DEVELOPMENT OF AN AUTOMATED AND DEDICATED MEASURING SYSTEM FOR INTERNAL DIAMETER INSPECTION

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Abstract. Certain internal cylindrical surfaces require diameter inspection by means of bore gauges due to either shape-inherent difficulties or poor access to the measuring point. Measurements with such instruments, which call for skilled operator, are generally long and may present high uncertainty levels when inspecting mid-size or large part batches. Accurate measurements with low associated uncertainty and cost-effective inspection time are decisive to quality and productivity improvement, since dimensional information is essential to ensure that parts produced by several manufacturing processes lie within specifications. This work aims to present the development of an automated and dedicated diameter measuring system that simulates bore gauge inspection. An industrial robot, which was employed to manipulate inductive type displacement probes, replaces the human operator. In order to achieve measurements, a Delphi language object-oriented algorithm was developed to provide communication among displacement probes, a microcomputer and the robot control system, by means of an AD/DA acquisition board. Measured values were compared to pertinent metrological standards. The results were consistent and demonstrated the efficiency of the proposed measuring system, both technically and economically

Keywords: Measurement automation; industrial robot; bore inspection

1. INTRODUCTION

Several industries are concerned about qualifying a product, as competition is getting fiercer and fiercer. Therefore, qualification processes are becoming more demanding. Consequently, the techniques to enhance measurement processes are gaining visibility, since knowing the dimensions is essential to ensure that the pieces produced through several manufacturing processes lie within specifications.

Industrial competition requires the development of automated systems and pursuits productivity and quality enhancement that promote objectivity and speed up measurement processes, within a metrological dimensional perspective. For instance, there are industries that produce hundreds of thousands of cylindrical pieces that have simple geometry, whose diameter must be controlled in terms of micrometers.

The evolution of technology and the development of new measurement systems integrated to manufacturing process provided some changes. Tasks that were previously carried out by humans may know be performed by machines (Sakakibara, 2003).

This technology was created in 1954, when coordinate-measurement machines (CMMs) were brought to the industrial scenario. This way, complex measurements could be obtained. Previously, they were carried out with conventional instruments in specialized Metrology laboratories. However, using CMMs is not always viable - for instance, when measurement of serial pieces are done without temperature control (Griffith, 1994).

An automated measuring system may be implemented using an industrial robot equipped with adequate sensors to perform the measurement. However, the use of industrial robots as measuring systems is not trivial and the low positioning accuracy consists a serious restriction. Regarding coordinating measurement, the accuracy levels presented by the industrial robots nowadays do not suffice to present good results.

Kato et al, 1991, presented a measuring system that used a robot with a displacement sensor that was used to measure circularity error. The robot placed the sensor in three distinct points over the piece and measurement was carried out at each point. As measurement range was ±2 μm, a piezoelectric actuator placed the displacement within the range to perform the measurement. When the authors compared the results with the measurement conducted using a conventional instrument, they found errors in 17% in the 1 μm (10 to 12 lobes) components.

Regarding non-contact measurement, many enterprises have been implementing the use of laser scanning placed at the edge of the manipulators aiming to carry out the so called more accurate measurements. Nevertheless, the accuracy has proved to be related to the robot accuracy itself, i.e. about 0.1 mm. Therefore, some precaution should be taken into consideration when the position of the robot is used as a reference for laser-scanning measurement.

Lee and Park, 2000 designed an algorithm to inspect parts whose measurement was carried out using laser scanning. Boillot and Uota, 2002 performed some measurement using a robotic arm and an optical laser sensor to check weld nugget in automobiles chassis. Picard, 2002, designed an algorithm o assess and correct the positioning of parts in

robotic vehicles assemblage. These examples consist of applications that demand a low level of precision, where measurement is performed using the robot position as a reference.

Robotic systems are commonly used in measurement with wide tolerance range. This is due to the absence of an adequate reference to conduct measurement.

This paper is focused on the viability of the integration between metrology and productive systems and aims to implement an industrial robot that measures and exams the internal parts of cylindrical pieces, promoting speed in inspection, as well as high adaptability of the systems to measure diameters.

Industrial robots present large positioning errors that compromise the equipment coordinating system so it may not be used as reference for accurate measurements (Miller, 1988). In order to integrate this system to measure internal diameters, a robot was used together with linear variable differential transformers (LVDT), correcting the robotic system errors regarding the values that were measured. LVDT are not sensitive to temperature changes, according to Beckwith and Buck, 1991.

Mechanical devices were projected and implemented to measure test rings and map their position. The robot was programmed and the measurement system applied. Simulations, tests and analysis were carried out so the results would be satisfying and according the tolerance indexes previously determined. The internal diameters' standard deviation and mean were calculated.

2. PARTS OF THE SYSTEM

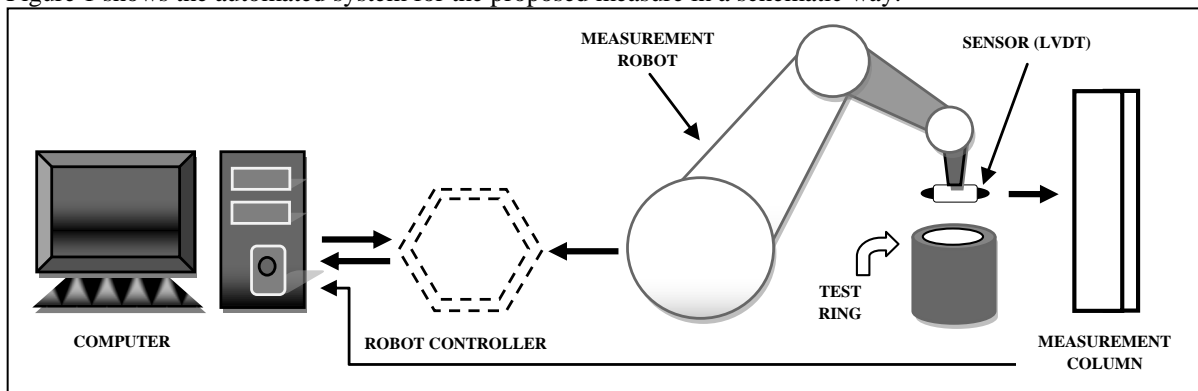Figure 1 shows the automated system for the proposed measure in a schematic way:

Figure 1. Automated system for measuring internal diameters (ASMID)

The measuring signals obtained by the displacement transducers are sent to the measurement column. This column converts the digital-analogical data and sent it to the computer to be analyzed. An analogical-digital (AD)/digital-analogical (DA) conversion module is responsible for the interface between the measurement equipments and the data gathering routine.

A six-axes industrial robot is programmed and prepared so communication with external systems is possible. The model used in this experiment was ABB's IRB140. It was designed for manufacturers that use automation based on robotic systems.

The sensor device was created to be used in external and internal measurements of cylindrical pieces with flexible adjustments, providing more measurements with different diameters. Only internal measurements were carried out in this research. In order to perform the measurement, transducers were attached to the sensor devices, together with its salient pointers. Figure 2 shows the sensor device with the displacement transducers.
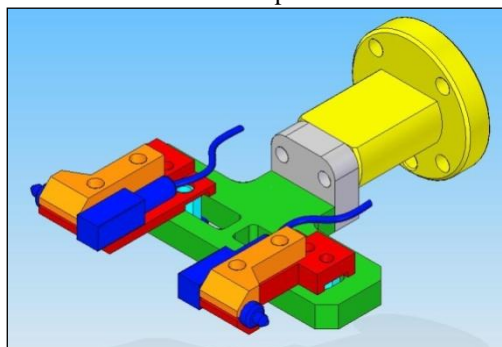

Figure 2. Sensor devices with LVDT

The demodulation of the analogical measurement signal provided by the displacement sensors (LVDT) was performed through the measurement column TESA TT500. The communication between the column and the data acquisition board is established through a parallel cable.

A piece case was designed to place the piece in such a way that there was enough room for the sensors. In addition, this case provides the piece steadiness and places it in an adequate position to be measured. The case was attached to a table made of granite which enhanced the stability and alignment of the piece.

In order to calibrate the system a Mitutoyo ring was used. Its internal diameter is 69.995 mm. Two test rings were made and their internal measures were slightly different: 69.945mm and 70.045mm. The other rings had dimensions that were similar to the ring gauge.

3. THE EXPERIMENT

An online program was used to move the robot. It consisted of a manual controller to place the robot in the working area. Each programming instruction to manipulate the robot was regarding the path, position, displacement speed, tools, and the dimension of the precision area.

In order to diminish the calibration time consuming for ring gauge and the measurement of the test rings, the distance between the robot and the piece must be aligned. This will minimize the movements performed by the manipulator inside the ring.

The tool central point (TCP) of the manipulator was defined. When TCP is determined, the information obtained from the manipulator wrist coordinating system (xyz) is stored and transferred to the base of wrist. This way, programming the robot movements is feasible. The measurement of the internal diameters of the rings was carried out. It was possible after determining TCP, aligning the sensor device and designing the computer program.

The algorithm was designed to better visualize the routine of the calibration and measurement programs. Figure 3 shows the corresponding flow chart.
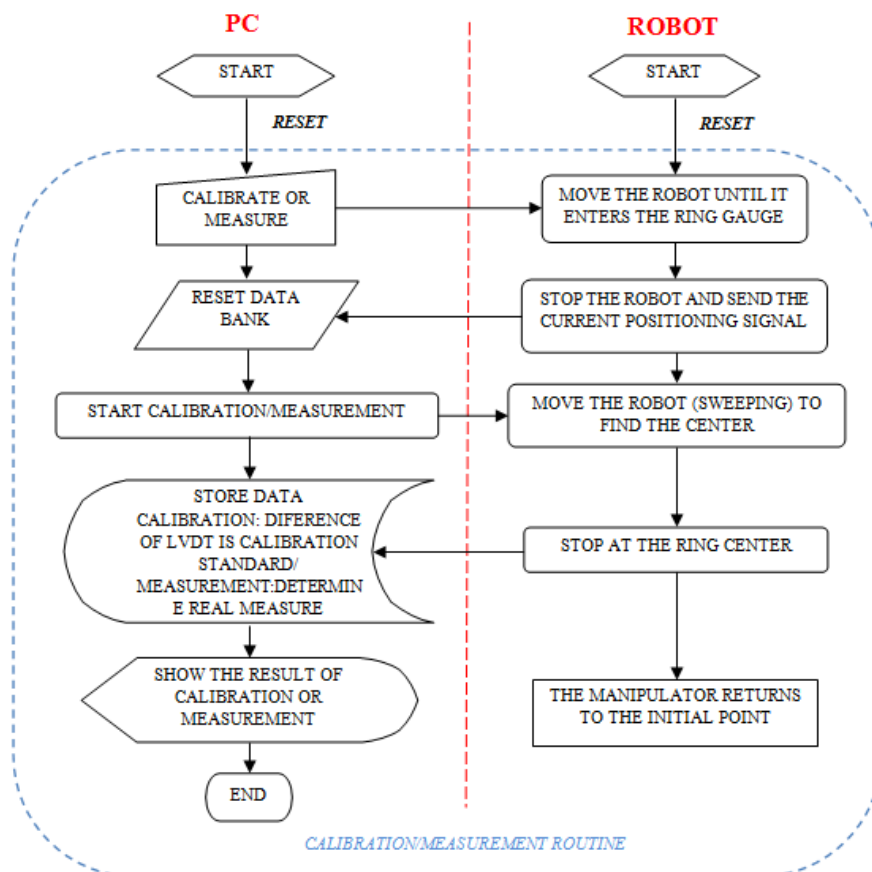

Figure 3. Calibration and measurement routine

The standard measure ($S_{MEASURE}$) enters the measuring program and is shown at the screen. The standard value used is equal to 69.995mm. The LVDT calibration difference ($\Delta_{LVDT_{CALIBRATION}}$) is obtained after the end of the translation movement during the calibration and is equal to the "zeroed" standard. The variation ($\Delta_{LVDT_{MEASURE}}$) is obtained after the end of the translation movement during the measurement, and is equal to the difference between LVDT measure (obtained during the measurement routine) in relation to the LVDT measure (obtained during the calibration routine).

The measurement equation obtained by the transducers to carry out the real measurement ($R_{MEASURE}$) is shown below:

$$R_{MEASURE} = S_{MEASURE} + \left(\Delta_{LVDT_{CALIBRATION}} - \Delta_{LVDT_{MEASURE}}\right)$$ (1)

The measurement procedure is similar to that of a comparator bore gauge. Thus, the first step consists of calibrating the sensors using the ring gauge. The sensors are moved to the inner part of the ring gauge and translation movements are performed (See figure 4).
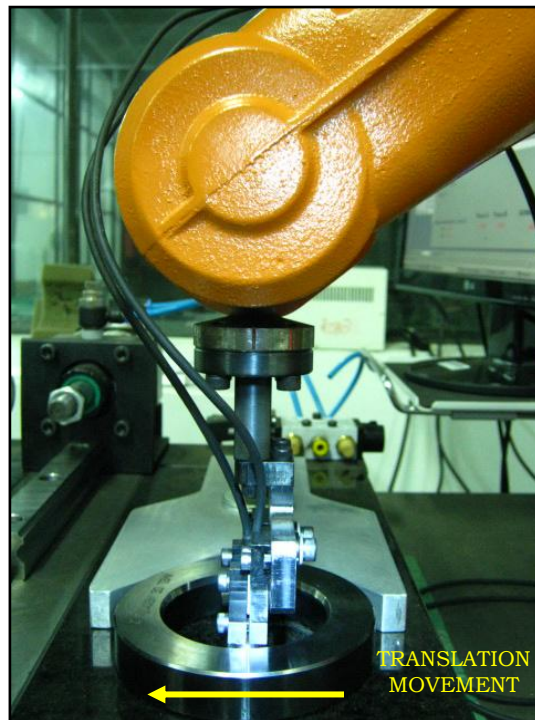

Figure 4. The robotic translation movement

The translation movement makes sure the sensors determine the largest distance between two points in the internal circumference of the ring gauge. It corresponds to the calibration of the comparator bore gauge.

Calibration and measurement were carried out according to the following steps:

- The beginning of the movement from the programmed starting point;
- The robot moves so the sensors are adjusted inside the ring gauge. The manipulator moves towards the inner part of the ring and the robot starts the measurement;
- The robot moves back to the starting point. This is the end of the movement.

After calibration is performed, the ring gauge is substituted for the test ring. The same procedure is undergone.

The result is shown automatically on the graphic measurement interface. There is a free slot in this interface where the name of the piece is written. The measurement data is transferred to a sequential data bank.

The measurement of the test rings and the ring gauge were done considering the following measurement devices: internal micrometer with three pointers, comparator bore gauge, coordinating measurement tridimensional machine.

4. RESULTS

The results were compared with the proposed system.

The ring gauge was calibrated using *Máquina Universal SIP – Model 302M*. The results obtained after measuring the diameters of the standard and test rings five times are shown in table 1.

Table 1. Results of the calibration of the ring gauge and test rings.

		Measured value (mm)		
		Ring gauge	Ring test 1	Ring test 2
Number of measurements	**1**	Ø 69.9962	Ø 69.9479	Ø 70.0432
	2	Ø 69.9961	Ø 69.9482	Ø 70.0424
	3	Ø 69.9959	Ø 69.9473	Ø 70.0445
	4	Ø 69.9959	Ø 69.9475	Ø 70.0413
	5	Ø 69.9960	Ø 69.9481	Ø 70.0426
Mean ($\bar{x}$)		Ø 69.9960	Ø 69.9478	Ø 70.0428
Standard Deviation (S)		0.0001	0.0003	0.0010

The rings were calibrated using radial direction. It means that cylindricity measurement error was not considered. Therefore, a position to measure them was determined. This position is the same that was used in the calibration of the sensor device, so that the average calibration value is accurate.

Several measurements of the test rings were carried out. The collected data was saved automatically in a *Delphi* software data bank. This software was also used during the measurement of the internal diameters.

The measurement was done with two test rings, alternating them, as shown in table 2.

Table 2. Results of the measurement test – Test rings 1 and 2.

Number of measurements	Results of the measurement test – Test rings 1 and 2 (mm)			
	Automated System for Measuring Internal Diameters (ASMID)	Coordinate-measure Machines (CMMs)	Internal Micrometer with three pointers	Comparator Bore Gauge
1 (1)	69.951	69.952	69.95	69.95
2 (2)	70.040	70.040	70.04	70.04
3 (1)	69.952	69.952	69.95	69.95
4 (2)	70.040	70.041	70.04	70.04
5 (1)	69.951	69.950	69.95	69.94
6 (2)	70.040	70.041	70.04	70.04
7 (1)	69.952	69.954	69.94	69.95
8 (2)	70.040	70.044	70.04	70.04
9 (1)	69.951	69.954	69.95	69.95
10 (2)	70.036	70.042	70.04	70.04
11 (1)	69.951	69.952	69.95	69.95
12 (2)	70.040	70.042	70.04	70.04
13 (1)	69.952	69.952	69.95	69.95
14 (2)	70.040	70.040	70.04	70.04
15 (1)	69.950	69.953	69.95	69.95
16 (2)	70.040	70.041	70.04	70.04
17 (1)	69.950	69.950	69.95	69.95
18 (2)	70.039	70.040	70.04	70.04
19 (1)	69.952	69.954	69.94	69.95
20 (2)	70.037	70.040	70.04	70.04
21 (1)	69.948	69.952	69.95	69.95
22 (2)	70.040	70.042	70.04	70.04
$\bar{x}$ (1)	69.9509	69.9522	69.9481	69.9490
$\bar{x}$ (2)	70.0392	70.0411	70.0372	70.0381
S (1)	0.0011	0.0013	0.0038	0.0028
S (2)	0.0013	0.0011	0.0044	0.0038

5. CONCLUSION

The measurement of the internal diameters for serial pieces using the automated system (ASMID) proved to be more viable than the other measurement methods in terms of flexibility, measurement process automation, precision, measurement time consuming and access to the measurement area.

The flexibility of the sensor device makes internal and external diameter measurements possible for several ranges. The presence of a human operator is not necessary since the process is automated. The automated system enhances productivity as the measurement process is not interrupted. The cost of the automated system is lower if compared to a CNC machine measurement.

The degree of accuracy of the automated system is higher than the ones provided by conventional instruments, micrometer and comparator bore gauge. This is due to the use of displacement transducers (LVDT) and the measurement column that offers 1 µm resolution.

Measurement time consuming in the proposed system is lower than that of the coordinate-measurement machines because the first does not need to be prepared to measure.

6. ACKNOWLEDGEMENTS

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