Accuracy Enhancement of 3 Axis Vertical milling Machine Centre

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***Abstract*— There are various ways which leads for enhanced performance of machine centre. Precision Machine tool must perform accurately in changing environment and working conditions. The factors which affect precision are static, kinematic, thermal and dynamics response. I.e. geometric alignment of slide ways, bed, thermal gradient in spindle, ball screw and wear of parts etc.**

This paper presents estimate and compensation of geometric error for 3 axis Vertical Milling Machine centre. Experiment test is carried out using ball bar test to check accuracy. The aspect of this is to predict and reduce errors. Validation of the same is done by experimental analysis.

Keywords*— Accuracy, ball bar system, vertical milling machine centre , geometric error, spindle vibration)

I. Introduction

To have effective functioning of the machine tool, its critical components need to function with commendable accuracy and reliability. As the user at the other end needs more functional capabilities in the machine tools, the designer has to play the key role in satisfying the above requirement.[1] The Laser interferometer & ball bar are the most useful and economical devices to characterize CNC machine tools. A simple check with a ball bar can often provide much of the information needed to verify a machine's performance. If the machine is out of accurate performance, the same tool can provide the data to diagnose many errors. [3] A simple dial gauge is used to check the proper assembly and measure the geometric accuracy of the machine.

As the machine is assembled, all components alignment is checked using dial gauge. Standard alignment test carried out using ball bar gauge. Before a machine tool goes into operation, it's essential to check straightness, squareness, circularity. Especially Machine structure (Bed, Table, column, saddles, Slides, Ball screw & nut assembly, Ball screw support bearings, Metal bellow coupling, Guides, Drives (spindle & feed drives),Machine tool spindle, Spindle bearings, Feedback devices accuracy is tested. Machine spindle is one of important component of machine tool. So here machine tool accuracy test is analyzed using dial gauge, ball bar and spindle vibration test.

II. CNC Vertical Machining Center Model with the Following Main Features

TABLE I. Specifications of Vertical Milling Machine

Particular	Characteristic
X Axis travel	820 mm
Y Axis travel	510 mm
Z Axis travel	510 mm
Main Spindle Power	10.5 kW / 13.5 kW (30 min rating)
Max Spindle Speed	0-10000 rpm
Spindle with chiller unit	BT-40
Distance from Spindle face to Table	150 – 660 mm
Spindle Motor Power (30 min Rating)	10.5 kW / 13.5 kW

III. Measuring Tool and its Specification

A dial gauge indicator is a device consists of pointer, dial, clamp, tool holder. At the reference base the gauge is clamped and dial gauge pointer is set to zero. And alignment test is carried out by moving the probe to straight line or the gauge can be rotated to check the proper circularity of machine axis. From the observation the component is aligned properly.

The ball bar measuring system is run to measure the error or difference in radius using software. It contains transducer. The ball bar is fixed on table and rotated around it. Blue tooth is connected to the suitable computer. The ball bar diagnosis shows the error magnitude and shows the contouring performance and deviation. It shows the graphical as well as numerical representation. [2]

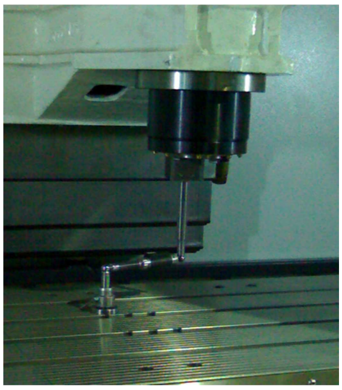


Fig. 1 Measurement by Double ball bar system

TABLE II. SPECIFICATION OF QC 20 BALLBAR MEASUSURING INSTRUMENT

Element	Characteristic
Resolution	0.1µm
Ballbar measurement accuracy	± (0.7 + 0.3% L) µm
Ballbar measuring range	±1.0 mm
Sensor stroke	-1.25 mm to +1.75 mm
Maximum sample rate	1000 Hz
Data transmission Bluetooth, Class 2	10 m typical
Operating range	0 °C - 40 °C
System case dimensions	395 x 300 x 105 mm

The ball bar can be used to diagnose pitch errors, thermal distortion, scaling errors and radial deviation. In addition the software will automatically calculate the positional tolerance of the machine.[2]

Set-up is quick and easy. The QC20 ballbar is mounted between two repeatable magnetic joints. A simple G02 and G03command program is used for the test. The machine performs two consecutive circular arcs. One test is in the clockwise direction, the other in the counter-clockwise direction. The QC20 ballbar accurately measures any variations in radius during the test. Various machine tool inspection equipments are there e.g. Laser Interferometer System, callimeter, Grid Encoder and Comparator System. Laser systems apply both static and dynamic tests. The static tests include basic measurements such as linear and squareness. The dynamic tests evaluate positioning error.

IV. ACCURACY AS PER VDI/DGQ 3441 :

TABLE III. ACCURACY CHARACTERISTIC

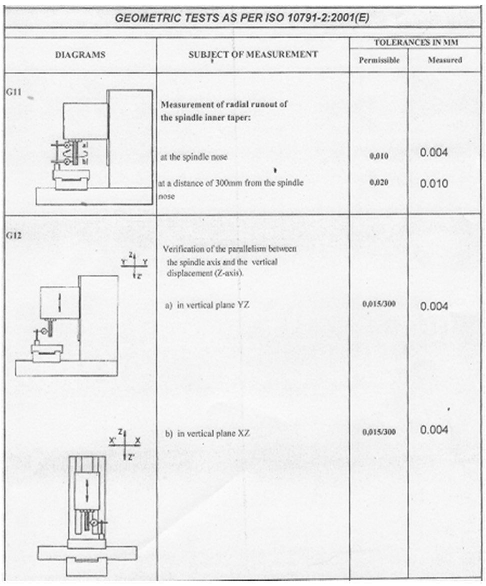
Element	Characteristic
Positioning accuracy	0.008 mm
Repeatability	+/- 0.003 mm

VDI/DGQ is (Verein Deutscher Ingenieure Deutsche Gesellschaft fur Qualitat) guideline for Statistical Testing of the Operational and Positional Accuracy of Machine Tools Basis.

This guideline describes the basic principles of the statistical test methods. It is of direct application to the testing of machines which are tied to a particular component, that is for all special machines where the parts to be machined are clearly defined.

V. CALIBRATION AND COMPENSATION

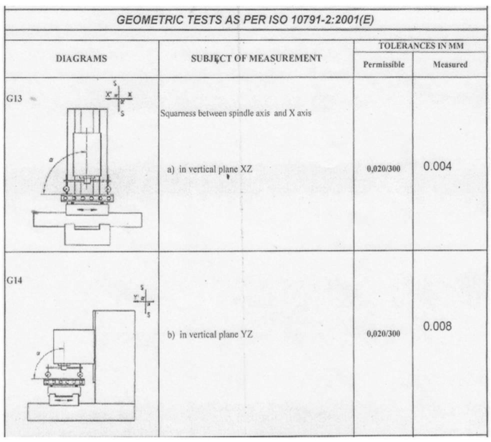
Using dial gauge indicator of “mitutoyo” first the geometric accuracy test is carried out. The test is carried out and final measurement is as shown below. Radial run out of the spindle inner taper, parallelism between the spindle axis and the vertical displacement in vertical XZ and YZ plane and squareness between spindle axis and X axis in XZ and YZ plane is checked. Before dispatching the machine tool this test will be checked whether it is within the permissible value or not. Otherwise it has to be carried out in the permissible value for accurate final geometry of work piece.



GEOMETRIC TESTS AS PER ISO 10791-2:2001(E)

DIAGRAMS	SUBJECT OF MEASUREMENT	TOLERANCES IN MM Permissible	Measured
G11	Measurement of radial runout of the spindle inner taper:		
	at the spindle nose	0,010	0.004
	at a distance of 300mm from the spindle nose	0,020	0.010
G12	Verification of the parallelism between the spindle axis and the vertical displacement (Z-axis).		
	a) in vertical plane YZ	0,015/300	0.004
	b) in vertical plane XZ	0,015/300	0.004

Fig. 2.1 Geometric test of spindle



GEOMETRIC TESTS AS PER ISO 10791-2:2001(E)

DIAGRAMS	SUBJECT OF MEASUREMENT	TOLERANCES IN MM Permissible	Measured
G13	Squarness between spindle axis and X axis		
	a) in vertical plane XZ	0,020/300	0.004
G14	b) in vertical plane YZ	0,020/300	0.008

Fig. 2.2 Geometric test of spindle

The ball bar plot simulator allows the user to see his test results on screen and then to change various machine geometry, play and dynamic parameters, so that errors can be compensated. And finally scenarios can be seen on the ball bar plot and on circularity and positional tolerance values [6-7]. The circular interpolation test permits a very detailed examination of the accuracy of a plane and dynamic properties of a machine.

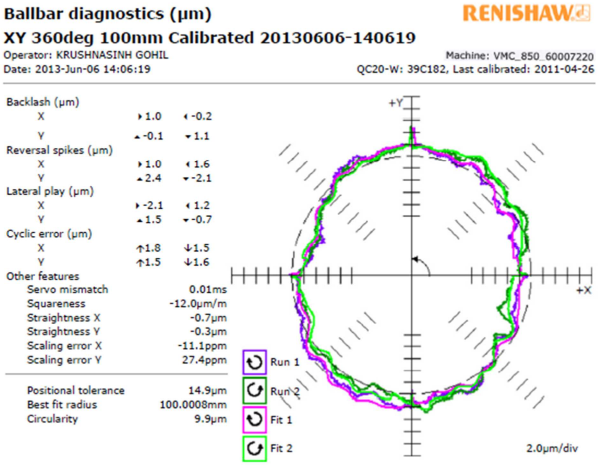


Fig. 3 Ballbar diagnosis plot in XY plane

Ballbar diagnostics table RENISHAW

XY 360deg 100mm Calibrated 20130606-140619

Operator: KRUSHNASINH GOHIL Machine: VMC_850_60007220

Date: 2013-Jun-06 14:06:19 QC20-W: 39C182, Last calibrated: 2011-04-26

Error	Magnitude		Independent circularity		Ranking
Backlash X	► 1.0	◄ -0.2µm	1.0µm	(6%)	(9)
Backlash Y	▲ -0.1	▼ 1.1µm	1.1µm	(6%)	(8)
Reversal spikes X	► 1.0	◄ 1.6µm	1.6µm	(9%)	(4)
Reversal spikes Y	▲ 2.4	▼ -2.1µm	2.4µm	(14%)	(2)
Lateral play X	► -2.1	◄ 1.2µm	1.1µm	(7%)	(7)
Lateral play Y	▲ 1.5	▼ -0.7µm	0.9µm	(5%)	(10)
Cyclic error X	↑1.8	↓1.5µm	1.7µm	(10%)	(3)
Cyclic error Y	↑1.5	↓1.6µm	1.4µm	(8%)	(5)
Servo mismatch	0.01ms		0.3µm	(2%)	(12)
Squareness	-12.0µm/m		1.2µm	(7%)	(6)
Straightness X	-0.7µm		0.4µm	(2%)	(11)
Straightness Y	-0.3µm		0.1µm	(1%)	(13)
Scaling mismatch	-7.7µm		3.8µm	(23%)	(1)
Scaling error X	-11.1ppm				
Scaling error Y	27.4ppm				
Cyclic pitch X	20.0000mm				
Cyclic pitch Y	30.0000mm				
Calculated feedrate	1499.9mm/min				
Centre offset X	-0.3µm				
Centre offset Y	0.5µm				
Positional tolerance	14.9µm				
Best fit radius	100.0008mm				
Circularity	9.9µm				

Test parameters

Radius	100.0000mm
Feedrate	1500.0mm/min
Start/End/Overshoot	180°/180°/180°
Run sequence	CW CCW
Test position	XY
Sample rate	58.824Hz

Fig. 4 Ballbar diagnosis analysis.in XY plane

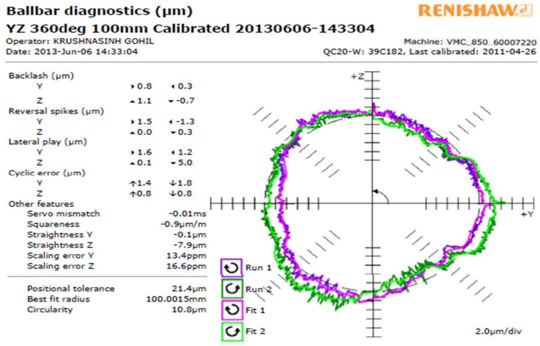


Fig. 5 Ballbar diagnosis plot in YZ plane

Ballbar diagnostics table RENISHAW

YZ 360deg 100mm Calibrated 20130606-143304

Operator: KRUSHNASINH GOHIL Machine: VMC_850_60007220

Date: 2013-Jun-06 14:33:04 QC20-W: 39C182, Last calibrated: 2011-04-26

Error	Magnitude		Independent circularity		Ranking
Backlash Y	► 0.8	◄ 0.3µm	0.8µm	(5%)	(7)
Backlash Z	▲ 1.1	▼ -0.7µm	1.1µm	(7%)	(6)
Reversal spikes Y	► 1.5	◄ -1.3µm	1.5µm	(10%)	(4)
Reversal spikes Z	▲ 0.0	▼ 0.3µm	0.3µm	(2%)	(9)
Lateral play Y	► 1.6	◄ 1.2µm	1.4µm	(9%)	(5)
Lateral play Z	▲ 0.1	▼ 5.0µm	3.3µm	(21%)	(2)
Cyclic error Y	↑1.4	↓1.8µm	1.6µm	(11%)	(3)
Cyclic error Z	↑0.8	↓0.8µm	0.7µm	(5%)	(8)
Servo mismatch	-0.01ms		0.1µm	(1%)	(11)
Squareness	-0.9µm/m		0.1µm	(1%)	(12)
Straightness Y	-0.1µm		0.1µm	(0%)	(13)
Straightness Z	-7.9µm		4.0µm	(26%)	(1)
Scaling mismatch	-0.6µm		0.3µm	(2%)	(10)
Scaling error Y	13.4ppm				
Scaling error Z	16.6ppm				
Cyclic pitch Y	20.0000mm				
Cyclic pitch Z	22.0000mm				
Calculated feedrate	1500.4mm/min				
Centre offset Y	0.3µm				
Centre offset Z	0.4µm				
Positional tolerance	21.4µm				
Best fit radius	100.0015mm				
Circularity	10.8µm				

Test parameters

Radius	100.0000mm
Feedrate	1500.0mm/min
Start/End/Overshoot	180°/180°/180°
Run sequence	CW CCW
Test position	YZ
Sample rate	58.824Hz

Fig. 6 Ballbar diagnosis analysis.in YZ plane

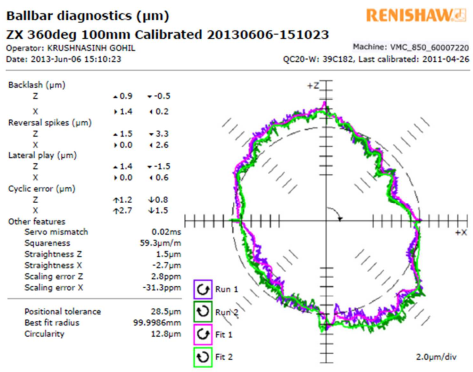


Fig. 7 Ballbar diagnosis plot in ZX plane

Ballbar diagnostics table RENISHAW

ZX 360deg 100mm Calibrated 20130606-151023

Operator: KRUSHNASINH GOHIL — Machine: VMC_850_60007220

Date: 2013-Jun-06 15:10:23 — QC20-W: 39C182, Last calibrated: 2011-04-26

Error	Magnitude		Independent circularity		Ranking
Backlash Z	▲0.9	▼-0.5μm	0.9μm	(4%)	(9)
Backlash X	▶1.4	◀0.2μm	1.4μm	(5%)	(6)
Reversal spikes Z	▲1.5	▼3.3μm	3.3μm	(13%)	(3)
Reversal spikes X	▶0.0	◀2.6μm	2.6μm	(10%)	(4)
Lateral play Z	▲1.4	▼-1.5μm	0.8μm	(3%)	(10)
Lateral play X	▶0.0	◀0.6μm	0.4μm	(1%)	(13)
Cyclic error Z	↑1.2	↓0.8μm	1.1μm	(4%)	(8)
Cyclic error X	↑2.7	↓1.5μm	2.5μm	(10%)	(5)
Servo mismatch	0.02ms		0.5μm	(2%)	(12)
Squareness	59.3μm/m		5.9μm	(24%)	(1)
Straightness Z	1.5μm		0.7μm	(3%)	(11)
Straightness X	-2.7μm		1.4μm	(5%)	(7)
Scaling mismatch	6.8μm		3.4μm	(14%)	(2)
Scaling error Z	2.8ppm				
Scaling error X	-31.3ppm				
Cyclic pitch Z	25.0000mm				
Cyclic pitch X	20.0000mm				
Calculated feedrate	1499.4mm/min				
Centre offset Z	-0.6μm				
Centre offset X	-0.6μm				
Positional tolerance	28.5μm				
Best fit radius	99.9986mm				
Circularity	12.8μm				

Test parameters

Radius	100.0000mm
Feedrate	1500.0mm/min
Start/End/Overshoot	270°/270°/180°
Run sequence	CW CCW
Test position	ZX
Sample rate	58.824Hz

Fig. 8 Ballbar diagnosis analysis in ZX plane

When an axis is being driven in one direction and then has to reverse and move in the opposite direction, instead of reversing smoothly it may pause momentarily at the turnaround point. This appears as short spikes that appear on either axis reversal point. This could mean servo response time is poor and excessive friction in axis. [7]

VI. Measurement of Head vibration at Spindle axis

As the whole machine tool is assembled, its working is checked by taking performance and operation test. Head vibration checked at spindle axis. If the head is unbalanced then it is required to do its balancing. During the performance check the instrument as shown in figure 9 will check vibration in mm/s at various point of spindle head. It will do analysis checking at various speeds for number of observations. If the balancing is not proper than it will be done by adding or removing mass.

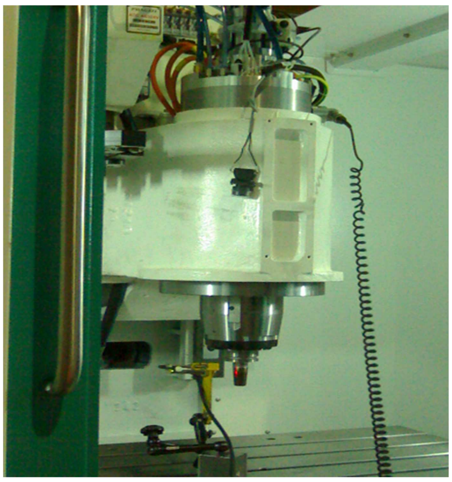


Fig. 9 Vibration testing

Performance and Operation Tests — ISO 1940 / 1 -1986

Measurements of Head Vibration At Spindle Axis

Spindle : JYOTI Sr.No.526 :dt: 13/06/2013

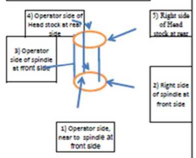
Spindle Type: BT40

Condition:

Spindle 8000 RPM

Observations

Rotation RPM	Vibrations in mm/s 1	2	3	4	5
1000	0.003	0.010	0.006	0.005	0.002
3000	0.008	0.008	0.020	0.007	0.010
5000	0.050	0.060	0.005	0.010	0.095
7000	0.075	0.365	0.080	0.028	0.410
8000	0.070	0.350	0.045	0.010	0.255



LIMIT VALUE 2.5 mm / sec.

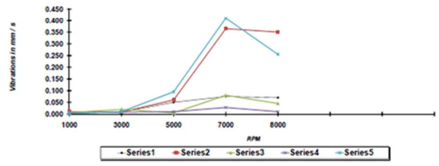


Fig. 10 Records chart of vibration

VII. Conclusion:

In this paper ball bar is used to diagnose machine centre accuracy and test carried out for spindle vibration. The on-line inspection gives probable causes of machine error and offers information for how best to fix them. Powerful software examination facilitates judgment of specific machine errors. Each error is ordered as per its significance to over all machine accuracy. Quick response can be achieved from laser, ball bar system which ultimately reduces product rejection and product cycle time.

In this further static, dynamic and thermal analysis also can be carried out using experimental set up and software analysis also can be done to get high accuracy and error compensation.

Acknowledgement

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