MANAGEMENT AND PRODUCTION ENGINEERING

INRIM - Advanced Metrology for Management and Production Engineering

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Context of the research activity	The Thematic Grant includes six research Topics (listed below), with a specific title and proponent Supervisor/s. The applicants have the possibility to identify the specific topic they are interested in. Topic 1: Development of nano and micro force primary standards Topic 2: Development of new micro-Laser Doppler Vibrometer (µ-LDV) technique for the improvement of traceability in Instrumented Indentation Testing Topic 3: Traceability for indentation measurements in Brinell, Vickers and Knoop hardness Topic 4: Ultra-high Precision Absolute Earth Gravity Measurements Topic 5: Optical sensors for next generation telecommunication satellites Topic 6: An holistic approach to process measurements at the factory floor: from MEMS sensors to AI industrial applications
	Topic 1: Development of nano and micro force primary standards The development of micro- and nano- force standards is becoming increasingly important in the fields of advanced manufacturing, micro-electromechanical systems (MEMS), microfluidics, nanotechnology and pharmaceutical and medical devices. High accuracy surface tension and mechanical properties of materials measurements will be crucial in improving production processes and assessing its quality, particularly where coating or nano-deposition processes are used. In the above areas new measurement technologies are being or have been developed and the key is applying the technologies to specific measurands and to achieving acceptance by the end-user communities. However, the development of accurate and reliable measurement techniques for forces at these scales is still in its infancy. This

proposal aims to address this gap by developing micro- and nano-force primary standards that can be used to calibrate and verify the accuracy of force measurement devices at these scales. As a result, there is a need to develop new techniques and standards to generate known accurate and reliable force measurements at low uncertainty levels. The objectives of this proposed PhD thesis are to:
1. Develop micro- and nano-force primary standards that can be used to calibrate and verify the accuracy of force measurement devices at these scales.
2. Investigate the effects of surface interactions, friction, and adhesion on micro- and nano-force measurements.
3. Evaluate the related uncertainties and influencing factors
4. Develop computational models to simulate micro- and nano-force interactions and investigate the factors that influence measurement accuracy

Topic 2: Development of new micro-Laser Doppler Vibrometer (µ-LDV) technique for the improvement of traceability in Instrumented Indentation Testing
Instrumented indentation testing (IIT) is a widespread mechanical characterisation technique that, for its flexibility, speed and non-destructiveness, meets quality control requirements of Industry 4.0 and European Green Deal. IIT achieves thorough, bulk-to-local, mechanical characterisation of many properties, as Young's modulus, stress-strain curves, which conventionally require costly destructive tests. Traceability is key for industrial adoption of IIT. However, as noted by literature, several calibration methods are available but are impractical and ambiguously defined. By applying a new developed microscopy technique, based on micro-Laser Doppler Vibrometer (µ-LDV), and by investigating measurement uncertainty influence factors, this proposal aims to develop robust and practical calibration methods to improve traceability.
The objectives of this proposal are to:
1. Develop an improved practical and clear direct and indirect calibration methods for frame compliance of IIT devices, catering for different test scales (nano, micro, macro) and technologies, catering for frame compliance nonlinearity, and report sensitivity analysis of main influence factors for measurement uncertainty
2. Develop an improved practical and clear direct and indirect calibration methods for indenter tip geometry and area shape function, based on micro-Laser Doppler Vibrometer Microscopy (µ-LDV) analysis, catering for different test scales (nano, micro, macro)
3. Develop a dynamic calibration framework for IIT devices used for dynamic mechanical characterisation of materials, which includes the identification of suitable ¿-LDV techniques and related measurement uncertainty, catering for different test scales (nano, micro, macro) and technologies. This will entail strict prescription in terms of experimental procedure, mathematical modelling and governing factors. Investigation shall address three ranges of IIT (nano, micro and macro), as per ISO 14577-1:2015

Topic 3: Traceability for indentation measurements in Brinell, Vickers and Knoop hardness
Hardness is an important mechanical property of materials that not only specifies the surface strength of products, but also gives us information about other mechanical properties. For this reason, it is very important to perform precise and accurate, briefly reliable hardness measurements in almost all fields of engineering. Some of the most important hardness measurement methods are Brinell hardness, Vickers hardness and Knoop hardness, where

Objectives	hardness measurement is mainly based on the determination of the size of a residual indentation, the measurement of which is completely dependent on the imaging and processing instruments, operators and any software used, and there is significant inconsistency among testing laboratories due to the lack of a well-defined indentation measurement methodology. In this PhD activity, it is aimed to overcome this problem by studying the parameters that influence indentation measurements for different instruments, methods, operators and software, and constitute a methodology for consistent and traceable hardness measurements at the level of National Metrological Institutes and calibration and testing laboratories. The proposal is part of an European project funded by EURAMET. The objectives of this PhD proposal are to: 1. Determine the geometry of the 3D impressions in materials of different hardness using the three different methods to cover the different curvatures of the indent and find out at which point the indenter was still in contact with the material during the indentation attempt comparing it with the classic measuring method 2. Investigate the influence of short-term creep, indenter's geometry, temperature, instrumentation, and the alignment of the applied load in Brinell, Vickers and Knoop hardness tests. 3. Develop a model describing the effects of the various application conditions in relation to the different types of hardness testing machines at NMI, calibration laboratory and user levels 4. investigate the possibility of performing automatic measurements of the diameter of circular shaped Brinell indentation, the diagonal length of square shaped Vickers indentation and diagonal length of equilateral shaped Knoop indentations. Topic 4: Ultra-high Precision Absolute Earth Gravity Measurements The value of the local acceleration due to gravity and its variations with time is of interest in a wide field of physical sciences, such as metrology, geophysics and geodesy. Factors that account for the gravity changes are the earth's rotation, departures of its surface from an equipotential spheroid, density variations that occur within the earth, geodynamical and tectonic processes. Measurements of the acceleration due to gravity are performed by absolute gravimeters, traceable to the units of length and time. For decades, at INRiM, a transportable ballistic rise-and-fall absolute gravimeter (IMGC-02), which is the current Italian primary standard, has been developed and maintained. It uses laser interferometry to measure the symmetrical free rising and falling motion (unique instrument in the world adopting symmetrical motion) of a test mass in the gravity field with a relative uncertainty in the order of 10-9. Nevertheless, the system, beyond needing further improvements to perform more accurate launches, to reduce vibration transmission and to decrease the uncertainty related to the observation site, is rather overperforming for the uncertainty levels (around 10-5) required by calibration laboratories, thus a new transportable and more suitable absolute gravimeter has to be developed. The PhD activity will be mainly focused on such tasks. The PhD candidate will be also involved in in-situ measurements, comparisons and relevant activities aimed at realizing a reference network for absolute gravity and at establishing the International Height Reference System/Frame (IHRS/IHRF) in the Italian area. Such a task is part of a research project of relevant national interest funded by MUR. The PhD course will include: • theoretical and experimental activities to improve the IMGC-02 transportable absolute gravimeter, and in particular, the inertial reference

	system, the new launch system, and the other influence factors • development of a new transportable and more suitable absolute gravimeter addressed for calibration laboratories at an uncertainty level of 10 5 • measurements on different observation sites, mainly in Italy • scientific support in the realization of a reference network for absolute gravity and at establishing the International Height Reference System/Frame (IHRS/IHRF) in the Italian area Topic 5: Optical sensors for next generation telecommunication satellites Next generation telecommunication satellites will operate on higher bands (Q/V band) and with more accurate antenna pointing with respect to actual satellites. For this purpose, they will be equipped with large diameter reflectors (of the order of 10 m) which will have to be oriented towards the target with extremely high accuracy. At the same time, the satellite uses a star tracker to define its orientation with respect to space, so it is necessary to establish a metrological link between the star tracker and the antenna. To this end, ESA commissioned INRIM to design an optical device called ATOM (attitude optical monitor) which measures the differential attitude of the two objects on three angular degrees of freedom: pitch, yaw and roll. The objective of the PhD research is the realization of the device, the test and modeling of the single functional parts, the realization and testing of the vacuum chamber used for the characterization and execution of the test campaign. Topic 6: An holistic approach to process measurements at the factory floor: from MEMS sensors to AI industrial applications The perspective candidate will work on one or more of the following research topics, according to her/his affinity, knowledge and skill: · Measurements of physical, technological and environmental quantities by means of MEMS sensors and uncertainty estimates associated with industrial processes. This would include the selection and analysis of specific industrial processes, the identification of key process parameters, and the metrological characterisation and validation of measuring instruments · Application of AI (artificial intelligence) methods to improve the metrology involved in selected industrial applications, from the measurement process to the development of a digital calibration certificate (DCC). · Investigation of IIoT (Industrial Internet of Things) systems for real-time data acquisition and processing. This would include the integration of MEMS sensors in a process for the monitoring of a production system and the identification of process KPIs.

Skills and competencies for the development of the activity	Topic 1 Skills on mechanical measurements, measurement uncertainty assessment, Finite Element Method (FEM) programs, Matlab and LabVIEW development environment are appreciated, but not mandatory.Topic 2 Topic 2 Skills on mechanical measurements, measurement uncertainty assessment, Finite Element Method (FEM) programs, Matlab and LabVIEW development environment are appreciated, but not mandatory. Topic 3 Skills on mechanical measurements, measurement uncertainty assessment, Finite Element Method (FEM) programs, Matlab and LabVIEW development environment are appreciated, but not mandatory. Topic 4 Electronic prototyping, signal processing and conditioning, dynamic systems control and integration, mechatronics automation, mechanical

the activity	measurements, optical-interferometric systems, measurement uncertainty assessment, Finite Element Method (FEM) programs, Simulink and hardware in the loop, LabVIEW and C ++ development environment are appreciated, but not mandatory. Topic 5 Electronics, matlab simulation, image analysis, finite elements analysis, optics Topic 6 Basic knowledge in metrology (measurements of physical quantities). Basic knowledge of measurement and control systems and its management. Basic knowledge in statistics, data management and processing. Knowledge of the principles of laboratory instrumentation.