IMPORTANCE AND CONTROL OF GEOMETRIC AND KINEMATIC ACCURACY IN PRECISION MACHINING OF PARTS IN ASSEMBLY OPERATION ASPECT

Znaczenie geometrycznej i kinematycznej kontroli dokładności maszyn w dokładnej obróbce części w aspekcie operacji montażu

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A b s t r a c t: This paper presents general characteristics of methods for measuring kinematics and geometry of CNC machines. Implementation of the selected control methods at numerical centres is shown. The mentioned centres are a part of flexible production lines used for the production of parts in the aviation industry used to assembly power transmissions that require high-precision components. Adapted control methods allow automatic planned mode or forced mode to test the machine's suitability for the machining process. The assessment applies to geometry and kinematics of the CNC machine.

K e y w o r d s: CNC machine, FMS, control of accuracy, tests of machines

S t r e s z c z e n i e: W pracy przedstawiono ogólną charakterystykę metod pomiaru kinematyki i geometrii maszyn CNC. Pokazano implementację wybranych metod na centrach numerycznych. Wspomniane centra są częścią elastycznych linii produkcyjnych wykorzystywanych do produkcji podzespołów w przemyśle lotniczym, używanych do montażu przekładni mocy wymagających precyzyjnych komponentów. Dostosowane metody kontroli pozwalają - w trybie automatycznym lub wymuszonym - przetestować zdolność maszyny do procesu obróbki. Ocena dotyczy geometrii i kinematyki maszyny CNC.

S ł o w a k l u c z o w e: maszyna CNC, elastyczne systemy produkcyjne, kontrola dokładności, testy maszyn

Introduction

Manufacturers of aviation parts are facing growing requirements related to delivery times, low prices and a high quality of finished products. To meet those needs, solutions in the form of flexible manufacturing systems (FMS), are increasingly used. One of the important aspects accompanying the production on FMS lines is the quality of machining, more precise mapping of the programmed shape in accordance with the quality requirements. When the machine is delivered to the user, the manufacturer performs tests for confirming its accuracy. The mentioned accuracy changes or degrades over time and requires constant diagnosis. The issues discussed in the article refer to the accurate machining of aviation parts that function in the assembly and are components in manufacturing assembly operations. For these parts, assembly operation is determined by the accuracy of the machining operations, where the dimensions must be kept within the assumed tolerance. Checking accuracy of machining machines is the subject of many studies [5, 7, 8, 11]. In the traditional manufacturing system, on conventional or numerical machines, the operator performs measurements and dimensional corrections during the process. These activities in the case of spatially complex parts (aviation power transmission housings), which are produced in the FMS system using five-axis machines, is complicated and often impossible due to technological conditions and EHS (environment, health and safety). The need for geometrical and kinematic control of the accuracy of the machine on which the part is produced, results from the machine zero point shift occurring during manufacture. This results in a shift in the position of the geometrical parts machined in the given operation relative to the base surface. In machining parts, which in the undertaken case are elements of the power transmission gearbox, such a shift is unacceptable because it is related to the occurrence of relative positioning errors visible during assembly operations, often without the possibility of their removal. These are, for example, errors in the setting of the axis of the mating shafts that prevent the product from functioning properly. Thus, the only way to ensure correct functioning of the product and its assembly is to accurately manufacture the components of the assembly. Ensuring high machining accuracy requires the use of control and supervision of machining operations. The use of existing accuracy control solutions on the market is associated with a relatively long machine downtime.

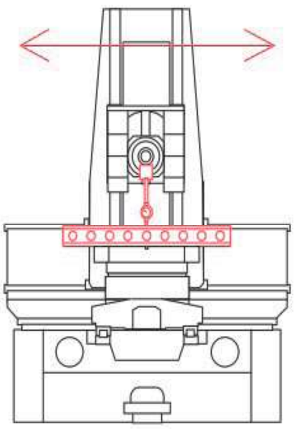
The article presents the most commonly used methods for diagnosing geometry and kinematic errors of CNC machines and also solutions resulting from research and implementation work, operating in automatic mode on FMS lines, which are used to assess the machine's suitability for the machining process.

Used methods for measuring machines accuracy

• Measurement of geometry using reference instrumentation

One of the basic tests enabling the assessment of the machines geometry condition are measurements made in accordance with the provisions of international standards ISO230 and ISO10791. They contain, *inter alia*: checking the straightness of motion in all linear axes in the possible planes of the basic machine system, perpendicularity between linear axes and test of angular linear motion deviations. Fig. 1. shows diagram for measuring the straightness of the X axis movement in the XY and ZX planes on a horizontal 5 axis CNC machine.

a]



b]

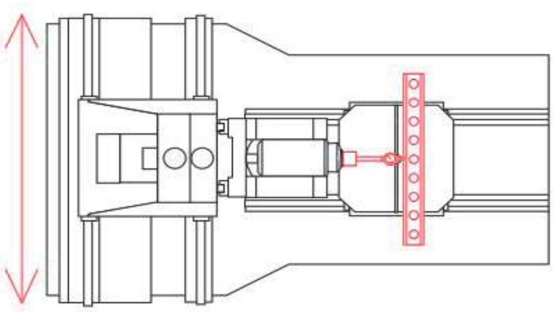


Fig. 1. Checking of straightness of the X-axis motion (ISO 10791-1 - G1): a) in the vertical XY plane (EYX) b) in the horizontal ZX plane (EZX) [2]

For this type of measurement, there are used reference instrumentations such as: granite straightedge, granite square or granite triangle. Dial gauges with appropriately selected resolution are used as measuring tools. The disadvantage of this type of measurement is keeping the machine out of production for a long time.

The advantage of this method is the relatively low cost of purchasing the equipment needed to perform the measurements.

• Measurements of kinematic and geometric accuracy using a telescopic kinematic bar

The measurements using a kinematic rod are based on analysing the shape of a pie chart that is performed in three parallel planes. One of the most popular systems used for this purpose is the Renishaw Ballbar QC20-W [1]. It is a wireless system consisting of a telescopic rod with magnetic ball joints on both ends (Fig. 2.). One of the joints is placed on the stationary machine table and the other in the spindle. Between them there is a telescopic rod with a precise measuring system installed inside.

a)

b)

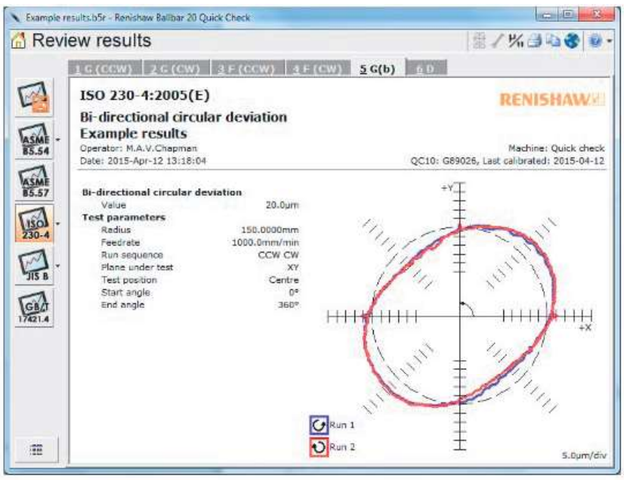


Fig. 2. Renishaw system: a) Renishaw QC20-W Ballbar b) Renishaw analysis in accordance with ISO230-4 [1]

The CNC tool machine shall be programmed to perform interpolation circular motion in parallel planes XY, XZ and YZ in the direction of CW and CCW. The collected data is sent to a PC, where Renishaw software calculates the parameters of total accuracy (circularity, circularity deviation), in accordance with such international standards as ISO230 and ANSI / ASME B5.54 or Renishaw's own analysis reports. The report uses mathematical analysis to diagnose many individual machine errors such as backlash, recurrence error, regular vibration, irregular vibration, lag error, scale error, axis perpendicular error, etc. Data is displayed in graphic or numerical format. It is possible to test the simultaneous work in five axes using a Ballbar. The test is performed similarly to the method of milling a control cone in accordance with ISO 10791-7 (NAS979), but without cutting process load. The analysis software will correctly calculate the circularity, but the machine diagnosis requires careful interpretation because the system is designed mainly for 3-axis tests [1].

The disadvantages of the Ballbar system is fact that the measurements are only carried out in a narrow space limited by bar lengths (commercial lengths vary from 50 to 600 mm). The measurement path must always be in the shape of a full circle or arc.

The advantage of the Ballbar QC20-W system is that it can be used in workshop conditions due to its resistance to dirt. The wireless transmission allows testing with closed machine covers. Based on the measurements made, the diagnostic program is able to determine with what accuracy the element can be made at a given machining centre.

• Measurement of positioning accuracy and geometry using a laser interferometer

Laser interferometers are the devices most commonly used for measuring the accuracy of numerically controlled machines as well as for their calibration. An example of such a solution is a Renishaw XL-80 laser interferometer [6]. With its help, after applying the appropriate optical configuration (Fig. 3.), it is possible to perform:

- linear measurements thanks to which the positioning accuracy along the measured axis is determined, backlash etc.,
- angular measurements, enabling the determination of vertical and horizontal deviations along the concerned axis,
- straightness measurements, enabling determination of the error in vertical and horizontal planes for the movement of the considered axis,
- rotary axis measurements, which enables assessment of positioning accuracy for rotary axes,
- measurement of perpendicularity, which allows the assessment of the nominal angle deviation of two selected considered axes.

a)

b)

c)

d)

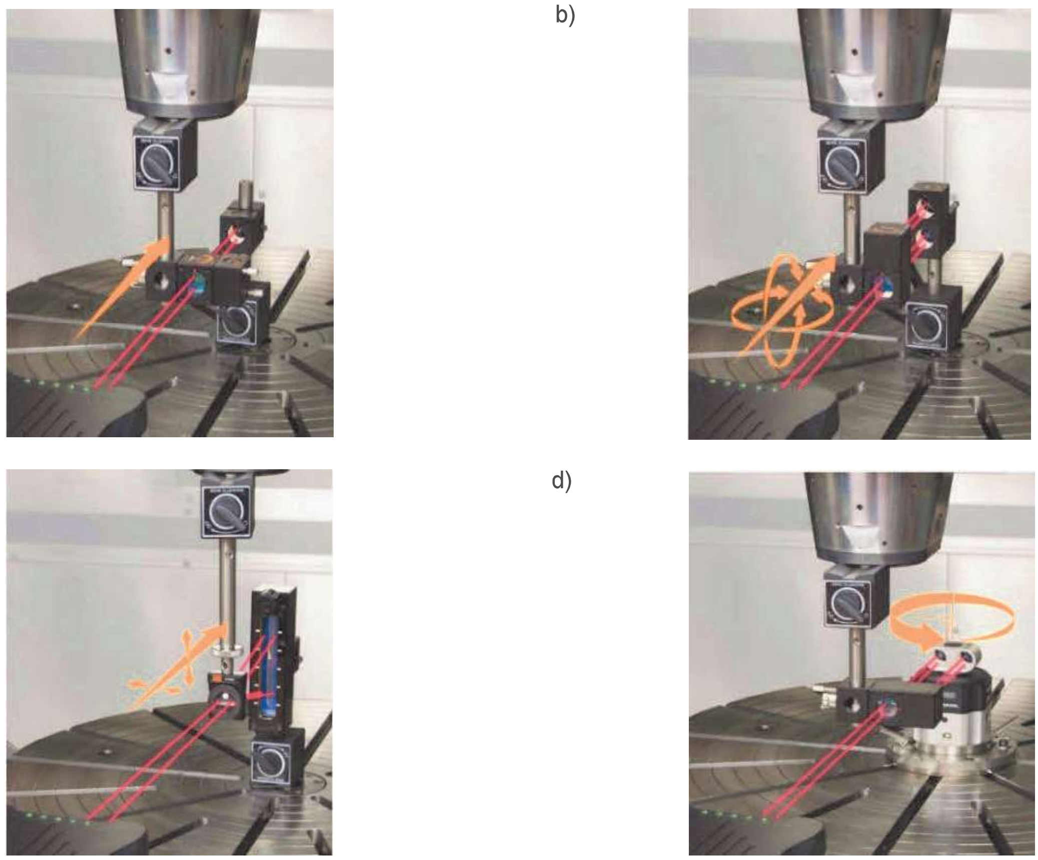


Fig. 3. Renishaw XL-80 laser interferometer in the configuration for: a) linear measurements, b) angular measurements, c) straightness measurement, d) rotary axis measurement using the XR20-W head [6]

The advantages of this measuring method are, versatility of applications, high accuracy, the possibility of using over long distances. With the use of appropriate software, it is possible to generate a measurement report in accordance with international standards (ISO 230-2).

The disadvantage is the need to take measurements with the machine's open covers, optics that require careful handling, long time out of production due to preparation and measurements of the machine tool.

Own procedures developed in flexible manufacturing systems for measuring the geometry and kinematics in automatic mode

• Rectangular master part

The first example of this realization is the use of an master part in the form of a cuboid measuring 250x250X220 mm and a hole diameter of 60 mm (Fig. 4.), installed on a movable pallet stored in an automatic fixture store. The FMS line on which the project was carried out consists of six horizontal milling centres: three five-axis machines in the TT system (tilting - rotary table), and three four-axis t-machines (rotary table). The numeric centres are equipped with Sinumerik 840D Powerline control. The entire line is managed by the central JFMX system [16].

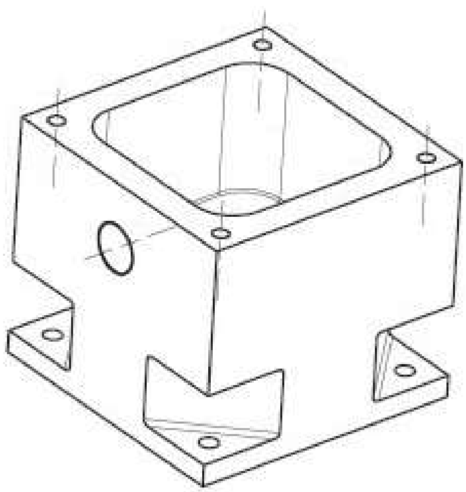


Fig. 4. Isometric view of the rectangular master part

A common problem that occurred during the operation of the machines installed on this line was related to the thermal deformation of the machine's body. That contributed to the change of their geometry, resulting in changes of machine zero position and had a significant impact on the kinematic center point during axis rotation. After every problem with the quality of structural components manufactured on the machine in question, the analysis of finished product indicated potential problems with the machine geometry. So the procedure implemented by the manufacturer was performed to determine the geometric correctness [9, 10]. These activities took about two hours. In case that machine compensation was necessary, the time was extended to three hours. It should be noted, that not always the quality problems of the produced components were due to the geometric reasons of the machines, in such cases the previously mentioned two-hour tests were a waste of time.

To automate the machine verification process, a CNC program was created using an rectangular master part in the form of a cube, an RMP60 probe [12] and Sinumerik measuring cycles [13].

The program's task is to measure the selected characteristics of the reference master cube, which enables the assessment of parameters such as:

- correctness of the probe RMP60 calibration [12],
- correctness machine zero position in X, Y, Z axes,
- correctness of machine's geometry in the range, perpendicularity of machine axes [X,Z], [Y,Z].

Fig. 5. View of the rectangular master part with the RMP60 object probe placed in a 4-axis horizontal machining center

The measured characteristic values are automatically saved on the disk of the central computer managing the entire production line, which allows access to information at any time.

The most important feature of the self-testing program is the function that, after completing the measurement, if necessary, when the assumed tolerance is exceeded, it blocks the production on a given machine and by using sound or light signals and appropriate M-functions calls the operator. The controller display shows information about the characteristic that has been exceeded. At the production line management stand, a prompt is displayed pointing out the machine being blocked. If the problem concerns the correctness of machine zero position, it is possible to automatically correct the machine parameters in the service mode. After re-verification of the machine's suitability for the process, if the tested parameters are within the tolerance, the machining centre is unlocked and restored to production.

The automatic test, taking into account the automatic correction, lasts approximately 10 minutes, which gives considerable time savings, and allows significantly reducing the number of non-compliant parts produced on the FMS line in question. The improvement of the quality of manufactured parts allowed improving the assembly operations performed on the manufactured structural components (no calibration required for mating the components, etc.).

• Reference master sphere, reference master solid

As part of the research and implementation work carried out on the FMS line in the company dealing with the production of aviation components, a system was developed and implemented whose task is to plan or force to analyse the suitability of the machining centre for the process. The aforementioned line consists of three horizontal machining centres: five axis in the HT configuration (Fig. 6.), and a high storage warehouse for tooling. The whole is handled by a automatic conveyor whose task is to transport fixtures between machining centres, loading stations and fixtures magazine.

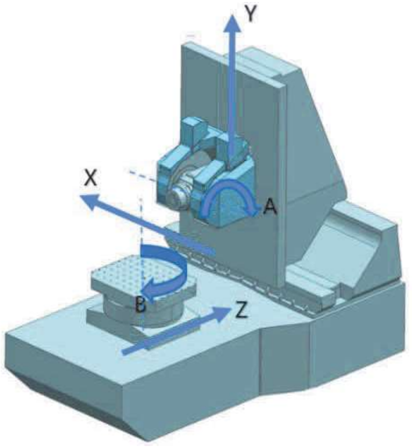


Fig. 6. Horizontal machining center with a rotary table and tilting head (HT)

Due to the variety of the manufactured elements, variability of loads during machining and relatively short series, it was necessary to constantly monitor machining centres for process suitability. For this purpose, measurement procedures were developed using the probe, master object in the form of a cuboid with the characteristic dimensions of 750x750 mm, and two reference spheres placed on the machining pallet (Fig. 7). The measurement procedure was divided into several stages. The individual stages were designed to reflect, as far as possible, the acceptance instructions contained in the standards [4, 9], and the acceptance documentation of the machine manufacturer [2].

Fig. 7. View of the calibration master (two reference sphere's, calibration column), together with the RMP60 probe, inside 5-axis machine center

First, the cuboid temperature is measured to compensate for the nominal geometrical values of the artefact. The temperature is measured by probe TP44.10 [3].

The next stage is the analysis of the geometrical properties of the machining centre using the RMP60 object probe [12] and measuring cycles [14]. Straightness measurements of individual linear axes are made in the YZ, ZX, XY planes. The angular relationships between the YX, YZ and XZ axes are also checked.

The next step is to assess the correctness of the machine zero position, and to check the error of parallelism of the rotation axis of the table B in relation to the Y axis in the ZY and XY planes. The assessment of these parameters is made by measuring the position of two artefacts in the form of reference balls whose position in space is changed by means of the rotation axis B in three characteristic positions (B0, B-90, B-180).

The acceptable deviations were adopted in accordance with the acceptance requirements contained in the purchase contract of the analysed machining center [2, 9, 10].

In case of positive result of the above measurements, the correctness of geometric vectors is tested; they are used to define 5-axis transformations (TRAORI, TCARR) [15]. The measurement takes place in such a way that with the help of the object probe three positions of the measuring ball are read for each of the two rotary axes (A, B) [14]. The results obtained in this way are compared with the current settings.

Similarly to the described example from subchapter Rectangular master part, reports are generated and if necessary, production is blocked on the tested machine centre. If the tolerance for machine zero position or the permissible deviations for kinematic vectors is exceeded, it is possible to automatically calibrate the above parameters in the service mode. Auto calibration is possible only when the geometrical criteria (straightness, perpendicularity) are met.

Conclusions

The technology of assembly operations in aviation industry is closely related to the accuracy of machining parts. In the case of assembly with incomplete interchangeability of parts, one can afford lower accuracy. This lower accuracy can be corrected by assembly methods using compensators or selection. However, there are parts where full interchangeability is required and assembly accuracy is decisive. These types of parts are produced on CNC milling machines implemented in the FMS lines discussed in this article. In such cases, the accuracy of machining determines not only the usefulness of the part but also the costs of the production.

The practical application of the solutions presented in the article (chapter: Own procedures developed in flexible manufacturing systems for measuring the geometry and kinematics in automatic mode), has significantly improved the accuracy of the parts, which eliminated a number of deficiencies or the need for re-corrective machining to ensure proper assembly of the assemblies and functioning of the product. The introduced control on expensive aviation parts significantly reduced costs and processing time.

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