POSSIBILITY OF PRECISION DIAGNOSTICS OF MACHINE TOOLS

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Abstract:

This paper deals with machining precision and precision of manufacturing machines and the possibility of regular diagnostic of machining centres in order to increase the productivity and quality of machining process.

Keywords: precision, monitoring, technical diagnostics, measurement, production machines, CNC machines

1. INTRODUCTION

The demands of modern industry to meet ever-tighter tolerances and to comply with international quality standards, mean that the performance of manufacturing machinery has never been more important. Process control and improvement is the key to raising quality and productivity, so increasing company's competitiveness. The quality of every component produced on a CNC machine is highly dependent on the machine's performance. Problems with a machine inevitably result in inspection failures, scrapped components and unexpected down-time. All too frequently, quality and inspection procedures identify problems after components have been produced. However, this is often too late to rectify any of the incurred scrap and down-time costs. For this reason, it is essential that machine performance is checked before component manufacture.

In metrology, motion control, machine calibration, dental CAD/CAM and spectroscopy, measurement system inovations enhance precision, efficiency and quality. New measurement systems (CAQ) assess, monitor and improve the static and dynamic performance of machine tools, co-ordinate measuring machines (CMMs) and other position-critical motion systems.
Quality of products is more and more important. It has become one of the most discussed and solved problems. Continuous acceleration is a characteristic feature of the current technical development. It is determined by continuous differentiation of customer needs. On the other hand, the production is going up and, at the same time, the requirements for quality of products and precision of machines are increased as well.

In the past the selling price used to be the chief factor but now the quality of products is more and more crucial. Increasing quality costs are obvious as well. They include cost of defective work or their possible repairs, customer claims, cost of testing and inspection.

There is a task for machine users. They need to gather evidence for verification and document the precision of machinery, to minimize cost due to low quality production and machine breakdowns, to classify machines according to valid standards and follow the trends in precision development.

The importance of systematic measurements is increasing, however it is not always fully appreciated. It often comes into existence not earlier than at the moment when production fails and defects occur. However, the troubleshooting is usually much more expensive than a perfect check-up.

Time is money, and time spent manually setting work-piece position, setting tools and inspecting finished products is better invested in machining. Machine productivity is increased, downtime reduced and scrap minimised.

2. TECHNICAL DIAGNOSTICS

With technical dignostics we support:

- very high assurance and reliability with perspective on prolongation of maintenance cycles and reduction of further damage,
- objective technical condition must be determined without dismounting and operation discontinuation,
- evaluation must be done based on reliability of whole machine system.

From the viewpoint of complex solution technical diagnostics can be divided:

- discovery of rising malfunction – detection,
- assesment of defective unit or node – localization,
- prognosis of remaining operating life – prediction.

Diagnostics from the viewpoint of machinery setting-up:

- preassembly diagnostics,
- diagnostics after final assembly - during debugging and final inspection,
- operating time diagnostics - service, inspectional or monitoring.

vibrodiagnostics

- periodical machinery and tools measurement, bearing condition monitoring and detection of dynamic conditions like unbalance, abaxiality etc.,
- non-periodical measurement of problematic machinery,
- implementation of vibrodiagnostics into maintenance system.

tribodiagnostics

- basic analysis of oil and lubricant samples,
- for haulage contractors and construction machinery,
- for processing machinery and tools.

NC and CNC machinery diagnostics

- accuracy of CNC machinery progression monitoring,
- circular interpolation according to ISO 230-4,
- geometry measurement according to ISO 230-1.

NC and CNC machinery diagnostics

Machine tools condition monitoring is main prerequisite for maintainig production quality as well as necessary requirement in quality control systems according to ISO 9001 standards. Observe machinery preventive geometry according to production wasters is obsolete. Current tendency is to foresee - predict machinery condition and ensure production quality accordingly. Following this it is possible to ensure satisfactory production even on machinery with worse characteristics.

This provides monitoring by decreasing machinery service costs and at the same time maintain high production quality by means of NC and CNC machinery diagnostics. This is applied throughout our customer base especially companies working in machinery industry.

Registry is being compiled from performed measurements which gives us continual view of machinery development. Which particular machine tool is capable of fulfiling requirements for manufacturing accuracy can be assessed with use of this registry. With this clasification and its periodical repeating is possible to decrease scrap costs comming from allocating product to particular machine. By observing development trend of manufacture accuracy is possible to schedule machinery maintenance/repair before major malfunction occurs. This will significantly decrease costs caused by machinery breakdowns. Customer gets overview of his machine pool accuracy including machinery accuracy protocols according to ISO 9001 standards.

2.1 Diagnostics according to ISO 230 – 1

Geometry measurement (Schlesinger)

Machine tool basic geometry measurements (perpendicularity, straightness, flatness, circumvolution, alignment, and axis identity) according to ISO 230-1.
Measuring is always carried out on unloaded machine. Measuring period depend on machine type. Protocol is compiled from actual measurement and contains:

- Table of measured data,
- Machine`s condition evaluation,
- Recommendations on found faults.

Supplemental measurement (machine-table flatness, machine bed lead etc.)

Flatness and true position of machine-table measurement, machine bed lead, by preparative, dial gauge, electronic water level MINILEVEL.
Measuring is always carried out on unloaded machine. Measuring period depend on machine type. Protocol is compiled from actual measurement and contains:

- Measurement schematics,
- Graphic representation of actual shape or position of machine tool,
- Machine`s condition evaluation.

Machine tools set-up (establishing of equilibrium)

Machine tools set-up (establishing of equilibrium) is important especially for lathes where it has direct connection with machine tool geometry, headstock spindle and carriage axis alignment.
Machine tool set-up is laways followed by control measurement according to ISO 230-1.
Protocol is compiled from actual measurement and contains:

- Measurement schematics,
- Table of measured data,
- Machine`s condition evaluation,
- Recommendations on found faults.

2.2 Diagnostics according to ISO 230 – 4

Geometry measurement and measurement of drive adjustment by circularity analysis.

Geometrical errors can be catched up with this measurement (perpendicularity, straightness, backlash, cross clearance…), electronical errors (drive unit delay, trailing error, gauge linear error).
Measuring is always carried out on unloaded machine. Measuring period depend on machine type and number of measured planes.
Protocol is compiled from actual measurement and contains:

- Circularity analysis according to ISO 230-4,
- Table of measured data,
- Table and diagnosis of measured errors,
- Machine`s condition evaluation,
- Recommendations on found faults - development trend of measured errors is compiled at periodical measurement.

Correction into selected control systems
Up to certain levels of mechanical errors (based on dynamical measurement) is possible to input corrections into control system to achieve improvement of machine tool accuracy.
This includes constrol systems: Heidenhain TNC 307 to 530i, MEFI, Sinumerik 810D, 840D, GE FANUC series 0,5,6,16,18,20,21,16i,18i,20i,21i.
Corrections input into control system follows machine tool control dynamical measurement according to ISO230-4. Protocol is compiled from this measurement (see geometry measurement).

Supplementary static measurement of repeatability

This measurement is suitable for production in large series when repeatability of tool or workpiece impositioning into position is emphasised.
Measuring is always carried out on unloaded machine. Measuring period depend on machine type and number of measured planes.
Protocol is compiled from actual measurement and contains:

- Graphical representation of tool impositionig into position,
- Table of measured static repeatability data,
- Table of measured maximal repeatability data,
- Machine`s condition evaluation.

2.3 Diagnostics according to ISO 230 – 2

Laser (interferometric) geometric measurement

This is so far the most accurate machinery diagnostics.

Machine geometry can be catched up with this measurement (perpendicularity, straightness, flatness, cross clearance, backlash, gauge adjustment).

Measuring is always carried out on unloaded machine. Measuring period depend on machine type and number of measured planes.

Protocol is compiled from actual measurement and contains:

- Graphical representation of error behavior along measured axis length,
- Table of measured data,
- Machine`s condition evaluation,
- Recommendations on found faults.

<u>Measurement of gauge adjustment including corrections</u>

This measurement can adjust gauge (non-linear) which means that measured axis is divided into given number of smaller positions (2 000 mm min. for 5 measured positions) which are compensated according to actual measured error.

Measuring is always carried out on unloaded machine. Measuring period depends on number and length of measured axis.

Machine is measured before corrections first. Corrections are inputed and control measurement is carried out.

Protocol is compiled from actual measurement and contains:

- Graphical representation of error behavior before corrections,
- Table of measured data before corrections,
- Graphical representation of error behavior after corrections,
- Table of measured data after corrections.
-

3. DIAGNOSTICS ACCORDING TO ISO 230–4 WITH RENISHAW QC10 BALLBAR

Precision of parts machined on NC and CNC machines depends crucially on the machine precision. This statement results in significant consequences both for the manufacturers and users of CNC machines. The manufacturers are led by customer requirements to production of precise machines which would be fully able to keep the guaranteed parameters in the long-term period. At the same time they have to be able to prove these parameters in compliance with the internationally recognised standards. They solve problems in the field of workpiece inspection, rejects / defectives, idle times, decreased productivity, and long-term low quality.

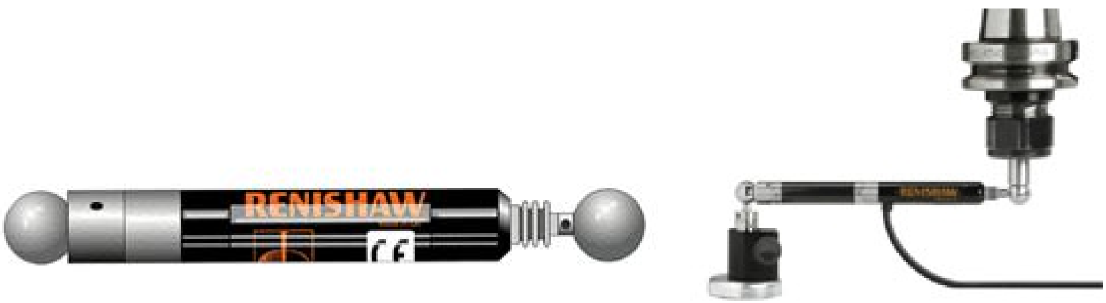


Fig.1 *QC10 ballbar*

Renishaw's QC10 ballbar is a linear displacement sensor based tool that provides a simple, rapid check of a CNC machine tool's positioning performance to recognised internationals standards. QC10 ballbar system is a CNC machine tool diagnostic system. It consists of a calibrated sensor within a telescopic ball-ended bar, plus a unique mounting and centration system. It is not to be confused with the fixed length ballbars used for CMM (coordinate measuring machine) calibration. A ballbar test involves asking the machine to scribe a circular arc or circle. Small deviations in the radius of this movement are measured by a transducer in the ballbar and captured by the software. From the data supplied (via a PC interface) the systems software automatically detects and diagnoses a range of machine geometry, and motion errors. Recognised in many international standards for machine tool performance testing, the system is widely used by machine tool end users and OEMs and is considered vital equipment by many calibration service companies.

Fig. 2 *Renishaw QC10 ballbar test work and next software*

The ballbar accurately measures any deviations in the circle radius during the test. The shape of the ballbar plot indicates the major sources of machine error. Powerful software gives automatic analysis and diagnosis of specific machine error characteristics. Each error is ranked according to its significance to overall machine accuracy. Overall machine accuracy is graded with a value for circularity and positional tolerance.

The Renishaw QC10 Ballbar and its software are used to measure geometric errors present in a CNC machine tool and detect inaccuracies induced by its controller and servo drive systems. Errors are measured by instructing the machine tool to 'Perform a Test' which will instruct it to scribe a circular arc or circle. Small deviations in the radius of this movement are measured by a transducer and captured by the software. The resultant data is then plotted on the screen, to reveal how well the machine performed the test.

If the machine had no errors, the plotted data would show a perfect circle. The presence of any errors will distort this circle, for example, by adding peaks along its circumference and possibly making it more elliptical. These deviations from a perfect circle reveal problems and inaccuracies in the numerical control, drive servos and the machine's axes. Test times will vary with test radius and machine feed rate but typically will be 10-15 minutes.

The QC10 ballbar is an extremely versatile tool designed to be used on a large variety of machines. The standard system can be used to test 3-axis CNC machines such as horizontal and vertical machining centres. With the addition of other accessories detailed below, the QC10 ballbar can also be used to test a much wider range of machines. For 2-axis CNC applications, a special retractable centre mount, the VTL adaptor, is used. This enables typical 2-axis machines such as pick and place machines, laser cutting machines and vertical turning lathes etc. to benefit from QC10 ballbar diagnosis.

System specification :

Resolution : 0.1 µm (4 µin)
Ballbar sensor accuracy : ±0.5 µm (at 20 °C) ±20 µin (at 68 °F)
Maximum sample rate : 250 values per second

Extension bars	: 50 mm, 150 mm, 300 mm
Operating range	: 0 °C - 40 °C (32 °F - 104 °F)
Calibrator accuracies	: ±1 µm (50 mm) (at 20 °C) ±1 µm (100 mm)
	±1 µm (150 mm)
	±1.5 µm (300 mm)

4. MEASURING USING RENISHAW QC10 BALLBAR ACCORDING TO ISO 230 – 4

<u>Parametres of measuring :</u>

Machine	: Hurco WMX30t
Test specification	: XY 360deg, 100mm, 500 mm/min
Freedrate -	: 500 mm/min
Radius	: 100 mm
Start/End/Overshoot	: 0°/360°/180°
Run sequence	: CCW / CW
Test position	: machining (working) position
Sample rate	: 19.231 Hz

Fig. 3 *Measuring on Hurco WMX30t with using Renishaw OC10 ballbar*

Software output of measuring :

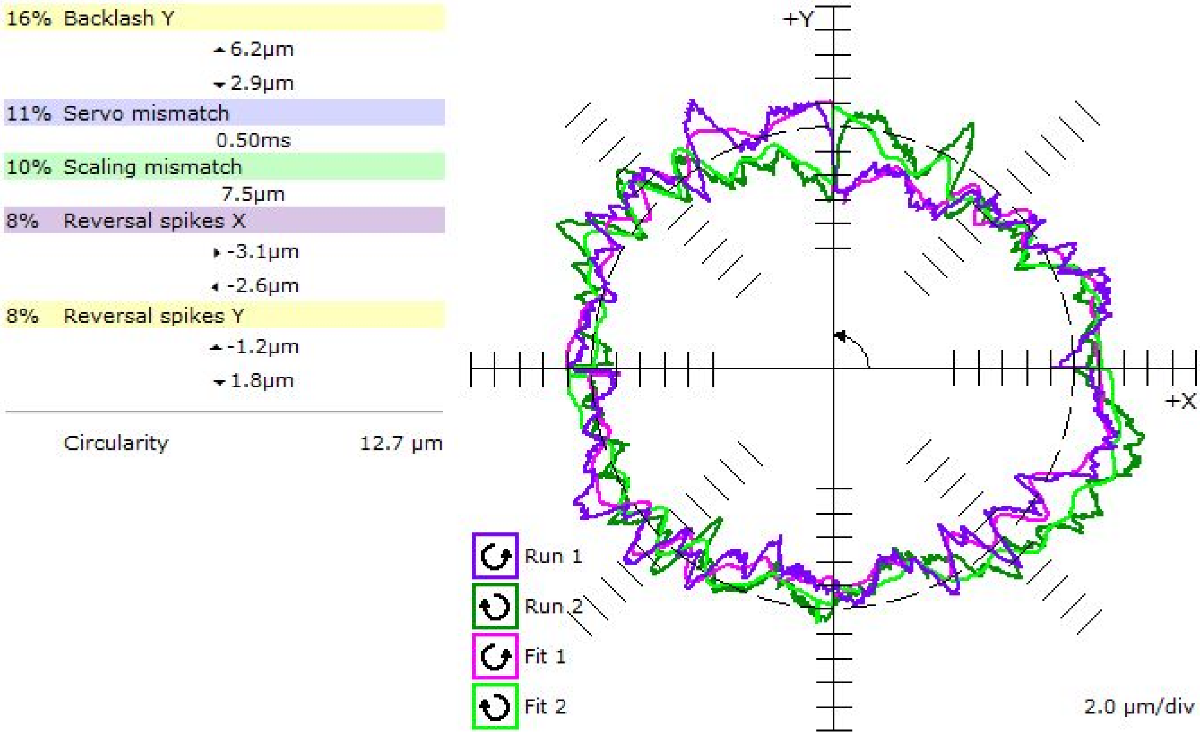


Fig.4 *Percentages ballbar output*

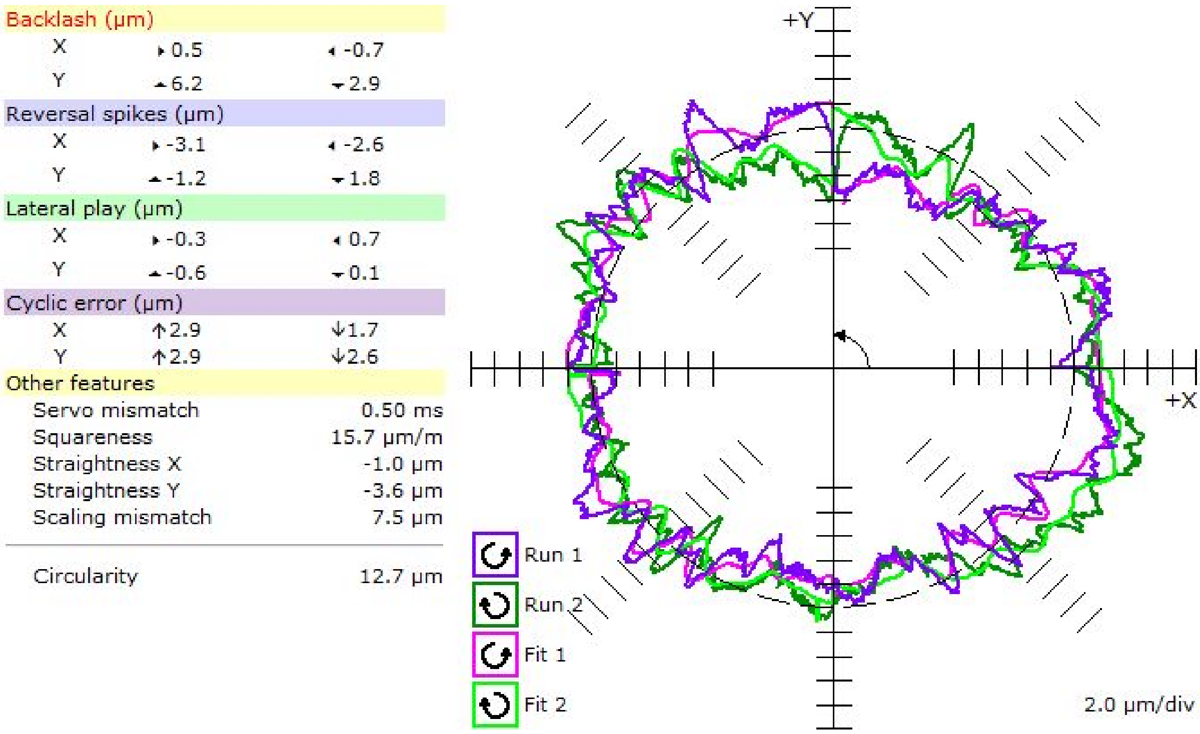


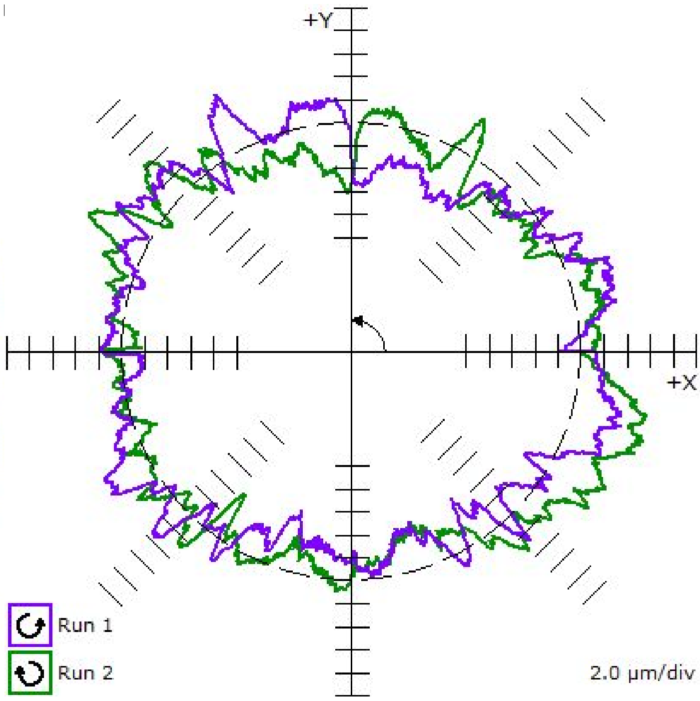
Fig. 5 *Diagnostics ballbar output*

Dynamic ASME B5.54

Non Roundness	12.7µm	
Maximum deviation	6.6µm	343.0°
Minimum deviation	-6.1µm	91.0°

Test Parameters

Radius	100.0000mm
Sample rate	19.231Hz
Feedrate	500.0mm/min
Run sequence	CCW CW
Plane under test	XY
Test position	lavo,500
Start angle	0°
End angle	360°
Overshoot angle	180°
Centre offset X	28.3µm
Centre offset Y	-13.7µm
Calculated feedrate	498.3mm/min



Circular Deviation

Value (CW)	12.1µm
Value (CCW)	10.8µm

Radial Deviation

Ballbar must be calibrated

Calculated feedrate

✓ Value (CW)	498.3mm/min
✓ Value (CCW)	498.3mm/min

Circular Hysteresis

Value	7.7µm
Location	119.0°

Fig. 6 *Dynamic ASME B5.54 output and circular hysteresis according ISO 230-4*

Error	Magnitude		Independent circularity		Ranking
Backlash X	▸0.5	◂-0.7 µm	0.7 µm	(2%)	(10)
Backlash Y	▴6.2	▾2.9 µm	6.2 µm	(16%)	(1)
Reversal spikes X	▸-3.1	◂-2.6 µm	3.1 µm	(8%)	(4)
Reversal spikes Y	▴-1.2	▾1.8 µm	3.0 µm	(8%)	(5)
Lateral play X	▸-0.3	◂0.7 µm	0.4 µm	(1%)	(12)
Lateral play Y	▴-0.6	▾0.1 µm	0.4 µm	(1%)	(13)
Cyclic error X	↑2.9	↓1.7 µm	2.9 µm	(8%)	(6)
Cyclic error Y	↑2.9	↓2.6 µm	2.9 µm	(7%)	(7)
Servo mismatch	0.50 ms		4.2 µm	(11%)	(2)
Squareness	15.7 µm/m		1.6 µm	(4%)	(9)
Straightness X	-1.0 µm		0.5 µm	(1%)	(11)
Straightness Y	-3.6 µm		1.8 µm	(5%)	(8)
Scaling mismatch	7.5 µm		3.7 µm	(10%)	(3)
Cyclic pitch X	16.0000 mm				
Cyclic pitch Y	16.0000 mm				
Calculated feedrate	498.3 mm/min				
Centre offset X	28.3 µm				
Centre offset Y	-13.7 µm				
Circularity	12.7 µm				

Fig. 7 *Ballbar diagnostics table*

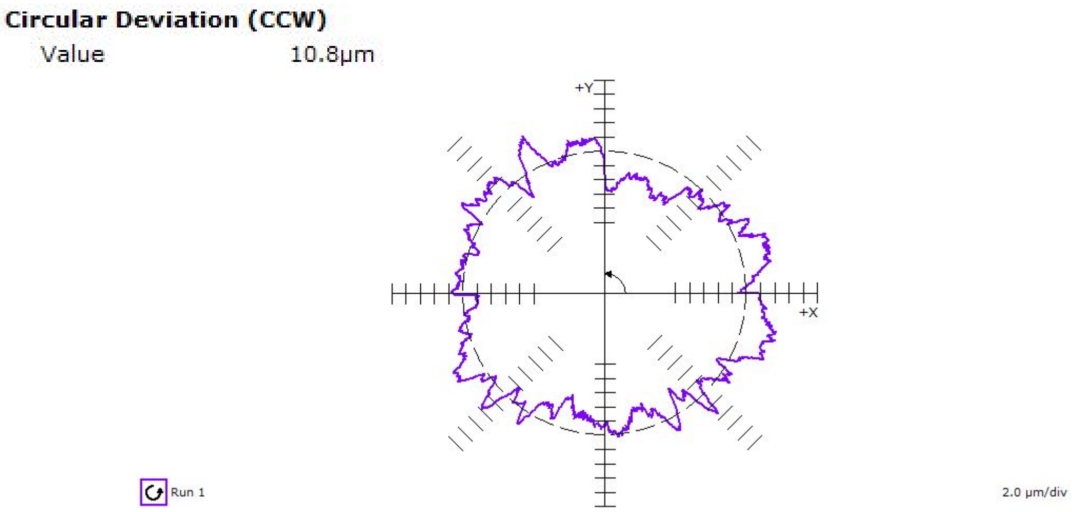


Fig. 8 *Circular deviation in CCW direction*

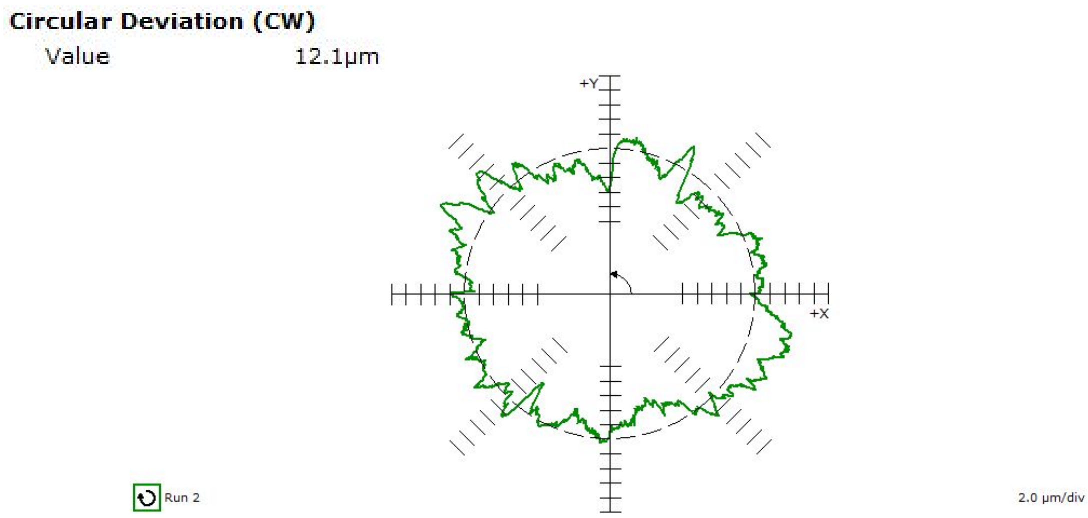


Fig. 9 *Circular deviation in CW direction*

CONCLUSION

The quality of every component produced on a CNC machine is highly dependent on the machine's performance. Many inspection procedures take place after the component is produced. This is too late. To avoid scrap it is better to check the machine before cutting any metal. Determining a machine tool's capabilities before machining, and subsequent post-process part inspection, can greatly reduce the potential for scrap, machine downtime and as a result, lower manufacturing costs. It doesn't matter if your machine is new or old, all have errors. Process control and improvement is the key to raising quality and productivity.

Renishaw's probing systems cut almost all costly machine down-time and eliminate scrap components associated with manual inspection and setting. Renishaw's QC10 ballbar offers the perfect solution. A quick 10 minute test is all that is required to assess the performance of machine. The quickest, easiest and most effective way to monitor machine tool condition. The ballbar kit provides a complete, powerful and portable solution. Pinpointing the specific machine faults enables efficient, targeted machine maintenance, minimising downtime. Plan predictive maintenance programs by tracking machine performance.

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