

IMPROVEMENTS IN CONTACTLESS TURBIDIMETERS WITH FREE-FALLING STREAM TECHNOLOGY

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Abstract: The paper describes the idea and the corresponding research concerning some improvements in the contactless turbidimeters designed with the so called free-falling stream technology. The aim of such improvements is to raise the metrological performance and reliability of on-line industrial turbidimeters of the mentioned type.

Keywords: contactless turbidimeter, photodetector, free-falling stream technology.

1. INTRODUCTION

Turbidity – an expression of the optical properties of a liquid that causes light rays to be scattered and absorbed rather than transmitted in straight lines through a sample. The cause of the light scattering is the presence of small particles having optical properties different from ones for the liquid medium. So it is possible to measure turbidity by light attenuation or by intensity of scattered light.

The typical field of application for such measuring devices is in the drinking water treatment process to control and monitor the quality of the different treatment steps. Other fields of application: control of demineralizers at heat electric power plants, monitoring of sewage, various processes in food industries (especially in breweries).

Every turbidimeter includes a light source and a photodetector (one or more) which can be in direct contact with a liquid medium or not. In the latter case we deal with a contactless turbidimeter.

Contactless turbidimeters possess the obvious advantage in comparison with contact ones. That is the opportunity of unattended operation over a long period of time. This opportunity takes place due to the absence of fouling on optical elements (light sources and photodetectors). Consequently there is the stable transparency of optical channels.

Two general types of contactless turbidimeters exist: with translucence of plane surface (PST) [1] and with translucence of a free-falling stream (FFST) [2]. Each of them has special constructive features and preferable working range of turbidity. Turbidimeters of PST-type are more preferable for very turbid liquids. FFST-turbidimeters are applicable in rather wide range of turbidity and have good metrological performance.

A layout drawing of FFST-type turbidimeter is shown in Fig. 1. Light is directed from source 1 through open space to a stabilized flowing water surface that is formed by a special fluid sample container 2 surrounded by catch basin 3 with a

drain. Light penetrates through water to outlet 4 in the center of container bottom and make free-falling stream illuminating in accordance with turbidity of water. Brightness of falling stream is registered by photodetector 5 separated from the stream by air gap.

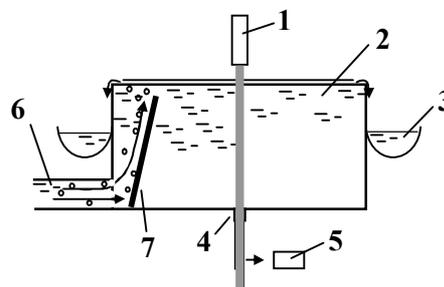


Fig. 1. FFST-type turbidimeter:

- 1 – light source; 2 - fluid sample container with water overflow; 3 - drainage; 4 - outlet; 5 – photodetector;
- 6 – inlet; 7 – trap for air bubbles

Turbidimeters of such type have susceptibility to accidental fluctuations of the falling stream direction and shape. Such fluctuations may be produced due to vibrations, instability of input flow and accidental inclinations of the sample container.

2. PROPOSED DESIGN

Some features of the proposed FFST-type turbidimeter are illustrated in Fig. 2. In addition to traditional solutions (such as sample container and drainage arrangement) authors propose and explain other elements improving measurements. For example, ring-shaped multisensor photodetector 9 allows to minimize influence of fluctuations of free-falling stream 8.

The idea to use many photosensors distributed evenly around the falling stream instead of a single photodetector is based on the following: if we use a set of photosensors with summation of their signals then the stream moving away from some photosensor would produce signal decreasing in this photosensor. However at the same time this decrease would be compensated by signal increasing in a photosensor to which the stream comes nearer.

We can make speculative assumption concerning a number of distributed photosensors: the more this number is the better the result is. However without preliminary modelling

it is difficult to conclude about a reasonable number of photosensors.

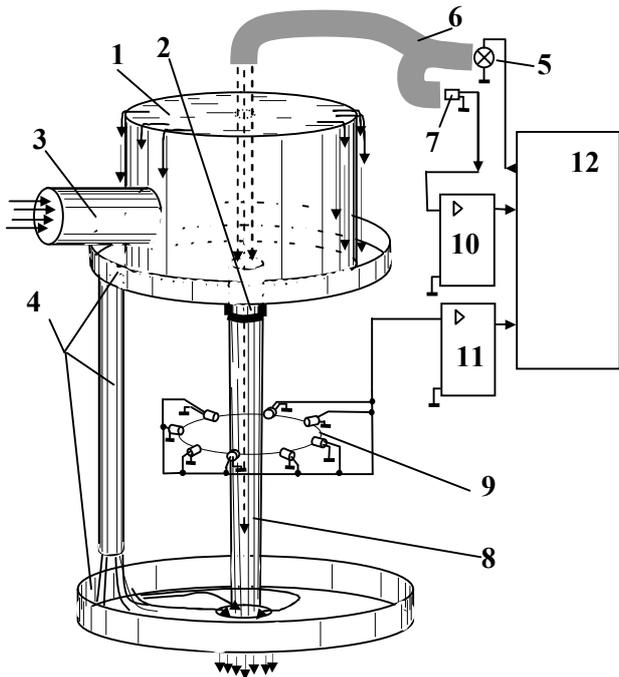


Fig.2. The proposed layout of FFST-type turbidimeter: 1 – sample container with water overflow; 2 – bottom outlet; 3 – inlet; 4 – drainage system; 5 - light source; 6 – dual track fiber bundle; 7 - photodetector; 8 – free-falling stream; 9 - ring-shaped multisensor photodetector; 10,11 – amplifiers; 12 - controller

3. MODELLING

Suppose the multisensor photodetector consists of N sensors (s.1..s.N) distributed evenly along a circumference of radius R around the falling stream. A cross-section of the stream in the plane of the distributed sensors is shown in Fig.3. The centre of the stream cross-section 1 is located in the centre of the rectangular coordinate system with axes X and Y . Deviated location of stream cross-section 2 may be in any point inside the circumference.

The mathematical model for estimation of behavior of the sum u of all sensors' signals u_i as a function of Δ and α was developed, where Δ – deviation of the stream, α – an angle between the deviation direction and the axis X . The model was developed under certain assumptions, such as:

- 1) cross-section of the stream is considered as an illuminating point and only this point was examined;
- 2) output signal of each sensor is in a direct proportion to cosine of incidence angle (θ);
- 3) illuminance at the input of a sensor is in an inverse proportion to square of distance r between the source (the centre of the stream cross-section) and a sensor.

Finally the model was obtained as it follows:

$$u_i = \frac{kI \left(R - \Delta \cos \left(\frac{2\pi(i-1)}{N} - \alpha \right) \right)}{\left(\Delta^2 + R^2 - 2R\Delta \cos \left(\frac{2\pi(i-1)}{N} - \alpha \right) \right)^{3/2}} ;$$

$$u = \sum_{i=1}^N u_i ,$$

where I – brightness of the source; k - proportionality coefficient; i – index number of a sensor.

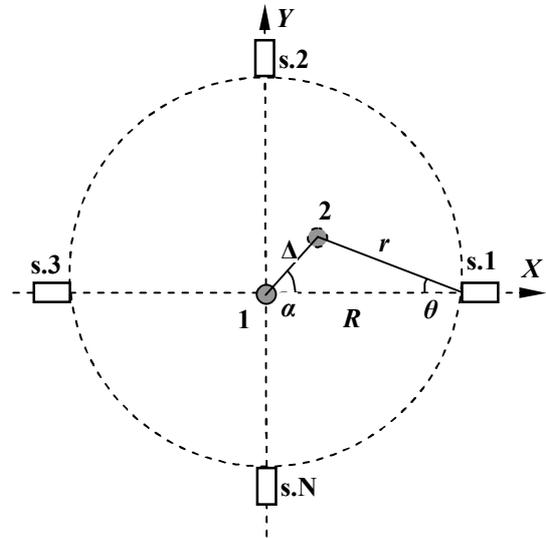


Fig.3. Cross-section of the falling stream in the plane of the distributed sensors

The model allowed to obtain 3D-plots (Fig.5) for the relative estimation of u as a function of Δ and α . The results were calculated as ratio u/u_0 , where u_0 is the sum of sensors' signals with the not deviated stream. So we can observe the behaviour of the summary photosensors signal shift induced by stream deviation. The plots in Fig.5 show the ratio u/u_0 for different values of the photosensors number N .

A relative shift of u may be expressed percentagewise as well. Thus, the value $u/u_0 = 1,6$ corresponds to 60%, $u/u_0 = 0,8$ corresponds to -20% and so on.

Note that if $N > 3$ the shift of u is always positive ($u/u_0 > 1$). Increasing N we can significantly improve the ratio u/u_0 . It means that application of the proposed multisensor photodetector proves its efficiency. But if N is greater than 8, the maximal value of the ratio (under the determined value of $\Delta = 2$ mm) is stable and equals 1,03 (3% of u_0). Obviously, it is not reasonable to increment this number further.

Therefore, the described solution doesn't exclude influence of the stream deviation completely. The cause of the boundedness is in nonlinear dependence of u_i on r and θ .

Hypothetically, a certain conversion f must exist which, after application to each of sensor signals u_i before their summation, would help to produce a result u not depending on the stream deviation (Fig.4).

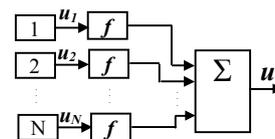


Fig.4. The proposed conversion scheme

Really, we found out a few types of simple conversions that provide a satisfactory results.

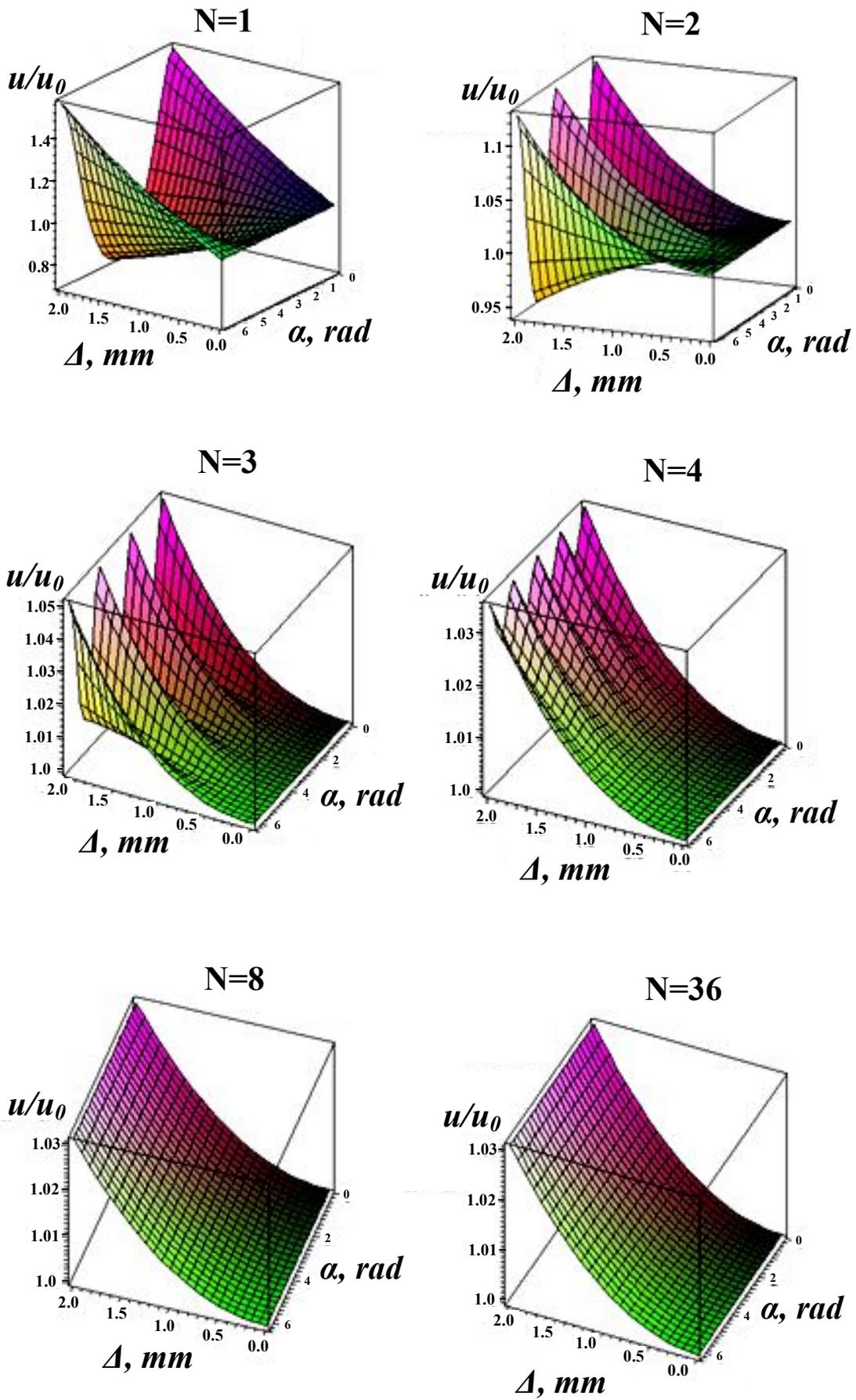


Fig.5. Results of calculating u/u_0 for $N=1, 2, 3, 4, 8, 36$

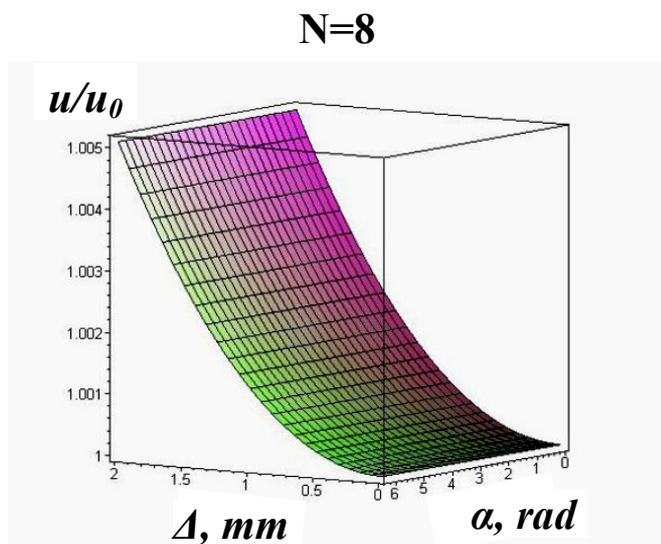
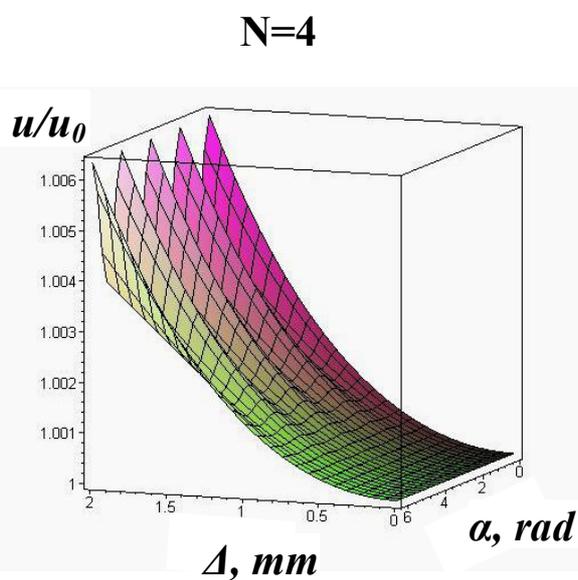
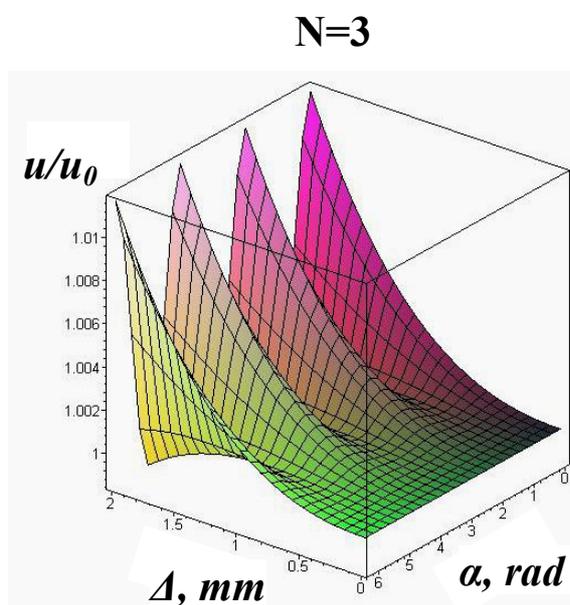
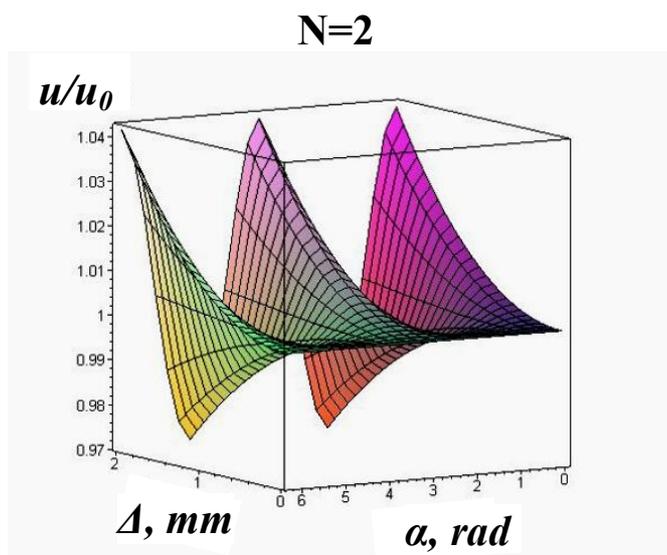
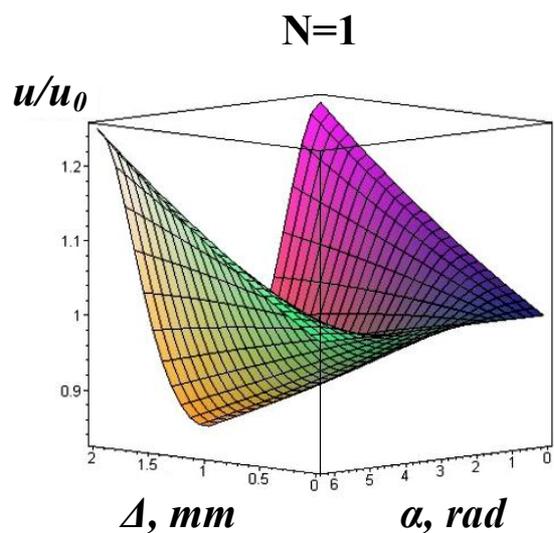


Fig.6. Results of calculating u/u_0 for $N=1, 2, 3, 4, 8$ (after additional conversion of u_i)

The elementary way is to extract the root from each photosensor signal value with following accumulation of the derived values. The positive influence of such a conversion is a considerable reduction of the sum u value shift (improvement of the ratio u/u_0).

As we can see (Fig.6), the ratio u/u_0 for the second method in comparison with the corresponding cases for the first method (Fig.5) under the same conditions is considerably better.

Thus, when $\Delta=2\text{mm}$ and $\alpha=0$, relative change of the sum u equals to: 60% for the first method and 25% for the second method for one sensor; 15% and 4% correspondingly - for two; 6% and 1,2% - for three; 3,5% and 0,65% - for four; 3% and 0,5% - for eight sensors. As in the first method, with the further increase of the photosensors quantity N , the shift of value u will not decrease.

Therefore, the second method of signal processing makes possible to neutralize the stream deviation influence quite efficiently.

5. CONCLUSIONS

1. Application of the proposed multisensor photodetector proves its efficiency.

2. Preferred number of sensors is from 4 to 8. To increment this number further is not reasonable. The reached level of additional error produced by deviation of the stream (for example, this error is about 3% for $\Delta=2\text{ mm}$) is almost not reducible when increasing N .

3. The simple mathematical operation (such as taking the root) under sensor signals u_i before their summation could improve the result. The additional error produced by deviation of the stream may be reduced by this method significantly (3-6 times).

6. REFERENCES

- [1] US Patent № 5400137, Int. Cl. G01J 003/30, Publ. March 21, 1995.
- [2] "On-line turbidimeter WTM-500", Sigris-Photometer AG Datasheets, accessed at: <http://www.photometer.com/en/products/details/downloads>