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MEASUREMENT AND ANALYSIS OF CNC MACHINE TOOL ACCURACY IN DIFFERENT LOCATION ON WORK TABLE

Ivan KURIC[1,*], Matúš KOŠINÁR[2], Miroslav CISÁR[3]

[1)] PhD, Prof., Eng., Department of Automation and Production Systems, University of Zilina, Slovak Republic
[2)] PhD, Eng, Department of Automation and Production Systems, University of Zilina, Slovak Republic
[1)] Ing., Eng, Department of Automation and Production Systems, University of Zilina, Slovak Republic

Abstract: *Machine tool accuracy is characterized by the ability of the machine to produce parts of the required shape and dimensions keeping the required tolerances and to achieve the desired surface roughness. Requirements for accuracy of the machine tools result from the required precision of components manufactured on the machine. Geometric accuracy of the machine tool is the precision of shape and position of its individual parts and their mutual movements. Accuracy of parts machined on CNC machines depends crucially on the machine accuracy. The paper deals with possibility of geometrical accuracy monitoring of CNC machine tools with Renishaw Ballbar QC 20 in different locations at the work table. Renishaw's QC20 Ballbar is a linear displacement sensor based tool that provides a simple, rapid check of a CNC machine tool's positioning performance to recognized internationals standards. QC20 Ballbar system is a CNC machine tool diagnostic system. It was compared machine accuracy during the operation in three different positions of work table: central, left side, right side at the different speed. It was analysed the accuracy in these different places. The measurement was performed on milling machine tool Haas VF – 4DHEv*

Key words: *machine toll, diagnostics, roudness deviation, measurement, Ballbar QC20.*

1. INTRODUCTION

Nowadays in era of debt crisis, many end-users constrict budget for regular machine maintenance. However significant initial savings later may lead to many times higher costs even existential problems of the company. Regular machine and accessories maintenance is essential requirement to keep machine working properly and reliable as long as it is possible in order to keep continuous production according to schedule.

Care of the machinery is essential requirement to hold good machine condition, which guarantee smooth production and eliminate unexpected disturbance. Therefore is needed spend effort to protect machine health. In presence are diagnostic possibilities virtually unlimited and machine users have wider options for choosing suitable diagnostic method than in the past.

Choosing optimal diagnostic method for measure machine accuracy is necessary to gain information about complex machine health and ensure a balance between the time machine downtime and measurement cost. Machine user faces challenges of provable verifying and documenting the accuracy of machinery, minimizing costs due poor quality production and machines downtime, machine classification according to current standards and monitoring trends of their accuracy. Machine tools are hearth of almost every production company and take critical role in company because it realize technological functions, provide productivity and required quality [1 and 4].

Productivity and accuracy are different aspect of machinery suppliers assessing. Production Company environment is very dynamic and requires economical production of increasingly smaller production batches and with increasing accuracy. High cutting performance for roughing and high accuracy for finishing is required more often than it was in the past.

Therefore increases importance of machine tool rigidity, dimensional stability and its effect on by temperature. Key role in stabilizing the temperature conditions of the machine is positioning the feed drive.

2. MACHINE TOOL ACCURACY

Machine tool precision is characterized by the ability of the machine to produce parts of the required shape and dimensions keeping the required tolerances and to achieve the desired surface roughness. Requirements for precision of the machine tools result from the required precision of components manufactured on the machine.

Because on one machine are usually manufactured different surfaces of a component of different geometric shapes, it is necessary to respect the accuracy of fundamental dimension elements of machine, such as: flatness and straightness of guide surfaces, alignment clamping surfaces, parallelism of axes with guides, the perpendicular shaper required from the spindle axis with the clamping surface of the table, etc. Compliance with the required accuracy of manufacture and assembly of parts and machine nodes can achieve static precision of the

[*] Corresponding author: SK-010 01 Zilina, Slovak Republic
Tel.: 041/513 2807;
Fax: 041/5652 940;
E-mail addresses: *ivan.kuric@fstroj.utc.sk* (I. Kuric),

machine tool, also called geometric precision can be achieved [6].

Geometric accuracy of the machine tool is the precision of shape and position of its individual parts and their mutual movements. Precision machine tool is primarily determined by accuracy of the individual parts and its nodes. Because these parts are produced by conventional machining methods, their dimensions, shapes and relative positions are determined on the drawings by tolerances, which have to be in manufacturing and assembly process precisely observed.

Machining accuracy is affected by a number of uncertainties and variations arising in the carrier system of the machine (elastic and thermal deformation of the machine tool body, the contact deformation in moving and static parts), in individual drives, control system, measuring system, tool and workpiece itself. The accuracy of machine tool accuracy is determined by drives (spindles, slides, tables …), and their relative position during machining. Machining accuracy along with manufacturability determine the productivity, quality and efficiency of production. Among the many indicators of the technical level of machine tools has given priority to their work accuracy.

Real shape, size and surface of workpiece can be different from ideal shape, which is defined by drawings, only in narrow limits in order to allow parts meets purposes to which it was designed and allow their easy (especially automatic) assembling. Identify and measure the uncertainty of each single point of the actual machined surface is virtually impossible. Therefore, to establish and define the types of deviations – surface roughness, shape deviations, location deviation, and deviation from their nominal values.

Requirements for machine tools accuracy result from the necessary accuracy of parts produced on a given machine. There is need to maintain the accuracy of more fundamental dimensional axes with the direction perpendicular to the axis of the spindle and the clamping surface of the table below in order to keep accuracy of multiple different shapes at one workpiece, which is usually machined by different operations but in same machine tool.

Accuracy of machine tool is determined mainly by accuracy of its parts and nodes. These parts are made with common manufacturing technologies, their size, shape, roughness and relative positions are determined on the drawings with the tolerances that must be precisely monitored during their production and assembly. By following tolerances in manufacture and assembly of parts and machine nodes static accuracy (also called geometric accuracy) of machine tool can be reached.

At present, to the fore comes progressive forms of maintenance (predictive, proactive) based on maintenance according to actual machine tool condition and its situation in production. For these types of maintenance is important purposefully and regularly receive information about machine tool status. Based on this information, is possible to create a number of requirements for maintenance hits, including a range of additional information as is requested period Trouble shooting, repair type, nature and probable cause of damage and the like.

The purpose of obtaining this information is to keep the machine in a reasonable state of readiness with regard to the production requirements and maintenance action is delayed to the best possible moment [2 and 3].

3. INACCURACY OF MACHINING

Total inaccuracy of machining can arise from series of factors. Among them, these are the most significant [4].

- inaccuracies due to elastic deformation of technology system machine – tool – workpiece from the cutting forces and resistances;
- inaccuracies caused by thermal deformations of technological system;
- inaccuracies due to wear and tear of cutting tool,
- inaccuracies of machine sorting and of workpiece material composition;
- inaccuracies due to distortions in the workpiece by clamping forces;
- inaccuracies due to geometric and kinematic machine tool inaccuracies;
- inaccuracies due to geometric irregularities of the cutting tool;
- inaccuracies due to internal stresses in the workpiece material;
- inaccuracies due oscillation in the technological system;
- inaccuracies due to fluctuations of input size parameters of the workpiece and the material inhomogeneity.

From the list above it can be stated, that the most important factor of machining accuracy is the machine tool and its accuracy.

4. MEASUREMENT OF ERRORS IN CNC MACHINE TOOLS

The main content of modern fault diagnosis should include real-time monitoring technology, failure analysis (diagnosis) techniques and troubleshooting methods in three parts.

Access to the fault location from the information, to the exclusion of failure, as a separate technology development, but also as a common diagnosis coordinated development of the technology. CNC machine tool commonly used the following method of diagnosis [1, 6]:

- *Direct method:* Use of sensory organs from the maintenance personnel to observe the fault occurrence of various sound, light, taste and other anomalies, see CNC machine tool system of the various modules and circuits, with or without traces of burning and injuries to quickly narrow down the fault to a module or a printed circuit board. This is a basic and commonly used method.
- *CNC system self diagnostics:* CNC system self-diagnostic function, has become an important measure of performance indicators CNC, CNC system self-diagnostic features real-time monitoring of CNC system working state. Once the abnormal situation occurs, immediately displayed on the CRT alarm message, or by light-emitting diode indicates the causes of the fault block, which is CNC machine fault diagnosis and maintenance of the most effective and direct way.
- *Functional program testing method:* Functional program testing method is commonly used in the numerical

control system functions and special features programmed by hand or automatic programming method, a functional test program compiled, into the NC system, and then let the CNC system to run the test procedures to check the tools perform these functions the accuracy and reliability, and then identify the possible fault location and cause of the malfunction.

• *Module exchange:* The so-called module exchange is generally the cause of the failure cases, the use of an alternate printed circuit board, templates, integrated circuit chip or component replacement questionable part of the functional unit of the same template or mutual exchange of metastasis observed failure to quickly determine the fault location method.

• *The principle of analysis:* CNC formed according to the principle of the work of the various components from the system theory to analyze and judge to proceed from the logic circuit fault doubt on the analysis of levels and characteristic parameters of the logic to determine the fault location method. This method is very demanding on the maintenance staff must be familiar with the whole system or each component works in order to locate the fault location.

• *PLC procedural law:* According to PLC alarm information, access to the PLC program, the corresponding alarm control module program, more related to I / O device logic state, determine the fault.

CNC machine fault diagnosis of parameters of inspection as well, measurement comparison, percussion, Local heating method, isolation method and the open-loop detection, etc., these methods have their own characteristics, maintenance, often while using the integrated use of several methods, gradually narrow the scope of analysis and failure to achieve the purpose of troubleshooting.

Fault diagnosis of CNC machine tools has been a troubled operation, maintenance personnel problems. Because CNC machine tools reliability of the safety and work efficiency for the direct production units have a huge impact, expert systems in fault diagnosis field application, implemented based on empirical knowledge of human experts, equipment and system fault diagnosis technology.

CNC machine tools as a complex nonlinear system, give full consideration to changes in natural conditions and human errors, how to combine fuzzy technology and the advantages of artificial intelligence, concluded a more intelligent fault diagnosis method, efforts will be needed later direction.

5. GEOMETRIC ERRORS

Generally agreed that the geometric error of CNC machine tools caused by the following aspects [1, 7]:

• *The machine´s original manufacturing errors:* Refers to the work of the various components of the composition of the surface of tool geometry, surface quality, between the position errors caused by machine motion error is the geometric error of CNC machine tools produced by the main reason.

• *Machine control system error:* Including the machine shaft servo error (contour following error), CNC interpolation algorithm for the error.

• *Thermal Deformation Error:*As the machine's internal heat source and environmental thermal disturbances leading to the structure of machine tool thermal deformation resulting from errors.

• *Cutting process system load caused by deformation caused by the error:* Including machine tools, cutting tools, workpiece and fixture deformation caused by errors. This type of error is also known as "Let the Knife", which the shape distortion caused by processing of parts, especially when machining thin-walled parts or when the use of slender knives, this error even more serious.

• *Vibration Machine Error:*In cutting, the CNC machine tools and processes because of the flexible process variable, the greater the possibility of running into unstable regions, which aroused a strong flutter. Lead to deterioration of the surface quality of workpiece and geometry of the error.

• *Detection System Test Error:*Include the following aspects:

- due to the manufacturing error of measurement sensor and its Application in the installation of machine tools of measurement error caused by sensor feedback system's own error,
- errors due to machine parts and bodies as well as in the use of the deformation measurement sensors caused the error occurred.

• *Outside interference error of:*As the environment and changes in operating conditions caused by random error.

• *Other errors:*Such as the programming and operation of the error caused by the error.

In accordance with the above error characteristics and the nature of the error, grouped into two broad categories: the systematic error and random error.

Systematic error of CNC machine tools is the inherent error of machine tools, with repeatability. CNC machine tool geometric error is the main component also has repeatability. Use of the features to them "off-line measurements", can be used "off-line test - the open-loop compensation" Technology to be amended and compensation, to reduce, to the purpose of enhanced precision machine tools.

Random error with a random, must be used "on-line test - closed-loop compensation" approach to the elimination of random errors on the machining accuracy of the method of measuring instrument for measuring the environment, demanding and difficult to promote.

6. 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 conditions evaluation,
- recommendations on found faults – development trend of measured errors are 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 control 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 condition evaluation.

7. PRODUCTION PROCESS ACCURACY

Precision engineering is an important trend in contemporary device construction and metrology. To achieve the demanded tolerances and surface quality in sub-micrometer and nanometeric area, the design of the parts production must use highly sophisticated device instruments and metrology. These trends arise from the electronic industry, which began with the miniaturization, density of components increasing and switching speed.

Since the 1975 nanotechnology appeared on the scientific field. This concept was introduced by Taniguchi in order to identify production, in which the resulting tolerances lying in the nanometer area.

Extrapolating the specification of existing and previous production machines (such as precision lathes and grinders) to a new generation of production machines, it can be quite correctly concluded that the accuracy of between 0.1 μm and 1 nm in the industry will be required before 2 000.

This was a pessimistic forecast from Taniguchi, because this achievement has already been accomplished before the year 1995. This objective was achieved only through the development and application of high precision manufacturing processes and high-precision measurement techniques, which exist outside the normal methods and instruments.

Tolerances in manufacturing continue are reduced steadily. On one hand, you can observe their close relationship to the increasing customer’s requirements and consumers on product quality and quality of process management processes.

On the other hand, this development began in early twentieth century and lies on the line, pointing to the field of nanotechnology. Improving the accuracy of one ISO degree during every decade continues. Reducing the tolerances of components and their form elements is becoming ever more important in their interaction and correlation with surface quality.

8. DIAGNOSTICS OF CNC MACHINE TOOLS BY RENISHAW BALLBAR QC-20

Precision of parts machined on NC and CNC machines depends crucially on the machine precision. This statement results in significant consequences both for the manufacturers and users of CNC machines. The manufacturers are led by customer requirements to production of precise machines which would be fully able to keep the guaranteed parameters in the long-term period. At the same time they have to be able to prove these parameters in compliance with the internationally recognised standards. They solve problems in the field of workpiece inspection, rejects / defectives, idle times, decreased productivity, and long-term low quality [7, 8].

Renishaw's QC20 Ballbar is a linear displacement sensor (Fig. 1) based tool that provides a simple, rapid check of a CNC machine tool's positioning performance to recognized internationals standards. QC20 Ballbar system is a CNC machine tool diagnostic system (Fig. 2). 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 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. Recognized 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 Ballbar accurately measures any deviations in the circle radius during the test. 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

Fig. 1. Measurement of geometrical inaccuracy of CNC machine tool with QC20 Ballbar.

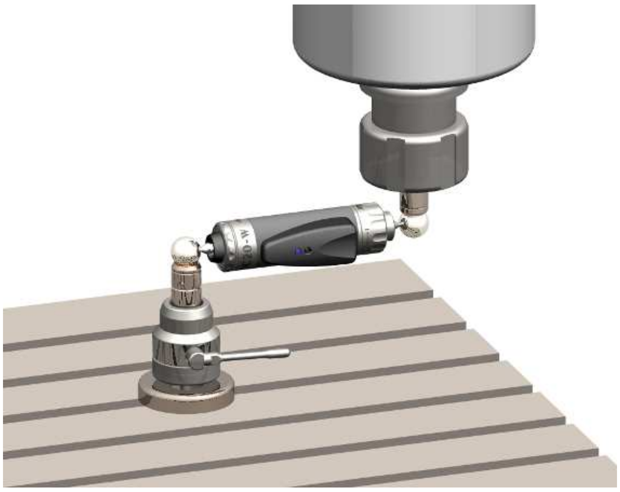

Fig. 2. Principle of measurement with Renishaw equipment QC20 Ballbar.

according to its significance to overall machine accuracy. Overall machine accuracy is graded with a value for circularity and positional tolerance.

The Renishaw QC20 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.

The QC20 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 QC20 Ballbar can also be used to test a much wider range of machines. For 2-axis CNC applications, a special retractable center 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 QC20 Ballbar diagnosis.

The *diagnostics options* are*:*

- Analysis of circularity according to ISO 230-4,
- Non-circularity according to ASME B 5.57.

Furthermore, we carry out analysis of circularity deviations and quantify the proportion of possible individual causes to the total deviation. The final result of diagnostics is then given by the percentage – or possibly by the absolute value – of influence of individual errors to the total precision error. All these results can be reliably documented by printouts given at the measurement protocol which includes attachments mentioned below:

- diagnostics chart with percentage scores of individual parts,
- diagnostics chart with absolute scores of individual parts in µm.

Using the diagnostics measurement not influencing the course of production it is possible to find out effect of the actual servo delay, dead movement error in detected axes, servo adjustment error, cross clearance error, cyclic error, perpendicularity error, straightness error, measurement adjustment error and total state of adjustment of drives of all axes. The machine can be tested in all planes. Monitoring of the machine precision development trend and repeatability diagnostics are secured by diagnostics blocks:

- trend analysis,
- maximum repeatability,
- statistical repeatability.

It is possible to create archive out of the measurements carried out and to obtain continual view of the development of the machine parameters, which is another advantage of this system. Using this type of diagnostics it is possible to monitor the precision development trends of NC and CNC machines. It is possible to determine the machine which is able to fulfil the precision requirements of the given type of parts.

Using this classification and its periodical recurrence it is possible to reduce the cost of rejects / defectives due to incorrect matching of products to machines. In addition, the cost originated in the machine removal can be reduced, as it possible to determine the need of repair before any serious breakdown might occur. The repair is less expensive and, in addition, the time of the necessary machine downtime is minimized.

9. MACHINE TOOL MEASUREMENT IN DIFFERENT LOCATION AT THE WORK TABLE

Measurement of accuracy a machine tool is carried out on Haas VF - 4DHE. Machine tool is 4 years old. Machine tool machining light alloy, not as burdened with heavy machining of alloys. Technical parameters are in Fig. 3.

Machine tool	HAAS
Model	VF - 4DHE
Spindle	Vertically 7500 rpm
Machine weight	6030 kg
Table size	1321 * 457 mm
Operating length	1270 mm
Cross travel	508 mm
Control system	Haas CNC control

Fig. 3. Machine tool HAAS VF – 4DHE.

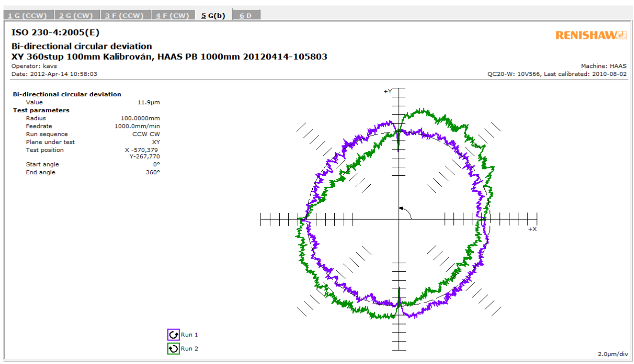

Fig. 4. Evaluation Bi-directional circular deviation using software Ballbar.

Fig. 5. Comparison od circular deviation in different positions.

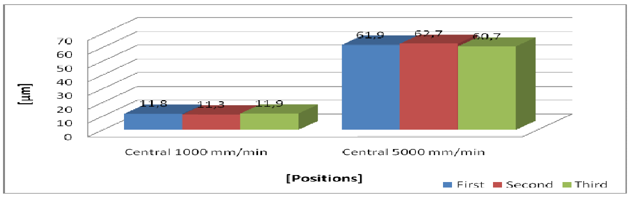

Fig. 6. Comparison of circular deviation in different feed rate.

ENVIRONMENT DATA PRINT-OUT

Mode : Linear displacement File: HAAS PB.rtl

Stroj: Výr. no.:
Datum:2012-04-14 09:18 Testoval:
Osa :X Pozn.:1000mmmin

Specifikace:

Data	Start	End	Units
Time :	2012-04-14 09:18	2012-04-14 09:42	
Air temperature :	24.02	24.09	deg C
Air pressure :	968.20	968.00	mbar
Rel. humidity :	49.18	48.57	%
Material Temperature 1 :	21.95	22.00	deg C
Material Temperature 2 :	--NC--	--NC--	deg C
Material Temperature 3 :	--NC--	--NC--	deg C
Exp. Coeff :	11.70	11.70	ppm/deg C
Environment factor :	0.31640722	0.31640705	

Fig. 7. Experimental data.

We measured in the three different positions at the feed rate 1 000 mm/min. In the central position we measured on the two feed rate: 1 000 mm/min and 5 000 mm/min.

Test conditions which were measured, we can see in the Fig. 7. We calibrated the device Ballbar QC 20, before the measurement. We wanted to detect difference accuracy (circular deviation) at the machining in different positions.

In Fig. 4 we can see Ballbar software, which are evaluated according to ISO 230–4. Comparison of results of measurements at feed rate 1000 mm / min in three different positions can be seen in Fig. 5. From the figure it results that the most accurate is the center position, where even greater accuracy achieved by the left position. The right position of work table we see bigger inaccuracy compared to central position. This may be due to several factors such as the rigidity of the machine.

Comparing central location at different speeds, we found large differences in accuracy – Fig. 6. Here we compare it at travel speed 1 000 mm/min and 5 000 mm/min. The results are evaluated, at machining of precision machined parts we have at smaller speeds.

10. CONCLUSIONS

Determination of inaccuracy of CNC machine tool is very complex task. There are a lot of influences in the machine tool as all components and nods have some inaccuracy.

The quality of every component produced on a CNC machine is highly dependent on the machine's performance. Many inspection procedures take place after the component is produced. This is too late. To avoid scrap it is better to check the machine before cutting any metal.

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. It doesn't matter if your machine is new or old, all have errors. Process control and improvement is the key to raising quality and productivity.

This article we draw attention as affected by the accuracy of machine tools for working in different parts of the work table. Machining machine tool according to the manufacturer is accurate for machining to within 0.02 mm. Therefore, if they would produce parts with such precision, the component should be placed to the center position. We also found as at different feed rate changing accuracy.

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