A NEW METHOD FOR DIRECT MEASUREMENT OF REFRACTION INDEX OF AIR WITH AN OPTICAL RESONATOR

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ABSTRACT

Interferometer methods are used for the high accuracy measurement of distance by specifying the measurement of the air index. Since the measurement of the refraction index of air is in atmosphere, the refraction index of air is dependant upon temperature, pressure and humidity. For the measurement of the refraction index of air, Eden's formula [1] is usually used. The formula depends upon the atmospheric values and the CO_2 concentration.

1 THE MEASUREMENT OF THE REFRACTION INDEX OF AIR BY THE FABRY-PEROT INTERFEROMETER

The refraction index of air is very important and does not have any value of units, which determines the optical density of the environment. We can write: $n = \frac{\lambda_0}{\lambda}$, where λ is the wavelength of the electromagnetic radiation in an environment and λ_0 is the wavelength of the radiation with some frequency in a vacuum.

The measurement of the refraction index of air by the Fabry-Perot interferometer calculates the refraction index of air using the Eden's formula, which has an accuracy of 10^{-6} and consequential it is the specification used by the Fabry-Perot interferometer. This is the direct method of measurement of air and has an accuracy of 10^{-8}.

Fabry-Perot (F.P.) interferometer is an optical resonator. For the interferometer with plan parallel mirrors (1) expresses the relationship between distance of the mirror and the resonance as such:

$$2nd = \lambda_0 (m + e) \qquad (1)$$

n –the refraction index of air of the environment in the F.P. interferometer

d –mirror distance
m –the whole resonance order
e – fraction order of the resonance
λo –the wavelength of the laser etalon in the vacuum

The Fabry-Perot interferometer for measurement of the refraction index is composed of two circuit mirrors. The area between the mirrors is divided into an inner and outer part. The inner par is permanently evacuated and the outer part is in the atmosphere.

$$d = \frac{\lambda_o}{2}(m_1 + e_1) \quad \text{(1a)}$$

$$d = \frac{\lambda_o}{2n}(m_2 + e_2) \quad \text{(1b)}$$

The design of the construction of the Fabry-Perot interferometer is very important. The distance of the mirror of the inner and outer parts has to be the same. Therefore we have chosen a special connecting material called Zerodur, which has a low thermal expansivity of only $5x10^{-8}$ m/K. Hence constant temperature expasivity is very important factor for our measurement.

The whole resonate order is defined as how many half wavelength are between the mirrors of the resonator. The fraction order of the resonance is described as the untuned resonator and defined as the fraction of half-wavelength over whole resonance order. If it is the frequency of the laser beam in the resonance then $e_{1,2} = 0$.

To determine the interval where the exact value of the refraction index of air, which is calculated from the Edlen formula. From knowledge of atmospherics values and using the Edlen formula the value of the refraction index of air has been calculated to have an accuracy of 10^{-6} and consequentially a specification up to 10^{-8} by the Fabry-Perot interferometer. The range of the value of refraction index of air is shown in the next equation (2).

$$n_2 - n_1 = \frac{\lambda_0}{2d}\left(m_2 - m_1 + e_2 - e_1\right) = \frac{\lambda_0}{2d}\left(\Delta m + \Delta e\right) \quad \text{(2)}$$

where m_1 is whole count of half-wavelength in the inner part and m_2 is whole count of half-wavelength in the outer part of interferometer.

After tuning both lasers to the resonance of the Fabry-Perot interferometer ($e_{1,2}=0$), the difference between the counts of the half-wavelength of the laser beams in both parts of the interferometer, which is the maximal one. Thereafter we get

$$n_2 - n_1 \leq \frac{\lambda_0}{2d} = \frac{1}{2d}.\frac{c}{\nu_0} = \frac{\Delta\nu}{\nu_0}, \quad \text{(3)}$$

where $\Delta\nu$ is the distance between the resonator lines and it also describes the range of frequency where tuning is possible.

For practical use the measurement of the refraction index of air requires the difference in frequency measured between the both parts of the Fabry-Perot's interferometer. For the resonance distance line of the inner part we get equation (4), and for outer part we get equation (5).

$$\nu_1 - \nu_0 = \frac{c}{2n_1 d} \quad \text{(4)}$$

$$\nu_2 - \nu_0 = \frac{c}{2n_2 d} \qquad (5)$$

Further from (4) and (5) we get equation (6), which calculates the refraction index of air for both parts of the interferometer, which are measured from the frequency value.

$$\Delta n \cong \frac{\nu_1 - \nu_2}{\Delta \nu_{vac}} = \frac{\Delta \nu_{12}}{\Delta \nu_{vac}}, \qquad (6)$$

where we get $\Delta\nu_{vac}$ from equation (4).

2 WORKPLACE FOR MEASUREMENT OF REFRACTION INDEX OF AIR

The whole configuration is detailed in Fig. 1.

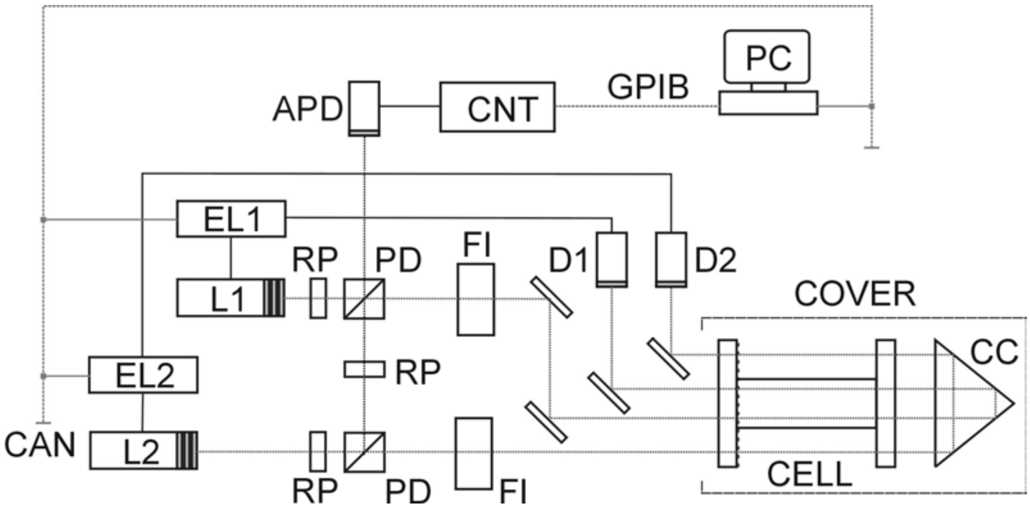

Fig. 1: *Whole configuration for the measurement of refraction index of air*

The main part of the configuration for measurement of the refraction index of air is the Fabry-Perot resonator. The resonator is divided into two parts, a permanently evacuate cell and a part which is in the atmosphere. For measurement two He-Ne lasers with the possibility for tuning resonation of modes are used.

Both laser beams are in the polarization divider *PD,* which is divided into two parts. The first part directly goes into the laser's detector with an avalanche photo diode *APD*. The second part goes through the Fabry-Perot resonator and is detected in detector *D1* and *D2*.

The suitable direction of the vector polarization of the laser beam is the half-wavelength board *RP.* The Faraday isolators *FI* are used as filters for the backward bounce of the elements of optical composition.

The electronics configuration for the driving of lasers *L1* and *L2* are very important. The whole measurement is totally automatically controlled. The frequencies of the laser beams are tuned by a personal computer PC and digitized electronics EL1 and EL2, which are connected to the PC through Controller Area Network (CAN). The signals from the photo detectors *D1* and *D2* are also sent to the PC. This works as a feedback.

Signal from the photo detector APD (radiofrequency signal) is the difference between the signals of lasers *L1* and *L2* and is sent to the counter via a GPIB bus and then to the PC. This then produces a text composed of the frequency values. These values are used to calculate the refraction index of air.

In the environment of a Fabry-Perot interferometer it measures the values of atmospheric air. For the measurement it uses a measurement unit, which contained sensors for the measurement of atmospheric pressure and relative humidity. The unit is connected to the special measuring (digitized) card. The measurement card manipulates all the measured values and sends the data via a bus CAN to the PC.

3 MEASUREMENT PROCEDURE AND SOME EXPERIMENTAL RESULTS

The refraction index of air calculates atmospheric values with an accuracy of 10^{-6}. For this calculation it uses the R.Fíra's formula. The formula is derived from Edlen's formula [1]. For our calculation the R.Fíra's formula is better to use because with the Edlen's formula it is necessary to calculate the pressure of steam with [Pa] units, but with our configuration it measures the relative humidity in [%] units.

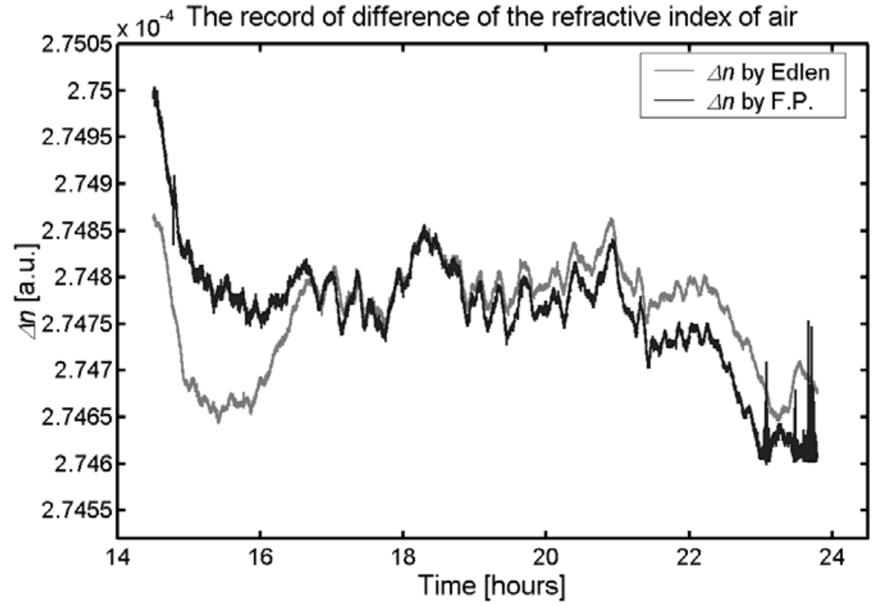

Fig. 2: *The difference in the time curves of the refraction index of the vacuum and air measured by the Fabry-Perot interferometer and calculated by Edlen formula.*

For a higher accuracy for the refraction index of air of up to 10^{-8} the designed optical configuration of Fabry-Perot interferometer is used. The lasers, *L1*and *L2* (He-Ne, 633 nm) are tuned by an electronic system for the attainment of resonance in the Fabry-Perot interferometer (d = 145,68 mm).The resonance is detected in *D1* and *D2*. On the detector output the maximal value is at the resonance. At the same time it activates a regulation feedback, which stabilizes the frequency of the lasers and holds the state of the resonance. If both parts of the Fabry-Perot interferometer are evacuated then the difference of the frequency of the lasers would have a less accurate stabilization frequency of the laser beams. The difference would be only zero potential. The outer part of Fabry-Perot interferometer is not evacuated. Hence the atmospheric air is there and therefore the speeds of the lasers beams in the outer and inner parts of Fabry-Perot interferometer are different. The difference of the lasers frequencies of lasers *L1* and *L2* are in equations (4) and (5)). The difference between the lasers frequencies are related to the difference of the refraction index of the vacuum and the refraction index of air (6).

In the scope of our experimental values the refraction index of air in our laboratory was measured. All measurements were taken over a time scale of approximately 9 hours (14.30 to 23.45). The aim of our experiment was to measure the refraction index of air in the laboratory. The times curves of the difference of the refraction index of the vacuum and the refraction index of air can be found in Fig. 2.

4 CONCLUSION

The aim of the work is the experimental verification using the refraction index of air method using a Fabry-Perot interferometer. From the long-term measurement we obtained a value of refraction index of air for the laboratory and obtained $n = 1,00024762$. The value of the refraction index of air is an average of the nine hour experimental work. The values measured by Fabry-Perot and the values calculated by Edlen's formula are different only at the beginning. An explanation for this difference can be attributed to the individual concentrations of the atmosphere before the measurement and during the measurement. The difference in this measurement carried out in the laboratory is attributed to people moving around in the laboratory. The equations calculated the individual concentrations of the air.

The accuracy of the direct method of measurement of the refraction index of air is measured by using the Fabry-Perot interferometer. The distance of the mirrors has to be determined with high accuracy. In our case it is 145.68 mm. The material for construction of interferometer has to be constructed with minimal thermal expansivity. In our case we chose Zerodur with a thermal expansivity of $5x10^{-8}$ m/K. The choice of the mirrors for the interferometer is also very important. The width of the resonance line directly depends on the reflectance of the mirrors. Hence if the width of the resonance line is small the accuracy of the fraction order of the resonance (e_1, e_2) is higher. In our case we used mirrors with reflectivity of 98,5%. It corresponds to a width of resonance line of an interferometer of 5MHz.

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