WOOD RESEARCH
64 (4): 2019
637-646

QUALITY CONTROL SYSTEM OF WOODEN FLANGES BASED ON VISION MEASUREMENT SYSTEM

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(Received March 2019)

ABSTRACT

The paper presents a design of a robotic product control system made for the wooden flange production line. The system has been designed for installation in automated production lines that allow the production of short product batches with a quick change of the type series of the manufactured products. The purpose of the work was to develop a flexible quality control system that would enable the development and adjustment of the product parameters control procedure to various product type series. The quality control station has been designed with an industrial robot and a set of 2D and 3D vision systems that take measurements of the set of parameters described for wooden flanges used in the production of cable drums. The paper presents the description of the parameters of the product subject to quality control and the premises adopted in the design process of the station. The image analysis method has been presented as developed for selected product parameters, in the scope of measurements on the image, along with the presentation of measurement results.

KEYWORDS: Wood product quality, vision measurement system, image analysis, quality control system.

INTRODUCTION

The increase in the production efficiency of technological lines installed in the wood industry necessitates the introduction of solutions that enable the automation of the quality control process. The quality control made by operators is no longer possible in many cases due to the high production efficiency of the production lines. Statistical process control is insufficient due to the requirements set by customers defined as "zero defects". These requirements force the inspection of all products in terms of compliance of the product parameters with the quality control specifications required by customers. Manufacturers of machines and technological lines are forced to implement systems that check product parameters as part of in-process inspections directly at the production stations. The final inspection is also required to verify the quality of the finished products just before shipment to the customer.

Non-destructive testing techniques are used to build inspection systems in the tasks of testing the internal structure of wood (Bucur 2003, Meinlschmidt 2005, Wei et al. 2009). Imaging based on ionising radiation, thermal imaging, microwaves, ultrasound, and magnetic resonance is used. Artificial neural networks are also used in the construction of advanced inspection systems for assessment of wood parameters, e.g. in the task of classifying thermally modified wood (Nasir et al. 2019). The authors used wood moisture content, assessment of water absorption, swelling ratio, colour, hardness and dynamic modulus of elasticity as a set of features that enable classification of wood. Quality control and measurement systems based on the use of vision systems are successfully employed in technological lines in the wood industry and can carry out a very wide range of tasks. The vision methods usually use 2D monochrome or colour image analysis. This type of imaging is used in the search for knots or other surface defects (Hu et al. 2004, Sandak and Tanaka 2005). 3D imaging described in the paper is also used (Kowal and Sioma 2012, Sioma and Socha 2016, Sioma et al. 2018). The advantage of 3D imaging is the ability to perform a much larger number of measurements and tests, especially in spatial measurements, complementing and extending the quality control and measurement methods used.

The presented work proposes the construction of a quality control station equipped with an industrial robot and vision systems. The robot's task will be to position the vision systems in relation to the controlled surfaces. The positioning of the measuring system will be implemented based on information about the series of the manufactured products and will match the quality control and measurement requirements assigned to each product.

The task of the vision measurement system will be to determine the parameters stated in the quality control specification such as: checking the presence of holes, measuring the diameters of holes, measuring the width of the grooves, checking the presence of assembly elements, etc. The assumption was that the robot's arm will be able to positioning 2D or 3D vision systems allows you to adjust the functionality of the station's operation to the changing requirements of the quality control specifications. The combination of the vision system and the industrial robot was intended to achieve high degree of flexibility in positioning the vision measurement system in relation to the controlled products and the possibility of adding new quality control and measurement programs flexibly with the introduction of new products.

The vision inspection station was designed for an automated line producing wooden flanges for drums used to transport electric cables. The line has the capacity to produce flanges with diameters from 600 mm to 2600 mm and flange thickness from 38 mm to 100 mm. It is fully automated, allowing the selection of product series and additional parameters of the flange by the operator on the HMI (Human Machine Interface) panel. All operations of material preparation, material formatting, drilling and milling of holes and grooves, and assembly of materials into the finished product are carried out automatically. After the completion of technological operations, the finished products (flanges), are transported to the palletizing module and prepared for transport. In the next stage of production, two flanges are joined with steel assembly elements and auxiliary elements made of wood into the final product, i.e. a cable drum (Fig. 1a).

It was assumed that in the final stage of flange production, an additional quality control station will be built to perform measurements and quality control tests in accordance with the quality control specification required by the recipient. Analyzing the quality control specification for each type of products to be inspected, a set of parameters was developed, which should be determined for each flange leaving the production line (Fig. 1b).

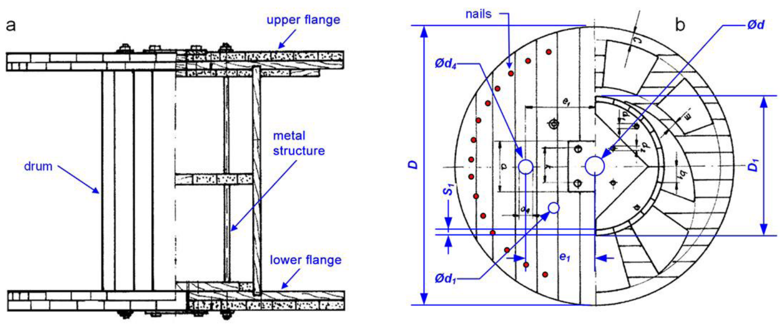

Fig. 1: a) The cable drum construction. *b) Parameters checked on the flange.*

These parameters include measurements of:

- the outside diameter of the flange [D] with the analysis of the diameter variation on the flange,
- the groove diameter [D1] with the analysis of diameter variation on the flange,
- the diameter of the central hole marked on the flange as [d],
- the diameter of the carrier holes marked on the flange as [d4],
- the distance between the axis of the driving hole and central hole axis marked on the flange as [e1],
- diameter [d1], bolt holes with the number of holes,
- the width of the keyway [S1] and the quality of its execution,

and determining of:

- the number of nails used to assemble the flange,
- the depth of the groove,
- the width and angle of inclination of the chamfering of the outer edge of the flange.

In addition, it was assumed that each flange should be inspected for visible damage to the surface in the form of cracks or the presence of knot holes visible on the surface of the boards.

MATERIAL AND METHODS

The use of an industrial robot on a measuring station results from the need to provide flexible positioning of the vision measuring system mounted on the robot's arm relative to the product. Due to the large dimensional variation of products manufactured on the production line, this solution will provide the possibility to change the position of the measurement system in the working space of the station, but also enable the optical axis of the vision system to change orientation of the flange surface which is necessary when checking the surface and edges of the holes. At the stage of preparing the guidelines for the design of the station, a number of assemblies were adopted, which had to be included in the design process of the position.

It has been assumed that the duration of the entire quality control procedure cannot necessitate stopping the technological process. This means that the execution time of the measurements should be approximately half of that of the flange production cycle performed with the highest efficiency. For the developed solution and the adopted measurement parameters, it is about 20 seconds for flanges with diameters ranging from 600 mm to 2600 mm.

Another assumption adopted in the project was to provide automatic flange stop and to carry out measurements in automatic mode without human action. After stopping the product on the line, the imaging process, image analysis and determination of the adopted measurement parameters are carried out. Measurement results are presented to operators on operator panels integrated in the station with simultaneous signalling of the detection of the defect and their indication on the product image. It was assumed that all measurement results along with the time stamp will be recorded in the company's database to allow the quality control of the current production and analysis of the causes of defects over a long-term production period.

On the basis of the premises, a design of the quality control station was drawn up with a steel structure for the assembly of the robot and the transport line. The robot is mounted on the mounting plate on a sliding supporting beam to provide for an additional change of the configuration of the station and matching the body of the robot to products that may be put into the production in the future. The robot used was Kawasaki RS010L with the maximum range of 1925 mm.

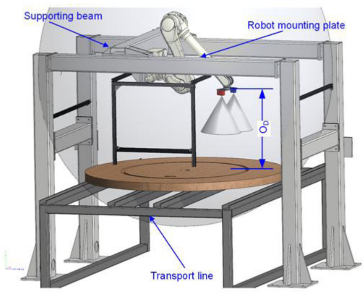

Fig. 2: Quality control station with an industrial robot and vision systems.

The presented solution enables flexible setting of the vision system installed on the robot's TCP port at various heights above the surface of the flange. The height of camera settings is described in the figure by the [O_D] parameter. The robot arm with the camera mount system can be set to a height of 0 to 2.5 mm above the surface of the flange. This range results from the way the robot is mounted on the supporting structure and the maximum allowable range of the robot while maintaining the required orientation of the optical system of the cameras relative to the surface of the flange. Even at a distance of O_D = 1800 mm, it is possible to observe the entire flange with the largest projected diameter of 2.6 mm. With the measuring camera system, it is possible to take measurements of all external parameters of the flange and selected diameters of technological openings, e.g. of the central hole. For detailed measurements, such as grooves or screw holes, a camera equipped with an optical system for precise measurements from the distance of 330 mm was used. The set of cameras was selected based on the analysis of the technical documentation of the type series of production flanges and the range of dimensions for the parameters to be measured on the flanges planned for production in the automated technological line.

The selection of image sensors in cameras and the selection of optical systems for cameras are based on the required measurement resolutions described for each of the adopted parameters. It should be noted that the measurement resolution will change with the distance from the flange surface. When increasing the imaging distance, the field of view (FOV) increases but the resolution of the measurement decreases. When selecting vision systems, the distance of imaging and the expected resolution of the measurement should be taken into consideration when selecting the sensors used in the vision system. For measurements with large field of view, matrices with higher resolution in pixels should be selected, at the same time based on matrices of larger sizes, e.g. 4/3" units (Fig. 3).

For measurements over the whole surface of the flange, a 4/3" monochrome CMOS sensor with the resolution of 4112 x 3008 pixels was selected, with the pixel dimensions 3.45 μm x 3.45 μm, with the lens *f* = 8mm (Fig. 3a). Assuming the effective field of imaging with 3000 x 3000 pixels resolution and real imaging field size equal of 3000 x 3000 mm, the measurement resolution was determined as:

$$\Delta R = 3000 \text{ mm} / 3000 \text{ pixels} = 1 \text{ mm/pixel} \quad (1)$$

For measurements with a smaller field of view (FOV), matrices with lower resolution in pixels based on the 2/3" matrix (Fig. 3b) may be selected. The analysis of the optical path indicates the possibility of observing the 354 mm x 265 mm field of view from the distance of 333 mm. For this configuration, the lens *f* = 8mm should be used for the designed 2/3" matrix. Assuming the effective field of imaging with the resolution of 2000x2000 pixels and the real size field of imaging 250 x 250 mm, the measurement resolution was determined as:

$$\Delta R = 250 \text{ mm} / 2000 \text{ pixels} = 0{,}125 \text{ mm/pixel} \quad (2)$$

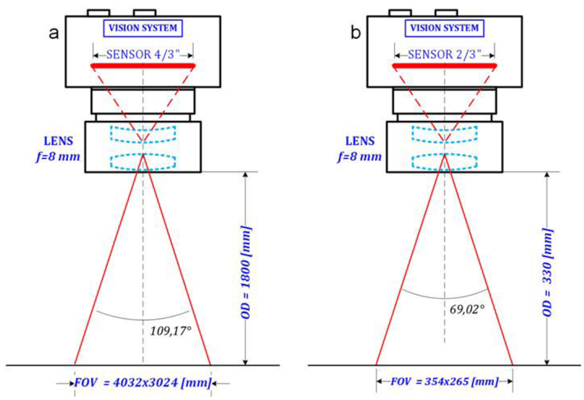

Fig. 3: Lens parameters: a) FOV for O_D = 1800 mm. b) FOV for O_D = 330 mm.

The measurement resolution can be increased with higher-resolution matrices (more pixels) or with sub-pixel processing during measurements – which is a much cheaper solution and sufficient enough in many applications to achieve the required measurement resolution. Another important parameter of the imaging is the choice of the lighting type. In the example, dark field light lighting is used to illuminate the surface of the flange from the illuminators mounted on two sides of the quality control station (Fig. 4a).

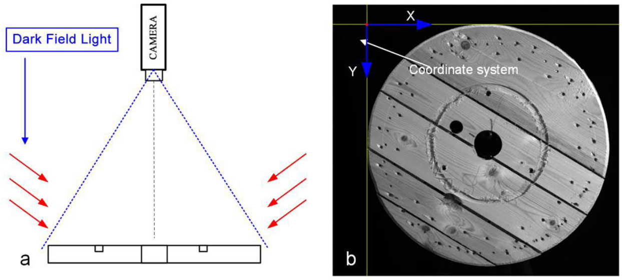

Fig. 4: Flange imaging with the 4/3" sensor.

This system allows the control of both the angle of the flange's lighting and the number of the illuminators used. In the imaging process, illuminators should be set up so as to ensure uniform and continuous illumination of the flange surface. This is very important due to the need to ensure repeatable lighting of the flange surface under changing lighting conditions in the production line. Additionally, the lighting should be selected that eliminates reflections on the surface of the flange (which may make it difficult to detect the edges and openings used in the process of measuring the geometric parameters of the flange). Fig. 4b shows the sample flange image on which the upper and left edge of the flange defining the origin of the XY coordinate system has been set. This system will be used in the measurement process to position the algorithms of edge detection and areas in the image.

RESULTS AND DISCUSSION

Measurement analysis of the image is based on the determination of a set of points describing the edges visible on the product image, which are then used to determine the description of circles, determination of radii, diameters, and distances between selected edges. The measurement of the outer diameter of the flange includes the determination of the coordinates of the points that describe the edge of the flange with the algorithms of image intensity analysis (Fig. 5).

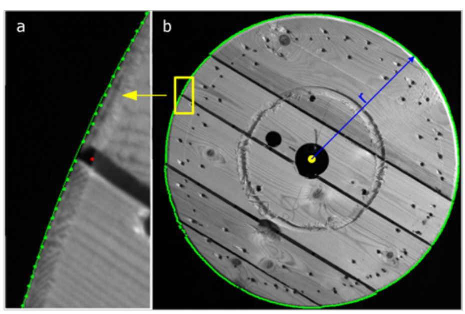

Fig. 5: Flange edge description and determination of the flange diameter.

On the basis of the point's analysis, a circle describing the flange and its centre was defined. An iterative algorithm for minimising the distance squares function between the required circle and the set of points was used for this. As a result, the location of the centre of the flange with sub-pixel resolution was determined. Then, on the basis of the measurement of the distance between the centre of the flange and each of the points of the edge of the flange, a set of 720 rays was determined, and then the diameter of the flange. Fig. 5b presents the image of the flange with the points marked on the edge, and Fig. 5a shows the magnification of the selected flange area and the presentation of the distribution of points on the edge.

To measure smaller diameters of openings in the flange, a higher resolution vision system was used, with the same algorithm as described above. However, for most holes, the number of points on the edge was reduced to the maximum of 90. This allowed the shortening of time measurement while maintaining a good measuring resolution of 0.1 mm. Fig. 6 presents the example of the measurement of the distance between the centres of two holes marked on the flange.

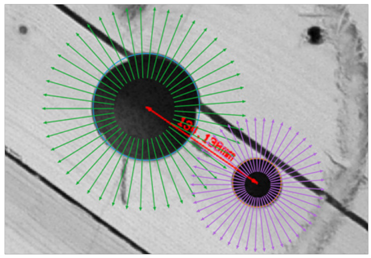

Fig. 6: Measuring the distance between two holes.

The groove milling depth measurement is carried out on the basis of the image analysis of the surface of the flange illuminated with a laser beam, with the laser triangulation method described in detail in (Sioma 2015). The laser beam is projected on the surface of the drum at a constant angle to the flange surface (Fig. 7a). Image recording with a camera whose optical axis is perpendicular to the surface of the flange allows the observation of the shift between the images of the laser lines depending on the height difference between the surfaces (Fig. 7b). Analysis of the image of the laser beam on the image allows the reproduction of the required spatial information – here, the depth of milling. In the first stage, the beam visible on the surface of the flange is analyzed. For a set of points showing its location, the measurement base is determined. Then an auxiliary measuring line is visible inside the groove.

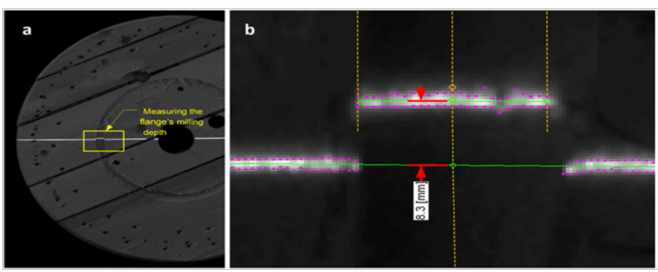

Fig. 7: Measuring the flange's milling depth.

On the basis of the measurement of the distance between the baseline on the surface and the auxiliary line in the groove, the depth of the groove is determined as:

$$z = x/tg(\beta) \tag{3}$$

where: z - groove depth,
x - distance between the baseline on the surface and the auxiliary line in the groove (Fig. 7b),
β - known angle of the laser setup, i.e. between the laser plane and the normal to the flange surface.

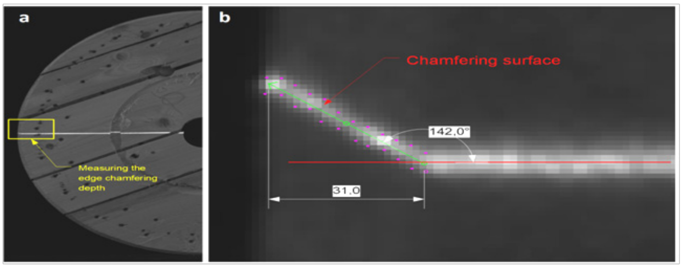

Fig. 8: Measuring the flange's chamfering surface.

With laser triangulation, the parameters of the chamfering of the edges of the flange are also determined. The sample measurement of the chamfered surfaces along with the presentation of the results prepared for the operator is presented in Fig. 8.

CONCLUSIONS

The paper presents a design developed for the industry, including the automation of the production process and the process of controlling the production of wooden flanges for cable drums. Increasing the production efficiency of the flanges resulted in the need to develop a quality control system with better flexibility and functionality. A major challenge was to develop a quality control system for products manufactured in short series with a flange diameter from 600 mm to 2600 mm. Additionally, different types of flanges are produced with one diameter, where the number of holes, the diameter of the grooves, or the number of millings and chamfers change. High variability of product dimensions and the number of controlled parameters of the product made it necessary to use a robot that has the function of a positioning system for vision measurement systems. The choice of the RS010L robot with the range of 1920 mm was due to the possibility of flexible positioning and orientation of the vision system with respect to each of the controlled elements on the surface of the product with the diameter of up to 2600 mm and easy programming of any movement trajectory. In the measurement system, two cameras were used to display a scene of 3000 x 3000 mm at the resolution of 1 mm, with another one for imaging a field of vision with smaller dimensions 250 x 250 mm, but 8 times better resolution of 0.125 mm. Both cameras are used in the quality control process and, depending on the guidelines in the quality control specification, perform separate measurement tasks. The laser triangulation method used in 3D surface imaging was also employed in the implementation of the measurements. In case of measurements on the flange, it is used to measure the depth of grooves and chamfering of the edges. It is also possible to inspect the internal surfaces of holes and to measure the depth of drilling holes.

The station discussed in the paper, owing to the use of an industrial robot and a set of vision systems, allows for the implementation of a wide set of parameters to be checked on the surface of the flange. Due to the possibility of positioning and orienting the cameras in relation to each of the controlled surface elements, the measurement process can be repeated and analyzed statistically. The number of measurements and their repetitions are limited only by the time resulting from the step rate of the technological line. Such a station enables the staff to prepare practically any quality control program and adjust the quality control program to new types of flanges added to the production.

In addition, it was assumed that the quality control process will be carried out in an automated mode to allow the measurement of the key product parameters and their analysis and generation of feedback for the production technology control system.

ACKNOWLEDGEMENTS

This paper was written as part of statutory research carried out at the AGH University of Science and Technology, Faculty of Mechanical Engineering and Robotics, Department of Process Control in Laboratory of Process Automatization and Vision Systems.

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