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INSPECTION OF TABLEWARE GLASS PRODUCTS AT THE HOT END OF PRODUCTION LINE

Key words: machine vision, quality inspection, glassware, fluorescence.

Abstract: The paper presents an analysis of the capability of developing a system for on-line inspection of tableware glass products at the hot end of a production line. In the first part of the article, based on literature review and experimental studies, monitoring and inspection techniques used in the glass industry are presented. On the basis of conducted research, the author proposes an inspection method based on a fluorescence effect which is an alternative to known techniques based on infrared radiation.

Inspekcja wyrobów szklanych na gorącym końcu linii produkcyjnej

Słowa kluczowe: wizja maszynowa, kontrola jakości, szkło użytkowe, fluorescencja.

Streszczenie: W artykule przedstawiono analizę możliwości opracowania systemu kontroli jakości on-line produktów szklanych na gorącym końcu linii produkcyjnej. W pierwszej części artykułu przedstawiony został przegląd literatury oraz badań z zakresu technik monitorowania oraz inspekcji wykorzystywanych w przemyśle szklarskim. Następnie na podstawie wykonanych badań laboratoryjnych autor zaproponował metodę inspekcji wykorzystującą efekt fluorescencji, która może stanowić alternatywne rozwiązanie dla znanych metod, w których wykorzystywane jest promieniowanie podczerwone.

Introduction

Glass manufacturing is one of the medium- or even low-margin industries branches, depending on the type of articles produced. High-margin glass articles represent a small percentage in the entire glass industry. The company's financial results are directly proportional to the product yield obtained. This is why a low level of material waste is required. Often, manufacturers need to get a performance that is much above 90% to make the production process profitable. In the case of glassworks, this means a shift from product control to process control at all its stages, i.e. from input raw materials, through melting, moulding, stress relief, and packaging. Each stage of the process should be strictly controlled, because fluctuations in process parameters at any of its stages almost always affect the final product quality. In order to increase the profitability of production, the consumption of raw materials, energy, the mass of unit products, and labour consumption must be decreased at the same time. In recent years, the trend of reducing the unit weight to obtain more articles from 1 ton of glass is noticeable. It is achieved by lowering the density of the glass; however, but also, and perhaps first and foremost, the aim is to reduce the thickness of the walls and bottoms of the products. This is particularly evident in the case of packaging glass. In order for the product for packaging applications to fulfil its tasks at the recipient, it must be as homogeneous as possible, for example, in terms of wall thickness or the chemical composition of the glass itself. The guidelines developed for the glass industry in the USA provide a list of issues that are critical to productivity, which include the modelling of manufacturing processes, quality control, and improvements in process control systems. The assumed goal for the glass industry for 2020 assumes, among other things, to reach the level of six sigma quality for glass products, which seeks no more than 3.4 defects per million units. [1].

1. Tableware glass manufacturing monitoring and inspection systems

The technology of tableware glass manufacturing consists of two stages, the cycle of glass mass technology and the technology cycle, which produces the final glass products. The stages of glass manufacturing are illustrated in Fig. 1. It is worth noting that, in the classic approach, there is no inspection of articles before the annealing lehr on the “hot end” of the production line.

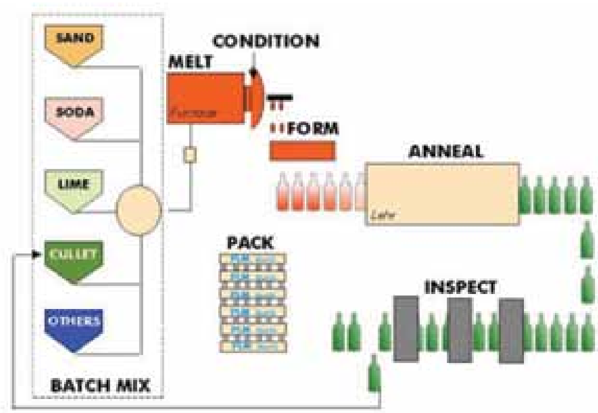


Fig. 1. Glassware manufacturing process [2]

Methods for monitoring the process of melting in a glass furnace have been described in numerous scientific publications and technical information [3]. The measurement techniques allow monitoring the uniformity of the set in the furnace prior to melting, temperature measurements in different zones of the furnace, and the evaluation of the condition of the surface of the molten glass (Fig. 2).

During the operation of the furnaces, there is a possibility of damage to the refractory lining, which may result in leakage of hot molten glass. Diagnosis of glass furnaces using thermovision (Fig. 3) is based on measurements of temperature distribution on their external surfaces [6]. On this basis, the heat accumulation sites where failure is most probable can be located.

Glass forming is an intermediate stage in the glass manufacturing process. It comes in between glass melting and annealing. Glass containers are produced in a two stage moulding process by using pressing and blowing techniques. There are five essential stages in production [7].

- Obtaining a piece of molten glass at the correct weight and temperature;
- Forming the primary shape in a first mould by pressure from compressed air or a metal plunger;
- Transferring the primary shape into the final mould;

a) b)

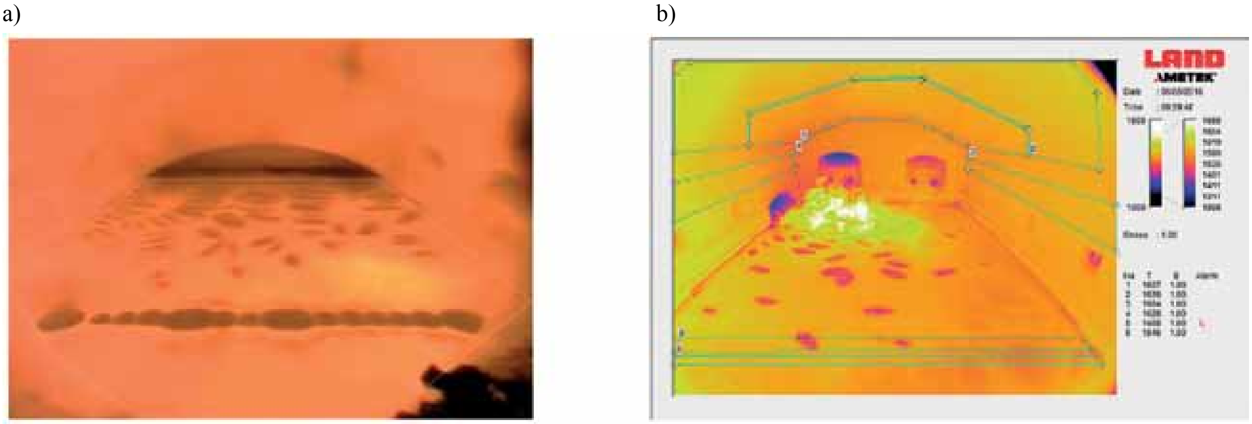


Fig. 2. Sample images of the molten glass surface: a) STG Combustion Control [4], b) AMETEK Land [5]

a) b)

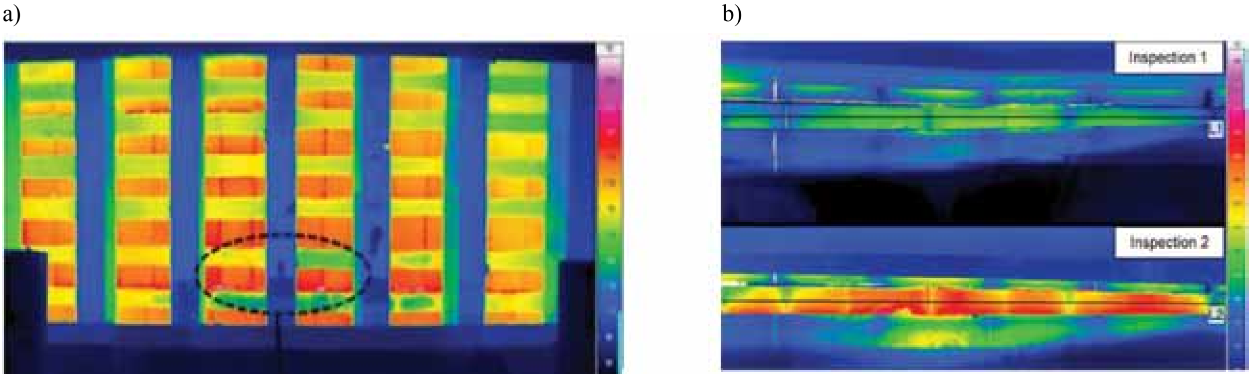


Fig. 3. Thermograms of the glass furnace surface: a) bottom, b) sidewall [6]

- Completing the shaping process by blowing the container with compressed air to the shape of the final mould; and,
- Removing the finished product for post forming processes.

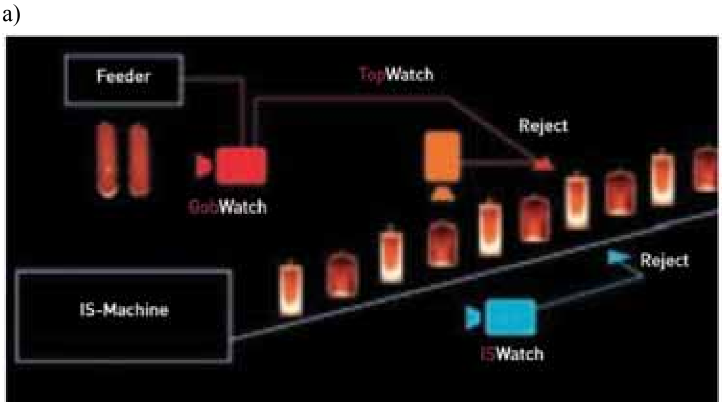
In the container glass industry, the control of the temperature and also gob weight is critical (Fig. 4). Both the stability of the process parameters and the products after the exit from the forming machine are also controlled. The distribution of glass in the article after leaving the forming section is particularly important. Special inspectors working in the infrared area are used for this purpose [8].

The distribution of glass in the finished product is one of the most important product parameters which dependents on many variables. In multi-section forming machines, despite the same glass being applied to all sections, the setting of one section may differ from the setting of another section or the rest, and the glass variability itself, ambient conditions, instrumentation or instability of the media (e.g., air, vacuum) enforces continuous control, and in case of deviations, the correction of process parameters. The only solution is to constantly inspect each article at the hot-end of production line. Commercially available systems use both visible and infrared cameras (Fig. 5) and can inspect over 600 products per minute.

One of the stages in the glass manufacturing that usually occurs after forming is annealing. For this reason, it is necessary to effectively evaluate stresses in order to eliminate defective products, the use of which may involve the risk of cracking or other damage [12]. In most cases, statistical stress control is applied with the use of specialized laboratory devices (Fig. 6).

Some cold end inspectors also check the state of stresses in the glass. Appropriate stress levels are necessary, for example, for the glass cutting process in the production of flat glass. There are some types of container glasses that require constant stress control in the on-line version. However, the main task of the cold end inspectors is a very thorough inspection of product dimensions and the detection of various types of defects [14], which should guarantee the highest efficiency (nearly 100%) and the lowest percentage of "false positives." Working conditions for cold end inspectors are much less demanding than in the case of hot end inspection. Usually, inspectors have a compact construction, up to 4 meters long and about 1.5 meters wide (Fig. 7). The number of cameras, depending on the applied solutions, is from 6 to 12.

a)



b)

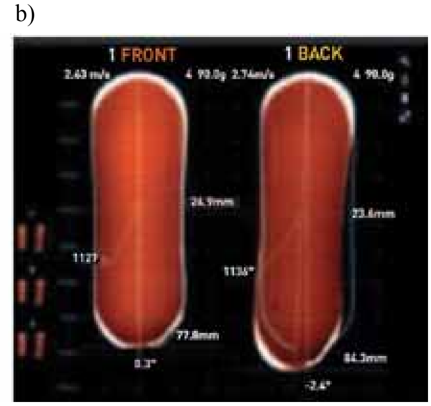
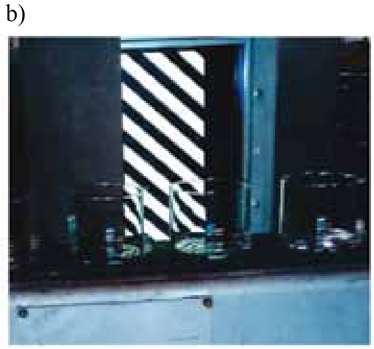


Fig. 4. Hot end monitoring system: a) overview, b) gob inspection sample images [8]

a)

b)



c)

Fig. 5. Hot end inspectors: a) OTTO Vision [9], b) JLI vision [10], c) XPAR Vision [11]

a) b)

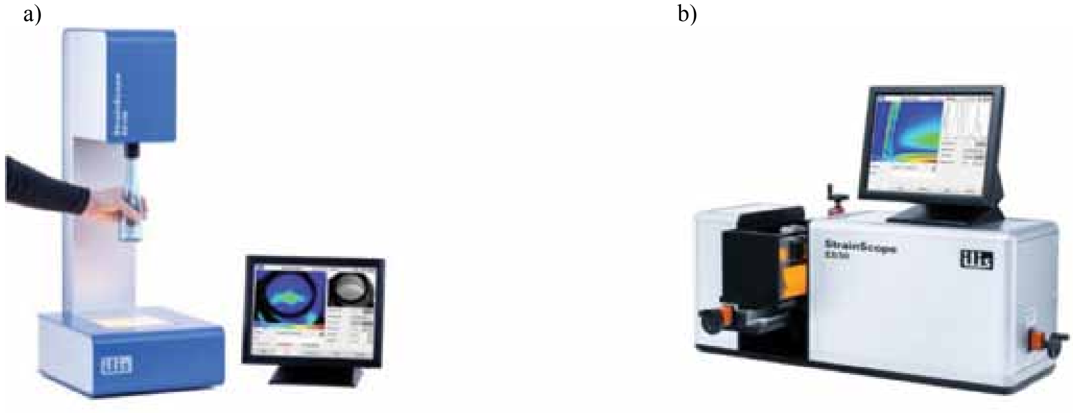


Fig. 6. Real time polarimeters: a) measurement of annealing stress in container glass b) measurement of wall stresses in thermally strengthened tableware [13]

a) b)

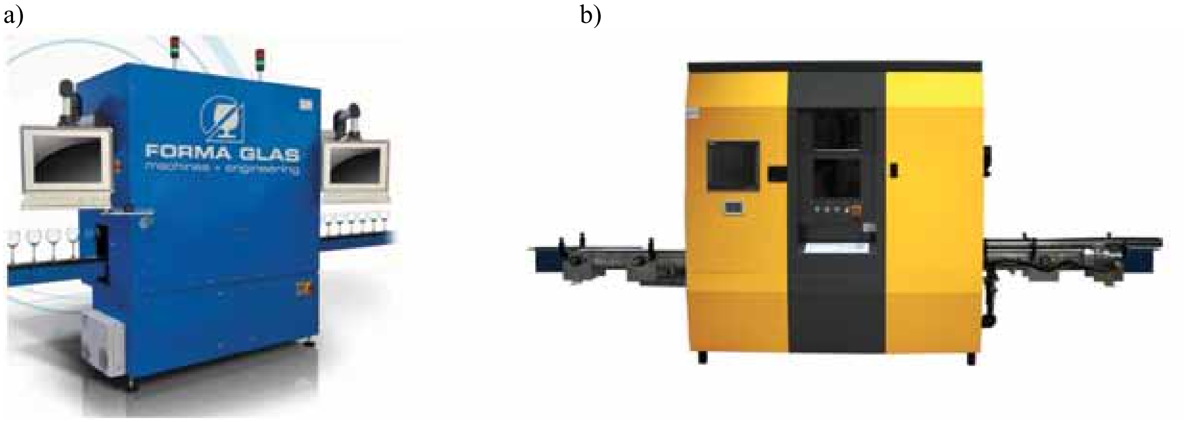


Fig. 7. Cold End Inspectors: a) Forma Glass [15], b) E3Tam [16]

2. Concept of hot end inspection system

Due to very different types of production lines occurring at the glassworks, before starting the system design, it is important to determine the actual environmental conditions. For the considered case, the designated place of system installation is located in the zone directly before of the rotary conveyor that transfers articles to the cross conveyor of the annealing lehr (Fig. 8). The location is characterized by limited access and high ambient temperature exceeding 60°C at the inspection area.

The subject of inspection is axisymmetric articles made of soda-lime glass not coloured and with maximum dimensions: height 200 mm, diameter 150 mm. The required inspection speed must correspond to a production of 180 articles per minute. According to manufacturer requirements, the hot-end inspector must inspect selected geometric parameters and defects. One of the main functions of the system control of the upper edge of the products was assumed (Fig. 8c). The inspection results can be used as feedback information for the forming machine operator about the correct positioning of the elements of the tooling set. In order to meet the manufacturer's assumptions about the type of detected defects, two imaging systems are necessary. The camera located above the inspection object will enable the detection of upper edge defects (Fig. 9a). The second camera will allow defect detection on the side surface (Fig. 9b). In this setup, products are illuminated in the direction of the camera, which captures radiation reaching the sensor due to the transmission through the object.

Due to the fact that inspection of the side surface at the hot end is part of many inspection systems, it will not be the subject of further considerations. However, it is worth noting that, among the commercially available systems, only one solution was identified [17] that serves to control the upper edge of the products. This system uses an infrared camera and is based on the heat emitted by the inspected articles. Its functionality is limited only to the positioning of the product and not to dimensional control. This is mainly due to the fact that

a) b) c)

Fig. 8. Installation location of the hot-end inspector: a) overview, b) inspection area, c) control of the upper edge for tooling positioning

a) b)

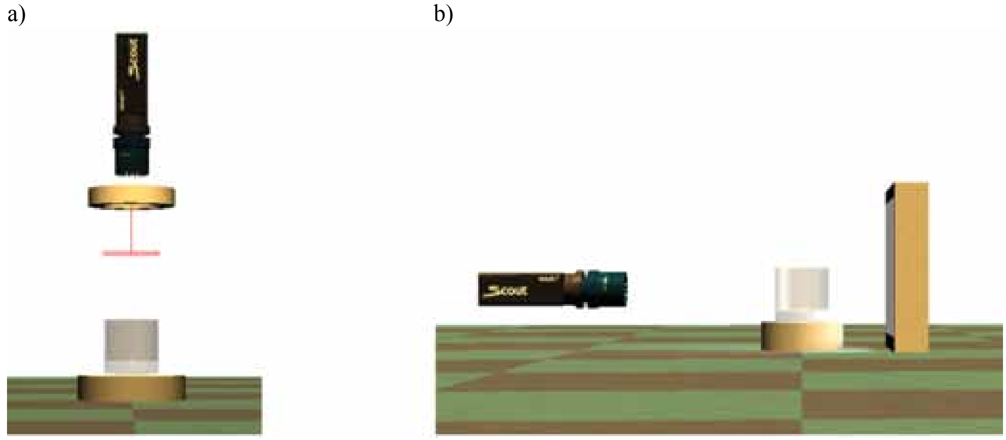


Fig. 9. Required imaging systems for inspection of (a) the top surface and (b) of the side surface

infrared cameras have low resolution sensors, usually not exceeding 1 Mpx.

3. Laboratory experimental setups and results

The main objective of the conducted research was to develop a lighting method that will enable obtaining high contrast images with simultaneous application in real industrial conditions while ensuring the longest possible service life. In order to validate the capabilities for inspection of upper edge of articles at the hot end, an experimental setup was made. In the first tests, the upper white light ring light was used (Fig. 10a). Due to the way light interacts with glass materials, it is very important to ensure a uniform surface on which products are transported. This is not possible at the hot end where the surface of the transporting elements has random patterns that change over time as a result of wear (Fig. 10b). Therefore, classic object lighting methods give poor results, and it is not possible to obtain an image with high contrast edges (Fig. 10c).

Due to unsatisfactory results in the second approach, it was decided to use an imaging system with ultraviolet light (365 nm). Soda-lime glass has the high ability to emit electromagnetic radiation after being activated by high energy radiation (Fig. 11a). This property is referred to as fluorescence. It depends on the material's purity and structural characteristics as well as the radiation's excitation energy and excitation wavelength [18].

In order to reduce the undesirable reflections (Fig. 11b), a band-pass filter was placed between the lens and the camera, which blocks UV radiation and near-infrared NIR [19]. As a result, a high contrast image was obtained allowing the thickness measurement of the upper edge of the product (Fig. 11c). However, the use of upper illumination is not advantageous, due to the low temperature resistance of the LEDs (up to 40° C). For this reason, at a later stage of the work, the tests were subjected to the configuration with side bar illuminators, separated from the heat source at a suitable distance, which were directed only at the upper edge of the products. In addition, a 5Mpx camera and lens with a high temperature resistance (up to 60° C) were used (Fig. 12a). The optical resolution of the imaging system for the horizontal field of view HFOV=200 mm is approx. 0.08 mm.

The use of simultaneous triggering of the camera and UV illuminators made it possible to shorten the exposure time to approx. 2 ms., which allows to significantly reduce the blurring effect [20] on the processed images. Fig. 12b shows an example of a recorded image on which the internal and external edges of the upper surface of the product were marked. In the presented brightness profile for the developed system (Fig.13b), the inner and outer edge of the article can be clearly identified, which was not possible using visible light (Fig. 13a).

a) b) c)

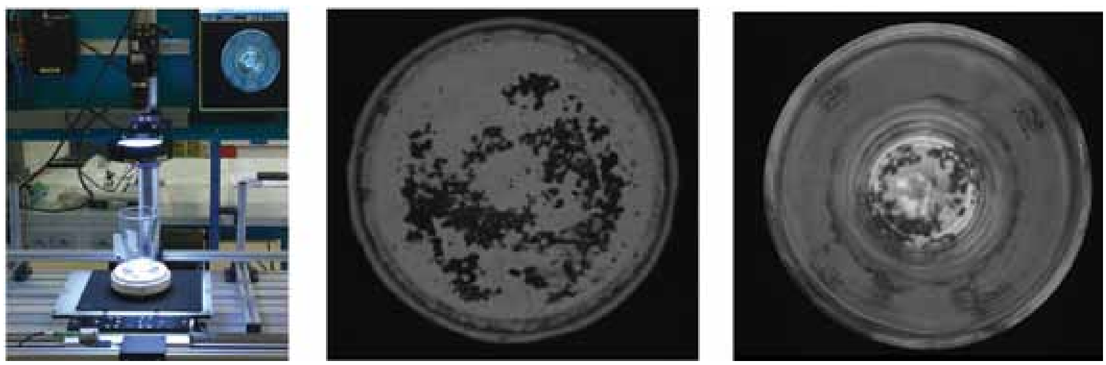


Fig. 10. Experimental setup with the use of visible light: a) overview, b) transporting base, c) sample image

a) b) c)

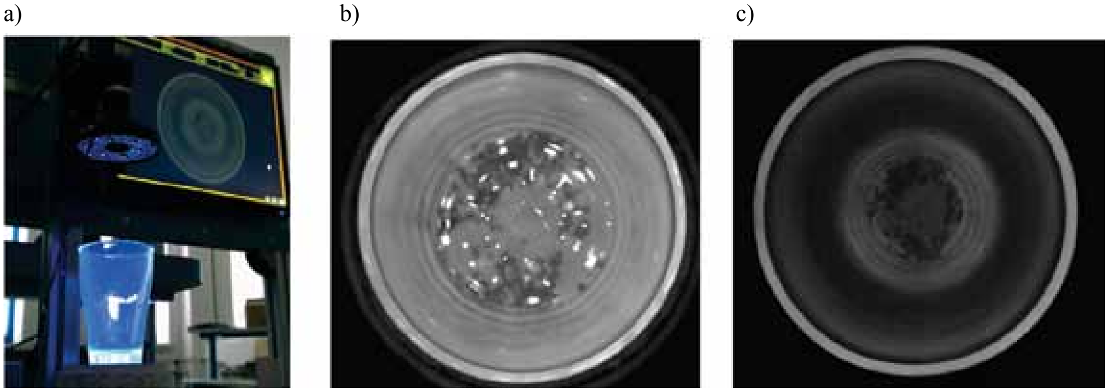


Fig. 11. Experimental setup with use of upper UV light: a) overview, b) image without filter, c) image with filter

a) b) c)

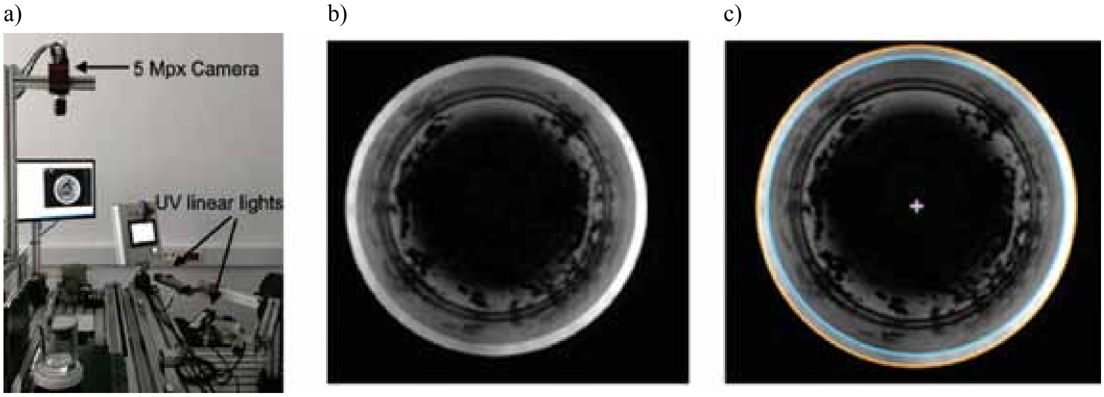
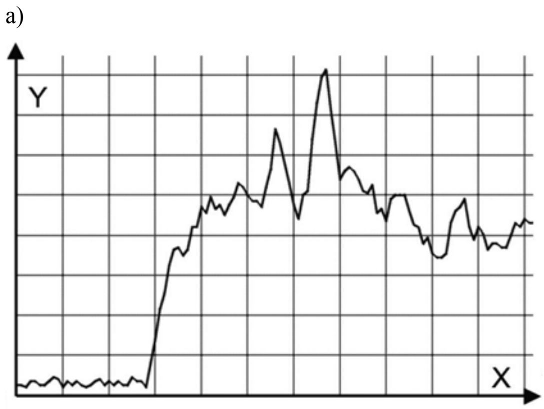


Fig. 12. Experimental setup with use of side UV light: a) overview, b) sample images (raw and with marked detected edges)



Y [10 grey levels/div], X [10 px/div]

Fig. 13. Sample edge brightness profiles: a) visible light ring light, b) final setup with the use of side UV light

On the basis of such an image, it is possible to determine the radius, ovality, and displacement of the centre of the outer circle relative to the inner circle. An advantage of the developed imaging system is the significantly lower price and higher resolution compared to solutions based on infrared cameras. However, the limitation is the need to provide an enclosure that limits the adverse impact of external light on the inspection results as well as blocking the hazardous of ultraviolet radiation to humans.

Conclusions

High competition on the glass products market enforces manufacturers to use inspection and monitoring systems at every stage of their production. Process control alone does not guarantee high yields in the glass industry which leads to lowering financials results of the glasswork. Only the combined methods of process and product control in real time allows for quick information and quick actions to maintain high process stability. An additional benefit of using machine vision inspection systems is the receipt of statistics for technologists to constantly improve the technology. In glassworks cooperating within a corporation, this allows for the exchange of good practice and analysis of the causes of disruptions in the manufacturing process.

A great benefit of using inspectors at the hot end is quick feedback information for the operators of forming machines. Inspection of articles only at the cold end is associated with the long delay needed for the products to pass through the glass annealing lehr until the measurement is made. In many cases, this time can be up to several hours. Therefore, a large number of products can be defective causing large financial losses. The presented inspection method can be a good alternative to expensive systems using infrared cameras.

Future work will be focused on building a prototype system equipped with an appropriate enclosure and a cooling system. Tests carried out under real conditions on the production line will allow the verification of the proposed method. Another direction of research will be laboratory tests for developing a lighting system for products with non-typical shapes.

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