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Support and verification of the production process of optical fiber cables using LabView environment

Abstract

In the paper, there is described an original application supporting the production process of optical fiber cables. The production process was improved by automatic search of potential tubing locations, which was conducted using the extension Vision Builder by National Instrument, producer of LabView software. The paper presents production processes that occur during execution of optical fiber ending. The proposed enhancements aim to minimize human factor that could contribute to destruction of the semi-finished product during transport of the optical fiber to the other side of the protection jacket and reduction of production process duration. The proposed vision system was created with NI Vision Builder tool. For the purposes of the conducted work, a control panel was also executed combining minimized functions for controlling the quality of the performed inspection. The user can load images to be analyzed and see the final result of the vision system analysis along with the decision in the form of a message regarding the permission for performing the tubing process or its deny.

Keywords: optical fiber, NI Vision Builder, optical fiber cable, LabView.

1. Introduction

Considering the field of data transmission by means of optical fibers, one can notice that optical fiber production is based on two types of fibers. These are multi-mode and single-mode fibers. The noticeable difference between them is utilization of data transmission area [1]. Multi-mode fibers use much greater area required for light beam transmission, which prevents free data transmission on long distances, while single-mode fibers use smaller part of the area which makes the signal less disturbed and thus enables its transport over greater distances (due to the intrinsic fiber attenuation). Multi-mode fibers are used on short distances, while single-mode ones on long ones reaching even up to dozens of kilometers [2]. The production of a proper optical fiber requires extreme precision and laboratory facilities of high-glass dust-free conditions. Figure 1 presents differences in the surface quality of the produced fibers connected at the production level (dust conditions) and in the laboratory (dust-free conditions). The fiber size is 125 μm.

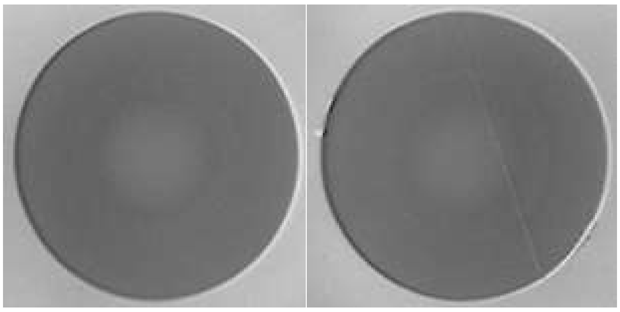

Fig. 1. Presentation of fiber optic surface under two different production conditions, image taken with microscope for controlling fiber optic surface, zoom 400×

An important difference between images in Figure 1 is the line passing through the optical fiber end surface, shown at the second image. The difference, no matter how small, can eliminate optical fiber ending from further production processes, as this will disturb the light beam and as a result will heavily increase the signal attenuation parameter.

The first coating in a fiber optic cable is its insulation made of brittle, plastic-like material. It coats the fiber on its entire length. Such a coating is to separate the fiber from external conditions. Another coating, not used in the all types of cables, is a coating made of dedicated gel. It plays an important role in maintaining stable conditions of the optical fiber. Stable conditions means here conditions preventing the fiber from hitting the insulating surface. There is a gap between the first coating and the optical fiber surface of approx. 0.4 mm. Omitting this isolating surface at the production stage could lead to early damage to an optical fiber.

Another layer that affects tensile strength is a layer using Kevlar fibers. **Kevlar is a light and extremely strong polymer material of aramid group.** Kevlar (PPTA, poly-paraphenylene terephthal-amide) is obtained in reaction of polycondensation of dicarboxyl acid chlorides with aromatic amines. Currently, aramid fibers are produced in a process of low-temperature poly-condensation of para-phenylenediamine (PPD) monomers and terephthaloyl chloride (TCL). Kevlar is a lightweight material of density equal to 1.44 g/cm^3. Individual fibers tested under laboratory conditions have the tensile strength of level of 3620 MPa. Kevlar maintains its properties at temperatures ranging from −200°C to 245°C. In contact with fire, Kevlar does not melt, but undergoes decomposition at temperature of approx. 500°C, without producing toxic substances. The last layer of the optical fiber is a layer made completely of flexible plastic whose purpose is to isolate other layers from the external conditions. This layer is to protect the fiber against physical damages. Physical damage means here accidental scratches that may occur during the final assembly [3].

2. Production of optical fiber cables

The optical fiber production process starts from proper isolation and leaving purified, isolated fiber till the whole amount of degreaser evaporates. At this stage, the optical fiber is also pasted in the external component known as ferrule. Ferrule is a thin sleeve made of metal, glass, plastic or ceramics. It is used for adjusting, aligning and protection of exposed ends of optical fibers. It determines the stability of fiber optic connection during an incidental lateral or axial movement of the optical fiber. Ferrule is glued to the fiber or mounted using a bush. Ceramic ferrules are believed to be the best ones, as they join well to the glass and have similar coefficient of thermal expansion. Two types of ferrules are the most common in today's market. The first type of ferrules has the diameter of 2.5 mm, the second one –1.25 mm. The second type is used to reduce dimensions of fiber optic plug. It is estimated that it is used for approx. 70% of today market demand.

The previously mentioned connection between the fiber and ferrule is done by injecting some adhesive to its inside. The entire optical fiber surface must adhere well to the internal part of ferrule opening. However, it must be remembered that the "inserted" fiber has a diameter of 125 μm, while the opening has a tolerance of $125^{+0.5}$ μm (single-mode fiber). This is a very precise insertion, as there is only a gap of 0.25 μm for each side at the opening wall. Multi-mode ferrule has higher manufacturing tolerance of level +2 μm to 2.5 μm.

Another production stage is a process of heating the optical fiber in a dedicated furnace. This takes approx. 1 hour at the temperature appropriate for the applied adhesive, including its viscosity. After removing ends from the furnace, next step is a polishing process involving four stages. The initial stage is cleaning the ferrule from remaining substances of the previous process. This is done using the polishing foil of high grain size – approx. 10 μm. The next two stages involve using the diamond foil of lower grain size. For some ends, the polishing starts even from using the foil with grain size up to 12 µm. The last stage is finishing that uses properties of chemical reaction that occurs during a physical contact between the ferrule surface and polishing foil, which as a result gives the high quality of the optical fiber ending surface [4].

The external surface of the ferrule is inspected using a measuring instrument called the interferometer. An optical interferometer, as an optical instrument uses electromagnetic wave interference in the infrared, visible light or UV range. Fiber optic interferometers are equivalent to all known volume interferometers, where the path of light beam is enveloped in the structure of a single-mode fiber or a polarization maintaining fiber. The typical surface measurement report is presented in Figure 2.

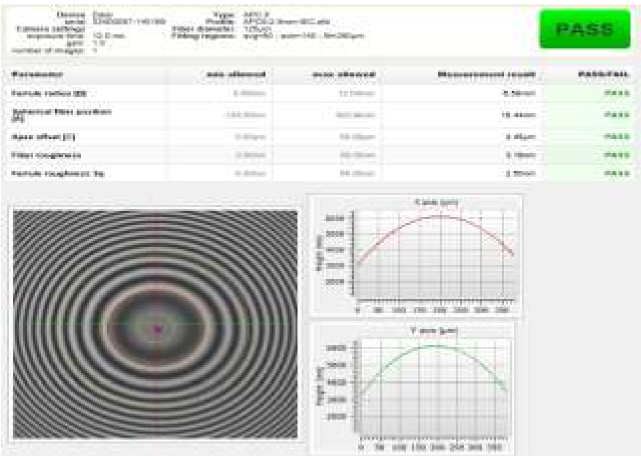

Fig. 2. Process report for optical fiber ending measurement

It clearly shows that in this case the ferrule surface is not as flat as it may seem, but rather rounded. Such a surface allows eliminating the shape and dimension differences of ferrules in a joint, as it could contribute to increasing the final attenuation parameter expressed in dB [5]. Rounding of the surface supports the optical fiber connecting process. If is defined using the following parameters: radius of curvature, undercut/protrusion, apex offset. The final effect being sought is presented in Figure 2. This is an optical fiber, one can be sure, not to cause any troubles when measuring data transfer parameters. Figure 3 presents the results of a ferrule surface 3D simulator.

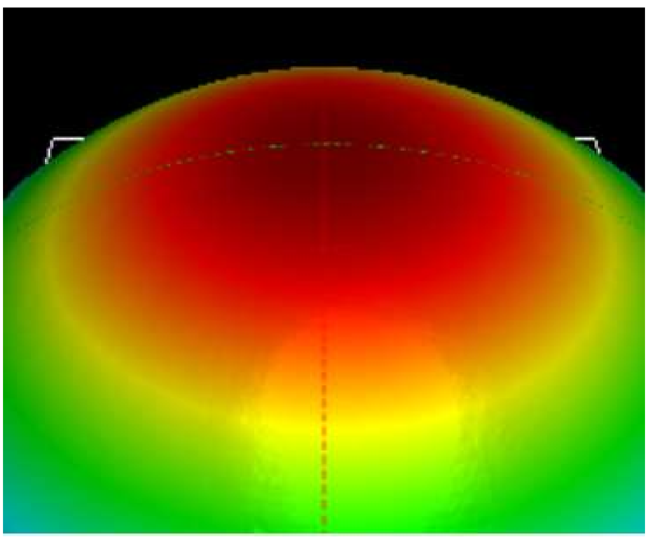

Fig. 3. Ferrule external surface simulator

After completing all the process of the optical fiber production, the quality control takes place, where the optical fiber is controlled by measurement of the data transmission quality. There are many measurement methods available. There are several fundamental differences between them such as: the use of an auxiliary fiber, making one-side or two-side measurement, changes in the electromagnetic wavelength. The main used wavelengths are: 1310 nm and 1550 nm [6].

Limit parameters are set depending on the type of the plug and the used fiber. The main parameter describing the quality of the transmitted light pule is a total optical fiber attenuation expressed in dB. It shows even the smallest impurities at the connection of two plugs, or the ferrule external surface that is outside tolerance limits of the attenuation parameter. The result of this measurement can say whether a given optical fiber is suitable for use, or does it have so high attenuation to prevent free data exchange.

Maintaining the surface parameters of the ferrule in established standards is very important due to the relation between the final parameters of the optical fiber connection – two coupled plugs. The relations are shown in graphs of Figure 4. It can be seen that increasing the Apex Offset parameter expressed in µm plays a very important role in terms of the final attenuation parameter for an electromagnetic wave beam at the contact of two plugs. The standard limit value regulated by an international standard is the attenuation maximum for a single-mode fiber of 0.25 dB [7]. The graph shows that this value is obtained when the limit value of Apex Offset parameter is at the level of 1 µm.

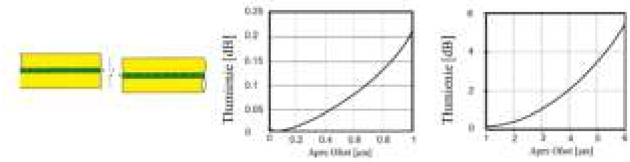

Fig. 4. Effect of Apex Offset on optical fiber attenuation

ODTR (Otpical Time Domain Reflectometer) is also an important measurement as it tells with a very high accuracy whether there is any damage of the cable. The distance approach is necessary to determine where and why the attenuation of the cable has a given value. OTDR sends into the optical fiber short light pulses and measures the reflected returning signal as a function of time. As the returning signal is many times weaker than the noise, in order to improve the measurement accuracy, the averaging of many such measurements is performed (it averages noise to zero, leaving the usable signal). Delay and intensity of the reflected signal arriving at the detector describes the parameters of the optical connection. During propagation of the pulse sent from the ODTR along the fiber, two phenomena are observed: Rayleigh scattering and Fresnel reflection. ODTR measurement starts from tests of the measuring system and the tested object. Then, operating parameters are verified and adjusted. Initial settings include: optical fiber type (multi-mode or single-mode), wavelength, optical fiber refractive index (so-called integrated refractive index provided by cable manufacturers by ODTR purposes). Three main measurement parameter selected by the operator are: length range, pulse width, data acquisition time.

Another test, known as very low level control is the one using spectrum visible to the human eye. This is usually a red beam from widely available semiconductor lasers. At optic fiber fracture or its bend, where it was in contact with the plug, a red point will appear. This means that, at this point, there is a damage that disqualifies the fiber complete functionality.

3. Automation of production process, optical fiber tubing

For the purposes of the conducted research, there was an attempt to show discrepancies between optical fiber cables that transmit light pulses over a distance of 30 m (they have on or at maximum two fibers in a duplex version), and those that can transmit pulses over much greater distances of several kilometers. Cables used for such tasks on small distances are patchcord cables. For very long industrial cables (trunk lines), preparation for operation is different than for patchcords. The fiber must be separated to view internal protective layers. After separation and fiber cleaning, a tubing process occurs. This is a stage involving placing the optical fiber in a prepared before joint tubes of the maximum diameter of 0.5 mm depending on the requirements. One cable may contain from 4 up to maximum of 144 optical fibers.

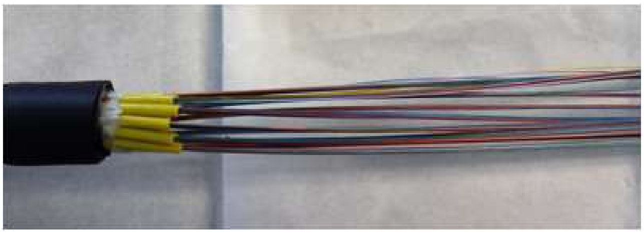

Fig. 5. Cable structure with 144 optical fibers

After pulling to the other side of the fiber cleaned with isopropyl alcohol, it will be possible to form an ending in the form of the required optical fiber plug. The cross-section of such an ending looks as follows: starting from the center, first the fiber, second layer is a tube usually made of plastic such as polypropylene (PP), next one is Kevlar and external cladding protecting the optical fiber against mechanical damages. It should be noted that the strength of the external layer is determined by the materials it is made of.

In the currently used production methods, the tubing process is the responsibility of the personnel working at a given stage of the technological process. An error, or even small distraction can lead to breaking the fiber. Elements of the potential tubing point are very small, of dimensions of 0.5 mm order. Breaking even a typical group of 144 fibers may lead to shortening the entire cable. The optical fiber tubing is performed in an orderly manner. The orderly manner means here, inserting fibers from left or right, from above or below. Never randomly. This aims to prevent optical fiber breaking at the stage of basic technological processes. Finding the place that would not be conflicting for two fibers plays a crucial role. The order of the performed processes is presented in Figure 6.

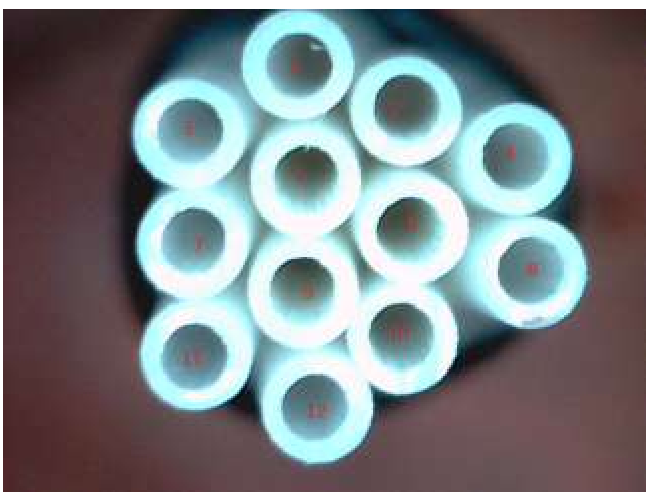

Fig. 6. Method for finding potential tubing points for optical fiber cables

The quality of fiber optic trunk line depends greatly on the method of cable preparation for the tubing process. It is required that optical cables have as best capacity for tubing as possible, i.e. the best separation of fibers from each other, which occurs after cleaning fibers using dedicated chemicals. Sticking together two fibers could lead to damaging one of them during tubing of fiber-optic trunk line. The optical fiber tubing shall be possible using a manipulator that picks the cleaned optical cables. The manipulator takes them from the place where there are only optical cables with removed gel residues. The manipulator arm would have to take such fibers from the temporary storage. Cleaning fibers from the vibration-damping gel would still have to be performed by the personnel. It shall be noted that the cleaning process of such amount of optical fibers is connected with a high probability of breaking one of them. However, the fiber cleaning is much shorter and does not require such high manual skills in comparison to tubing.

In order to improve the above technological process, a vision system was designed. The vision system is to correctly identify potential tubing points together with showing the tubing method (left-right) or (from above-below). The task of the vision system prepared in the LabView programming environment is to identify the point of potential insertion of the optical fiber to the tube. Data from the vision system in a form of a point graph [X, Y] will be exported to a spreadsheet in order to simulate data transmission between the analyzing and executive system, i.e. between the vision system and the manipulator.

4. Vision system for tubing

Vision systems become now much more popular than even 20 years ago. More and more often implementations of vision systems in a technological process result also from the pursuit of improving the production quality and reducing the duration of production processes.

National Instruments Vision Builder is a customizable tool for analysis and comparison of data from a camera. This tool standardizes system operation and improves potential edition of an algorithm in a graphical manner. Processing image from the device whose task is to observe the robot working area shall become much easier by using a black and white filter on a color image. In this manner, the image analysis shall be performed based only on the gray level analysis. A single pixel writes the value of shade on 8 bits, which allows writing shades of gray of values from 0 to 255. By zooming in the image to a size that would show a single pixel there is a possibility to observe individual colors that make up the image as shown in Figure 7.

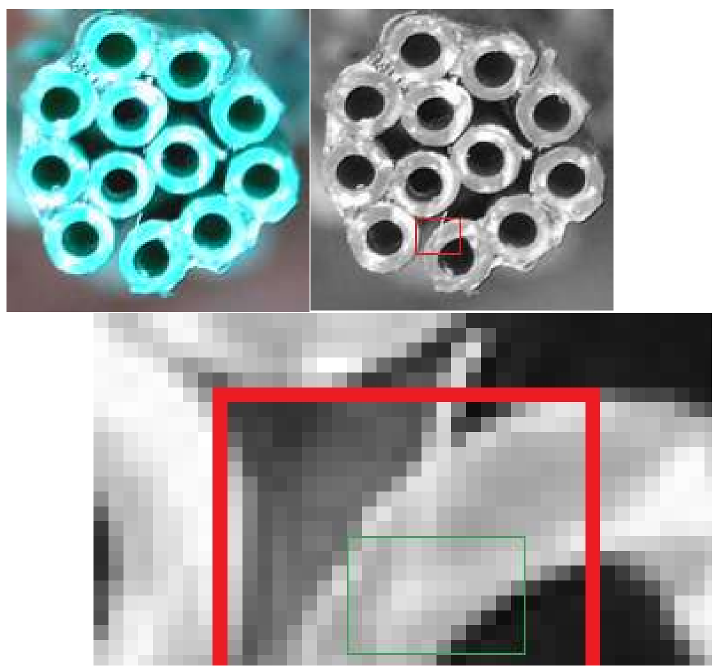

Fig. 7. Presenting effect of applied grayscale filter (square raster)

In order to simulate the measurement of gray level written as a number in the range from 0 to 255, where 255 is full white and 0 is full black, a matrix grid was made. It shows the factors enabling image analysis. Saving to memory cell makes it mathematically possible to perform the differential image analysis. For color images, there are three colors: red, green and blue. The other colors are the result of mixing these three. The grid simulating values that entered to a single cell have size 8 per 12, i.e.: 8 lines and 12 columns. Figure 8 shows the representation of image written to memory cells (fragment of a photography). Table 1 presents the numerical values representing the values of gray shade from Figure 8.

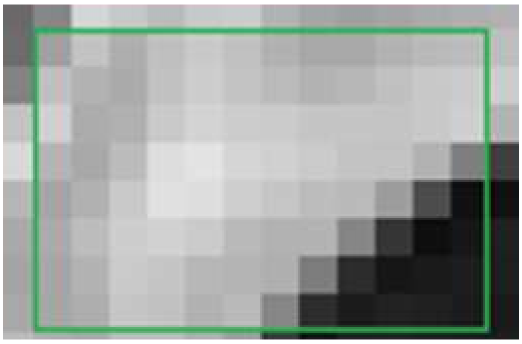

Fig. 8. Saving gray level to a single memory cell

Tab. 1. Numerical values representing the values of gray shade from Figure 12

	1	2	3	4	5	6	7	8	9	10	11	12
1	125	165	141	150	153	157	154	151	150	165	170	171
2	154	132	124	150	155	159	159	157	158	168	169	180
3	183	130	151	206	210	165	166	167	168	168	170	185
4	115	125	128	205	212	177	169	167	168	168	140	85
5	132	115	151	160	161	160	171	166	165	130	54	17
6	105	112	150	159	164	153	168	169	127	55	18	48
7	125	129	148	155	151	152	148	123	51	30	45	47
8	125	131	147	154	152	154	120	51	25	48	47	45

The image is processed in order to determine key observed objects. The image may require pre-filtering to improve its usability. This may involve correcting the brightness and contrast, removing the noise, bringing out the edges or removing the excessive information. An often used approach is binarisation, involving converting a gray-scale image to black and white one, with pixels of values only 0 and 1. This is an approach sufficient to detect a light object on a dark background and conversely. Usually, the analysis does not have to cover the entire image, only its fragment. Selection of Region of Interest (ROI) containing crucial elements for the analysis reduces the number of required calculations.

In order to initiate works aiming to implement image analyzing algorithm, available programming environments (for example: Matlab) were reviewed and LabView with NI Vision Builder was selected as a result. The main reason for choosing a LabView is a big possibility of the package in the field. Optical matching, pattern recognition, counting number of elements, object measurement and classification are only few basic commands that may be used for analysis of the loaded image. Another step of image preparation for the analysis, was determination of the analyzed region. Depending on the element sizes it can have various sizes. In case of the optical fiber tubing it is necessary to analyze the entire working area of the manipulator. In order to analyze the photography, the range of such an analysis must be defined. The violet line is a border line of the analyzed area (Fig. 9).

The correct image analysis will be performed after applying a relevant filter on the frame from the situation analyzed under the microscope. Applying the filter to the image is necessary to begin the image analysis in a gray scale. A color image has representation of three colors, while gray shades only one in a range of filling from 0 to 255. This means that the vision system stability shall increase by decreasing the number of the analyzed color to one, as only one number will be used to compare the adjacent pixels. Depending on the analyzed image, and especially the dominant color, one should choose an appropriate filter eliminating one of three colors. This relationship is very useful to visualize individual analyzed elements that can be performed using NI Vision Assistant. Selection of the number of colors in terms of image processing aims at finding a middle ground between the image and quality and size of image representation in memory cells. In the first step, the image is downloaded in a relatively high number of colors and only after that, in subsequent stages, the number of practical colors is reduced.

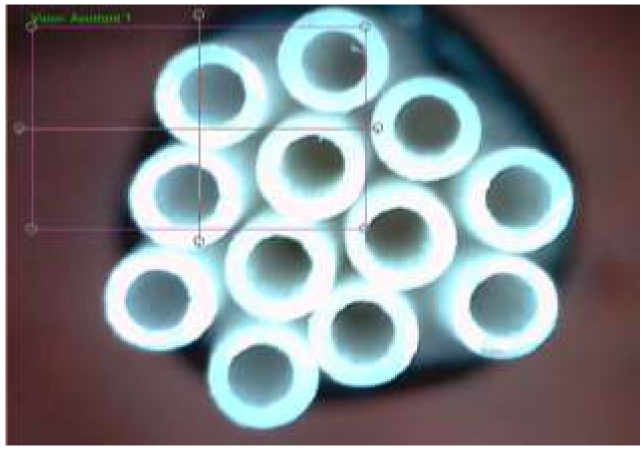

Fig. 9. Marking the working area of the image processing algorithm

Practically three types of images are used: binary, monochromatic and color image. Monochromatic images containing many gray levels allow performing the advanced analysis of individual elements depending on the requirements. Internal filling of an individual pixel in the region of a single tube to a solid gray level is necessary to achieve a proper difference in luminescence in a gray scale between opening and optical fibre cladding. NI Vision Assistant software enables selection of correct saturations, i.e. colour intensity filling.

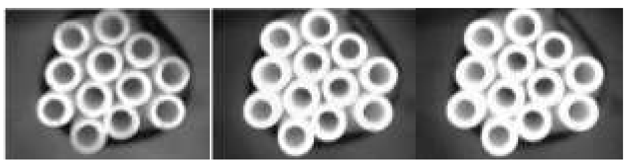

Fig. 10. Main classes of digital image interpretation: R, G, B, from the left

HSV name comes from the first letters of terms describing colour: H - Hue, of values of degree from 0° to 360°; S - Saturation described as deviation from the radius of the base; V - Value, white light power. In the three described cases, individual elements are segregated in the following order: HSL Hue plane - regulation of Hue, HSL Saturation plane - regulation of saturation, HSL as a regulation of the white light power level. In order to show the differences, three images are presented with the filters applied (HSV - Hue plane, HSL - Saturation plane, HSL - Luminance Plane) shown in Figures 11 and 12.

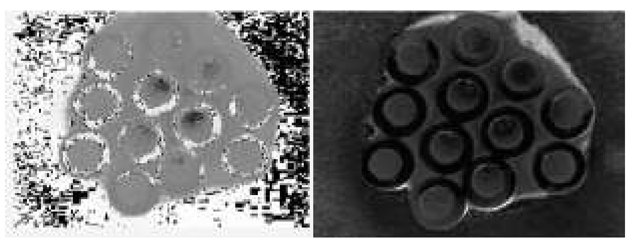

Fig. 11. HSV (Hue Plane) and HSL (Saturation Plane)

Finally, the HSL filter was selected. Applying this filter showed greatest differences between the values of filling of an individual pixel in black and light color defined as a difference in the values of filling individual pixels between the lowest and highest value of the gray shade value. This shall mainly help to make it possible to analyze the image mathematically in order to distinguish the tube and its inside. Figure 12 presents the image with the applied HSL filter. It shows the difference in the brightness of the tube inside and casing. After applying such a filter, the algorithm for searching the potential tubing point shall be more immune to randomly found points.

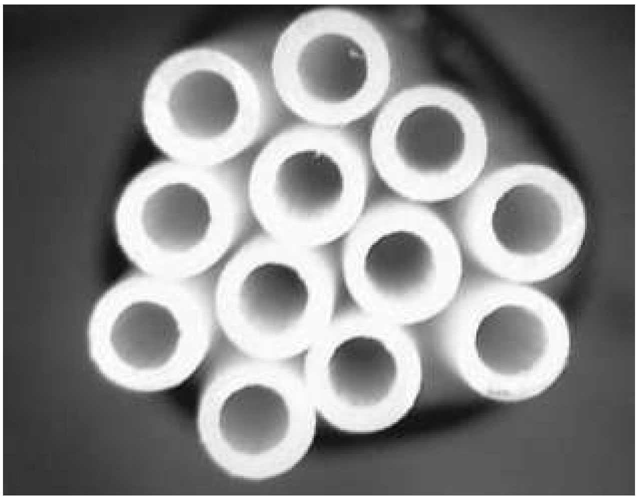

Fig. 12. HSL (Luminance Plane)

5. Locating potential tubing point

After applying the pre-filter, it was possible to move to a next stage, where points in a two-dimensional coordinate system, i.e. values of X and Y axes, would be found. Locating information is required to export coordinates to the manipulator control system. As already mentioned, tubing cannot be started from tubes in the center of the system, as this could lead to damaging a single fiber. Therefore, the main information that should be obtained at this stage is twelve points of potential optical fiber tubing and tubing order. To that end we shall use object detection from inspection stage chart that locates solid objects.

Inspection in order to find a spot, where is the center of the tube, uses the threshold principle. The threshold principle involves determination of the threshold value X (keeping in mind the image brightness scale) that will find a closed number of pixels. The closed number of pixels that would include pixels of the assumed gray shade threshold value is defined as the tube inside. The shades below this value will become spots separating potential tubing points from each other. Therefore, the obtained binary image will adopt the following relation:

$$k(x,y)=\begin{cases}1 & \text{for} f(x,y) \geq X \\ 0 & \text{for} f(x,y) < X\end{cases} \tag{1}$$

where: $k(x, y)$ - loaded image, $f(x,y)$ - analyzed point, X - threshold value. Moving to software with the image imported for the tube analysis, it is necessary to calibrate the parameters. After starting a new inspection, the previously prepared image is visualized with a randomly set range of the displayed image analysis. Segmentation, i.e. dividing the image into parts defined as regions uniform in terms of such properties as color, gray level, or the places that are defined as zero-one (binary images) can have different chosen uniformity criteria.

Figure 13 presents the object before calibration. The spot marked blue shows that the gray scale value has been set as default towards the values of white. This results from the fact that dilatation is observed towards light colors within a single tube. These regions are defined at this stage as 1 value and as such are saved to memory.

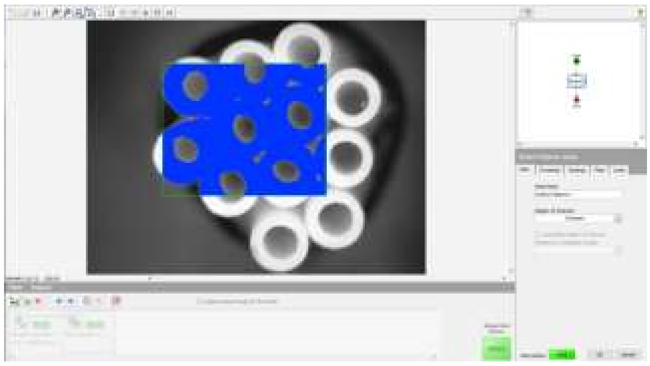

Fig. 13. Image segmentation before calibration of the segmentation process

The erosion may be interpreted as a minimum filter that assigns to each point a minimum of pixel values in its vicinity. While the dilatation is a reverse transformation in relation to the erosion and can be defined as a maximum filter. The already mentioned dilatation phenomena means that the object increases its size by a certain number of pixels depending on the set value. In the case of potential tubing points, those are the rings that decrease or increase in size as the set value changes. Figure 14 shows the erosion and dilatation phenomena.

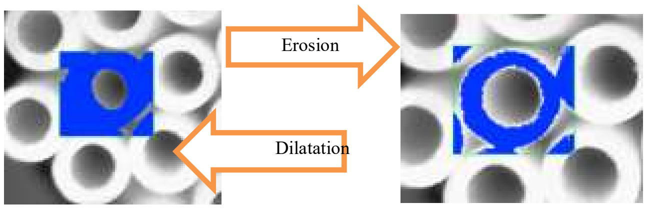

Fig. 14. Erosion and dilatation phenomena based on the potential tubing point of the optical fiber

Finding the potential tubing point of the optical fiber can be done in two ways. The first one involves finding a jacket displayed in the system as a ring. The second is finding an opening visible as a solid circle. In order to obtain the value of a single pixel filling and to compare two methods, an experiment was performed that should be useful when choosing one of two possibilities. Faultless classification in finding the center of the potential tubing point shall help to decrease the number of errors made by the system. Figure 15 presents an image where the process of finding objects was performed by thresholding values of bright elements understood as a ring. Controlling the threshold filling value in both cases occurs by the dilatation and erosion processes.

The method for finding elements with thresholding bright values the first and the fundamental relation was found. The rings were connected into one which made this method unable to separate individual potential tubing points. Switching to the method with thresholding dark values can lead to separating openings and dividing them into single values. Fig. 16 presents the found and perfectly separated individual tubing points for the optical fiber cable.

The dependence between the element separation and the quality of conducted inspection is clearly shown. The already mentioned separation principle plays a very important role as joining two regions of potential tubing points would be defined in the system as a point of the above-threshold value of filling a single pixel, thus preventing the possibility of finding the potential tubing point of the optical fiber. In the example shown in Fig. 16, sorting occurs according to the threshold value of filling, in increasing order. The values of point filling are as presented in Tab. 2. The first column shows the filling value, two next ones show *X* and *Y* position of the center.

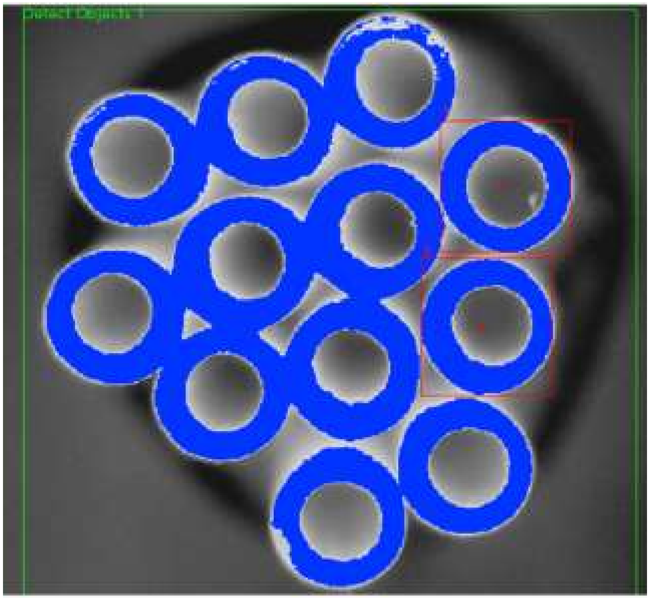

Fig. 15. Finding elements with the priority thresholding of bright elements

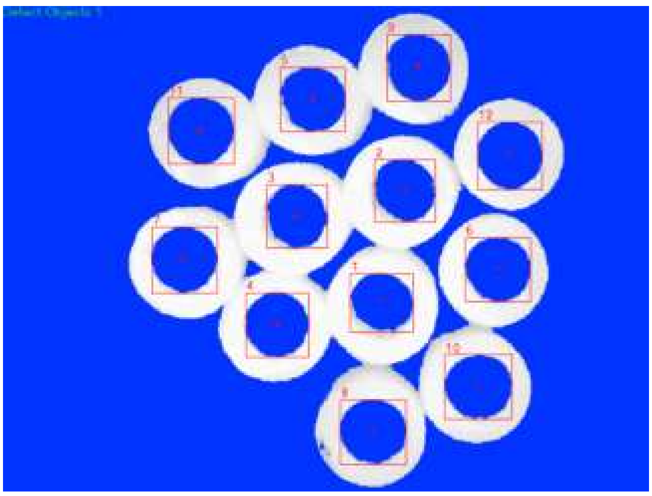

Fig. 16. Finding tubing points with priority thresholding of dark elements

Tab. 2. The values obtained by the analysis of the presented case of finding potential tubing points (finding dark points)

	Area	*X*	*Y*
1	2648.00	375.15	291.40
2	2786.00	397.69	181.22
3	2792.00	291.39	206.98
4	3044.00	271.63	313.88
5	3101.00	307.60	91,.8
6	3158.00	489.23	259.37
7	3179.00	180.39	249.72
8	3197.00	366.12	418.82
9	3198.00	410.95	60,.2
10	3199.00	470.13	374.97
11	3284.00	196.82	122.77
12	3307.00	500.58	147.26

Searching for tubing points based on the ring proved to be not stable enough due to the lack of separation between the rings and openings. The method of finding "solid" elements proved to be much more efficient taking into the account the lower level of contact between the tested elements.

Identification of tubing points shall be based on the priority of finding tube inside (opening). Moreover, the number of found dark points shall be defined that would mean potential tubing points. If the threshold value towards maximum and minimum is exceeded at this stage, the status of a given step shall return an error, thus critically interrupting the tubing stage. At the production stage, when cutting group of pipes is performed manually, a case when the optical fiber cannot be tubed occurs statistically in 3 of each 100 cases, which corresponds to the probability of damaging one optical fiber cable. It shall be kept in mind that breaking even one cable makes operation in the subsequent production stages impossible. The broken fiber can be shortened but it must be diligently kept in the documentation to be delivered to the customer. Fig. 17 presents two cases where the tool interpreting the situation under the microscope makes a decision preventing data exports to subsequent process stages.

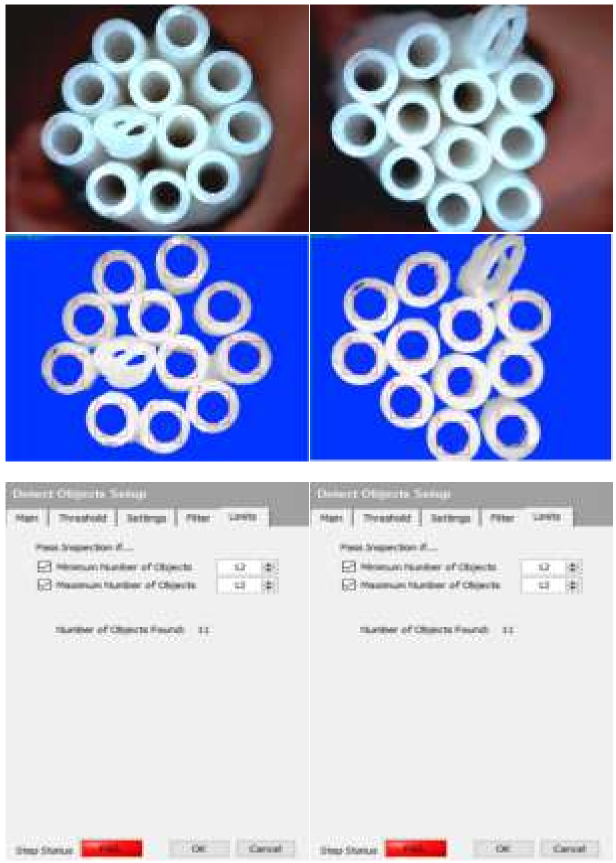

Fig. 17. Errors preventing moving to the next process stage

In the conducted stage, axial sorting that shall enable collision-free tubing process is required. The segregation method is presented in Fig. 18. The window for sorting elements in ascending order is marked in yellow. On the right side, an inspection result of the vision system is shown. The priority of ascending order is shown in Y axis.

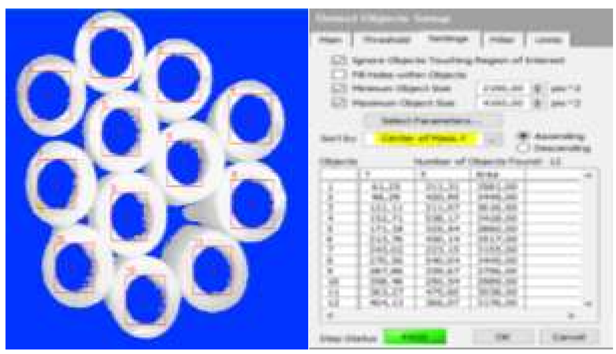

Fig. 18. Sorting potential points based on the Y axis

Segregation of potential tubing points of the optical fiber can be achieved in four different manners quite similar to each other during manipulator operation. The sorting can be as well set on descending values of the X and Y axes and inversely. Fig. 18 on the right side, the threshold values of the found elements were set, thus searching for tubing points will be in the range 2190 to 4160 px. The process of creating point inside the tube is a result of the internal algorithm of NI Vision Builder. When finding points in the range 2190 to 4190, a square will be drawn with the marked center. Sorting by the Y axis is also shown, thus, the first point is 61.25 y and 311.31 *x*, next one 96.29 *y* and 420.95 *x*, etc.

6. Simulation of position data export

The results of the analysis of potential points, where optical fiber cables are to export data to the manipulator movement processing system are presented in this section. Due to the high costs of investment that would involve a manipulator arm and a control system, it was decided to perform the simulation of data export from software analyzing the situation under the microscope to a spreadsheet. Export of all data defined in NI Vision Builder software can be performed by defining the range of necessary information. In order to facilitate the software operation, it was decided to create a control panel with implementation of the algorithm of action.

The main assumption involves the following parameters: decision on starting the tubing process, microscope view, number of iteration, data export file with .csv extension and potential statistical information on the quality of prepared tubes for separation of optical fiber cables.

The design of a panel showing the algorithm operation as final, aims to facilitate photography inspection for the user and improve the operation of the algorithm searching for potential tubing points. The main assumption of the panel was to display the image recorded by the microscope, as well as inspect the result including the message regarding permission to transfer the data for the subsequent stage, or denial (Fig. 19). Other tools can be called peripherals due to their structure reminding display of less important information such as the inspection time, the number of images to be analyzed and the size of all the files required for the analysis. In order to control the interval between the inspection, a function that allows stopping the inspection to a value set in a slide bar was created. This shall result in more dynamic control of clarity between inspections. It is possible to edit the values during software operation. This is an important element that improves the inspection, as the final user can stop the program operation and the image to be inspected at a selected convenient time interval.

In the main inspection panel, a function of adjusting the threshold value of a single pixel is locked. The panel on purpose contains only basic functions, as increasing their number for rapidly refreshing inspections would make it impossible to interpret all the data properly.

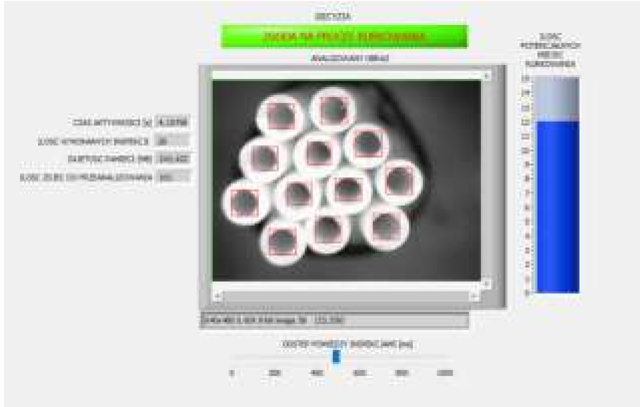

Fig. 19. Control panel of finding potential tubing points for optical fibers

In the first stage, the data required for the analysis must be selected and export conditions determined. The data from the inspection will be written to a single file. There is also a possibility of generating several .csv files added to a folder at intervals. After starting the inspection, each full cycle will be written to a respective column. The first stage is loading files, the final one – data export to file. The export stage is marked in blue. Data export from NI Vision Builder to the software simulating the input data to the manipulator can be performed in two ways. The first one involves export with .txt extension, which means that the system output data will be written as a text file. Another method of data export, i.e. export to a file with .csv extension means that the file can be used in a spreadsheet. The result of the program that is a .csv file was considered not clear enough. It has a very raw appearance, which will make it much harder to analyze the basic data. Due to that, it was decided to create another spreadsheet file that would arrange information in a more clear manner. A structure of the additional file will have two separated inspections showing the coordinates of a potential tubing point and a graph of the X and Y axes. Selection of the relevant required data will help arranging the output data from a vision system. Numerical values will be rounded to integrals. This was achieved by analyzing involving rounding the location of the potential tubing point to a size of a single pixel. The obtained possibility of graphical data analysis using such elements as a graph of potential tubing points shall help to ensure the correctness of the exported data. Under each inspection, position data of tubing points will be exported. The data come from NI Vision Builder and was obtained as a result of the image analysis. 10 inspections were analyzed for test purposes. It is possible to conduct another inspection in an analogous manner. It was concluded that the inspection values close to zero should be marked in red. The inspections presented in Fig. 20 present finding 2 points close to 0, inspection No. 5 showed that potential tubing points is dangerously close to the Y axis, while inspection No. 9 shows that there is a risk associated with point 7 on the X axis.

	1		2		3		4		5		6		7		8		9		10	
PMRS	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
1	432	244	430	214	318	274	373	309	388	309	174	237	239	336	358	368	395	177	389	272
2	339	186	340	288	431	266	254	288	337	[illegible]	277	292	363	171	278	177	461	355	196	199
3	323	290	326	171	262	176	326	207	445	206	379	243	441	344	260	280	260	332	320	181
4	234	354	251	358	201	204	440	191	268	316	381	362	345	285	368	251	492	251	353	389
5	456	360	476	363	305	76	194	189	327	215	288	180	257	212	469	197	287	211	274	286
6	354	393	223	243	379	162	328	422	383	69	281	404	465	238	388	123	369	289	245	397
7	426	115	366	404	492	171	139	293	207	204	384	132	339	406	246	397	[illegible]	101	470	369
8	225	241	538	153	256	376	222	394	518	308	483	309	479	121	173	217	514	135	432	165
9	540	274	421	96	395	388	500	294	458	416	290	68	273	102	470	317	354	409	504	409
10	234	126	540	271	568	260	448	393	563	109	479	101	377	57	295	50	199	136	361	72
11	322	61	311	61	501	352	380	87	276	108	172	356	165	144	187	105	417	64	157	315
12	530	166	211	121	434	67	267	95	496	99	193	125	157	256	154	331	184	247	250	96

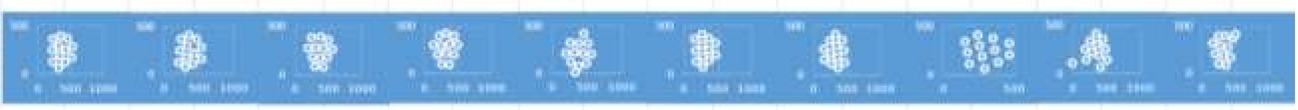

Fig. 20. Ten examples of inspections of potential tubing points on a vertical axis: PMRS - Potential tubing point of optical fiber, on horizontal axis: inspection No.9

7. Conclusions

Creating a vision system using NI Vision Builder expansion, allowed automation of a technological process that eliminates to a great extent a human error. The increasing use of vision systems can be observed in modern industry. This is confirmed by a very advanced accuracy in the optical fiber manufacturing process, and particularly their endings, with use of a vision system. A vision system today is used not only to measure elements of larger size, taking meaning inspection of elements of several centimetre size. Algorithm tests prove that vision systems can be used during analyses of much smaller elements.

Vision systems used in the field of producing optical fiber endings can be also applied in other production stages taking into account repeatability of the process and elimination of human factor that in extreme situations can eliminate optical fiber ending from subsequent production stages. Development of algorithm finding a potential tubing point of optical fiber encountered some difficulties regarding the process of image calibration depending on the lighting quality.

The system calibration involved obtaining as high as possible difference in luminance between the elements of the analyzed image (selection of the threshold value of single pixel filling). Obtaining such a difference in luminance was possible due to applying the stabilized lighting of the element from all sides.

8. References

[1] Fischer U.H.P., Haupt M., Janoic M.: Optical Transmission Systems Using Polymeric Fibers, In Tech, available from: http://www.intechopen.com/books.

[2] Takaaki O.: Recent Status and Trends in Optical Submarine Cable Systems, NEC Technical Journal, Vol. 5 (1), pp. 4-7, 2010.

[3] Fidler F., Knapek M., Horwath J., Leeb R. W.: Optical Communications for High-Altitude Platforms, IEEE Journal of Selected Topics in Quantum Electronics, Vol. 16, no. 5, September/October 2010.

[4] Wang X., Kitayama K.: Analysis of beat noise in coherent and incoherent time-spreading OCDMA, IEEE/OSA Journal of Lightwave Technology ,vol. 22, no. 10, pp. 2226-2235, 2004.

[5] Torounidis T., Andrekson P. A., Olsson B. E.: Fiber-optical parametric amplifier with 70 dB gain, IEEE Photon. Technol. Lett. 18, 1194–1196, 2006.

[6] Boggio J. M. C., Marconi J. D., Fragnito H. L.: Double-pumped fiber optical parametric amplifier with flat gain over 47-nm bandwidth using a conventional dispersion-shifted fiber, IEEE Photon. Technol. Lett. 17, 1842–1844, 2005.

[7] Hansryd J., Andrekson P. A., Westlund M., Li J., Hedekvist P. O.: Fiberbased optical parametric amplifiers and their applications, IEEE J. Sel. Top. Quantum Electron. 8, 506–520, 2002.

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