Detailed description of the proposed research

Title: Development of force primary standards in the nano and micro ranges

Description:
The development of micro- and nano-force standards is becoming increasingly critical in advanced manufacturing, micro-electromechanical systems (MEMS), microfluidics, nanotechnology, and pharmaceutical and medical devices. As these fields continue to evolve, the ability to measure and control forces at such small scales with high accuracy is essential for improving production processes, ensuring quality control, and enhancing the performance of emerging technologies.

A fundamental challenge in these domains is the absence of reliable traceability to the International System of Units (SI) for force measurements at the micro- and nano-scale. While force calibration in the macroscopic range is well-established and directly traceable to SI units via primary standards such as deadweight force machines, no universally accepted and traceable primary standard currently exists for forces in the micro- and nano-newton range. This lack of SI-traceable force standards presents significant obstacles for industries and research fields that require precise and repeatable force measurements at these scales.

Accurate determination of mechanical properties, surface tension, and adhesion forces is particularly crucial in applications involving thin films, coatings, and nano-deposition processes. Even slight inaccuracies in force measurements at these levels can lead to significant variations in material behavior, device performance, and product quality. In the absence of established SI-traceable micro- and nano-force standards, laboratories and manufacturers are forced to rely on independent, often inconsistent, calibration methods, leading to discrepancies in measurement results and a lack of comparability between different systems and institutions.

In response to these challenges, there has been a growing effort to develop new force measurement technologies. However, their practical implementation is hindered by the absence of a reference framework that ensures traceability to SI. The development of accurate and standardized force measurement techniques remains in its infancy, with many existing methods either lacking precision or failing to provide sufficiently low uncertainty levels required for high-precision applications.

This proposal aims to address this gap by developing micro- and nano-force primary standards that are directly traceable to SI units. These standards will provide a foundation for calibrating and verifying force measurement devices at these scales, ensuring that measurements are both accurate and comparable across different laboratories and industries. Establishing SI-traceability at these force ranges will significantly enhance confidence in force measurements, supporting the broader scientific and industrial communities in their pursuit of higher precision and reproducibility.

In addition to developing primary standards, this research will focus on understanding and mitigating the key factors that influence force measurements at small scales, including surface interactions, friction, adhesion, and environmental variables such as humidity and temperature. These influences become increasingly significant at the micro- and nano-scale and must be rigorously characterized to establish reliable force measurement techniques with SI-traceable accuracy.

A complementary approach will involve the development of computational models to simulate micro- and nano-force interactions. These models will aid in understanding the fundamental behaviors of forces at these scales, allowing for the refinement of experimental techniques and measurement methodologies. Simulations will also help identify sources of uncertainty and inform best practices for achieving low-uncertainty, SI-traceable force calibrations.

The primary objectives of this proposed PhD thesis are as follows:

1. Develop micro- and nano-force primary standards traceable to SI units to establish a reliable framework for force calibration at these scales.
2. Investigate the effects of surface interactions, friction, and adhesion on micro- and nano-force measurements to improve understanding and reduce uncertainty.
3. Evaluate uncertainties and influencing factors to enhance measurement accuracy and ensure low uncertainty in force calibrations.
4. Develop computational models to simulate micro- and nano-force interactions, contributing to improved measurement techniques and standardization.

By achieving these objectives, this research will provide a critical advancement in the field of precision force measurement, bridging the existing gap in SI-traceability for micro- and nano-force ranges. The development of standardized, SI-traceable force measurement techniques will support innovations in high-precision industries, improve the reliability of scientific research, and facilitate the widespread adoption of next-generation measurement technologies.