

Geometric Error Measurement Techniques in CNC Machines - A Survey

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Abstract— The CNC machines are the basic requirement of whole manufacturing industries. The current demand of higher accuracy achieved on machined components is increasing rapidly. The error generates during machining and the structural error of machine tools affect the quality of machined components. The various errors occurs in machines are mainly due to geometric error, thermal error, fixture dependent error and cutting force induced error. The geometric error contains major portions among all these errors. The measurement of geometric error components is the vast field of metrology and measurements. It is the necessary to measure the actual error in the work of error compensation. The mainly the geometric error components are measured through instruments like the laser interferometer, tracking interferometer, ball bar instrument and 3D probe ball.

Key words: CNC Machine, Types of Error, Error Measurement Methodology

I. INTRODUCTION

In current market computer numerical control (CNC) machine tools are widely used in industry for the fulfilment of the customer demands. The CNC machines is having some lucrative features which attracts the micro scale to macro scale industries. The CNC machines gives the flexibility to manufacture the complex components. The shape, size, material, motion and other flexibility exhibits by the machines, are the primary concerns of the industries. In the micro scale demand market the various technology are developed like micro machining, nanotechnology, MEMS due to the advancement in CNC machines. The macro scale industries are having the various applications through the material removal processes like milling, drilling, reaming, boring, turning, grinding, lapping etc., fabrication technology like rapid prototyping, and many unconventional machining techniques like Electro Discharge Machining (EDM), Electro Chemical Machining (ECM), ultrasonic machining, water jet machining etc.

Specially taking focus towards vertical machining centre (VMC), according to the motion flexibility given in the CNC machines, most commonly used VMC are, three axis VMC and five Axis VMC. Vertical machining centre with translational movements of along all axes is commonly called as TTT configuration. It is differ from 2 1/2 axis VMC in the sense that 3-axis movement are possible simultaneously, whereas in 2 1/2 axis VMC only 2 axis movement are possible simultaneously. However, according to rotational and translational axis, mainly three different configurations of 5-axis vertical machining centre are in practice. These are 3T2R, 2T3R and 1T4R configurations.

These all machine tools generates errors during the machining of the components. Also, the structural error of machine tool generate error at tool tip of the machines. The vibration, tool deflection, erroneous motion of spindle, cutting force, clamping force and thermal deflection are the another sources of errors in CNC machines.

The current work gives the idea about the types of errors mainly available in CNC machine tools. The error sources due to which the errors are exist or created are also explained. The geometric errors contains major part in total errors of machine tools. The measurement of actual errors are essential for error compensation. The methodology or the techniques used to measure the geometric errors are described in present paper.

II. TYPES OF ERROR IN CNC MACHINE TOOL

In CNC machines, some important key factors like cutting tools and machining conditions, resolution of the machine tool, the type of workpiece etc., play an important role for achieving higher dimensional accuracy. There are always some sources of errors remained, once these key factors are fixed to some extent. Consistent performance of the machine tool depends on ability of machine to accurately position the tool tip for required workpiece dimension. This is mainly limited by some kind of errors which are either within machine tool or on a periodic basis in regard to temperature changes or fluctuation in cutting forces.

These error sources ultimately lead to the types of error. These all errors could be affecting the dimensional accuracy in a very crucial ways. From the error sources, the errors are classified by mainly four errors [6, 7]:

- 1) Geometric error
- 2) Cutting-force induced error
- 3) Thermal error
- 4) Fixture dependent error

Geometric errors are those errors that are seen at the tool tip due to the differences in the actual and nominal dimensions and geometry of the machine components and couplings between them [2]. As far as 3-axis vertical machining centre is concerned, there are 21 components of geometric error is introduced in the modelling of kinematic error model. These geometric component are linear scale error (3 components), straightness error (3 components), flatness error (3 components), squareness error (3 components) and angular error such as roll, pitch and yaw (9 components).

Now a days modern machining techniques involving machining of hardened steel directly to it final form without the customary grinding operations. Heat generated due to cutting process is carried by the tool, the workpiece, the swarf and the coolant. This leads to the increasing thermal deformation.

In the fixture, the workpiece displacement during the clamping and machining can be a significant sources of displacement of workpiece [6]. Here, workpiece displacement is mainly caused by contact region deformation, slip, and lift-off.

Continuous usage of the machine tool leads to the continuous relative motion between the various elements of the machine members. It cause continuous increase in the temperature due to heat generation at the contact zones. This temperature variation within the element will cause the

deformation or expansion of machine elements and this will lead to relative displacement of the workpiece and the tool [7]. So it will adversely affect the accuracy of the machine component.

A C Okafor et al. [5] have worked with geometric error and thermal error. Mohsen Soori et al. [8, 10] have emphasis on geometric error, cutting force error and tool deflection error into account for their error compensation work. Most of researcher have put effort for geometric error [2-5, 8,-10].

The geometric error represent large portion of the total machine tool error during machining. It covers 70% error related to machine tool [2]. The next section presents the common methodology used to measure the geometric error components.

III. GEOMETRIC ERROR MEASUREMENT METHODOLOGY

The geometric error components such as scale error, straightness error, flatness error, squareness error and angular error are not measure from ordinary instruments. The special device like laser interferometer, tracking interferometer, 3D probe ball and double ball bar are used for the measurement of these error components [1]. This section presents the basic principle of these techniques.

A. Laser Interferometer:

Interferometers generally are used to measure very small displacements by using the wave property of light. The principle of the laser interferometer is shown in Fig. 1 [11].

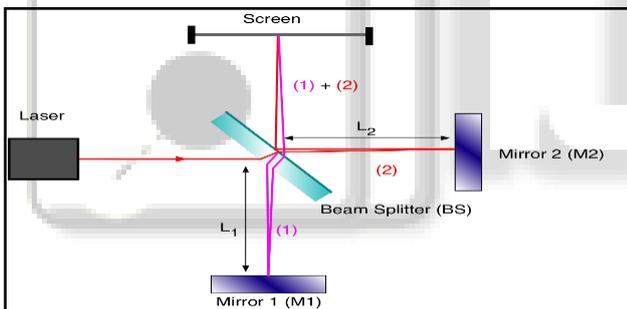


Fig. 1: Principle of Laser Interferometer [11]

The light from a laser is incident on a beam splitter (BS) which consists of a glass plate with a partially reflective surface. About 50% of the light is reflected from the surface and 50% is transmitted. The reflected light (beam 1) hits mirror M1 and is reflected back towards the beam splitter. The transmitted light (beam 2) as well is reflected back towards the beam splitter by mirror M2. 50% of the intensity of each reflected beam is transmitted/reflected towards the screen for observation. There the two beams overlap and constructive and destructive interference occurs depending on the relative phase shift between the two plane waves. Therefore this instruments allows you to observe distance changes of the order of the wavelength of light. The experimental setup with main part are also shown in Fig. 2 [11].

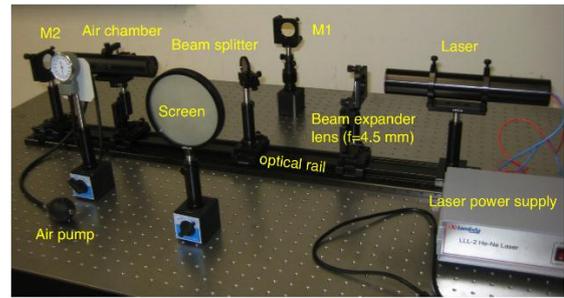


Fig. 2: Experimental Set Up Of Laser Interferometer [11]

B. Tracking Interferometer:

The concept is based on the measurement of relative distance change between reference points that are fixed to the base and points fixed to the machine head. These measurements are realised by a tracking interferometer, which is mounted on the work piece table and a retro reflector that is attached to the machine head. Fig. 3 [12] shows a typical set up.

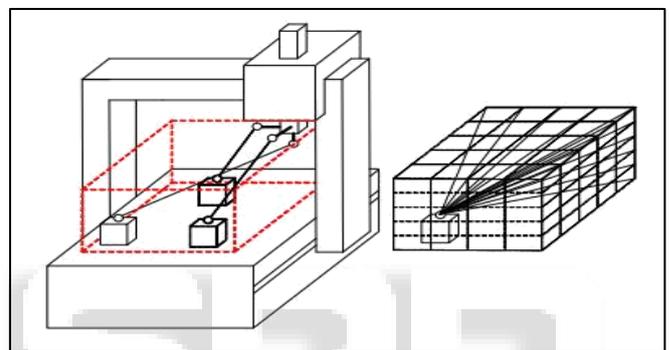


Fig. 3: Set Up For Tracking Interferometer [12]

For each combination, the machine is moved through a set of positions in a spatial grid. At each grid position, the machine stops and the associated measured distance is recorded by the tracking interferometer. The nominal distance change (under the assumption of a perfect machine) can be directly calculated from the position of the reference point and the positions of all three axes. Errors of the machine show up in differences between the measured and the nominal distance changes.

C. 3D Probe Ball:

The probe-ball device combines the basic idea of the well-known DBB and the three-dimensional (3D) measuring probe. As shown in Fig. 4 [13], the probe-ball device consists of a 3D measuring probe, an extension bar and a base plate with a central ball on the upper side.

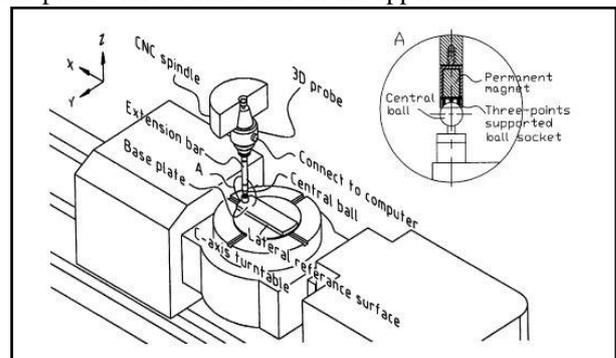


Fig. 4: Probe Ball Device [13]

The 3D measuring probe is equipped with standard taper as tool interface and can be mounted in the main spindle. The extension bar has a three points supported ball socket at the free end and forms a ball joint with the central ball on the base plate. The probe-ball measurement device. Central ball can be held together by magnetic force. The length of the extension bar determines the radius of the test spherical surface. The central ball is fixed on the base plate with a thread. The base plate has an auto centering collet at the lower side to ensure that the center of the base plate is on the center line of the turntable's reference mounting hole. The base plate has a lateral reference surface on the upper side to define the orientation of the base plate relative to the turntable. Upon mounting on the turntable, the reference surface is so adjusted that it is parallel to one linear machine axis, for example the X-axis.

D. Double Ball Bar (DBB) System:

Double Ball Bar (DBB) method is used for rapid tests for measure the motion error of a milling machine, a machining center or another machine tools which are driven by NC and have circular interpolation motion. The measuring equipment records the points on a circular curve, enlarges the extension or contraction of the bar and then shows them in polar coordinates, it is called the motion error trace. Then the trace is analysed and the volumetric accuracy is evaluated. Very valuable work concerning the phenomena in DBB measurements was studied in the laboratory of Kakino at late 80's. The most of later studies and work are based on this research. The following Fig. 5 illustrates the experimental set up for Double Ball Bar system.



Fig. 5: Experimental Setup of DBB System [14]

The DBB Double Ball Bar is a telescoping double ball bar linear encoder for performing circular interpolation tests with large radii to inspect primarily the machine tool geometry. The Fig. 6 shows the Double ball bar (DBB) instrument.

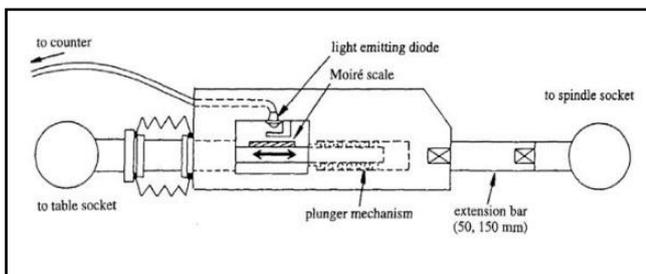


Fig. 6: Double Ball Bar (DBB) [14]

IV. CONCLUSION

The present paper emphasis on the basic instrument used for the geometric error measurement. The laser interferometer,

tracking interferometer, 3D probe ball and double ball bar (DBB) is having major application for geometric error measurement. The working principle of the all mentioned techniques are described.

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