INCREASING OF TECHNOLOGICAL PARAMETERS OF PRODUCTION AND MEASUREMENT MACHINES BY CAQ SYSTEMS

Ivan ĎURICA, Jozef PILC

Authors: ***Ivan Ďurica, MSc. Eng., Jozef Pilc, Professor, PhD.***
Workplace: ***University of Žilina, Department of Machining and Production Machines, 010 01 Žilina***
Address: ***Univerzitná 1, 010 26 Žilina, Slovakia***
Phone: ***++421 41 513 2807***
E-mail: ***ivan.durica@fstroj.utc.sk, jozef.pilc@fstroj.uniza.sk***

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.

Key words

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

Introduction

In metrology, motion control, machine calibration, dental CAD/CAM and spectroscopy, measurement system inovations enhance precision, efficiency and quality. New measurement systems assess (CAQ), monitor and improve the static and dynamic performance of machine tools, co-ordinate measuring machines (CMMs) and other position-critical motion systems.

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.

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.

NC and CNC machinery diagnostics

Machine tools condition monitoring (CAQ) 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.

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. 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.

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

Measurement of gauge adjustment including corrections

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.

Diagnostics according to ISO 230-2 with RENISHAW laser interferometers systems

For many years the industry standard method of measuring machine tool or CMM performance has utilised a free-standing laser on a tripod, in combination with remote (i.e. separate) interferometer and reflector optics, mounted directly to the machine table and spindle. Linear, angular (pitch and yaw) or straightness measurements, between table and spindle, can then each be made interferometrically with the appropriate choice of interferometer optics. The design of the Renishaw Laser Interferometer System is based on this established and proven method, which is shown schematically in Figure 1.

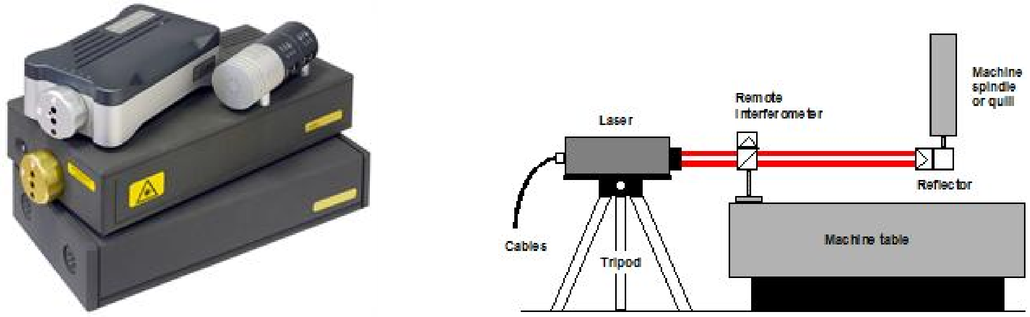


Fig. 1. *Renishaw XL-80 and ML10 laser head with compensator and at next picture tripod mounted laserinterferometer measurament*

Renishaw's laser interferometer systems (CAQ) 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.

Fig. 2. *Renishaw XL-80 measurement system with XC-80 compensator and sensors*

Laser interferometry technology:

As long ago as the 1880s, the use of light interference principles as a measurement tool was first demonstrated. Although the technology has been developed over the years since, the basic principle of using the very small, stable and accurately defined wavelength of light as a unit of measure has remained.

Laser measurement is accomplished through interferometry, a technique that uses the wavelength of light as the unit of measurement. A laser is used because the laser light is coherent, meaning that all the rays have exactly the same wavelength and are exactly in phase (see Properties of light). This means that the peaks and valleys of the component light waves are in perfect synchronisation. The wavelength of laser light from a helium-neon (HeNe) laser is 0.633 micron and by further sub-dividing the wavelength, Renishaw has achieved a resolution of 1.25 nanometres. The long term wavelength stability of the Renishaw ML10 Laser is (in vacuum) better than 0.1 ppm.

An interferometer system measures the change in distance by counting the number of wavelengths of light seen by detector optics. As the wavelength is known to great accuracy, then the overall distance can be calculated to great accuracy. An interferometer system or Michelson interferometer, comprises three optics : a polarising beam-splitter, and two retro-reflectors, or corner-cubes.

The following is a brief description of the optical interference principles which the Renishaw ML10 system uses to measure relative changes in optical path length, between measurement and reference arms of the interferometer. The figure shows a schematic diagram of the ML10 laser head, linear measurement optics, and the interference detectors, together with the laser beam paths.

The laser beam **(1)** emerging from the laser head is a circular polarised laser beam of single frequency light. When this beam reaches the polarising beam-splitter it is split into two components. The reflected beam **(2)** is vertically polarised light, and transmitted beam **(3)** is horizontally polarised light. As these beams travel to their retro-reflectors they have exactly the same frequency. These two retro-reflectors reflect these beams, **(2)** and**(3)**, back towards the beam-splitter.

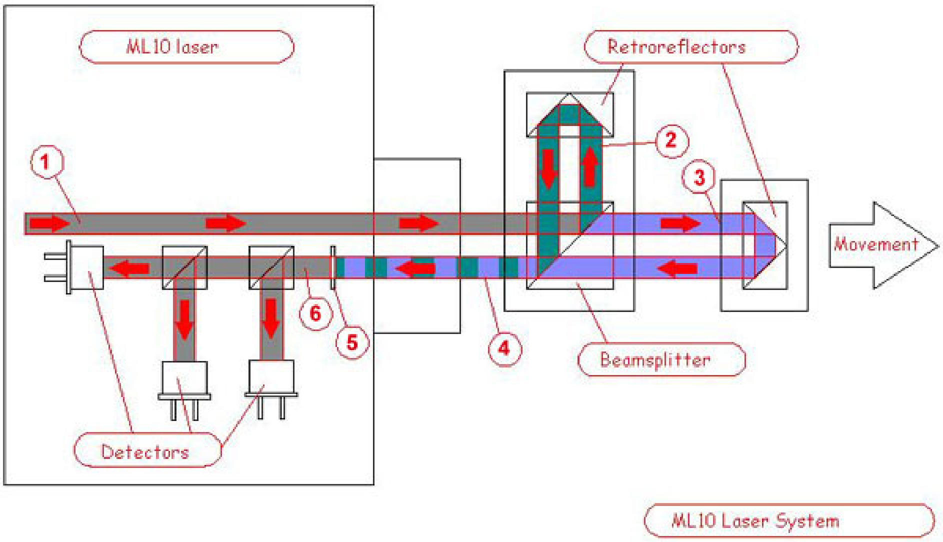


Fig. 3. *Principe of interferometry*

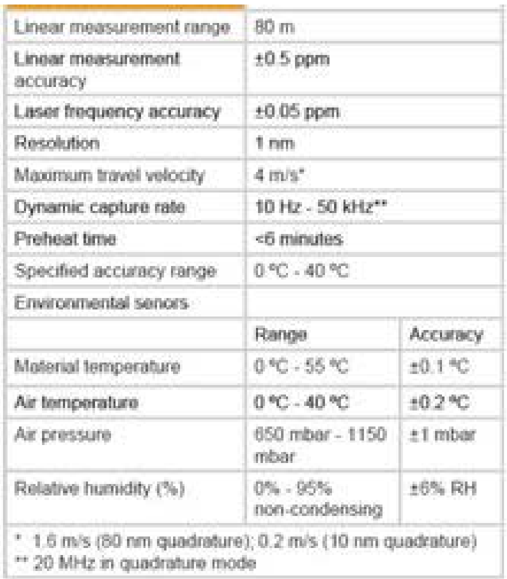
In linear distance measurement, one retro-reflector is usually rigidly attached to the beam-splitter, to form the fixed length reference arm of the interferometer, and other retro-reflector moves relative to the beam-splitter and forms the variable length measurement arm. The laser system tracks any change in the separation between the measurement arm retro-reflector and the beam-splitter, as the retro-reflector moves. Whilst it is moving, the frequency of the reflected laser beam from the moving retro-reflector is Doppler shifted, so that during movement, the frequencies of the two returned beams are not the same. This difference in frequency is directly proportional to the speed of movement. When the reflected laser beams reach the beam-splitter they are reflected or transmitted (as before), so that both beams are recombined and returned to the laser head.

This recombined beam **(4)** consists of two superimposed beams of different polarisations. One component is vertically polarised, and has travelled around the reference arm. The other component is horizontally polarised, and has travelled around the measurement arm. At this stage the two beams do not interfere with one another because they have different polarisations. When the beams enter the laser head, they pass through a special optic **(5)** which causes the two beams to interfere with one another to produce a single beam **(6)** of plane polarised light. The angular orientation of the plane of this polarised light depends on the phase difference between the light in the two returned beams. So, if the measurement arm retro-reflector is moving away from the beam-splitter, then the plane of polarisation spins in one direction, and if the measurement arm retro-reflector is moving towards the beam-splitter, the plane of polarisation spins in the opposite direction.

The beam **(6)** is then spilt into three and focused onto three polarisation sensitive detectors. As the plane of polarised light spins, each detector produces a sinusoidal output waveform. The polarisation sensitivity of the detectors are adjusted so that their outputs are in phase quadrature. (Three detectors are used to allow the system to eliminate background light, to distinguish the direction of movement, and to measure the distance moved.) These signals are very similar to the feedback signals obtained from many linear and rotary encoder systems, and are processed in a similar way, using very high speed direction discrimination, counting and interpolation electronics. This allows the laser system to measure changes in distance as the measurement arm retro-reflector moves. Because the laser wavelength is very short (633nm), and can be determined very accurately (to one part per million in air), the Renishaw laser can provide measurements with very high accuracy and resolution.

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. 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 XC-80 compensator is a key factor in 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.



Linear measurement range	80 m	
Linear measurement accuracy	±0.5 ppm	
Laser frequency accuracy	±0.05 ppm	
Resolution	1 nm	
Maximum travel velocity	4 m/s*	
Dynamic capture rate	10 Hz - 50 kHz**	
Preheat time	<6 minutes	
Specified accuracy range	0 °C - 40 °C	
Environmental sensors		
	Range	Accuracy
Material temperature	0 °C - 55 °C	±0.1 °C
Air temperature	0 °C - 40 °C	±0.2 °C
Air pressure	650 mbar - 1150 mbar	±1 mbar
Relative humidity (%)	0% - 95% non-condensing	±6% RH

* 1.6 m/s (80 nm quadrature); 0.2 m/s (10 nm quadrature)
** 20 MHz in quadrature mode

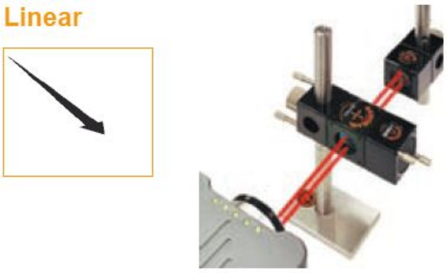
Fig. 4. *Renishaw XL-80 laser measurement system with XC-80 compensator, sensors and with parametres of system*

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 ie from $0^oC - 40^oC$ 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 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.

Measuring using RENISHAW XL-80 according to ISO 230-2

Type of measuring: linear positioning accuracy



Specification	Metric	Imperial
Linear measurement range	0 m – 80 m	0 in – 3200 in
Measurement accuracy (with XC-80 compensator)	±0.5 ppm (parts per million)	
Resolution	0.001 µm	0.1 µin
For measurements over 40 m it is recommended to use the long range linear accessory kit. Performance specifications for linear (above) and other measurement modes are quoted to 95% confidence level (k = 2), and are valid across the full environmental operating range.		

Fig. 5. *Measurement specifications*

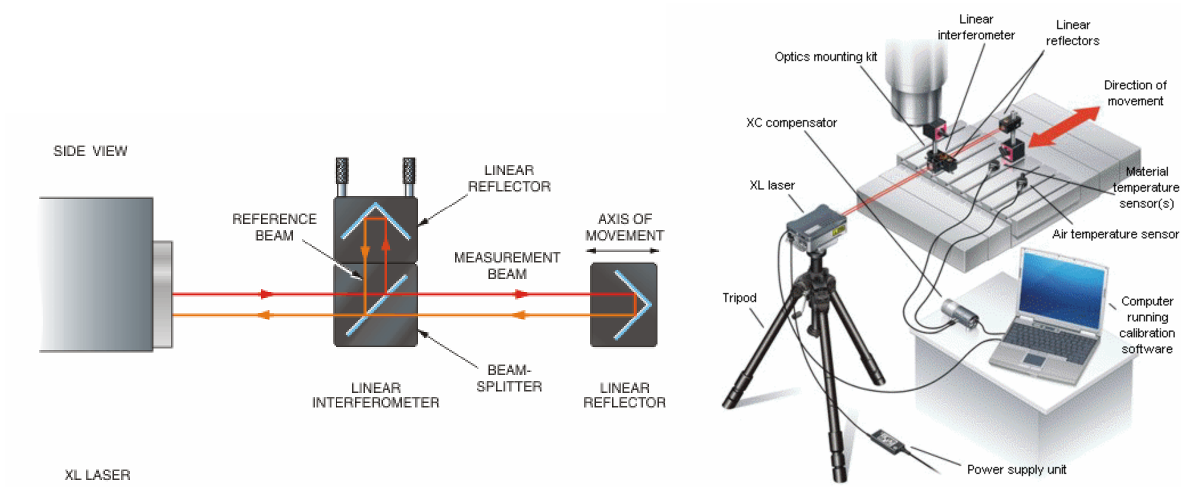


Fig. 6. *Principles of linear measurement and typical system set-up for measuring a position*

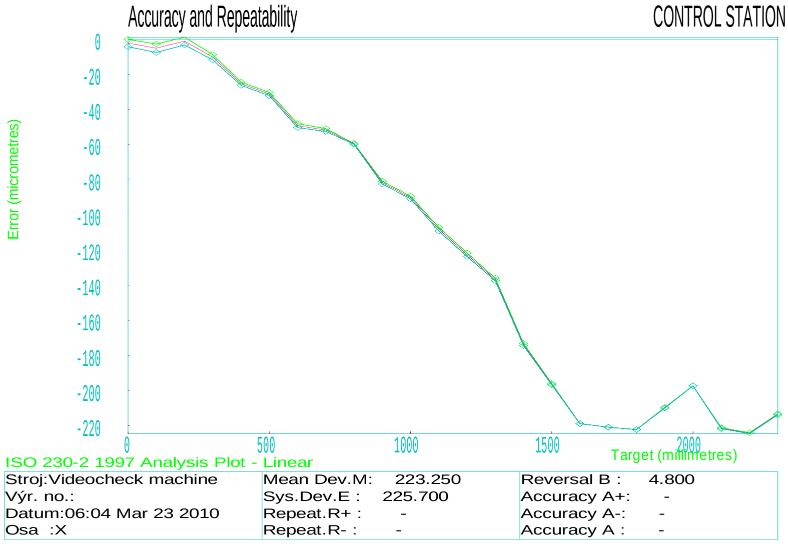
Parametres of measuring:

Machine:	Control videocheck machine	Air temperature:	start – 27,48 °C, end 27,43 °C
Mode:	linear displacement	Material temperature:	27,05 °C
Runs:	1 times , bidirectional	Air presure:	999,00 mbar
Measuring:	in X ax	Rel humidity:	start – 36,06 % , end – 35,94 %
Laser head Location:	direction on X ax	Environment factor:	start – 0,31638667, end –0,31638668
Time of measuring:	start – 6:43 , end – 6:49	Exp. Coeff.	11,70 ppm/ °C

Fig. 7. *Linear measuring on control videocheck machine for Ikea factory with using Renishaw XL80*

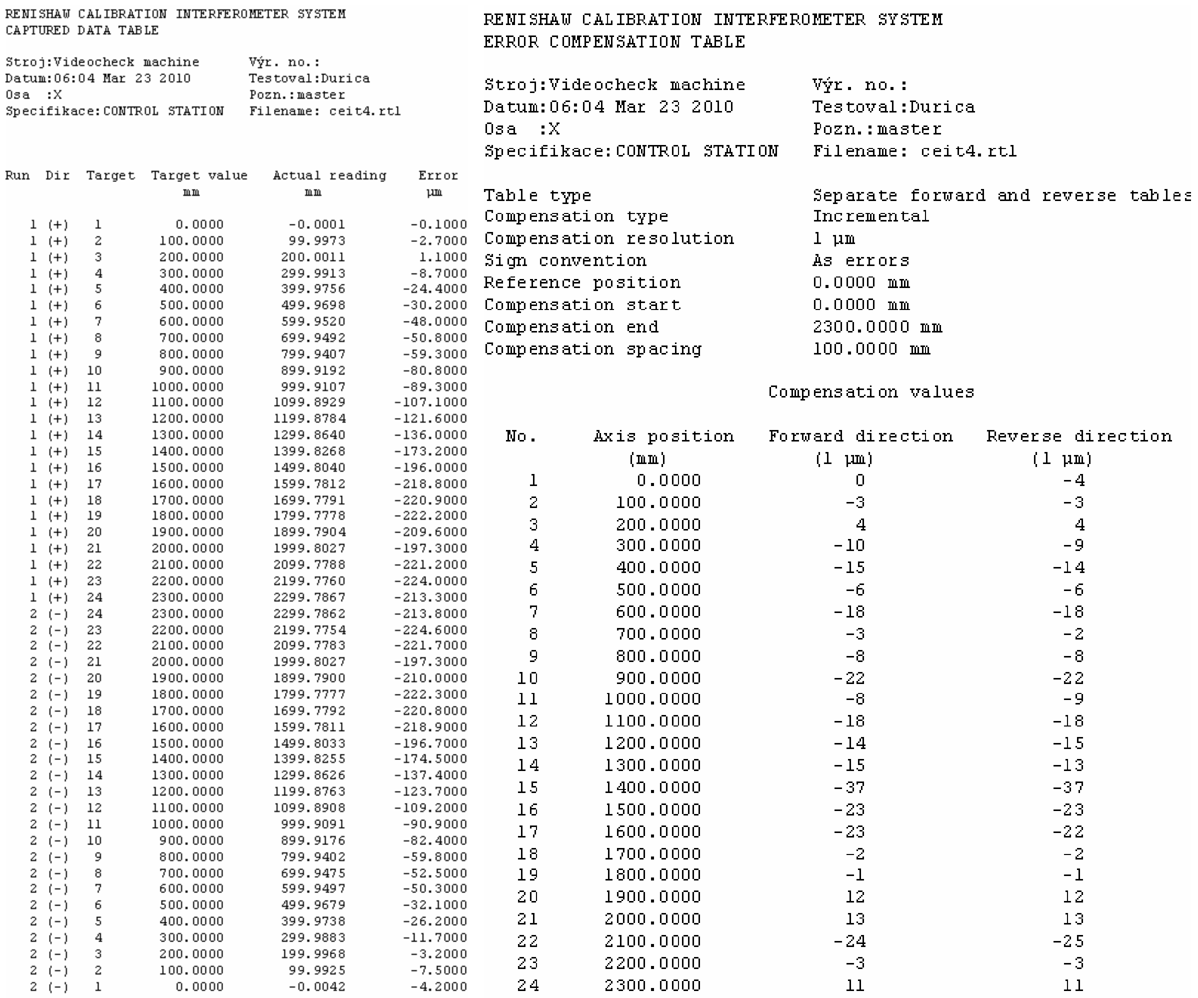
Measuring before setting

For this tour, we suggest spreading the targets between 0 and 2300 mm and using an interval of 100 mm.



```
Stroj:Videocheck machine    Mean Dev.M:    223.250   Reversal B :    4.800
Výr. no.:                   Sys.Dev.E :   225.700    Accuracy A+:     -
Datum:06:04 Mar 23 2010     Repeat.R+ :      -       Accuracy A-:     -
Osa  :X                     Repeat.R- :      -       Accuracy A :     -
```

Fig. 8. *ISO 230-2 1997 analysis plot*



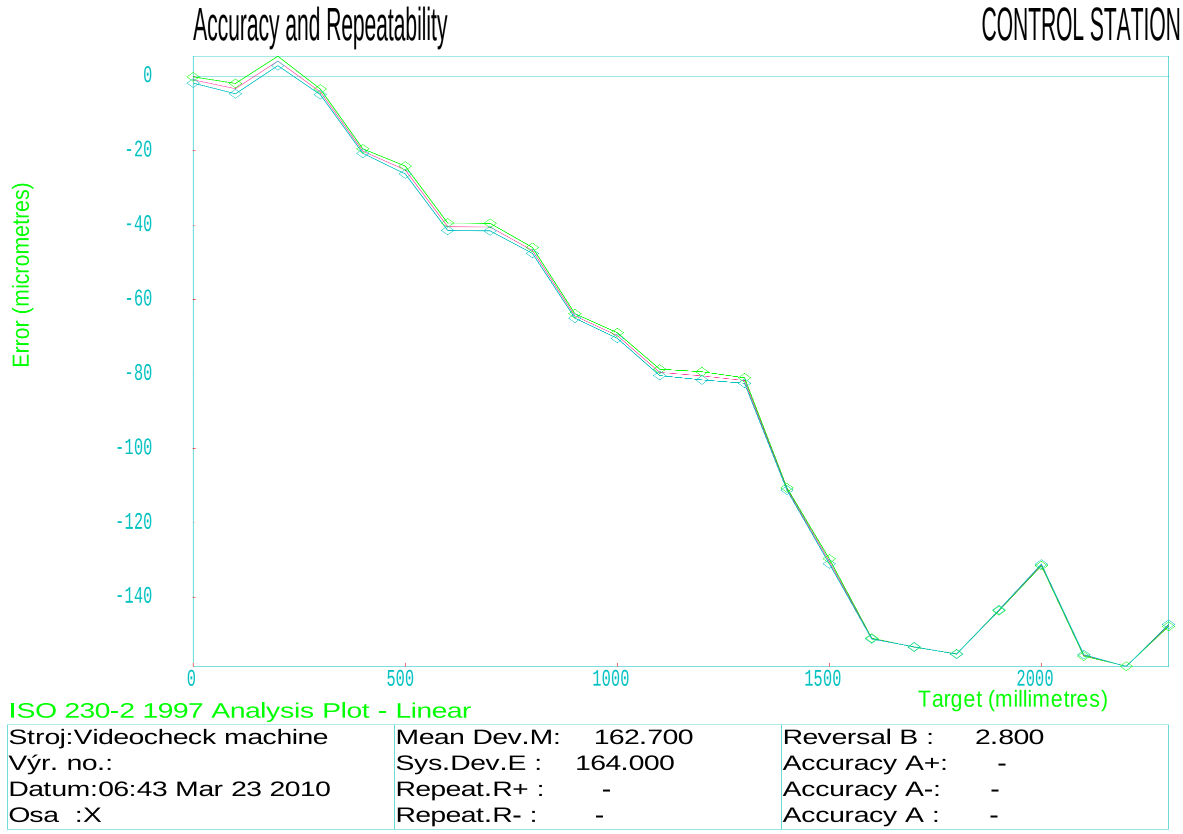
```
RENISHAW CALIBRATION INTERFEROMETER SYSTEM
CAPTURED DATA TABLE

Stroj:Videocheck machine        Výr. no.:
Datum:06:04 Mar 23 2010         Testoval:Durica
Osa  :X                         Pozn.:master
Specifikace:CONTROL STATION     Filename: ceit4.rtl


Run  Dir  Target  Target value   Actual reading    Error
                      mm               mm            µm

   1 (+)   1         0.0000        -0.0001       -0.1000
   1 (+)   2       100.0000        99.9973       -2.7000
   1 (+)   3       200.0000       200.0011        1.1000
   1 (+)   4       300.0000       299.9913       -8.7000
   1 (+)   5       400.0000       399.9756      -24.4000
   1 (+)   6       500.0000       499.9698      -30.2000
   1 (+)   7       600.0000       599.9520      -48.0000
   1 (+)   8       700.0000       699.9492      -50.8000
   1 (+)   9       800.0000       799.9407      -59.3000
   1 (+)  10       900.0000       899.9192      -80.8000
   1 (+)  11      1000.0000       999.9107      -89.3000
   1 (+)  12      1100.0000      1099.8929     -107.1000
   1 (+)  13      1200.0000      1199.8784     -121.6000
   1 (+)  14      1300.0000      1299.8640     -136.0000
   1 (+)  15      1400.0000      1399.8268     -173.2000
   1 (+)  16      1500.0000      1499.8040     -196.0000
   1 (+)  17      1600.0000      1599.7812     -218.8000
   1 (+)  18      1700.0000      1699.7791     -220.9000
   1 (+)  19      1800.0000      1799.7778     -222.2000
   1 (+)  20      1900.0000      1899.7904     -209.6000
   1 (+)  21      2000.0000      1999.8027     -197.3000
   1 (+)  22      2100.0000      2099.7788     -221.2000
   1 (+)  23      2200.0000      2199.7760     -224.0000
   1 (+)  24      2300.0000      2299.7867     -213.3000
   2 (-)  24      2300.0000      2299.7862     -213.8000
   2 (-)  23      2200.0000      2199.7754     -224.6000
   2 (-)  22      2100.0000      2099.7783     -221.7000
   2 (-)  21      2000.0000      1999.8027     -197.3000
   2 (-)  20      1900.0000      1899.7900     -210.0000
   2 (-)  19      1800.0000      1799.7777     -222.3000
   2 (-)  18      1700.0000      1699.7792     -220.8000
   2 (-)  17      1600.0000      1599.7811     -218.9000
   2 (-)  16      1500.0000      1499.8033     -196.7000
   2 (-)  15      1400.0000      1399.8255     -174.5000
   2 (-)  14      1300.0000      1299.8626     -137.4000
   2 (-)  13      1200.0000      1199.8763     -123.7000
   2 (-)  12      1100.0000      1099.8908     -109.2000
   2 (-)  11      1000.0000       999.9091      -90.9000
   2 (-)  10       900.0000       899.9176      -82.4000
   2 (-)   9       800.0000       799.9402      -59.8000
   2 (-)   8       700.0000       699.9475      -52.5000
   2 (-)   7       600.0000       599.9497      -50.3000
   2 (-)   6       500.0000       499.9679      -32.1000
   2 (-)   5       400.0000       399.9738      -26.2000
   2 (-)   4       300.0000       299.9883      -11.7000
   2 (-)   3       200.0000       199.9968       -3.2000
   2 (-)   2       100.0000        99.9925       -7.5000
   2 (-)   1         0.0000        -0.0042       -4.2000
```

```
RENISHAW CALIBRATION INTERFEROMETER SYSTEM
ERROR COMPENSATION TABLE

Stroj:Videocheck machine        Výr. no.:
Datum:06:04 Mar 23 2010         Testoval:Durica
Osa  :X                         Pozn.:master
Specifikace:CONTROL STATION     Filename: ceit4.rtl

Table type                      Separate forward and reverse tables
Compensation type               Incremental
Compensation resolution         1 µm
Sign convention                 As errors
Reference position              0.0000 mm
Compensation start              0.0000 mm
Compensation end                2300.0000 mm
Compensation spacing            100.0000 mm

                        Compensation values

  No.    Axis position    Forward direction    Reverse direction
              (mm)             (1 µm)               (1 µm)
   1          0.0000             0                   -4
   2        100.0000            -3                   -3
   3        200.0000             4                    4
   4        300.0000           -10                   -9
   5        400.0000           -15                  -14
   6        500.0000            -6                   -6
   7        600.0000           -18                  -18
   8        700.0000            -3                   -2
   9        800.0000            -8                   -8
  10        900.0000           -22                  -22
  11       1000.0000            -8                   -9
  12       1100.0000           -18                  -18
  13       1200.0000           -14                  -15
  14       1300.0000           -15                  -13
  15       1400.0000           -37                  -37
  16       1500.0000           -23                  -23
  17       1600.0000           -23                  -22
  18       1700.0000            -2                   -2
  19       1800.0000            -1                   -1
  20       1900.0000            12                   12
  21       2000.0000            13                   13
  22       2100.0000           -24                  -25
  23       2200.0000            -3                   -3
  24       2300.0000            11                   11
```

Fig. 9. *Capcured data table and error compenzation table*

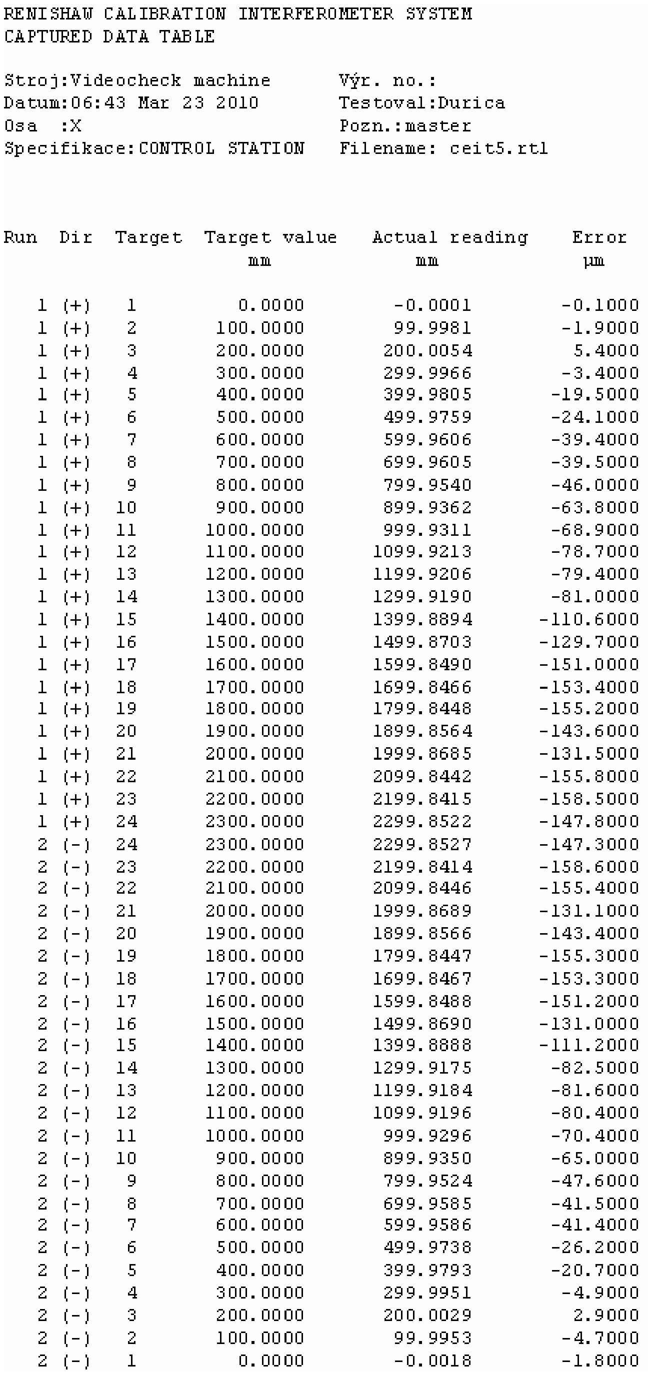
Measuring after setting (compensation)

For this tour, we suggest spreading the targets between 0 and 2300 mm and using an interval of 100 mm.



Stroj:Videocheck machine	Mean Dev.M: 162.700	Reversal B : 2.800
Výr. no.:	Sys.Dev.E : 164.000	Accuracy A+: -
Datum:06:43 Mar 23 2010	Repeat.R+ : -	Accuracy A-: -
Osa :X	Repeat.R- : -	Accuracy A : -

Fig. 10. *ISO 230-2 1997 analysis plot*



```
RENISHAW CALIBRATION INTERFEROMETER SYSTEM
CAPTURED DATA TABLE

Stroj:Videocheck machine      Výr. no.:
Datum:06:43 Mar 23 2010       Testoval:Durica
Osa  :X                       Pozn.:master
Specifikace:CONTROL STATION   Filename: ceit5.rtl


Run  Dir  Target  Target value    Actual reading    Error
                       mm              mm             µm

   1 (+)   1         0.0000         -0.0001        -0.1000
   1 (+)   2       100.0000         99.9981        -1.9000
   1 (+)   3       200.0000        200.0054         5.4000
   1 (+)   4       300.0000        299.9966        -3.4000
   1 (+)   5       400.0000        399.9805       -19.5000
   1 (+)   6       500.0000        499.9759       -24.1000
   1 (+)   7       600.0000        599.9606       -39.4000
   1 (+)   8       700.0000        699.9605       -39.5000
   1 (+)   9       800.0000        799.9540       -46.0000
   1 (+)  10       900.0000        899.9362       -63.8000
   1 (+)  11      1000.0000        999.9311       -68.9000
   1 (+)  12      1100.0000       1099.9213       -78.7000
   1 (+)  13      1200.0000       1199.9206       -79.4000
   1 (+)  14      1300.0000       1299.9190       -81.0000
   1 (+)  15      1400.0000       1399.8894      -110.6000
   1 (+)  16      1500.0000       1499.8703      -129.7000
   1 (+)  17      1600.0000       1599.8490      -151.0000
   1 (+)  18      1700.0000       1699.8466      -153.4000
   1 (+)  19      1800.0000       1799.8448      -155.2000
   1 (+)  20      1900.0000       1899.8564      -143.6000
   1 (+)  21      2000.0000       1999.8685      -131.5000
   1 (+)  22      2100.0000       2099.8442      -155.8000
   1 (+)  23      2200.0000       2199.8415      -158.5000
   1 (+)  24      2300.0000       2299.8522      -147.8000
   2 (-)  24      2300.0000       2299.8527      -147.3000
   2 (-)  23      2200.0000       2199.8414      -158.6000
   2 (-)  22      2100.0000       2099.8446      -155.4000
   2 (-)  21      2000.0000       1999.8689      -131.1000
   2 (-)  20      1900.0000       1899.8566      -143.4000
   2 (-)  19      1800.0000       1799.8447      -155.3000
   2 (-)  18      1700.0000       1699.8467      -153.3000
   2 (-)  17      1600.0000       1599.8488      -151.2000
   2 (-)  16      1500.0000       1499.8690      -131.0000
   2 (-)  15      1400.0000       1399.8888      -111.2000
   2 (-)  14      1300.0000       1299.9175       -82.5000
   2 (-)  13      1200.0000       1199.9184       -81.6000
   2 (-)  12      1100.0000       1099.9196       -80.4000
   2 (-)  11      1000.0000        999.9296       -70.4000
   2 (-)  10       900.0000        899.9350       -65.0000
   2 (-)   9       800.0000        799.9524       -47.6000
   2 (-)   8       700.0000        699.9585       -41.5000
   2 (-)   7       600.0000        599.9586       -41.4000
   2 (-)   6       500.0000        499.9738       -26.2000
   2 (-)   5       400.0000        399.9793       -20.7000
   2 (-)   4       300.0000        299.9951        -4.9000
   2 (-)   3       200.0000        200.0029         2.9000
   2 (-)   2       100.0000         99.9953        -4.7000
   2 (-)   1         0.0000         -0.0018        -1.8000
```

Fig. 11. *Capcured data table*

References:

[1] DEMEČ, P. *Presnosť obrábacích strojov a jej matematické modelovanie*. Košice: Vienala, 2001.

[2] PILC, J., ČILLIKOVÁ, M. *Trendy vývoja výrobnej techniky*. Žilina: Edis, 2004.

[3] KURIC, I., NOVÁK-MARCINČIN, J., COTETIU, R., UNGUREANU, N. *Development of Progressive Technologies - Computer Support for Progressive Technologies*. Vienna 2007, s. 253. ISBN 3-901509-28-3

[4] COTETIU, R., KURIC, I., MARCINČIN, J., UNGUREANU, N. *New Trend in Mechanical Design and Technologies*. RISOPRINT Cluj Napoca Publisher, 2005, 210 p. ISBN 973-751-084-4

[5] MARCINČIN, J. From computer aided manufacturing to virtial manufacturing. In *8th International/Expert Conference "Trends in The Development of Macninery and Assocoated Technology" TMT 2004*. Neum, Bosna a Hercegovina, 2004. pp. 535-538. ISBN 9958-617-21-8

[6] www.renishaw.com

[7] www.diagnostikastroju.cz

[8] www.lammb.cz

[9] www.measurementmachine.com

[10] www.paramcalibration.com

[11] www.kib.stuba.sk/view/detail_dp.php?id=784

[12] www.sjf.tuke.sk/transferinovacii/pages/archiv/transfer/1-1999/pdf/96-99.pdf