Contouring Accuracy in CNC Machine

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***Abstract* - With the expanding demand on the dimensional precision of machined parts, contouring accuracy regarding contour error has been, and keeps on being, a major worry in the configuration and control of continuous-path CNC machines. Current strategies for accomplishing more prominent accuracies can be delegated control methodologies or compensation approaches. A direct approach is initially explored which to keep the dynamics of the machine simple with the utilization of a simple proportional controller for the position feedback loop. It is demonstrated that with perfectly matched axial dynamics, flawless straight paths with no contour errors can be accomplished. With the expansion of a simple feedforward gain to compensate for radial errors coming about because of restricted bandwidth of the machine axes, flawless round shapes with no contour errors can likewise be accomplished. A tuning method, utilizing measured steady-state axial tracking errors, is then proposed to tune the gain to accomplish matched axial dynamics.**

***Key Words* - CNC machine tools, contouring error, machining accuracy, tracking error, machine axial dynamics**

I. INTRODUCTION

Computer numerical control (CNC) machine devices are presently broadly utilized as a part of the process industry. With an expanding request on the dimensional precision of machined parts, analysts are keeping on looking for different techniques to enhance the machining accuracy of CNC machines. Contouring accuracy as far as contour error is a major sympathy toward the CAM developers and end-clients of continuous-path (contouring) type CNC machines. Contour error is defined as the orthogonal component of the deviation of the actual contour from that desired.

In CNC machines, a section is fabricated by a part program which characterizes the geometrical measurements and assembling conditions, for example, feed rate and tool type. The part program can be physically composed or delivered by a computer-aided manufacturing (CAM) program.

One class of CNC frameworks is the contouring systems, in which the apparatus is cutting while the axes of motion are moving. For example, CNC milling machine. In these frameworks, the machine axis are independently determined and controlled with the goal that they take after the reference inputs created by an interpolator. The interpolator facilitates the movement among various axis by supplying the relating reference inputs to every axis of motion in order to create tool path important to machine the required/desired part. In most cutting edge CNC machines, the interpolator is fit for introducing linear, circular and occasionally parabolic contours.

II. CLASSIFICATION OF ERRORS

All in all, a machining centre comprises of a bed, column, spindle and its slide and the different liner and/or rotary axes. Each of these components adds to the aggregate error of the framework that is represented by the error budget. Errors can comprehensively be classified as

1. Geometric errors of machine components and structures
2. Kinematic errors
3. Errors induced by thermal distortions
4. Errors caused by cutting forces including
    a. by gravity loads
    b. by accelerating axes, and
    c. by the cutting action itself
5. Material instability errors
6. Machine assembly-induced errors
7. Instrumentation errors
8. Tool wear
9. Fixturing errors and others

Tracking and contouring errors are the piece of Geometric errors. Geometric errors are those surviving in a machine by virtue of its essential design, the inaccuracies built-in during assembly and as a result of the components used on the machine. All things considered, they shape one of the greatest wellsprings of error. These errors are worried with the quasi-static accuracy of surfaces moving in respect to each other. Geometric errors can be smooth and persistent or they could display hysteresis or arbitrary conduct.

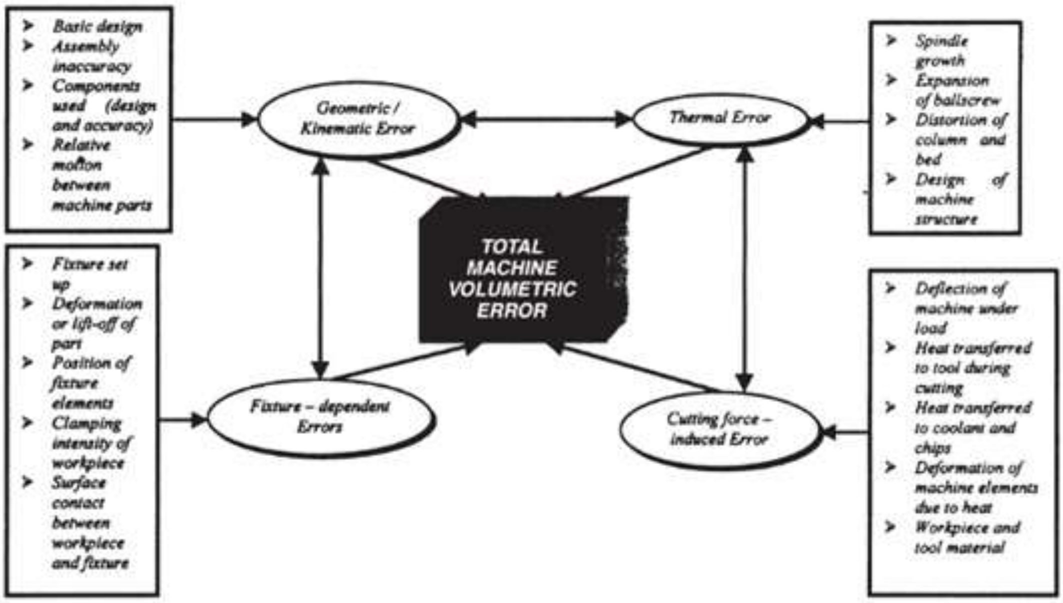

Fig 1: Overview of the error budget in a machine tool and the factors affecting it [1].

III. LITERATURE REVIEW

According to the paper published by R. Ramesh, M.A. Mannan, and A.N. Poo [2] in 2004, Investigation of Tracking and contour error control in CNC servo systems carried out. The paper include a few variables, for example, the dynamic response of machine axis, stability of control system, time and frequency response of servo system, in determining the final execution performance of machine instruments. They presumed that Conventional tracking control algorithms depend on the feedback principle. Utilizing a high feedback gain has serious constraints showing as increased noise sensitivity, generation of undesirable oscillations, and so on. Following the reference direction is general known ahead of time in most CNC frameworks, the future reference focuses are accessible to use in enhancing tracking accuracy. This prompted dynamic exploration in the region of feedforward controller outline including the presentation of a feedforward control. Enhancing the general control execution of a multi-axis machine tool is not as a matter of course guaranteed just by enhancing the tracking error of every individual axes. Contour error, which is a normal execution list for the assessment of multi-axis servo control frameworks, likewise should be successfully minimized.

According to Somnath Chattopadhyay [3], the general precision of the machine instrument is chosen by the mechanical attributes of the machine and in addition the qualities if the control framework driving the individual axes. They recognized different benefactors to this contouring error, and specifically assess the error because of stick slip movement utilizing scientific methods. They deduced in their broad research that if the two axes of a CNC machine are not perpendicular to each other than an oval way will come about. They inferred logical model utilizing simplified dynamic model of the X-Y tables of a typical CNC machine that stick-slip rubbing can possibly bring about contouring errors. The distortion is produced because of the way of the stick-slip friction at velocities equivalent or near zero.

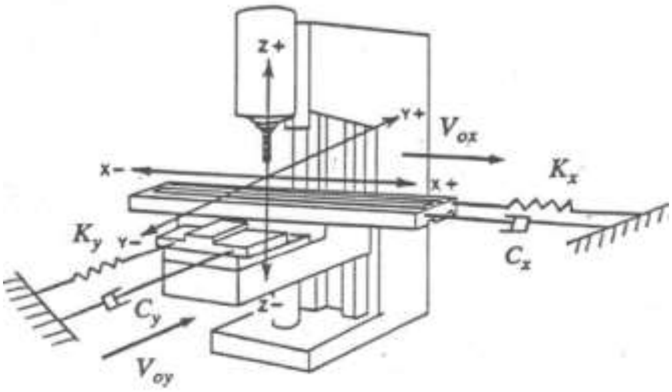

Fig 2: Basis for Mathematical Model of CNC Machine X-Y Tables [3]

In 2008, Xue-Cheng Xi, Aun-Neow Crap, Geok Soon Hong [4] presented a paper on improving contouring accuracy by tuning gains for a bi-axial CNC machine. According to them, the errors due to unmatched dynamics can be largely reduced by using a simple controller so as to keep the order of axial dynamics low and by tuning appropriately the proportional gains to match the dynamics. They assessed tentatively the proposed approach on 3-axes mini CNC machine. They evaluated experimentally the proposed approach on 3-axis mini CNC machine. They observed the effect of matched axial dynamics on liner and circular contour. They concluded that with the aforementioned axial dynamics matching and feed-forward compensation for radial errors, contour errors for both linear and circular contours can be greatly reduced. For the simple and not-so-well-built machine used in the experiments, average contour errors of lower than 0.1mm can be easily achieved.

Charlie A. Ernesto and Rida T. Farouki [5] composed an article on Solution of inverse dynamics problems for contour error minimization in CNC machines in 2009. According to them, CNC machines utilize input control frameworks to freely drive every machine axes keeping in mind the end goal to accomplish a given velocity of the apparatus along a given way, in respect to the workpiece. Because of the innate machine controller motion, it is difficult to react promptly to varieties in commanded path geometry and speed. Thusly, the real machine movement veers off from the sought movement in both path geometry (contour error) and speed along it (feed-rate error). Contour error brings about apparent mistake of the machined part shape, yet feed-rate error has the less genuine outcome of adjusting the general machining time. They proposed a strategy as a rule connection of PID (proportional integral derivative) controllers and its executions.

In 2010, Huanlao Liu, Xiaoning Xue and Guangyu Tan [6] introduced a paper in which they tentatively measured axis liner displacement error and backlash error and created models of backlash error including backlash error compensation as backlash error is the kind of geometric and kinematic error. In this paper they concluded that all linear position errors expanded linearly as for axis nominal position and are the most noteworthy toward the end of the axis travel extend even the backlash error adjusted. The backlash errors cause moderately substantial linear displacement error deviation between various headings at the same point in the axis. The backlash errors measurement is the function of the point in the axis. What's more, the accuracy of the machine increased after the backlash error compensated, so more attentions should be paid to the backlash errors in the machine tool production procession.

Radu-Eugen, Octavian, Gabriel and Valentin [7] presented a paper in 2010 that incorporated a strategy for enhancing the exactness of CNC machine apparatuses by method for a joint methodology: experimental tests and simulation. By This paper they introduces a methodology for enhancing the contouring accuracy of a CNC machining centre. They concluded by this paper that the proposed methodology is suitable to be executed at shop floor level, which is imperative in today's demanding production environment. A percentage of the errors were compensated either by mechanical modification of the feed axes or by utilizing internal compensation algorithms executed inside of the CNC controller. The authors proposed a straight-forward scientific model of a feed axis, based upon consistent exchange works and introduced a strategy for estimation of the model parameters. Additionally, the numerical character of the control framework was mulled over by presenting specific transfer functions.

According to T. Dam and P.R. Ouyang [8] regular issue with current manufacturing procedures is that, they use rapid machining is the capacity to precisely track a form of the end-effector. In this paper they examined another control technique developed in the position domain, and the created position space control is connected to a 3-axis CNC machine for contour tracking purpose. They proposed a novel control technique situated in the position space is proposed to enhance the contour tracking performance. By experiments and simulation they presumed that in position domain control, the movement of a master axis is tested and utilized as a kind of perspective to add to the position domain dynamic model, consequently it yields zero tracking error. Just the tracking errors of the slave motions will add to the general contouring error of the movement.

IV. CONCLUSION

Error compensation is a standout amongst the most vital regions of exploration at present as there are critical increases to be accomplished through this procedure. Be that as it may, in spite of the colossal measure of work done here, there are still a great deal of extents of examination. The Machine Tool Task Force, a gathering of universal specialists, suggests the accompanying for the fate of innovative work in machine tool metrology:

1. Though current instrumentation grants exact estimation of deviation from precise geometry, less difficult, less costly techniques are very alluring. Research and new methodologies around there ought to be energized,
2. Research ought to be led into the changing versatile twisting of machine basic segments and the extent of these impacts on part accuracy.
3. Methods and programming for the diminishment of a lot of information assembled in machine adjustment are earnestly required. Both graphical representation and decrease of parameter sets to a couple of delegate machine attributes are key.
4. Extensive examination work stays to be done to join singular machine deviations to shape an aggregate precision picture in three-dimensional space,
5. A standard estimation set that could be immediately introduced on a machine and would be for the most part material to no less than a class of machines is required.

V. REFERENCES

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