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BUREAU INTERNATIONAL DES POIDS ET MESURES

REPORT ON THE BIPM WORKSHOP ON CHALLENGES IN METROLOGY FOR DYNAMIC MEASUREMENT

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1 Executive summary

By Takashi Usuda, Chairperson of the Workshop

A BIPM Workshop on Challenges in Metrology for Dynamic Measurement was held at the BIPM on 15 and 16 November 2012. Participation at the workshop was by invitation only and included interested parties from National Metrology Institutes (NMIs) as well as industry. A total of 58 scientists from 21 States and Economies attended.

Rationale for organizing the workshop

Traceability from NMI level to calibration laboratory level is usually established under static conditions. However, there are some notable exceptions, such as for shock and impact mechanical quantities (measured at a few NMIs), where experimental approaches to dynamic calibration are required. Verification of dynamic measurement capabilities via key comparisons remains a long way off, due to a lack of validated methods and accepted procedures. Consequently, dynamic calibrations of measurement equipment at calibration laboratories and dynamic measurements at testing laboratories are rarely performed, or are performed without validation of the method's traceability and uncertainty.

There are, however, many demands from industry for dynamic measurements, with a view to improving efficiency, safety, and reliability as well as encouraging innovation. There are also many demands for dynamic measurements from the regulatory and legislative sectors.

Recent technical developments in data acquisition equipment, MEMS sensors, non-contact optical measurements, data analysis, etc., may facilitate the capture and analysis of time-dependent quantities. Some regional (e.g. EMRP project in Euramet) or international (e.g. IMEKO) activities on dynamic measurement have also been started recently.

Recognizing the importance of the emerging area of dynamic measurement and recent leading activities at the regional and international level, the BIPM organized and hosted a workshop on dynamic measurement on 15 and 16 November 2012, with the aim of bringing together experts from the NMIs with representatives from various industries needing traceable, reliable and comparable dynamic measurements across diverse measurement areas.

Programme

The subjects were selected from the fields of mechanical, thermophysical, and flow metrology, so that the topics well represent in the diverse fields. The subjects and speakers were selected by the Scientific Steering Committee: Takashi Usuda (Chair; NMIJ/AIST, Japan), Fredrik Arrhen (SP, Sweden), Thomas Bruns (PTB, Germany), Trevor Esward (NPL, United Kingdom), Jean-Rémy Filtz (LNE, France), John Wright (NIST, United States), and Nick Fletcher (Scientific Secretary; BIPM).

There were nine technical talks from invited speakers from both industry and NMIs, followed by a series of breakout sessions to discuss outcomes for specific areas. The programme is provided in Appendix 1 and the various presentations can be downloaded from a dedicated area on the BIPM website:

http://www.bipm.org/ws/AllowedDocuments.jsp?ws=DYNAMIC

General conclusions

This was a unique workshop as the theme included diverse measurement applications related by their "dynamic" nature. Some common and some area-dependent findings were identified.

Common findings across all areas:

- There is a need to clarify the terminology, which has to cover diverse quantities.
- Step function inputs and system identification provide the basic approach in a wide range of metrology applications. However, the generation of step inputs (measurand) is not always feasible.
- A common approach to the uncertainty evaluation is required from static to dynamic measurement, as well as from component to system level.

Area-dependent findings:

- In some applications, especially in the mechanical area, there are explicit and urgent needs for dynamic measurement. There are also requirements from the regulatory and legislative sectors, especially with respect to safety.
- Although the needs for dynamic measurement are not always apparent, in some applications there are hidden risks or hidden needs. It is important to identify these needs, and raise awareness of the needs among the stakeholders.

A summary of the individual sessions is provided in the following section of this report.

Participants agreed the need for continued activities on dynamic measurement. The activities may be:

- Joint activity with regular/*ad hoc*, regional/international meetings so that wider stakeholders can participate, especially from industries.
- Joint activity between the CIPM Consultative Committees (CCs) and the Joint Committee for Guides in Metrology (JCGM) so that more specific and intensive discussions can be held among scientists from NMIs.
- A series of such workshops would be appreciated, as diverse disciplines need to be reviewed and discussed transversely.

2 Session reports

2.1 Mechanical Quantities

By Thomas Bruns, Session Chair

Introduction

The initial session of the workshop was dedicated to the area of mechanical quantities, such as force, torque, pressure and vibration, this being one of the fields where active requests for improvements in dynamic measurement metrology are apparent.

In an effort to achieve the broadest possible overview, speakers were selected from the areas of measurement applications (Dr Tatsuo Fujikawa), sensor manufacturers (Dr André Schäfer) and metrology (Dr Gustavo Ripper).

A probably incomplete summary of impressions from the presentations is presented below.

Requirements:

- **Societal aspects** can be found for example in measurement problems related to safety. In many areas, the most prominent being automotive crash testing, dynamic measurements are of essential importance. Widely accepted international standards exist, defining procedures and documentary requirements. However, in many cases the results are not strictly comparable due to the lack of appropriate calibrations and in-depth understanding of the dynamic metrology, notably, but not exclusively, the associated measurement uncertainty. Related current concerns include worker’s safety, or household safety, in new fields such as service robots.
- **Economical requirements** are related to the above in terms of costly test repetitions due to non-comparability, unnecessarily large margins in design and construction of products because of their use in dynamic environments/applications, and large uncertainties in dynamic-related materials properties. Other requirements relate to the fuel or power efficiency of machinery. Combustion engines as well as electrical machinery generate substantial dynamic components in their respective drive trains, metrology of efficiency factors based on static traceability has reached the limits, and further improvements will require adequate traceability for the dynamic aspects to be included.
- The aforementioned power efficiency is also an **environmental requirement** as fuel or power consumption is reduced along with exhaust gas emissions. Hence, increasingly restrictive environmental regulations require an improvement in metrology for both adherence and surveillance purposes.

For mechanical quantities, the question of load ranges is always correlated with the question of applicable frequency ranges, as higher mechanical loads typically require larger and therefore heavier mechanical structures with lower characteristic frequencies. In the case of force and torque the transducer is an integral part of the system, so the “dynamic challenge” shifts with the range but persists regardless.

One approach to accommodating dynamics in measurement, taken by the manufacturers of instrumentation and also welcomed in some cases by the application engineers, is based on integrated (smart) electronics. This approach brings the full power of digital signal processing to the dynamic application; however, a shortcoming of this technology is the lack of transparency, and the huge increase in complexity, when it comes to calibration and measurement uncertainty. For an in-depth understanding of the system’s behaviour and of the data analysis in terms of input prediction a detailed knowledge of the internal workings of such instrumentation is essential.

The metrology infrastructure currently in place for dynamic mechanical quantities, namely vibration and shock, lags a long way behind that established for acceleration measurements. Future developments in the metrology of dynamic mechanical quantities might usefully consider the path already followed for acceleration metrology.

Conclusions from the breakout session discussions

Although the demand for traceable dynamic measurement of mechanical quantities is apparent throughout various fields in industries and the need for solutions is perpetually increasing, for the time being metrological services are virtually non-existent. In order to establish a proper metrology infrastructure, many features that are well in place in other metrology areas still need to be developed, implemented or established. A few of these, which were briefly discussed in the breakout session, are listed below:

- Traceable primary calibration services for dynamic quantities (devices, methods);
- Secondary services for dissemination (devices, methods);
- International documentary standards dealing with accepted, validated methods;
- Approved methodology for evaluating the measurement uncertainty;
- Allocation to the appropriate CIPM Consultative Committees;
- Key comparisons establishing the basis for mutual recognition;
- Service categories within the key comparison database (KCDB);
- CMC evaluation and entries.

National demands with respect to the most urgent needs vary according to the industries present in each country. Hence, a global approach focusing on a specific quantity does not appear feasible. Nevertheless, the participants agreed that an intensive exchange of information between experts, even on different quantities, could be very helpful in furthering progress. In this context, the comprehensive approach taken by a European research collaboration in the framework of the European Metrology Research Programme (EMRP), the joint research project "traceable dynamic measurement of mechanical quantities", was unanimously regarded as a prime example of how to address the coming challenges.

Discussion then turned to inhibiting factors, which were most prominently found in

- the huge financial investments necessary to implement the respective devices
- the human resources necessary in addition to the existing staff in order to implement additional services
- the structure of the typical NMI which does not easily accommodate interdisciplinary (horizontal) tasks such as those encountered in dynamic metrology.

It is up to the management of the national NMIs to decide upon new strategies which will enable them to implement a metrology infrastructure for their respective country but also for the region, which can fulfil the requirements of industry and society without neglecting or ignoring the vast impact of dynamic measurements.

2.2 Fluid and Flowmetry

By John Wright, Session Chair

Introduction

National Metrology Institutes have refined their flow calibration standards to produce steady state pressure, temperature, and flow conditions for customer calibrations with corresponding low uncertainty capabilities. However, many important flow measurement applications do not match these refined steady state conditions and in general calibration customers do not have the flow meter performance data necessary to determine the impact of real world unsteady conditions on their flow measurements. Dynamic measurement errors occur in billing applications of valuable fluids like natural gas and petroleum and research applications in the environmental, medical, and manufacturing sectors.

In some applications, the best approach to obtaining accurate results is to dampen the flow transients with mufflers or settling tanks and throttling valves. For others damping is not practical and dynamic flow meter calibration data are necessary so that instruments with a well characterized time response can be properly applied to a dynamic flow and users can make a reliable uncertainty analysis.

During the presentation session, Chuck Gray of Emerson / Micro Motion described the application of a Coriolis flow meter to batch filling of bottles and field proving of petroleum pipeline flow meters. Flow transients are accompanied by pressure and temperature transients that further complicate the measurement problems. Frederik Arrhen (SP) showed unexpected transient responses from various pressure transducers to a pressure step produced in a shock tube. The unusual responses are due to proprietary data processing routines designed to meet a particular customer need, but they are detrimental in other applications. (See also Section 2.4 below, on

System Identification and Calibration.) John Wright (NIST) gave a general review of dynamic flow applications (summarized below), control theory, and a NIST Transient Gas Flow Facility designed to mimic gaseous vehicle refueling.

Dynamic flow measurements are necessary for the environment, safety, manufacturing efficiency, accurate billing for gaseous and liquid fuels, and the efficient usage of fuels. Dynamic flow applications include:

- Flare gas: Release of gaseous hydrocarbons from remote drilling and refining stations, burned to reduce greenhouse gas effects, measured for environmental regulations. Sudden releases have wide dynamic range (>100). In 2011, flare gas releases were 150×10^9 m^3/yr worldwide (= 25 % of US consumption).
- Evaluating / designing internal combustion and jet engines: fuel, air, exhaust
- Reciprocating compressors and pumps: Natural gas pumping stations generate pulsatile flows of the order of 100 Hz. Many flow meters suffer unexpectedly large errors under pulsatile flow conditions.
- Blow-down calibrations of large gas flow meters: small compressors charge pressure vessels which are subsequently discharged to produce short duration but large flows. The uncertainty due to poor temperature and pressure control in the blow-down system leads to unacceptable uncertainties in steady flow applications.
- Flow control for process industries: A prerequisite of high quality flow control is a flow meter with sufficient time response.
- Blood flow: the human heart produces pulsatile flow making accurate measurements difficult in medical applications.
- Batch filling: Filling of bottles and other containers with food, detergent, paint, pharmaceuticals and other commercial products. Filling times are of the order of 1 s and errors lead to product disposal or regulatory penalties for the manufacturer.
- Flow meter calibrations with field provers: The petroleum industry uses the timed travel of a piston within a cylinder to calibrate flow meters used in pipeline applications. The sudden start and stop of the piston at the ends of travel lead to significant errors in meters with poor time response.
- Vehicle refueling: When vehicles powered by natural gas, hydrogen, or gasoline are refueled, sudden starting and stopping of the fuel flow can lead to totalization and billing errors, invalidate price competition, and lead to loss of consumer confidence.

Conclusions from the breakout session discussions

The action items from the 20-person breakout session were:

- Continue assessing industrial measurement needs, customer and product requirements, frequency range, including future needs.
- Survey available test facilities at NMIs and industry.
- Develop test methods, best practices, research on methods for generating various input waveforms at needed frequencies.
- Determine best reference meters to use in calibration facilities that generate dynamic flows for commercial flow meter performance testing.

- Develop uncertainty analysis approaches (at practical level for the application and user).
- Develop documentary standards: there are not standards on evaluating response of flow meters, no useful standards on pressure sensors.
- Determine how to report results and make them useful to customers. Formats that can be applied on specification sheets are needed for reporting instrument performance.
- Develop reference materials or devices, working standards, and methods for generating dynamic inputs.
- Add measurement service categories for dynamic measurands to the KCDB. Anticipate comparisons of NMI dynamic calibration capabilities.
- Develop expertise to provide education, consulting, and advice to customers on dynamic applications.

2.3 Thermophysical Quantities

By Jean-Rémy Filtz, Session Chair

Introduction

In the fields of thermal or optical metrology, the issue of dynamic measurements is crucial for many application areas. Although temperature scales, and radiometry and photometry scales are maintained at the highest level by NMIs by applying stationary or quasi-stationary measurements, use of dynamic techniques has for several decades been applied in thermal measurements and for material characterization.

In this area, there are two distinct needs to be considered:

(1) The measurement of dynamic phenomena in industrial applications requiring the use of a calibrated instrumentation for dynamic regimes or dynamic measurements;

(2) The characterization of thermophysical properties of materials requiring dynamic measurement techniques.

For the workshop, two areas of application were selected with the aim of highlighting the interest and specificities of thermal dynamic measurements in industry and in science for the characterization of advanced materials.

Dynamic temperature measurements are useful in many industrial fields, including energy (from production of to energy use and recycling), environment management, and manufacturing processes. In each case the main objectives are to better manage the production costs, the safety, the quality of any process or product, and the impact on the environment.

The field being very wide, for the purposes of the workshop one application for temperature measurements and a few applications for thermooptical properties of materials were selected and presented.

Finally, the scope of this session was:

- Dynamic characterization or dynamic calibration methods for various thermal quantities and measurement systems,
- Optimization of complex systems or measurements (multilayers or instrumentation),
- Time-dependent measurements and associated uncertainties.

During the first presentation, an interesting application in the field of dynamic temperature measurements was described. Ronan Morice (LNE, France) in cooperation with Benedict-John Willey (EDF, France) presented the case of a joint study focused on the *"Response of temperature sensors for civil nuclear applications"*. Characteristics of the dynamic measurement methods for temperature sensors were listed. In this case, metrological parameters to be managed are:

- Temperature: In the case of steady state conditions, existing calibration facilities and standards exist.
- Response time: Response time of temperature sensors, as well as tolerances on temperature accuracy, contribute directly to the assumptions for the optimal operation of the reactor in compliance with the applicable safety rules.

The latter parameter depends upon the heat capacity of the sensor and on the heat transfer of the system with the environment. The convective heat transfer depends also on the velocity of the fluid, the thermophysical properties of the fluid and the sensor material. Therefore, it was specified that the response time of thermometers needs to be validated in laboratory before any industrial use *in situ.*

In this case, it was decided to establish a joint programme for developing skills and capabilities between the end-user and the NMI. As a result of this collaboration, an innovative facility was co-developed by EDF (industry) and LNE (NMI).

The necessary high level metrology to be applied for managing critical parameters requires the following needs and actions:

- R&D required for improving confidence in the quality of measurements;
- Development of adapted facilities;
- Assessment of important influencing factors;
- Thorough evaluation of uncertainties;
- Technical assistance and exchanges.

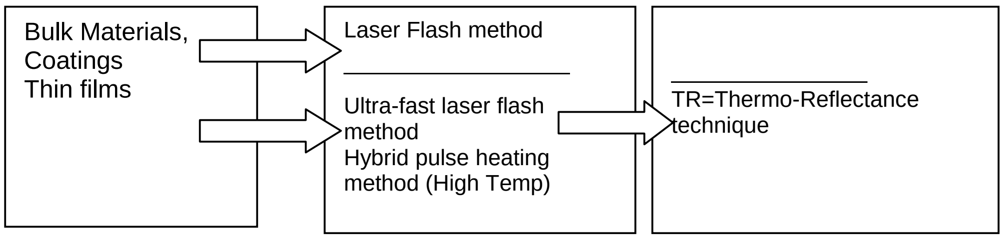
This work underlined the wide gap between the metrology scales and the challenging industrial dynamic measurements required for monitoring for instance a power plant. The presentation demonstrated how a National Metrology Institute can propose practical assistance for developing, at the highest metrological level, a special facility adapted to the metrological dynamic characterization of particular temperature sensors.

A second presentation describing the *"Dynamic measurements of thermophysical properties for material metrology standards"* was given by Tetsuya Baba (NMIJ/AIST, Japan).

Within the framework of a national research programme developed at NMIJ, Dr Baba highlighted the various techniques applied today for the characterization of thermal transport properties of materials (including both steady state and dynamic techniques).

The dynamic measuring techniques were described in detail.

(1) Pulsed light heating methods allow thermal characterization measurements (i.e of thermal diffusivity). Which technique should be developed depends on the state of the material.



(2) Impulse Response function and Transfer function allow the analysis of:

- heat diffusion;
- finite response time of temperature detection
- transfer function and areal heat diffusion time.

Wih application of the thermal quadrupoles method it was shown that this technique is very powerful. This explicit method allows representation of linear systems with simple geometries. Non-linear problems could also be treated if time remains untransformed.

Conclusions from the breakout session discussions

With respect to dynamic measurements in the field of thermal quantities, the objective of this session was to:

- Initiate a list of general capabilities of NMIs;
- Identify generic needs (triggers), issued mainly from industry;
- Identify technological challenges;
- Produce a draft outline of a roadmap segmented into three periods (short, middle and long term) in order to build metrological solutions addressing the challenges and societal needs.

The group considered that the following industries have expressed strong needs/ expectations:

- Energy; from production to use;
- Building;
- Transportation;
- Electronics (including for example storage memory, and new generation of lighting systems);

- In general, all industries using or developing new advanced materials

Implemented technologies requiring dynamic measurements include:

- Temperature measurements in real time dynamic situations;
- Heat transport properties in simple, layered or complex materials;
- Radiative properties and thermooptical properties of materials (for example thin films);
- Heat capacity measurements.

The general action items from the 20-person breakout session were:

- Be strongly attentive to the industrial needs, especially where dynamic measurements have to be applied;
- Consider practical solutions and the measurement techniques to be implemented;
- Identify capabilities (skills, facilities, methods...) available at different levels (NMIs, R&D laboratories, universities, and industry);
- Adapt methods and develop technical facilities (extended capabilities: temperature range, spectral range, resolution...);
- Develop reference/working standards, reference materials or instrumentations according to the needs;
- In a long term approach, consider the development of portable and versatile Reference Metrology Tools for performing high level on-site measurements;
- Complete skills and develop the scientific and technical expertise (modelling tools, uncertainties management and assessment, dynamic corrections of time-dependent measurements...);
- Prepare dissemination tools adapted to the needs of the end users: such as best practice guides, the upgrade of current (and development of) new written standards, training, consulting, etc.;
- A summary of the needs and solutions discussed in the breakout session is included on the workshop’s website.

This workshop dedicated to dynamic measurements in the field of thermal quantities provided a first step for exchanging and structuring the ideas. To achieve its goal this first step needs to be completed by a more thorough survey of the scientific and technical work carried out to date by NMIs, research laboratories and universities.

This work should allow the draft roadmap applied to dynamic thermal quantities to be completed. In addition and in order to develop this chapter at the international level, it will be necessary to cross this roadmap with other roadmaps developed at the regional level (Europe, Americas, Asia, and Russia). In Europe for instance it is important to follow the work of the *ad hoc* EURAMET groups (Thermal Quantities, Photometry and Radiometry) and the projects being undertaken in the context of research calls/programmes such as the European Metrology Research Programme (EMRP, with calls focused on Energy Environment, Industry, SI Broader Scope) and potentially also the EMPIR (currently under negotiation with the European Commission).

Information about the strategic prioritization of dynamic measurements as already carried out by a number of NMIs would also be useful. This should facilitate the research developments and help prioritize efforts to be provided in terms of investments and resources (manpower).

2.4 System Identification and Calibration

By Trevor Esward, Session Chair

Introduction

As calibration, uncertainty analysis and system identification are fundamental to all the science and application areas that were considered during the workshop, it is useful to begin with a short summary of some key issues that arose during presentations to the plenary sessions.

- Step function inputs are a common feature of many measurement and calibration systems and the responses to such inputs are almost always analysed using transfer function methods, often with the assumption that one is dealing with a linear time-invariant first order system. The measurement task then becomes how to estimate the time constant of the system. More complex systems were presented during the workshop, but the step function is a popular input signal for calibration and system identification in a wide range of metrology applications.
- There is a need for a clear definition of a dynamic measurement. Some practitioners (typically experimentalists in NMIs and in industry) adopt a pragmatic definition on the following lines: a *dynamic* measurement is a measurement where the physical quantity being measured (the measurand) varies with time and where this variation may have a significant effect on the measurement result, e.g., there is a need to correct the output of the measuring system for bandwidth limitations associated with the sensors, amplifiers and filters that are part of the measuring system.
- It is often not possible to find out what signal conditioning and signal processing routines are embedded in commercial instrumentation as many manufacturers regard these routines as part of their intellectual property and are not willing to disclose the details. This is unacceptable for uncertainty analysis purposes, as reliable uncertainty evaluation requires one to have knowledge of all factors that have an influence on the estimate of the measurand, including those influences that arise from data processing operations. A solution may be the provision of test data sets for dynamic measurement applications with which the embedded routines may be tested.

- It is important to recognise that uncertainty evaluation is not simply a measurement task, where one evaluates the uncertainty associated with an estimate of a measurand, but is also relevant to modelling, because all models are simplifications of the world, and choices of boundary and initial conditions and of solution methods affect the quality of the model output. In addition, data, such as those relating to material properties and other inputs to models, have their own associated uncertainties that arise because the data were derived from measurements or from models.

Conclusions from the breakout session discussions

The breakout session for system identification and calibration considered five topics to which it attempted to provide at least provisional answers. These are listed below and in each case the main conclusions from the breakout session are summarized.

1. *Guide to the expression of uncertainty in measurement (GUM): to what extent is it currently understood and used by industry metrologists, and can the GUM methodology be applied easily to industrial dynamic measurement problems?*

   Sascha Eichstädt of PTB's Data Analysis and Measurement Uncertainty Group gave a short presentation in which he argued that the GUM methodology and its requirement to begin by specifying a measurement model could not be implemented for the case in which the measurement problem is to estimate a function of time (space, wavelength) rather than a single-valued measurand. However, he mentioned two recently developed methods for cases in which the time-varying measurand has been discretised, so that it may be represented as a vector rather than as a function. The presentation is available on the workshop's website.

   There is a belief that the GUM in its present form is not easily understood by industrial metrologists. It might be helpful if at least one existing member of JCGM WG1 were given the responsibility for ensuring that the GUM takes into account industry views and requirements. In addition, there is a need to define what is meant by a *dynamic measurement*, as this is not currently addressed by the International Vocabulary of Metrology (VIM).

2. *How are dynamic measurement tasks tackled at present*: *ignore the problem and use static calibration data in dynamic situation, or make many repeat measurements to gain confidence in data but without reliable uncertainty analysis?*

   There was agreement that it is currently a common industrial practice to use either static calibration data to interpret dynamic measurements or to assess only repeatability and reproducibility of measurements rather than to perform uncertainty evaluations that attempt to take dynamic effects into account.

3. *Do we need new mathematics or new measurement/ sensing methods, or both, i.e., new sensors with sufficient bandwidth, or new deconvolution and signal*

correction methods? In addition, what is the current extent of signal processing expertise in industry?

For many dynamic applications it is not simply the limited bandwidth of a sensor that has to be taken into account but also the environment in which the sensor is to be mounted and used, as environmental effects couple to the sensor or act as additional loads.

Signal processing expertise in industry is probably sufficient for instrumentation and control purposes, and in cases in which commercial software packages such as LabVIEW, Matlab and Simulink are used. It is in uncertainty evaluation that there may be opportunities for improvement.

4. *How can NMI maths and uncertainties experts best support industry partners who have dynamic measurement problems?*

   The conclusions relevant to this question can best be understood by reference to the final slides from the presentation by Peter Loftus from Rolls-Royce, specifically that NMIs should engage with industry at the “system level”, consider in-situ calibration methods, and develop generic tools to support uncertainty analysis for dynamic applications. A pragmatic approach is required and there is an opportunity for the international metrology community to lead improvements in industry provided it is sensitive to context.

5. *Calibration certificates of the future, what might they look like: lists of numbers on paper, or software for digital correction filters?*

   Little thought has been given within NMIs to methods of disseminating the results of dynamic calibrations. There is a need for on-going dialogue between NMIs and industry about the nature of the information to be provided and how it might best be used.

3. Other dynamic measurement workshops

The international workshop series on Analysis of Dynamic Measurements, organized jointly by PTB, LNE and NPL as part of EURAMET interdisciplinary collaboration no. 1078 (Development of methods for the evaluation of uncertainty in dynamic measurements), provides the opportunity for specialists in dynamic measurement problems from NMIs, industry and academia to discuss their work and share experiences. The next workshop is planned for the spring of 2014 to take place in Turin and will represent an opportunity to continue the discussions that have begun at this BIPM workshop.

Acknowledgements

The BIPM and the Scientific Steering Committee express their thanks to the NMIJ/AIST (Japan) for their financial contribution to this Workshop. We thank the speakers for their valuable contributions, and of course the BIPM staff for their help with organizing and hosting this event.

Appendix 1: Programme of the Workshop

15 November 2012

09:00-09:10 Opening remarks, Prof. Michael Kühne, Director, BIPM
09:10-09:30 Statement of the objectives, Dr Takashi Usuda, NMIJ/AIST,

Session 1 Dynamic Mechanical Quantities (Force, Torque, Vibration, etc.)
Chairman: Dr Thomas Bruns, PTB
Co-Chairman: Dr Takashi Usuda, NMIJ/AIST

09:30-10:15 Invited talk 1
Title: Requested reliability of dynamic mechanical measurement in mobility, from automobile to service robot
Speaker: Dr Tatsuo Fujikawa, Japan Automobile Research Institute, Japan

10:15-11:00 Invited talk 2
Title: Challenges in dynamic torque and force measurement with special regard to industrial demands
Speaker: Dr André Schäfer, Hottinger Baldwin Messtechnik GmbH (HBM), Germany

11:00-11:30 Coffee break

11:30-12:15 Invited talk 3
Title: Dynamic measurements for mechanical quantity standards, from NMIs to industries
Speaker: Dr Gustavo Ripper, INMETRO

12:15-12:30 Discussion for Session 112:30-13:30 Lunch

Session 2 Dynamic Fluid and Flowmetry
(Pressure, temperature, and volume of fluid)
Chairman: Dr John Wright, NIST
Co-Chairman: Dr Fredrik Arrhen, SP

13:30-14:15 Invited talk 4
Title: Dynamic Liquid Flow Applications and Methods for Measuring Flow Meter Dynamic Response
Speaker: Mr Chuck Gray, Micro Motion, United States of America

14:15-15:00 Invited talk 5
Title: Flow Measurements for Gaseous Fuel Dispensers
Speaker: Dr John Wright, NIST

15:00-15:15 Discussion for Session 2

15:15-15:45 Coffee break

Session 3 Thermophysical Quantities
(Thermal properties, material properties, etc.)
Chairman: Dr Jean-Remy Filtz, LNE
Co-Chairman: Dr Takashi Usuda, NMIJ/AIST

15:45-16:30 Invited talk 6
Title: Response time of temperature sensors for civil nuclear applications
Speaker: Dr Ronan Morice, LNE, France

16:30-17:15 Invited talk 7
Title: Dynamic measurements of thermophysical properties for material metrology standards
Speaker: Dr Tetsuya Baba, NMIJ/AIST

17:15-17:30 Discussion for Session 3

17:30-18:00 Summary of the day (by Dr Takashi Usuda)

16 November 2012

Session 4 System identification and calibration
(Numerical analysis, GUM etc.)
Chairman: Dr Trevor Esward, NPL
Co-Chairman: Dr Thomas Bruns, PTB

09:00-09:45 Invited talk 8
Title: Industrial Requirements for Dynamic Measurements and the implications for metrology
Speaker: Mr Peter Loftus, Rolls-Royce, United Kingdom

09:45-10:30 Invited talk 9
Title: System identification and uncertainty analysis for challenging dynamic measurement applications: a case study in micro-Newton level force measurement
Speaker: Dr Ben Hughes, NPL

10:30-10:45 Discussion

10:45-11:15 Coffee break

Breakout sessions in 2 groups, 2 time slots

11:15-12:00
Mechanical Quantity: Chaired by Dr Thomas Bruns,
Thermophysics: Chaired by Dr Jean-Remy Filtz

12:15-13:00
Fluid and Flowmetry: Chaired by Dr John Wright,
Modelling and Uncertainty: Chaired by Dr Trevor Esward

13:00-14:00 Lunch

14:00-15:30 Wrap-up session
Chairman: Dr Takashi Usuda, NMIJ/AIST

15:30 Adjourn