THE SMART ELECTRONIC UNIT FOR PRECISE MEASUREMENT OF REFRACTIVE INDEX OF AIR IN A NANO-POSITIONING STAGE FOR SCANNING PROBE MICROSCOPY (SPM)

Václav HUCL, Martin ČÍŽEK, Zdeněk BUCHTA, Břetislav MIKEL, Josef LAZAR and Ondřej ČÍP

Institute of Scientific Instruments Academy of Sciences of the Czech Republic, Královopolská 147, 612 64 Brno, Czech Republic, e-mail: treak@isibrno.cz

Abstract

When the traceable measurement of dimensions of samples in scanning probe microscopy is needed the position of the probe tip has to be monitored by a set of laser interferometers. The measurement is done very often during standard atmospheric conditions so the changes of the refractive index of air have an influence to measured values of the length with $1.0 \times 10^{-4}$ relatively. Thus the measurement of the refractive index of air and application of the instantaneous value of the index to all of measurement interferometric axes is necessary. In the work we developed new concept of electronic unit which is able to monitor the refractive index of air on basis of measurement of weather conditions: temperature, humidity and pressure of the air. The unit uses modified Edlen formula for calculation of the refractive index. The next step of the work is verification of accuracy of the measuring capability of the unit. We tested the accuracy with reference unit which measure the refractive index of air by a set of etalon sensors. The expected accuracy of the smart electronic unit falls to the $4.1 \times 10^{-7}$ relatively. The important advantage of the unit is very low power consumption of electronics so the unit causes very small temperature effects to the measuring process.

Keywords:
Refractive index of air, precise measurement, laser interferometer

1. INTRODUCTION

The refractive index of air is very important value which makes an influence to precise laser measurement of lengths in the field of nanometrology. When a position of the scanning probe in the atomic force microscope is required a laser interferometry system is used. The precision of the position of the movable stage is then calculated on values from several interferometers at the same time. In this case each interferometer measures one axis of freedom. Usually the scanning of the sample is provided in the air and in this case measured values from interferometers have to be compensated by the value of refractive index of air. The main problem during the measurement of the refractive index is in homogeneity of the air close each interferometric axis. For this purposes there is necessary to have the measuring probes of refractive index of air unit at the same level to of height to preventing possible different gradients in this area.

2. METHODOLOGY

For simple and relatively precise measurement of the refractive index of air the non-direct measurement is possible. It leads to measurement of different quantities of the ambient air which bound the measuring area: temperature, relative humidity and air pressure. From known values of these quantities we are able to calculate this index on basis of several empiric formulas as Edlen [1], Bonsch and Potulski [2], Ciddor [3], or Fira [4]. In several cases also an additional measurement of concentration of few gasses is necessary to improve the precision of measurement.

In general all of above mentioned formulas came from fundamental equation founded by Edlen [1] by empirical measurement and comparison of calculated values with direct measurement of the index by interferometric way, i.e. laser refractometers [5,6]. Thanks to many years of verification and testing of the
Edlen formula some modification were done. The modified Edlen formula was calculated with the concentrations of the N2 (78.09%), O2 (20.95%), Ar (0.93%) and CO2 (0.044%). The relative accuracy of this formula is $1.0 \exp(-7)$:

$$(n-1) \cdot 10^{-6} = 2.87782 \cdot P \cdot \left[ \frac{1 + P \cdot (6.01 - 0.0972T) \cdot 10^{-6}}{1 + 0.003661 \cdot T} \right]$$

$$6.49 \cdot H \cdot (1.0005 + 2.3 \cdot T + 3.1 \cdot P)$$

where $T$ is the temperature of air [°C], $P$ is the pressure [Pa] and $H$ is the relative humidity [%].

On basis of the modified Edlen formula is possible to put together the measuring unit which has implemented a set of precise sensors, signal processing and final calculation of the refractive index of air in real-time.

3. EXPERIMENTAL SETUP

The subject of the work is a smart electronic unit which is able to measure the refractive index of air with high accuracy and in real-time. The necessary task of the unit is also in fast transfer the measured values into the central electronics where data from the multi-axes interferometer system is captured. The schematic diagram of the unit for precise measurement of the refractive index of air is presented in Fig. 1.

![Schematic Diagram of the Unit](image)

**Fig 1.** Schematic diagram of the smart electronic unit for precise measurement of the refractive index of air.

The main core of the electronic unit is the single-chip microcontroller Freescale 68HC08 [7], which is used to collecting data from sensors, calculation of the refractive index of air and transmitting measured and calculated data to PC. All of sensors are connected to the unit by a set of separated 16-bit Sigma/Delta Analog/Digital converters Analog Devices AD7715 [8]. This set of converters is chosen due to the requirement of very high resolution of each quantity and to prevent a possible noise coming from sensors and random electromagnetic spikes. The single-chip microcontroller does also a communication with PC through a serial communication bus. In that case we use Controller Area Network bus (CAN) [9] with CANopen communication protocol [10].

To temperature and humidity measuring is used sensor Humirel HTM2500 [11], which have integrated in one package both sensors. The temperature sensor is NTC thermistor type and measured temperature is evaluated from resistivity change on basis of calibration curve. The humidity sensor is capacitive one with special solid polymer structure, which has a high protection to chemicals and has the fast response time.
The humidity value corresponds to the value of voltage at the output of the sensor. The pressure is measured by Motorola MPXH6101A [12] piezoresistive transducer, which is based on silicon pressure probe. The air pressure corresponds with the value of voltage at the output as well as at the humidity sensor.

![Fig 2. Final realization of unit for precise measurement of refractive index of air](image)

We designed the unit for connecting of three additional temperature sensors which can be used to monitoring of the temperature in crucial part of the experimental setup with the scanning probe microscope. They are situated for temperature measurement of: the frame, the translation stage and the probe holder. Input circuits for additional sensors are designed for connecting Analog Devices AD22100 sensors [13], those are ratiometric temperature integrated circuits whose output voltages are proportional to the temperature in linear dependence.

![Fig 3. User interface to display measured and calculated values](image)

The unit is designed with the stress to minimizing of the power losses in the measuring area. All of circuits are chosen as a low-power. The view of the completed electronics is in Fig. 2. There are no voltage stabilization circuits or other heat producing devices. All of these parts are separated to the supplying card inserted into the main electronic rack where detection of interferometric values is also provided. The print-screen of the graphic user interface is in Fig. 3, where instantaneous value of the refractive index is visible.
4. EXPERIMENTAL RESULTS
Before the installation of the smart unit we provided calibration of all measuring sensors. We used etalon sensors from Vaisala company [14]. Then we put together experimental testing frame where Vaisala measuring unit for humidity, pressure and ambient temperature is used. We also installed the smart unit. Then we provided long-time measurement of the refractive index of air. The resulted values of all quantities are shown in Fig. 4.

![Graphs showing experimental results](image_url)

**Fig 4.** The record of values measured by the smart unit (red) and by Vaisala system (blue).
At the bottom record we have difference between measured refractive index of air values between Vaisala system and our smart electronic unit. As is visible the average difference for 80 ours of measurement is in 4.1exp(-7) level. This possible deviation can cause 0.4 nm errors for 1 mm range of scanning in the microscope.

5. CONCLUSION
The presented work showed the principle of measurement of the refractive index of air by non-direct Metod. We described technological scheme of the smart electronic unit which is very useful for measurement of the index in scanning probe microscopes. We presented comparison our unit with the Vasala etalon unit. We observed deviation of the refractive index measurement in 4.1exp(-7) level what is very low value. The unit is eligible to use with precise scanning probe microscopes equipped with multiaxes interferometric measurement system.

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REFERENCES