AND RELATED QUANTITIES | Lars Nielsen, DFM | Mass measurement | DFM |
| | ln@dfm.dk | Force and Pressure | FORCE |
| | | Volume and Density | FORCE |
| ELECTRICITY AND MAGNETISM | Carsten Thirstrup, DFM | DC electricity | DFM |
| | cth@dfm.dk | AC electricity | TRESCAL |
| | | HF electricity | TRESCAL |
| LENGTH | Jan Hald, DFM | Basic length measurements | DFM |
| | jha@dfm.dk | Dimensional metrology | DFM & DTI |
| | | Micro/Nano | DFM |
| TIME AND FREQUENCY | Jürgen Appel, DFM | Time measurement | |
| | jap@dfm.dk | Frequency | |
| THERMOMETRY | Jan Nielsen, DTI | Temperature measurement by contact | DTI |
| | jnn@teknologisk.dk | Non-contact temperature measurement | DFM |
| | | Humidity | FORCE |
| | | Moisture in materials | DTI |
| IONISING RADIATION | Claus E. Andersen, DTU | Absorbed radiation dose – Industrial products | DTU |
| | clan@dtu.dk | Absorbed radiation dose – Medical products | |
| | | Radiation protection | |
| | | Radioactivity | |
| PHOTOMETRY AND RADIOMETRY | Anders Brusch, DFM | Optical radiometry | DFM |
| | ab@dfm.dk | Photometry | |
| | | Colorimetry | |
| | | Optical fibres | |
| FLOW | Jesper Busk, FORCE | Gaseous flow (volume) | FORCE |
| | jrb@force.dk | Water flow (volume, mass and energy) | DTI |
| | | Flow of liquids other than water | FORCE |
| | | Anemometry | DTI |
| ACOUSTICS, ULTRASOUND AND VIBRATION | Salvador Barrera-Figueroa, DFM | Acoustical measurements in gases | DFM & HBK-DPLA |
| | sbf@dfm.dk | Acoustical measurements in solids | HBK-DPLA |
| | | Acoustical measurements in liquids | |
| METROLOGY IN CHEMISTRY | Michela Della Negra | Electrochemistry | DFM |
| | mdn@dfm.dk | Laboratory medicine | |
| | | Products and materials | |
| | | Food chemistry | |
| | | Pharmaceutical chemistry | |
| | | Microbiology | |
| | | Environmental chemistry | |
| INTERDISCIPLINARY METROLOGY | David Balslev-Harder | No subdivisions | |
| | dbh@dfm.dk | | |
| QUALITY | Lars Nielsen, DFM | No subdivisions | |
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