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Optical Inspection of CPVC Fitting Elbows and Fault Diagnosis of the Production Process

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Abstract

The topic of this study is the optical inspection of CPVC fitting elbows concerning the geometric parameters that can be detected in 2 dimensions. Based on the evaluation of the results, fault diagnosis has been set up for the production line by statistical calculations. The optical inspection was carried out in the Vision Development Module software environment produced by National Instruments, and the data were evaluated using Microsoft Excel.

Keywords*: Industry 4.0, image processing, quality control, CPVC, fault diagnosis.*

1. Introduction

The Fourth Industrial Revolution has had a huge effect on contemporary industrial, economic and social life. This revolution is often referred to simply as Industry 4.0.

Industry 4.0 is based on the smart networking of machines using information and communication technology. Machines with advanced sensing ability and the automation processes play an increasingly important role. Making the manufacturing processes more adaptive calls for the development of machine vision in areas such as positioning, object recognition and quality control.

2. Quality control in industrial life

The purpose of the quality control in an automated production line is to check the conformity of the product in particular. Conformity shows compliance with national-, professional, corporate standards and legislation or requirements **[1]**. The control always needs to relate to a specified quantity of material or quantity of lots. The process can be non-statistical or statistical. In the former case, the duty of the inspector is to establish the number of the sample required for the inspection based on the nature of the product and the manufacturing process.

On the other hand, the statistical method requires collecting regular quality control data. These data are processed statistically, which helps to classify them. The advantage is that the monitoring process is continuous over time due to regularity, so general conclusions can be obtained from fewer data and the nature of their changes can be seen.

There are basically 4 methods known: 100 % quality control, random quality control, statistical sampling quality control and manufacturer's declaration-based quality control **[1]**.

In the case of 100% quality control, the sample is the total number of the products. Each piece of the sample is monitored, but the inspection is limited to only certain properties. The advantage of the method is that the monitoring is comprehensive for the given property. The disadvantage is that other defects are not detected and only non-destructive test methods can be applied **[1]**.

Random quality control means only a certain part of the total number of sample items (e.g. 10 %). This quantity is optional **[1]**.

Statistical sampling quality control provides effective and reliable results. The advantage is that - thanks to continuity and statistical methods – the results can be applied nevertheless to a large number of items from a relatively small number of samples. It is established based on a rating method whether the items of the sample meet certain requirements, but in the case of the measurement-based method, the measured values are recorded and analysed as well [1].

In the case of manufacturer's declaration-based control method, the manufacturer issues a quality certificate regarding whether the products have reached the required quantity or not [1].

3. Principles of optical inspection

3.1. Tools of optical inspection

One of the most important technologies in industrial quality control processes is machine vision. Typically, the detected properties are external properties of the product, which can be a geometric parameter, the existence of objects or other optically perceptible properties. Units are the signal source and highlighting (image and illumination), the imaging device, the signal processing unit, the software component and the communication channel [2].

The signal source can be a moving or picture or a simple image. The highlighting tool improves the quality of sampling and quantization with illumination (Reflected, Bright Field, Dark Field, diffuse, focused etc.). The imaging device adapts to the physical property of the signal source and produces the digital image in conjunction with the signal processing unit. The user interface is provided by the software component, which has access to a knowledge database and has the necessary communication channel (e. g. Modbus TCP, EtherCAT) [3].

3.2. Process of machine vision

The first stage of image processing is pre-processing, which prepares the raw input data using simple operations and filters. The goal is to leave out the unnecessary visual information and eliminate the confusing differences (e. g. by using grayscale conversion). The pre-processing takes place at the pixel level [4, 5].

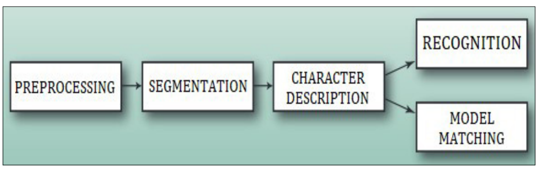

Figure 1. *The process of machine vision .*[4]

The next step is segmentation, which also aims to highlight the valuable information and discard the unnecessary information by separating the typical areas of the image. Its tools are sharpening algorithms, histogram curve transformation for colour- and brightness values [4, 5].

The information of the segmentation and the detection of the characteristic properties is compressed descriptors, so the recognition process is now information-based, not pixel-based. The process is facilitated by the knowledge database due to its elements being compared with the information of the descriptor algorithms. It can be provided by the company, but it can be a company-independent database as well [4, 5].

In addition to recognition, machine vision can also utilise model matching in order to decide whether a particular model can be used to fit and process, based on information of the descriptors. The first step is to associate a custom description and the second step is to paste and fine-tune the model [4, 5]. The steps of the machine vision process can be seen in **Figure 1.**

4. A CPVC fitting elbows

PVC (Polyvinyl-chloride) belongs to the group of thermoplastics, containing 47% chlorine and 43% carbon. The re-chlorination of PVC results in the CPVC material (Chlorinated polyvinyl-chloride), whose physical and chemical properties are significantly improved [6].

Thermoplastics are released into plastic state under the influence of heat and then re-formed in a solid state. This can be repeated. The raw material is administered in powder or granules. While thermoplastic pipes are made by extrusion, fittings are made with injection moulding technology [7]. **Figure 2** shows the main parts of an injection moulding machine.

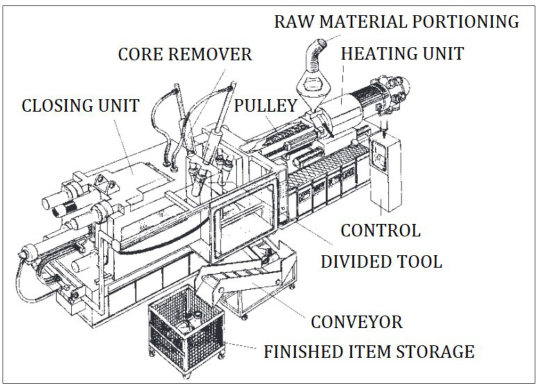

Figure 2. *Injection moulding machine* [7]

In the heated cylinder of the machine, the granules are melted (plasticised) with the help of the pulley, and then it squeezes the prepared plastic material into the closed cavity of the injection moulding tool. The generated forces are damped by the closing unit. The moulded workpiece is cooled through the tool until the material solidifies. After opening the divided tool and removing the cores that form the inside of the workpiece, the fitting can be removed [7].

5. The realised optical inspection

The optical inspection process was developed in the Vision Development Module environment produced by National Instruments. The software is capable of detecting, recognizing, counting, pattern- and property recognition, measuring the velocity and its vector of moving objects and performing tasks in the frequency domain [8].

During the inspection, external geometrical parameters of the following Genova 50705 1,2" CPVC fitting elbow were detected [9]. The dimensions of the item are shown in Figure 3 in mm.

The optical inspection includes 17 image processing sequences, during which the following geometrical dimensions are detected:

- the diameter of the elbows (both opening),
- the angle of inclination,
- the vertical length of the elbows
- the horizontal length of the elbows.

The first step is to load the digital image of the item, which is a 2268 × 2271 size digital image with an sRGB colour plane at 24-bit depth. Image processing in a 24-bit-depth image in RGB colour plane is resource-intensive, so the original image is modified to 8-bit depth by a Colour Plane Extraction function block without the red colour plane.

The objects have variable positions and orientations, so a reference system is required. In doing so, a certain corner of the actual elbow is trained and discovered with the Find Base Coordinate System function Block, which is the actual reference system through the Define Coordinate System function block.

The following edge detection operations are designed to find the pipe openings based on the 2 endpoints of the diameters using the Upper- and Bottom Edge Detector function blocks. During the detection, the first and last edges along a given line are revealed, which are the contours of the component. Diameters are measured using the Upper- and Bottom Diameter Calliper function blocks based on the number of pixels along the line.

The next geometrical parameter to be measured is the angle of inclination. The nominal value is 90°. Instead of 1 line, the edge is detected with many more detection lines perpendicular to the edge that is looked for. The line density results in a more accurate detection, but the use of unnecessary lines slows down the processing speed. During the detection, 90 lines perpendicular to the longer side were applied in an area of 1300 x 500 pixels with 40 dB detection value, specified detection direction and monitoring for changes in the intensity. The angle of incline is measured by a function block called Angle Calliper, based on the angle between the two lateral straights.

To measure the lengths of the elbows, the midpoints of the pipe openings are defined, which are the midpoints of the diameters sections. The lengths of the sections that connect the midpoints to the opposite sidelines and are perpendicular to the lateral lines, specify the values that need to be measured. The perpendicular straight is set through the Bottom- and Top Perpendicular Projection Calliper blocks, while the size values are measured by the Height and Width function blocks. The geometrical parameters are shown in Figure 4.

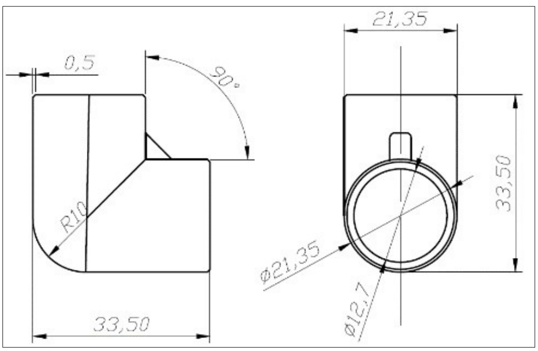

Figure 3. *Dimensions of the CPVC fitting elbow in [mm]* [10]

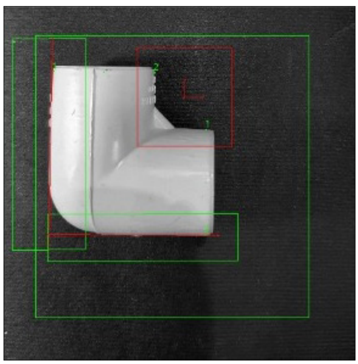

Figure 4. *The detected parameters*

6. Fault diagnosis of the production process

6.1. Results of the optical inspection

During the optical inspection, a sample of 30 items was checked. For the pixel-millimeter conversion of the applied optical settings, a manufacturer-controlled sample of 15 items was used. The results are as shown in **Table 1.**

The pixel numbers are not integer values, due to the fact that the image processing divides the quantities from the size of 100 pixels for the more accurate measurement, reducing the measurement error to one hundredth. In the case of the actual optical settings, the following relation was made:

$$1\,mm = 31{,}55\ pixel \qquad (1)$$

The values of the manufacturer standard in [mm], the angle and the pixels can be seen in **Table 2.**

The results of the optical inspection of the 30-element sample were processed in Microsoft excel and a summary can be seen in **Table 3.**

During the optical inspection, 1 defective product was detected, the diameter values were beyond the permissible tolerance.

Figure 5 shows the data distribution.

Table 1. *Results of the pixel-millimeter conversion*

	Manually	Optically
Pipe diameter	21.35 mm	673.60 pixel
Lengths	33.50 mm	1056.90 pixel
Angle	90°	90°

Table 2. *Nominal- and tolerance values*

	Nominal value		Tolerance	
	[mm]	[pixel]	[mm]	[pixel]
Pipe diameter	21.35	673.60	±0.1	±3.2
Lengths	33.50	1056.90	±0.5	±15.8
Angle	90°	90°	±0.5°	±0.5°

Table 3. *The processed data*

	Average	Deviation
Pipe diameter	21.3464 mm	0.03236 mm
Lengths	33.4802 mm	0.12474 mm
Angle	90.07°	0.05801°

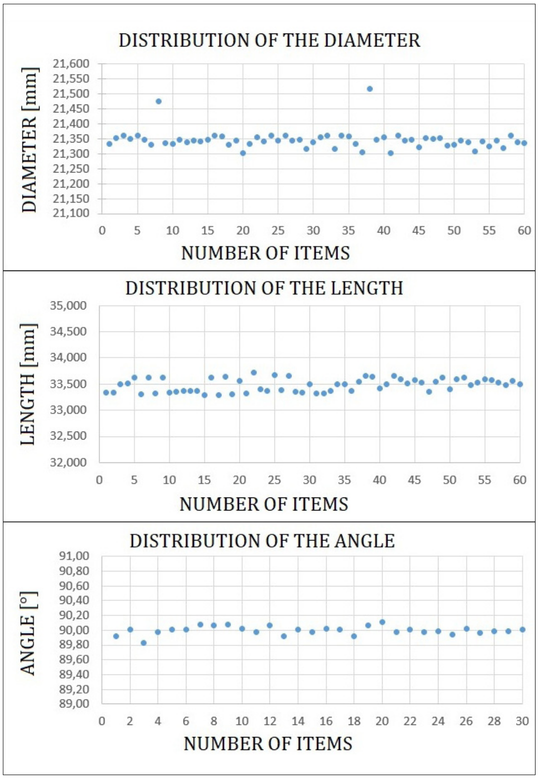

Figure 5. *Distribution of the data*

6.2. Results of the fault diagnosis

AThe results of the optical inspection show where the values of the sample located within the specified tolerance ranges, whether the machine is capable of producing items of the given quality or not. Machine capability and process capability can be defined **[10]**:

$$C_p = \frac{FTH - ATH}{6 \cdot \sigma} \qquad (2)$$

$$C_{pk} = \left\{\frac{\mu - ATH}{3 \cdot \sigma}; \frac{FTH - \mu}{3 \cdot \sigma}\right\}_{min} \qquad (3)$$

$$C_m = \frac{FTH - ATH}{8 \cdot \sigma} \qquad (4)$$

$$C_{mk} = \min(C_{ml}; C_{mu}) = min\left\{\frac{\mu - ATH}{4 \cdot \sigma}; \frac{FTH - \mu}{4 \cdot \sigma}\right\} \qquad (5)$$

where,

- *FTH/ATH* – – tolerance limit [mm],
- μ – average value [mm],
- σ – deviation [mm],
- C_p/C_m – process/machine capability index,
- C_{pk}/C_{mk} – index of the current capability of the process/machine **[10]**.

Table 4. *A The calculated indexesi*

	Process capability		Machine capability	
	C_p	C_{pk}	C_m	C_{mk}
Diameter	1.0299	0.9928	0.772463	0.7446
Length	1.3361	1.2832	1.00212	0.9624
Angle	2.8731	2.8578	2.154834	2.1433

The machine capability applies to a single machine or operation. The goal is to minimize the number of error factors that cause large changes. The processing capability takes all the effects which caused a change in the parameters into consideration (**Table 4**) **[10]**.

During the production, the external diameter of the elbows proved to be the critical parameter. The probability variable of the parameter (diameter [mm]) shows a normal distribution. Because $C_p = 1{,}02995$, is calculated for diameter, the tolerance range around the average value is $SL = 3C_p = 3{,}089$ standard deviation units at its natural fluctuation of +/-3σ. Accordingly, $C_{pk} = 0{,}9928$ shows that the expected value is closer to the lower tolerance limit. The falling outside the limit is less than 0,27 %.**[10]**.

7. Conclusions

Based on the results of the optical inspection, the production line is able to meet the customer requirements. The production process is stable, regulated and only accidental defects can be expected. Increasing the number of samples and inspecting them more frequently gives an even more credible picture, including timely changes in products made on the production line.

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