Control system, device and technologies for thin wire diameter measurement

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This paper presents the results of research regarding designing and manufacturing of a measuring device used to estimate the diameter of thin wires (0.015-1mm). The system uses the diffraction produced by a laser radiation and interprets the diffraction pattern. The designing and manufacturing stage of the measuring device using CNC milling machines as well as the logical scheme, the electronic components and the Lab View program are presented.

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1. Introduction

The industrial applications use laser measurement devices due to their special advantages: very good accuracy, contactless measurement, good repeatability and stability and a longer life time than classical measurement devices. In the present day, the use of automatic production systems the laser measurement devices found their place as a reliable testing solution for process steps and parameters or of the final product. One of the fields of use of such devices is wire and fibbers industry, especially copper wire for electrical motors and special applications and fiber optics industry. In these fields a constant diameter or a well controlled dimension is important in assuring the quality of final products.

For diameter measurement several solutions exist on the market and they are based on measuring the occlusion time.

This systems offers the advantage of speed and accuracy and a fairly simple and robust construction. More over it has the capability of continuous monitoring of the final product and may be used as a feedback for an automatic control system.

However, in order to measure correctly the diameter of the laser beam has to be smaller than wire diameter.

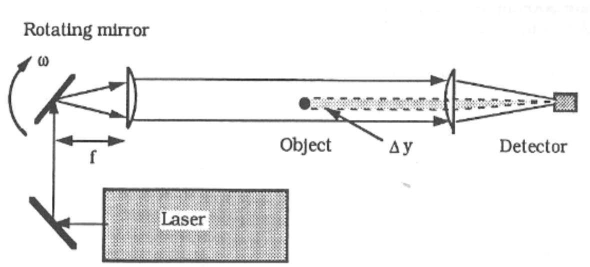

Fig. 1 The principle of diameter measurement by occlusion time.

If this condition is not satisfied the diffraction phenomenon may occur and the detector will not be able to detect any occlusion. In order to eliminate this inconvenient the producers of this devices use a well focalized laser beam. But even this solution has limitations in a fast moving process where the focal point of the laser may vary [1, 3].

In order to eliminate this problem a new design was proposed: using the diffraction phenomenon in order to estimate the wire diameter.

The wire behaves as a beam splitter and separates the beam in two sources of coherent light that generates a diffraction pattern on a screen, similar to Young device, [2]. The distance between interference patterns is closely related to distance between wire and screen, the wavelength of the laser radiation and the diameter of the wire, or the distance between the two coherent light sources.

2. Presentation of the suggested solution

Starting from this phenomenon, a measuring device was designed for measuring diameters of thin wires and microfibers.

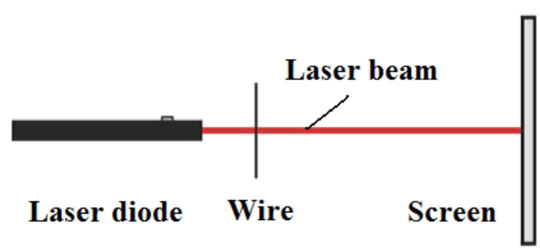

Fig. 2 Measurement system scheme.

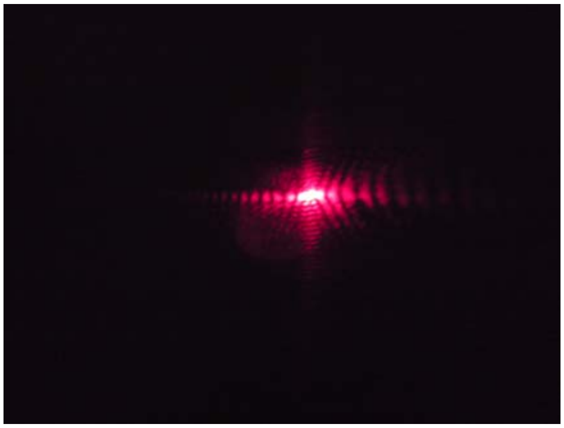

Fig. 3 Interference fringes captured after experimental arrangement.

In fig. 2 is shown the arrangement of such a device and in fig. 3 a diffraction pattern is presented.

In order to determine the diameter of a wire by diffraction there is necessary to know the wavelength of the laser source, the distance between wire and screen and to determine the distance between maximums of the diffraction pattern. The wavelength in this case was λ~650nm, it was chosen because of the popularity on the market of such laser diode type and by the sensibility diagram of the optical sensor which presents the maximum of sensibility in this region of the spectra [4, 5].

To determine the distance between maximums of the diffraction pattern an optical sensor was chosen, TSL210, a linear array of 640 photosensitive elements, grouped in 5 modules of 128 photodiodes. The sensor has an amplification circuit and a logical module that makes the usage of the sensor fairly easy by using a single clock signal and a signal for starting the reading of the array. Every photodiode is 120 µm in height and 70 µm in width with a centre to centre distance of 125 µm. [6]

The sensor is designed to be used in a wide range of applications like contact imaging, reading of the barcodes, edge detection or linear encoder.

Fig. 4. TSL210 optical sensor.

Knowing the constructive parameters of the sensor it can be determined the distance between the optical sensor, which will work as a screen for forming the diffraction pattern, and wire. This distance has to be determined considering a range of values for which the sensor can work; this condition is for the minimum distance between two maximums of the interference patterns has to be at least double of the distance

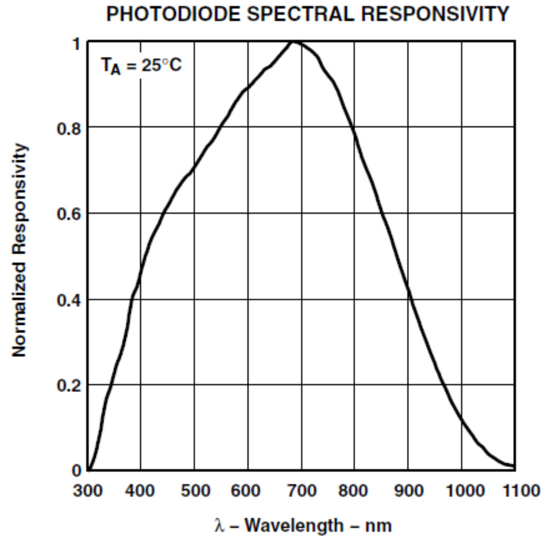

Fig. 5 Photodiode spectral responsivity.

between two photodiodes. This condition explains the fact that the maximums of the interference figure has to be clearly separated by a minimum. For example if the 0 order maximum is set on one photodiode, next to this photodiode has to be a minimum and on the third photodiode the 1 order maximum, as it is shown in fig. 3. The problem is solved using well established formulas used in study of wire diffraction [7,8]:

$$
\begin{aligned}
&a\sin\varphi_2 = 2.46\lambda\\
&a\sin\varphi_2' = -2.46\lambda\\
&a\sin\varphi_3 = 3.47\lambda \qquad (1)\\
&a\sin\varphi_3' = -3.47\lambda\\
&\sin\varphi_1 \cong tg\varphi_1 = \frac{|y_1 - y_0|}{L}
\end{aligned}
$$

where:

- a is the wire diameter;
- λ is the wavelength of the laser radiation;
- y_1 and y_0 are the coordinates of maximums on the screen;
- φ_1, φ_2, φ_3 are the angles made by maximums with horizontal direction, perpendicular on the screen;
- L is the distance between the wire and the screen.

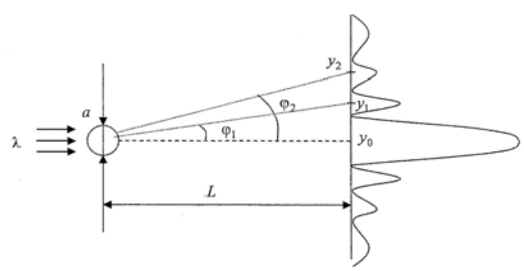

Fig. 6 Geometric representation of the working principle.

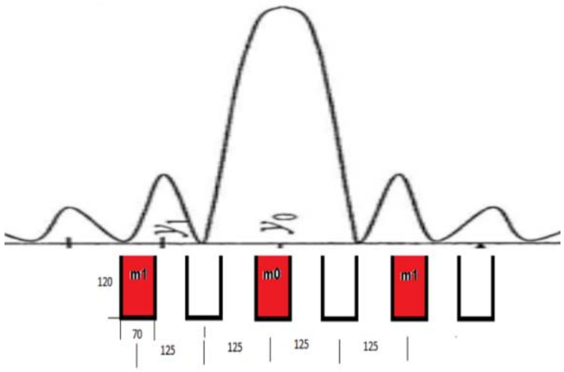

Fig. 7 Limit condition for sensing the diffraction pattern.

For designing the parts it was taken into account the sensor dimensions and the minimum determined distance necessary for the sensor to get the light signals.

In order to build the thin wire measuring device it was taken into account a stratified structure made of three components, the middle component is dimensioned to house the laser diode in a centered place, to secure in place the optic sensor and cutting ups for connecting wires. The other two parts are identical and are used to enclose the components placed in the middle of the system [9].

The outer parts have a 1.5-2 mm orifice used to feed the measuring wire placed according to calculate distance between wire and optical sensor.

The distance at which the feeding hole is placed from the optical sensor was determined form the previous formulas (1) and determined as:

$$L = \frac{|y_1 - y_0| \cdot a}{1.43 \cdot \lambda} \qquad (2)$$

In this case, y_0 is considered 0 to simplify the calculus and y_1 is double of distance between two consecutive photodiodes of the optical sensor.

In order to determine the actual diameter of the wire an electronic system and a software system had to be developed.

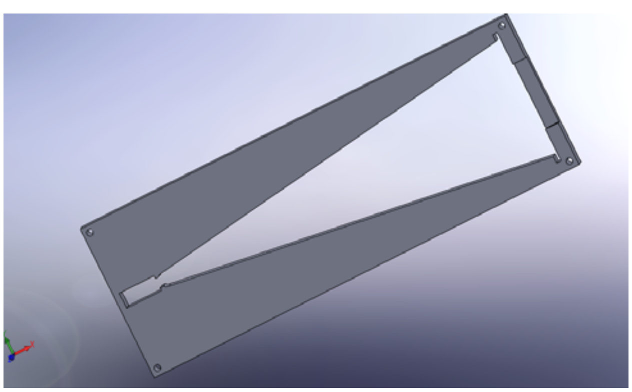

Fig. 8 Central body.

The manufacturer of the TSL210 optical sensor proposes in product data sheet two ways of connecting the optical sensor (fig. 9) and presents the reading sequence (fig. 10).

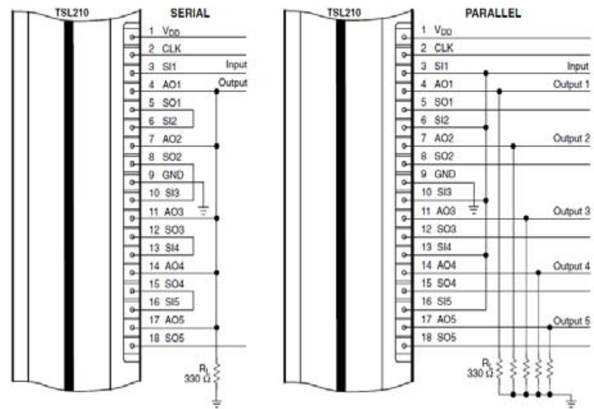

Fig. 9 Serial and parallel montage of the optical sensor.

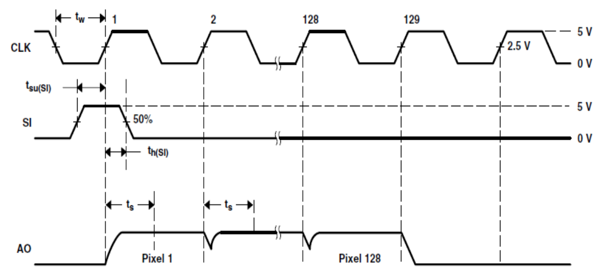

Fig. 10 Reading sequance.

The optical sensor allows two modes of connection, serial and parallel. In serial mode, the control montage has access at every photodiode once at a time and uses less connectors. Thow this way the reading speed is lower, the montage is simpler. On the other hand, the parallel montage offers simultaneous access to each of the 5 modules. The speed is much higher, but the montage becomes more complex as there are more outputs that need to be interpreted or converted into digital data.

The reading sequence requires a clock signal that shifts the pixels being read and a SI signal that starts the reading of the module. Every module has a common clock signal and a separate SI signal, AO analog output signal and a SO signal, that gives a feedback when the reading of all 128 pixels is finished. In serial connection, SI signal is the only one enebaled by the command circuit outside the sensor and the rest of the modules are eneabeled by the SO signal of the previous module.

The electronic system communicates with a PC using a communication protocol similar to RS232, but instead of using the COM port of the computer it uses LPT port, because Lab View allows a better access to this port and the port itself offers a greater flexibility [10, 11].

The designed communication protocol (fig 11) uses 3 communication channel for transmitting the data and 3 communication channels for receiving and checking the sent data [11].

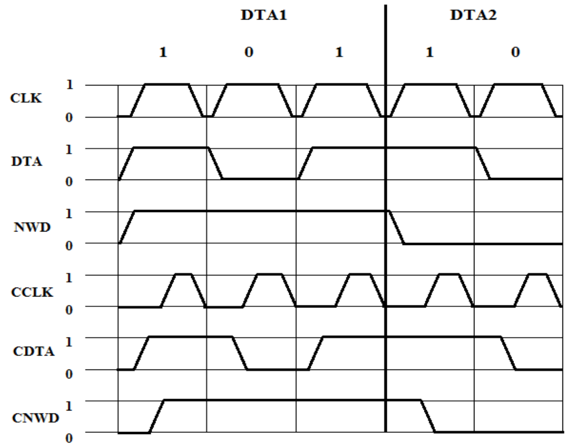

Fig. 11. Communications protocol chart.

The electronic system designed and built by our team needs to manage all the presented activities: read the sensor, convert the signal into digital data and send the data to Lab View software. A simple way to build it is by using a programmable microcontroller that can undertake all these tasks. Moreover, being a research product a good flexibility would help a lot in the process, the tuning for fine performance resuming only on software update of the microcontroller. Taking into account all the necessary tasks the choice was made on using a PIC16F684 microcontroller. This type of microcontroller is small (16 pin DIP), and easy to program in a high level programming language such as MikroPascal [11], [12]. The microcontroller has a programmable flash memory, an internal clock that may run without an external quartz oscillator up to 4MHz and configurable I/O ports. Furthermore, the microcontroller has a built-in 10bit analog to digital converter that allows a conversion for the voltage response of the optical sensor into a digital value. For connecting to LPT port the microcontroller, some digital SMD transistors were used as signal amplifiers.

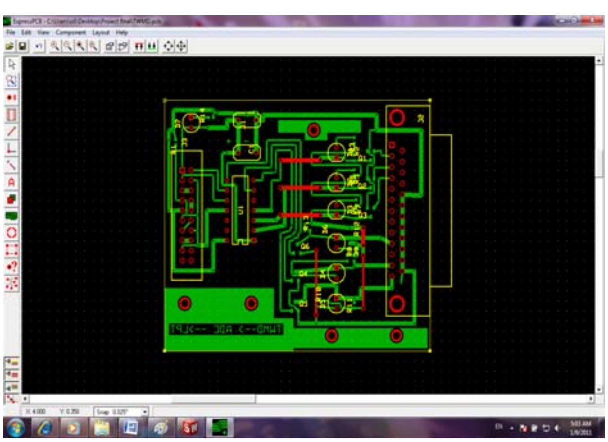

Fig. 12 Design of the printed circuit board using PCB Express.

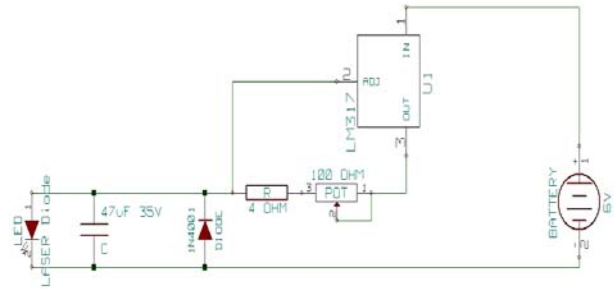

Fig. 13 Current-limiting circuit diagram for laser diode.

The laser diode used for this device is a common laser diode that emits at 650nm, without any optic devices added.

Because laser diodes have a great sensibility on current fluctuations and have a strict limit of the admitted current, a current limiting montage was used to power the laser diode. The main component of the current limiting circuit is the LM317 circuit that can be controlled by a potentiometer to set the value of the current (fig. 13). The test proved the circuit to work properly and it eliminates any dependence on powering voltage. The tests were performed using 3V, 5V and 12V with no damage on the laser diode or light intensity [12,13, 14, 15].

The firmware for the microcontroller was build following the diagram presented in fig. 14. The software has an initialization step, in which the ports, clock and analog convertor are configured. After the initialization a close loop starts. First the TSL sensor is read, one pixel per loop, respecting the signal diagram of the optical sensor. Next, the voltage delivered by the optical sensor is read and converted into a digital value. An internal procedure splits the value into an array of binary values and then the communication protocol materialized in a procedure of the firmware sends the array to the Lab View program. The communication is performed with respect to the presented signal diagram (fig. 11). After the data are transferred the loop continues until all the 640 pixels are read. Obviously, the loop may continue again, after a new initialization of the optical sensor.

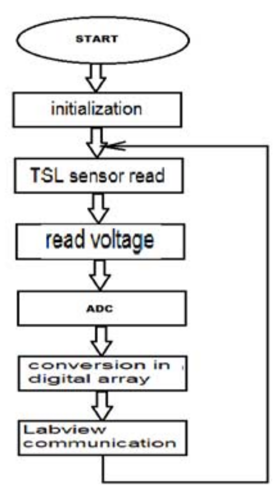

Fig. 14 Logic diagram of PIC 16F684 program.

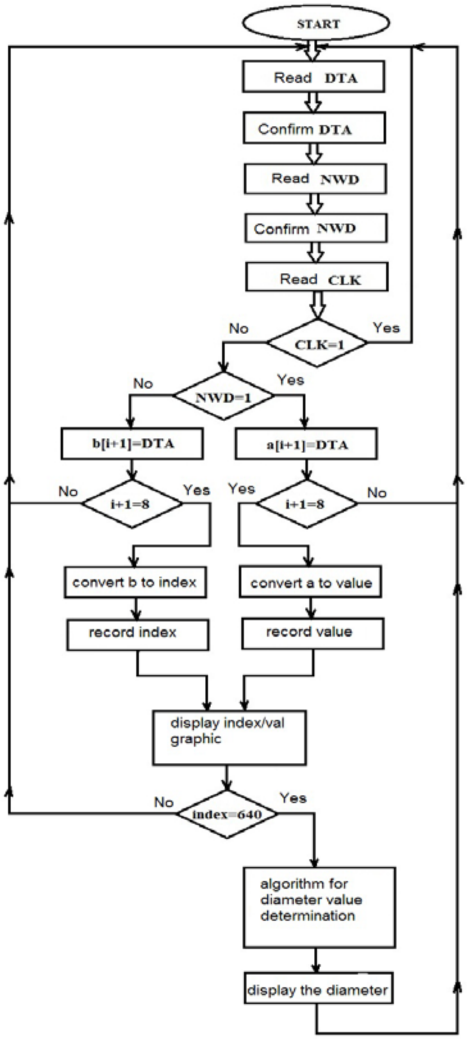

Fig. 15 Logic diagram for Lab View program.

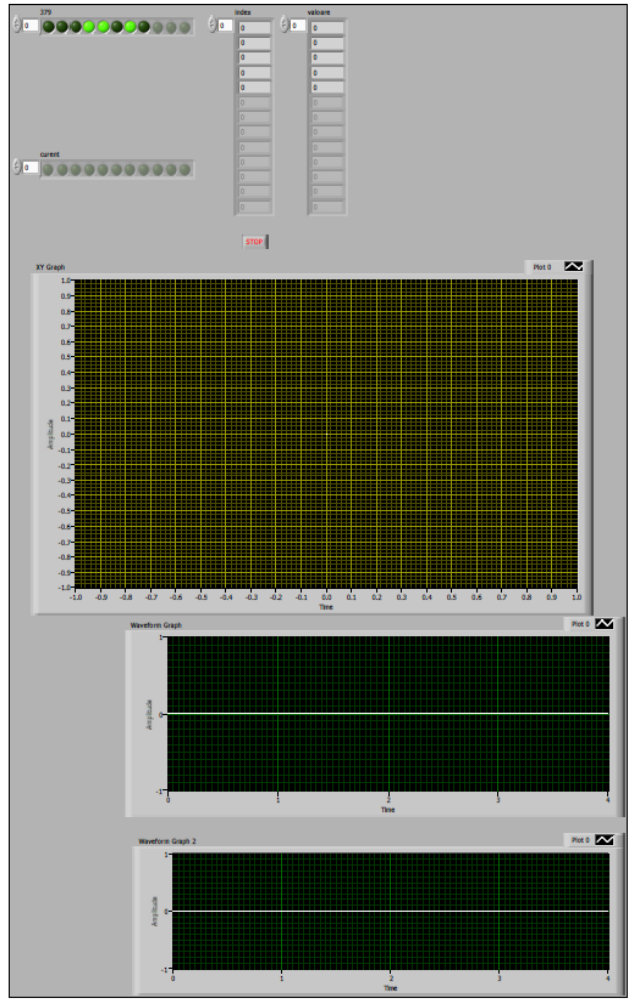

Fig. 16. Testing software interface contains port monitoring function, index and amplitude values display, graphic of the light amplitude on sensor and visualization of the transmitted data (index and amplitude) in order to identify possible errors.

The Lab View software developed for this project consists in an interface that allows the user to visualize the communication process and also to set the speed of the communication, the graphic of light amplitude on each photodiode of the optical sensor and the wire diameter that is measured (fig. 16). The software in this stage is not a final product, but testing software of the whole system, it doesn't allow the user to modify many parameters. However it's a useful tool in the development process of the final product and it may be converted to a VI library in order to be included in a larger application [16].

The Lab View software developed for this application uses two registries allocated to LPT port, 378 and 379. 378 registry is used to send the signal confirmation to the microcontroller, while 379 registry is used to receive the information from the microcontroller. All the signals are read at the same time and confirmation of the received data are sent to microcontroller. The data are recorded in a binary array only if the state of the clock signal changes, thus the microcontroller confirms the correctitude of the sent data [10, 16].

The software monitors at the same time the NWD signal (new Data), which separates the index of the pixels from the light amplitude on respective pixel. This solution was used in order to eliminate the bit count synchronization, so the system may read values of different numbers of bits, 10 bits for amplitude value and 8 bits for index value (fig. 15).

When the NWD signal changes state, the binary array is converted to a number and added to an integer array. As reading of the optical sensor is performed, the user may visualize on a graph the amplitude of the light. When all the data are read for all 640 pixels the step of actual diameter identifying commence. At first, it is necessary to identify the y_0 point from which the other maximums will be determined. This is done by selecting the maximum value of all the amplitude values recorded in the values array and its correspondence in the index array. For all the other maximums the procedure implies identifying the minimums and selecting, from the sub array determined by two consecutive minimums, the maximums. For every maximum determined this way the index value associated with it will be recorded. After going through all the records and after determining all the maximums the software chooses the first 3 maximums on the right and on the left of the y_0 point.

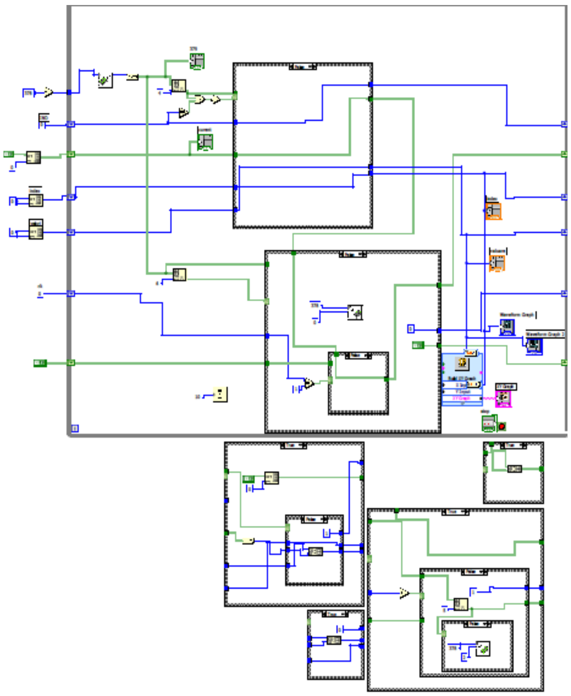

Fig. 17 Lab View Diagram of the software.

At this point the numeric calculus may be performed using the following formula to determine the dimensional correspondent:

$$y_i = \left| I_i \cdot 125\mu m - I_0 \cdot 125\mu m \right| , \qquad (3)$$

where I_i is the index of the current considered maximum and y_i is the distance between the order 0 maximum and i order maximum.

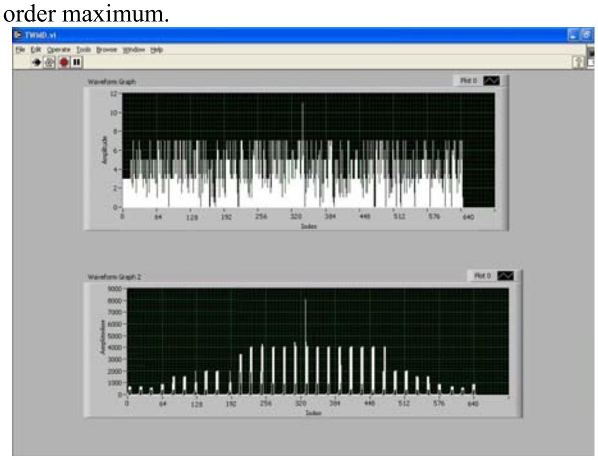

Fig. 18 Final results.

From this point the classical formulas may be applied in order to determine the diameter of the wire.

3. Conclusions

The presented system may be integrated in the structure of different automation system of fibber and wire manufacturing lines such as optical fibers or copper wires. The diameter of the final product may be measured continuously and the feedback may be used to correct the working parameters of the machine. By comparison to other wire and fiber measuring devices, the presented system offers the advantage of continuous monitoring, without contact between measuring device and product offering a high accuracy and a low sensitivity factor. Moreover the computed value is the average of 6 different determinations, so the value has a low error. The system may be improved to measure the diameter from two different planes offering thus information on circular deviation of the wire. Also the electronic system may be improved to compute itself the diameter of the wire and consequently increasing the measuring speed, by eliminating the need to communicate each value of the photodiodes.

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