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. 

Abstract (keywords): CNC, precision, performance monitoring, calibration, diagnostics, Renishaw

1. INTRODUCTION

1.1 Layout

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. 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 your machine performance is checked before component manufacture.

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. Workpiece dimensional and finish defects may result from bad tooling, worn spindles or workpiece clamping, but the major causes of defects can usually be attributed to positioning errors in the machine tool itself, the result of geometric, dynamic and play errors within the machine. Many errors can often be fixed in minutes, if only you knew where and what they were. It doesn't matter if your machine is new or old, all have errors. The secret of reject free production is to know just how good your machines are, and of what they are capable. In the past this may have been achieved by machining test (or "master") parts and then inspecting them. However, the process was time consuming and gave limited confidence when machining parts with geometries different to the master part.

Time is money, and time spent manually setting work-piece position, setting tools and inspecting finished products is better invested in machining. Probing systems cut almost all costly machine down-time and eliminate scrap components associated with manual inspection and setting. Probing systems are used by companies worldwide to increase productivity and improve part quality. They can be specified as standard equipment from most leading manufacturers. Ease of fitting allows probes to be retrofitted to machines already installed. Tool size and condition are important variables in any machining process. The challenge is to identify the size of tools before cutting the first part in a batch. Once machining is in progress, you need to be sure that the tools that you are using are intact and in good condition. High speed tool setting and checking on the machine tool reduces set-up time and minimises scrap.
To meet this demand, Renishaw produces measurement systems accepted worldwide as the industry standard to assess, monitor and improve machine performance. Machine productivity is increased, downtime reduced and scrap minimised. These systems combine the best available mechanical, electronic and optical technologies and have been designed for easy use, flexibility and portability. Systems normally reserved for research laboratories and standards rooms can now be used directly on the shop floor. A quick 10 minute test is all that is required to assess the performance of most machines. This systems makes pinpoint specific machine faults, reduce scrap, develop predictive maintenance programs, increase machine uptime and productivity, comply with ISO 9001:2000, ASME and other key machine tool performance standards. They are ultimate in portable comprehensive accuracy assessment and calibration of machine tools, CMMs and other positioning systems. The test is simple to set up and run and the latest software allows trend analysis and preset warnings at the click of a mouse. Easy-to-use software makes machine performance testing quick and easy. Results are analysed to a range of internationally recognised standards as well as a comprehensive analysis. Renishaw's laser interferometer and ballbar measurement systems assess, monitor and improve the static and dynamic performance of machine tools, co-ordinate measuring machines (CMMs) and other position-critical motion systems. [1, 3, 4, 5]

2. QUICKLY DIAGNOSE THE PERFORMANCE OF YOUR MACHINE TOOLS

2.1 QC10 ballbar

![QC10 ballbar](image1)

Fig. 1. QC10 ballbar telescopic sensor

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. The QC10 ballbar tests the performance of your machine tool. The test usually takes just a few minutes from start through to analysis and gives you a selection of reports, which highlight any problems and their probable sources, putting you in control. [3, 4]

![QC10 ballbar system](image2)

Fig. 2. Renishaw QC10 ballbar system
The quickest, easiest and most effective way to monitor machine tool condition. The QC10 ballbar kit provides a complete, powerful and portable solution – just add a PC and go! Setup is quick and easy with Windows® based software guiding the operator through each step. Test templates can be set up for standardised testing. The sensor is mounted between two repeatable magnetic joints. A simple G02 and G03 command program is all that’s required for the test. The HPS software includes an automatic part program generator. The machine performs two consecutive circular arcs, one test in the clockwise direction, the other in the counterclockwise direction. The ballbar accurately measures any deviations in the circle radius during the test. System data is sent directly to a PC via a standard RS232 link. Renishaw’s Ballbar 5 HPS software then analyses the data in accordance with ISO230-4, ASME B5.54 – B5.57, JIS B6194 or GB/T17421.4 machine performance standards. 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. Pinpointing the specific machine faults enables efficient, targeted machine maintenance, minimising downtime. ‘Hotlinks’ take you directly to the relevant section of the on-line user manual. The manual explains the possible causes for each type of machine error and offers advice on how best to fix them. The software includes a machine error simulator to help predict effect of maintenance in advance. Plan predictive maintenance programs by tracking machine performance. [ 3, 4 ]

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

![Image](image_url)
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. The 360° lathe adaptor enables the QC10 ballbar to be used on a wide range of CNC lathes. As with machining centres, it also allows a full diagnosis of lathe capabilities to be performed. To address smaller machines, the small circle accessory kit allows testing of CNC machines with shorter axis travel. Additionally, it can help to give an enhanced analysis of servo control systems on most types of machines. [3, 4, 5]

![Fig. 4. VTL adaptor, 360° lathe adaptor and Small circle VTL adaptor accessory kit](image)

### 2.2 Laser interferometer systems

Renishaw's laser interferometer systems are used for comprehensive accuracy assessment of machine tools, co-ordinate measuring machines (CMMs) and other position-critical motion systems. They offer the ultimate in high accuracy, repeatable and traceable measurement, using externally mounted beam splitters. There are two Renishaw laser systems for performance assessment; the XL-80 (new for 2007) and the ML10, which has been in service since 1988.
Renishaw has been designing, manufacturing and supplying laser interferometer systems for over 20 years. Its ML10 laser system has become a standard for accuracy and reliability in use, enabling linear measurements to be made to an accuracy of ±0.7ppm. It has become the leading high accuracy, portable machine calibration and measurement system worldwide. In 2007 it has been joined by the XL-80 laser system with enhanced measurement performance (±0.5ppm, 50kHz, 4m/s) in a highly compact, portable and easy to use package, bringing the benefits of laser interferometry to an even wider audience. [3, 4, 5]

ML10 measurement system

Since 1988 the ML10 laser measurement system (ML10 laser and EC10 environmental compensation unit) have represented the ultimate in calibration for machine tools, co-ordinate measuring machines (CMMs) and other position and motion critical systems. As well as the ML10 Gold Standard laser unit and EC10 Gold Standard compensator, please note that the ML10 is also available in two alternative configurations: the ML10X long range laser system and the ML10Q with quadrature output signals.

The ML10X enables linear measurements to be taken at up to 80 m (see spec sheets for maximum range of other measurement options). ML10X has all the features of the ML10 Gold Standard but with
enhanced return signal strength and a special long range shutter to attenuate the signal for shorter range measurements. The ML10X can also be used where signal attenuation is a particular problem (when using multiple optics) and allows greater flexibility in optical alignment. [3, 4]

![Image of ML10X quadrature output laser system and EC10 Gold Standard environmental compensator]

**Fig. 7.** ML10Q quadrature output laser system and EC10 Gold Standard environmental compensator

**XL-80 laser measurement system**

The new XL-80 laser system offers greatly increased portability, system accuracy and improved dynamic measurement performance. It is quicker and easier to use, whilst retaining the benefits of a pure interferometry based system, a proven technology that has made Renishaw laser systems the preferred choice of companies worldwide. [3, 4]

![Image of Renishaw XL-80 laser measurement system]

**Fig. 8** Renishaw XL-80 laser measurement system
The basis of the new system is a compact laser head (XL-80) and an independent compensator system (XC-80).

The XL-80 laser produces an extremely stable laser beam, with a wavelength that is traceable back to national and international standards. The laser frequency stability is specified as ±0.05 ppm over 1 year and ±0.02 ppm over 1 hour. This excellent performance is achieved by dynamic thermal control of the laser tube length to within a few nanometres. Linear measurement accuracy is an assured ±0.5 ppm, over the whole environmental range i.e. from 0 °C – 40 °C (32 °F - 104 °F) and 650 mbar – 1150 mbar. Readings are taken at 50 kHz, with a maximum linear measurement speed of 4 m/s and a linear resolution of 1 nm; even at maximum speed.
The XC-80 compensator is a key factor in your XL system’s measurement accuracy. Featuring “intelligent sensors” that process the readings at source, the compensator very accurately measures air temperature, air pressure and relative humidity. The design of the XC-80 and sensors ensures extremely accurate readings over the full range of operating conditions, from units that are built to withstand the daily handling that most systems will receive. [3, 4]

3. CONCLUSION
Improve performance through targeting maintenance and correct linear positioning errors using error compensation.
Over the last 15 years, the use of a specialised diagnostic tool - the Renishaw QC10 telescopic ballbar has gained widespread recognition as the best and most practical method for quickly checking machine positioning performance. The Renishaw QC10 ballbar is tried and tested. With such a simple test, its suitable for supervisor or operator use (options selectable) and the auto diagnosis software means you get useful information not data! There is a very comprehensive electronic manual along side training courses which is available to maximise what you can get out of the system. [3]
For example the QC10 system software:

The QC10 ballbar may collect the data but it is the Ballbar 5 software that gives the user valuable information. Ballbar 5 is a Windows®-compatible software package for machine tool performance analysis. [3]

4. REFERENCES