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COMPARISON OF CONFOCAL SENSOR FOR DIAMETER MEASUREMENT WITH MEASURING PROBE

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Abstract

The measurement and inspection of products and their dimensions in industry plays an important role in determining the quality of a product. Correct measurement is a key factor in production. Many companies are subject to stringent safety standards and specific product requirements. Accurate measurement ensures compliance with these guidelines, avoiding fines, penalties and legal complications. Effective measurement processes can identify inefficiencies, defects and areas for improvement, leading to cost savings. By detecting defects early in the production cycle, manufacturers can reduce waste and optimize resource utilization thereby reducing overall production costs. A fundamental principle of good measurement is to ensure that the measuring instruments are suitable for the specific application and that they meet the measurement requirements for the measurement parameter. The objective of the experiment is to verify and compare the measurement capability of a confocal chromatic sensor against a measurement probe used in production. The parameter to be measured is the diameter, since the correct diameter plays an essential role in the production of shafts or other cylindrical products. The results contained in the thesis highlight the importance and differences between the different measuring devices and the qualification to use the measurement of a given parameter.

Keywords:

Confocal chromatic sensor, Diameter measurement, Aluminum

1 INTRODUCTION

Accurate diameter measurement is crucial in a variety of industries to ensure quality control, precision production and safety. Different methods and tools are used in different industries to ensure the highest level of accuracy. According to ISO standards, the standard definition of diameter is the actual distance between two points in a section perpendicular to an axis that passes through the center of the cross-section, not the average or least squares value. To measure diameters and dimensions of manufacturing parts, various tools are used in industry such as, calipers, micrometers, vernier calipers, oscilloscope profilometers, laser measuring instruments digital calipers, optical comparator, coordinate measuring machine (CMM), etc. Each of these tools has distinct features and benefits that make it suitable for specific applications and industries. Digital gauges can be a good choice for diameters that are achievable around the perimeter of the part. However, coordinate measuring machines (CMMs) or comparable gauges may be needed for recessed or blocked diameters. Compared to calipers, comparative gauges with digital indications can provide better accuracy and resolution over a limited measuring range. For extremely large diameters, comparators can offer maximum accuracy, yet considerable care must be taken in the selection of measuring points and evaluation methods. Comparative gauges with spring contacts are more user-friendly for operators to operate than gauges that swing across the diameter. Compared to manual readings, automated data collection with digital indications can also minimize operator error. Comparison gauges and CMMs can measure a wider range of diameters than calipers. The measuring range can be increased even further with modular comparative gauges that have interchangeable rails. Cost and availability should also be considered, as large CMMs are expensive and may not be practical to measure in process. Hand tools such as calipers and comparative gauges are more affordable. It should be added that the industry and the specific application will determine which tool and method of diameter measurement is appropriate to use. Manufacturers can ensure that they are using the most appropriate technique for their requirements if they are aware of the specific features and advantages of each tool.

The researchers investigated a machine vision-based model for measuring the diameter of metal bars. The system uses a laser light source and a camera to capture an image of the rod for measurement purposes [Tan 2021]. The study describes a method that is implemented in a geometric dimension inspection unit for automated inspection of fuel pellet dimensions. Digital cameras with optical axes in the plane of the light strip are used to capture the image of the pellet [Meledin 2021]. In their work, the researchers propose a simplified analytical theoretical model to measure the conductivity and diameter of metal rods using frequency dispersive eddy current testing [Huang 2023]. This technique allows simultaneous measurement of the conductivity and diameter of metal rods, providing comprehensive data on their structure. Tests have shown that typical relative measurement errors range from 0.6% to 1.4%, demonstrating the high level of accuracy of this method. The advantage of laser measurements is their applicability to a wide range of materials. The authors report that they used a laser gauge to measure the diameter of the trunk [Teresneu 2022]. Computer image analysis technology is also used to measure the diameter. Segmentation techniques such as K-means clustering are used to accurately identify nanotubes in photographs. The k-means clustering technique has a higher level of accuracy in detecting and categorizing objects in photographs, leading to more accurate measurements of the internal diameter of nanotubes. This method has the advantage of being relatively simple to implement, making it accessible to users with less programming knowledge [Caro-Gutierez 2021]. The aim of the research is to improve product quality by reducing measurement inaccuracies. A regression model is used to find the relationship between predicted values, actual values and input parameters. The neural network (ANN) model consistently achieves prediction accuracy of and 95%, thus providing exceptional results in predicting outputs In addition, the use of the WASPAS technique is critical to increase the accuracy of the estimates produced in this study [Zende 2023]. A study focusing on a non-contact approach, often referred to as the projection shadow method, uses optical contouring to determine the geometric configuration of an item by determining the coordinates of its boundaries and calculating the necessary parameters based on them. The effectiveness of the procedure depends on the selection of a threshold level determined by the illumination used. Experimental findings have shown that this approach is able to achieve an error level of 0.24 µm when measuring objects up to 10 mm in diameter. Overall, the findings indicate that this technique is reliable and capable of providing accurate measurements of cylindrical objects using projection shading [Dvoynishnikov 2022]. The research work introduces a new method that specifically targets diameter measurement in industrial machine vision applications. The proposed approach for diameter measurement in industrial machine vision applications presents an innovative algorithm that combines subpixel counting with gray-level pixel information to improve the accuracy and speed of diameter measurement. The method provides improved performance in terms of accuracy, repeatability and computational time compared to previous systems, thanks to the use of sophisticated image processing algorithms, automatic threshold calculation and accurate image segmentation. This approach prioritizes industrial usability and efficiency, providing a reliable solution for accurate diameter measurement in production and quality control processes [Poyraz 2024]. One of the latest techniques for accurately measuring shaft diameters is the visual measurement method, which uses a pair of cameras. The measurement approach relies on a pinhole camera imaging model where 3D surface points are projected onto 2D image points [Li 2023]. For the measurement of micro-holes, an air measurement sensor has been developed that does not need a microprobe. The study investigates the influence of important factors such as inlet pressure and inlet nozzle diameter on the static properties of the sensor. A combination of theoretical modelling and experimental data is used. The aim of the research is to optimize the performance of an air measurement sensor for the accurate measurement of micro-hole diameters of less than 1 mm [Li 2023]. This paper presents a new diameter measurement system that uses a two-fiber grid (THFBG) to measure the diameter of a sample. The proposed system offers a larger measurement range compared to previous methods and exhibits minimal sensitivity to temperature changes. The diameter measurement system proposed in this study has potential applications in the measurement of cylindrical objects and bend curvature detection in some special measurement environments with strong electromagnetic fields or dust [Ren 2022]. In this article the researchers focused on the measurement of small holes using the SSEP method, which can also be classified as a non-contact method because there is no direct contact between the probe and the measured object, an indisputable advantage of our measurement is the possibility to verify the diameters of several types of materials and not only electrically conductive ones, as well as the possibility of detecting the circularity of the measured object [Bian 2019].

2 MATERIAL AND METHODS

In the experiment, a component (Figure 1.) made of aluminum alloy EN AW 7075 was used, whose mechanical and chemical properties are described in Tables 1 and 2. EN AW 7075 material is a robust aluminum alloy that is often used in aerospace and other demanding areas for its exceptional mechanical properties and strong fatigue resistance.

Tab. 1 Mechanical properties of material EN AW 7075. [Valencia 2008]

Maximum tensile strength	540MPa
Tensile yield stress	470MPa
Shear strength	331MPa
Fatigue strength	159MPa
Modulus of elasticity	71.7 GPa
Shear module	26.8 GPa

Tab. 2 Chemical properties of the material EN AW 7075. [Valencia 2008]

Si	Fe	Cu	Mn	Mg
0.40	0.50	1.2 - 2.0	0.30	2.1 – 2.9
Cr	Zn	Ti	Others	Al
0.18 - 0.28	5.1 – 6.1	0.20	0.15	The rest

Figure 1. Measured sample.

The sensor used for the measurements was from Keyence, namely the CL-P070 sensor (Figure 2.), which is a confocal sensor. These sensors are widely used in various industries to measure distance, thickness and profile with high accuracy. The main advantageous aspects of this sensor include high accuracy at the sub-micron level, making it ideal for applications that require high precision. The CL-P070 is a measurement sensor that can measure a surface without any physical contact, which is essential for sensitive or moving parts. Due to its dimensions, it allows easy integration into various machines and equipment. This sensor is suitable for measuring the height, width, thickness and position of objects. Enables easy integration into various machines and equipment. It is commonly used in manufacturing processes, quality control and research and development. It is often chosen in industry due to its capability and versatility as it can measure a wide range of materials including metals, plastics, glass and more. Thanks to its advanced algorithms, the probe measures both glossy and dark surfaces. It is commonly provided with software that offers an intuitive means of setting up, monitoring and evaluating measurements. The Keyence CL-P070, as part of the CL-3000 series, is a versatile and highly accurate instrument designed to meet the stringent requirements of today's industrial measurement applications. Its combination of non-contact measurement, high accuracy and seamless integration makes it a valuable resource in a variety of industries [Keyence datasheet].

Figure 2. Confocal sensor Keyence CL-P070.

The second measuring device used in the experiment is a measuring probe from HAAS, namely the HAAS Renishaw OMP40-2 type (Figure 3.). In the measuring probe is placed probe sphere with diameter of 6 mm. The HAAS Renishaw OMP40-2 measuring probe is a versatile and accurate measuring tool designed for use in CNC machines to ensure the accuracy of the machining process. It offers high-precision measurements, wireless communication, simplified setup procedures and versatile measurement options. The probe can measure a variety of features including holes, grooves, inserts and surface profiles. It is designed to withstand the harsh conditions of the machining environment, including exposure to coolant and high-speed operations. A touch trigger probe increases the machine's ability to measure wear directly on the machine, reducing the need for manual measurement and increasing overall accuracy and efficiency. It provides detailed measurement data that can be used for quality control and process improvement. The HAAS 40-2 measurement probe is an essential tool for CNC machining operations, providing highly accurate, real-time measurements that improve accuracy, efficiency and quality of machined parts. Its integration into Haas CNC machines enables seamless operation and automated inspection procedures, making it an asset in modern manufacturing environments. Probe repeatability is within ±1 micron (0.001 mm) [HAAS Service].

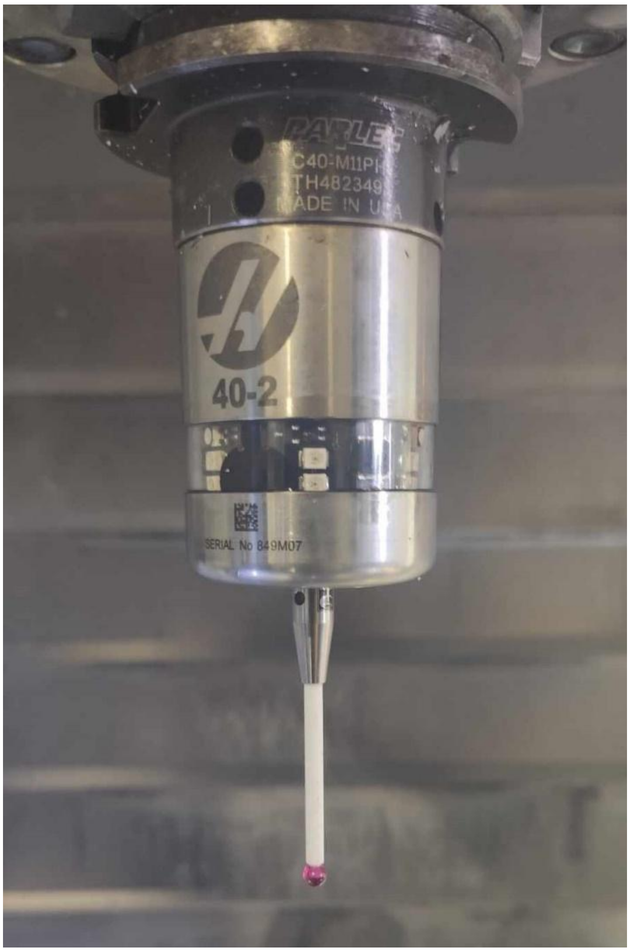

Figure 3. Measuring probe HAAS OMP40-2.

3 EXPERIMENTAL MEASURING

In our measurement, we focused on the capabilities and use of the confocal sensor in measuring the diameter compared to the measuring probe used in production. The measurement conditions under which the experiment was carried out are shown in Table 3.

Tab. 3 Measurement condition

Measurement condition	
Temperature	22.4°C
Pressure	97.085 kPa
Humidity	53.1%

Using the HAAS OMP40-2 measuring probe, we measured the diameter of the manufactured shaft. The probe is calibrated using a known reference point or calibration artifact to ensure accuracy. The control system of the CNC machine moves the probe to the measuring position. When the probe tip touches the workpiece surface, a signal is triggered. The machine records the position of the probe now of contact. The recorded positions are used to calculate dimensions such as lengths, diameters and angles. The machine software processes this data and compares it to the required specifications. The accuracy of the probe can be affected by the condition of the CNC machine itself, including table flatness, spindle misalignment and overall machine setup. The results of the measurements are recorded in Table 4. As can be seen, 4 measurements of 5 repetitions each were taken, and for each measurement the part was rotated 90° to ensure the circularity of the part.

Tab. 4. Diameter measurement with HAAS OMP40-2 probe.

	Measuring 1 (mm)	Measuring 2 (mm)	Measuring 3 (mm)	Measuring 4 (mm)
1.	16.956	16.951	16.956	16.961
2.	16.957	16.954	16.956	16.961
3.	16.957	16.952	16.957	16.961
4.	16.957	16.949	16.956	16.960
5.	16.957	16.952	16.956	16.961

After the diameter values were measured and entered the above table, the overall diameter was calculated from the measured values and the range between the largest (Dmax) and smallest (Dmin) measured diameter was determined. These data are shown in Tab. 5.

Tab. 5. Calculations of values from Tab.4.

Avg. (mm)	Dmax (mm)	Dmin (mm)	Range (mm)
16.956	16.961	16.949	0.012

The measurement was then carried out using a confocal sensor and the part was inserted into the lathe. At the start of the measurement, the sensor was configured to the initial zero point of the part and then the measurements were taken. For each point, 4 measurements were taken with a repetition count of 10. Every measurement, the component was rotated by 90° to get a comprehensive overview of the measured data so that the data could be compared with the data obtained from the probe. The following table (Table 6.) shows the data from the measurements with the component in the initial position, i.e. - 0°.

Tab. 6 Sample measurement in 0° position.

	Measuring 1 – 0°	Measuring 2 – 0°	Measuring 3 – 0°	Measuring 4 – 0°
1	0.000	-0.004	-0.002	0.002
2	0.000	-0.005	-0.002	0.002
3	0.000	-0.004	-0.002	0.003
4	-0.000	-0.004	-0.002	0.002
5	0.000	-0.005	-0.002	0.002
6	0.000	-0.004	-0.002	0.003
7	-0.000	-0.004	-0.003	0.003
8	-0.000	-0.005	-0.002	0.002
9	-0.000	-0.004	-0.002	0.002
10	0.000	-0.004	-0.003	0.002

Table 7 (Tab.7.) shows the measurement data of a part rotated by 90°.

Tab. 7 Sample measurement in 90° position.

	Measuring 1 – 90°	Measuring 2 – 90°	Measuring 3 – 90°	Measuring 4 – 90°
1	0.028	0.028	0.024	0.025
2	0.028	0.028	0.024	0.026

3	0.028	0.027	0.024	0.024
4	0.029	0.027	0.025	0.025
5	0.027	0.028	0.023	0.026
6	0.026	0.028	0.024	0.025
7	0.027	0.027	0.023	0.023
8	0.028	0.028	0.023	0.026
9	0.028	0.028	0.024	0.023
10	0.027	0.028	0.024	0.025

Table 8 (Tab. 8.) shows the data from the third measurement where the component was rotated by 180° compared to the starting point.

Tab. 8 Sample measurement in 180° position.

	Measuring 1 – 180°	Measuring 2 – 180°	Measuring 3 – 180°	Measuring 4 – 180°
1	0.029	0.030	0.029	0.030
2	0.030	0.030	0.029	0.030
3	0.028	0.030	0.029	0.030
4	0.030	0.030	0.027	0.030
5	0.029	0.030	0.027	0.029
6	0.029	0.029	0.028	0.030
7	0.029	0.030	0.029	0.028
8	0.030	0.029	0.027	0.029
9	0.028	0.028	0.029	0.029
10	0.029	0.030	0.029	0.030

Table 9 (Tab. 9.) shows the data we obtained from measurements where the part was rotated by 270°.

Tab. 9 Sample measurement in 270° position.

	Measuring 1 – 270°	Measuring 2 – 270°	Measuring 3 – 270°	Measuring 4 – 270°
1	-0.012	-0.010	-0.011	-0.013
2	-0.011	-0.009	-0.012	-0.010
3	-0.012	-0.009	-0.012	-0.013
4	-0.010	-0.010	-0.013	-0.013
5	-0.011	-0.009	-0.012	-0.011
6	-0.012	-0.009	-0.012	-0.013
7	-0.012	-0.008	-0.012	-0.013
8	-0.013	-0.008	-0.012	-0.013
9	-0.012	-0.009	-0.011	-0.011
10	-0.011	-0.009	-0.013	-0.012

Once the data was obtained, we processed the data by averaging the individual measurements and then calculating the overall average from each measured point on the component. The data are written in Table 10 (Tab. 10.)

Tab. 10 Averages from Tab. 5-8.

	0°	90°	180°	270°
Avg.	-0.001	0.026	0.029	-0.011

The total diameter of the part is 16.956 mm, as we can see in Table 5. The range between the uniform measured diameters is 0.012 mm. The largest measured diameter (Dmax) has a value of 16.961 mm, and the smallest (Dmin) has a value of 16.949 mm. To relate our measured deviations to the diameter, we must add them to the diameter of the part. For ease of visualization, we will consider the perfect circularity of the part. So, if we divide the maximum measured diameter (Dmax) by the radius, we get Rmax = 8.4805 mm and do the same with the minimum measured diameter (Dmin), so Rmin = 8.4745 mm. Thus, if we consider a coordinate system of X and Y axes, where the zero point will be at the center and these 2 circles with the maximum and minimum radii (Rmax and Rmin) will be inscribed in it, we will get the boundaries in which all the values measured by the HAAS OMP40-2 probe move. Then we add our measured deviations to the overall mean from Table 5 (Table 5.) to obtain the points in the X and Y axes. We arrange all these data in a table.

Tab. 11 Radius comparison.

	Y+	X-	Y-	X+
Rmax	8.481	-8.481	-8.481	8.481
Rmin	8.475	-8.475	-8.475	8.475
Avg.	8.478	-8.478	-8.478	8.478
0°; 90°; 180°; 270°	8,477	-8.504	-8.507	8.467

As can be seen in Table 11 (Tab.11.), after accounting for the deviations to the mean, the differences between the individual points are only minimal.

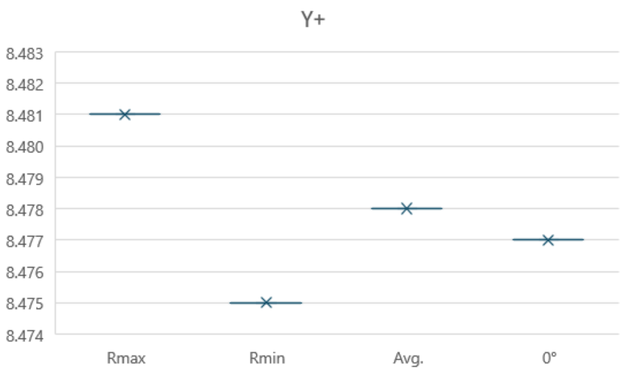

Figure 4. Graph of values Y+

Looking at (Figure 4 Graph of values Y+), we can see that the Avg. and 0° values are very similar since the measurement at this point represents the starting point of the calibration for the sensor measurement.

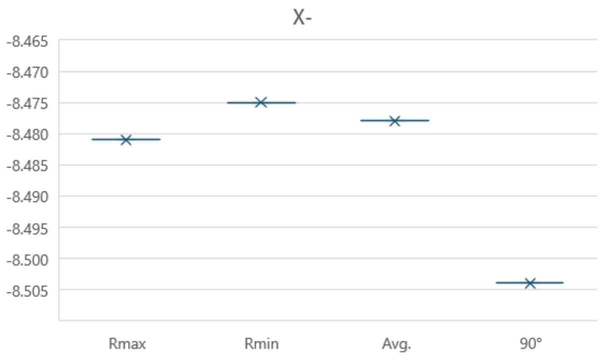

Figure 5. Graph of values X-

Figure 5 (Figure 5. – Graph of values X-) shows a comparison for the calculated radius values from the probe measurement and the calculated radius for the confocal sensor measurement.

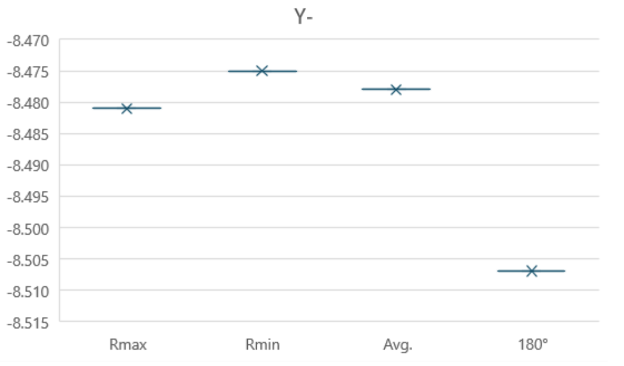

Figure 6. Graph of values Y-

Comparing Figure 6 with Figure 4, we can see a larger deviation from the mean down to negative values, which may indicate curvature or poor circularity of the product.

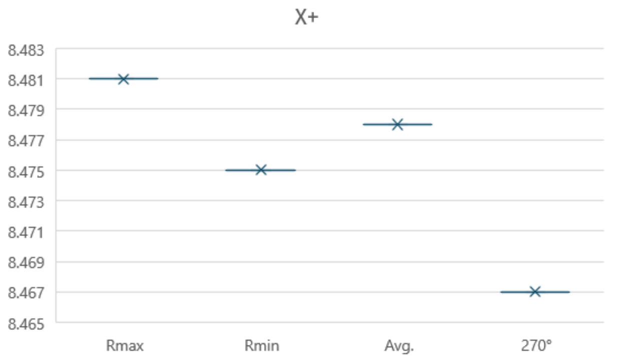

Figure 7. Graph of values X+

The following figure (Figrue 7. Grap of values X+) actually confirms that there may indeed be a faulty circularity of the product which cannot be detected by the probe because the probe measures the overall diameter of the product and not its deviation. In order to actually detect and verify the circularity it is necessary to measure the entire circumference of the component, which will be the subject of a further study.

4 CONCLUSION

In conclusion, we can confirm that after comparing the values, both measuring devices work at a very high accuracy. Since the deviations between the measurements are very small, we can conclude that the confocal sensor is suitable for measuring diameters and dimensions in industry. Since it is a non-contact measuring method, it has its advantages mainly in fast inspection and realistic safe operation. Compared to a touch-type measuring probe, which can be easily damaged by inexpert handling. In conclusion, it is up to each company to decide which way it wants to go and which method it chooses to control its products.

Summary of Differences

- Measurement Type: The OMP40-2 is a contact probe, while the CL-P070 is a non-contact sensor.
- Accuracy: The CL-P070 offers higher precision (±2.0 μm) compared to the OMP40-2, which focuses on repeatability in a machining context.
- Application Areas: The OMP40-2 is more suited for direct machining processes, while the CL-P070 is ideal for inspection and quality control in sensitive applications.

With this knowledge from the measurements, we can talk about the cause of the differences between the individual deviations. The main cause could be incorrect setting and too large a depth of cut, which resulted in the material being pushed away from the tool and, the circularity of the part was not preserved. With less material cut by the tool, a more accurate radius distribution for each axis (Y+; X-; Y-; X+) would probably have been maintained. As a result, it is possible that the part would not be suitable for use if it were to be stored in a tolerated hole. This manuscript may also contribute by appealing to manufacturers and recommending a more accurate dimensional check, as common practice is that only the final diameter is checked.

5 ACKNOWLEDGMENTS

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