Proceedings in MANUFACTURING SYSTEMS

Proceedings in Manufacturing Systems, Volume 9, Issue 1, 2014, 9−18 ISSN 2067-9238

PARAMETERS CONSTANCY − MUCH MORE IMPORTANT THAN THEIR VALUES

Corneliu GORNIC[1,*]

[1] Director, Senior research engineer, PROFEX CONSULT SRL, Bucharest, Romania

Abstract: *In techniques, in all branches (without exception, I think) the knowledge of a parameter, of a variable value would allow to take suitable measures for the negative influence compensation, diminishing of that one. If the considered parameter has an unforeseeable variation, evolution with sudden, random jumps it is hard to conceive that efficient compensation measures of its influence could be taken. On the contrary, if the error of that parameter, its deviation from a rated value is constant, or it is kept within statistic limits with a small 2σ, one could conceive efficient measuring and compensation measures. The paper is proposing to demonstrate that thing in the case of machine tools. It will be shown why some machine tools are accurate, but others in some limits, only. This paper is a continuation of a former one, referring to the bearing area.*

Key words: *machine tool, parameter constancy, accuracy, error compensation*.

1. INTRODUCTION

Actually, in the whole surroundings anything is neither permanent, nor constant. We, human beings, are claiming each other to offer, to provide goods and services of high and constant quality. In all engineering sciences it oughts to exist a permanent preoccupation concerning:

- highlighting the parameters disturbing the technological process, which are guiding to the variation of the products quality;
- control and compensation measures, methods, procedures of some errors, for assuring a constant product quality.

For any machine tool owner/user, when he is receiving an order to deliver a part or a batch, one put, in the main, the following problems:

1. To machine the part(s)-within the specified conditions into the manufacturing documentation-without the risk of scrapes appearance, sometimes in the whole working space, indifferent of the machining process duration or piece "position" in the batch to be machinedv

2. To achieve, to machine a "concordant" workpiece for the first time, without the need of the "test piece"v

3. To perform the processing within a time interval assuring the competitivity with other manufacturers and to frame within the agreed budget into the delivery contract.

For those reasons, it is necessary that the machine tool owner (his specialists) to know its behavior way, in various environment and operation conditions. He has to have the certainty (except some hazardous events) of the success "for the first time", to fulfill the above mentioned conditions.

* Corresponding author: Bd. Basarabia, No. 250, Sector 3, Bucharest, Romania,
Tel.: +40722570783;
E-mail address: *profexconsult@yahoo.com* (C. Gornic).

From the machine tool point of view, those conditions would be satisfied if:

i the machine tool accuracy would be the same within the whole working space;
ii the likely deformations would be linear and plan-parallel;
iii the machine tool stiffness would be constant, indifferent of the direction, or relative position of the moving assemblies;
iv the adjustments, variation range of the operating parameters to allow to the operator to get the required machining accuracy, within the competitive output conditions.

In the following they will be analyzed some parameters which are desirable to be constant in time and space. Indifferent of their value, their knowledge would allow to the operator and to the supporting technical team (engineering staff, programmer, technical leadership of the machining workshop) to take correction measures. Hazardous, non-linear variation of the magnitude of those parameters leads to a high uncertainty level, which compels the operator to perform numerous intermediary checks (measurements), and to a high risk to miss the enumerated goals.

Into another paper [7] I highlighted the importance of the bearing surface, both concerning the stability (stiffness) of an assembly, and the constancy of some parameters within the whole working space (the movement field of the mobile assemblies).

In this paper I would like to present several parameters of which "evolution" has a great impact on the machine tool accuracy in time and space, but I didn't proposed to approach the problems which the workpiece and the cutting tools are putting in reaching the performance parameters.

NOTE: As it is commented upon among the specialists, for a long period of time, there are different opinions concerning the term "accuracy/precision" and "error". Often by the two terms it is understood, actually, the difference between the rated value of a parameter (dimension, form, position etc) and its actual value materialized on the workpiece, which defines a movement, distortion, etc.

2. TEMPERATURE

The machine tools are operating in industrial workshops, which could be with controlled/stabilized temperature, or without installations assuring such control.

Generally, the first workshops are “blind” buildings, equipped with internal air circulation and temperature control (some times of the humiditay, too). Depending on the experience and other conditions, other measures could be taken.

In the second case, for diminishing at the minimum the potential negative influence of the environment, they are necessary several measures, among which:

- the avoidance of the influence of the concentrated heat sources on the machine structure (heating systems, direct sun light etc);
- the avoidance of the horizontal air streams (draughts) etc.

These are external factors to the machine tool, which must be taken into consideration by the user, and he must cooperate both with the workshop builder, and with the machine tool designer/builder.

Other factors which could negatively influence, from the thermal effects point of view, the machine tool accuracy parameters and their constancy, are connected to intrinsic machine tool components. They could be of design, technological, using, maintenance type.

The heat presence into the machine tool structure components has, as a main effect, the components dilatation. From multiple reasons (materials anisotropy, various masses, different dilatation and “a little” different heat transfer coefficients, design restrictions/blockings etc) the dilatation could lead to deformations, distortions. Instead of plan-parallel (foreseeable, known) deformations, which could be compensated, multiple rotations appear (around of instantaneous rotation centers), bringing about, finally, to appearance of deformations, distortions.

2.1. Effects

a. Uniform, proportional, plan-parallel dilatations, if:
- there is a uniform (internal and external) thermal field, namely a constant/linear temperature variation (depending on design, and technological, using, maintenance, external parameters);
- materials in contact have the same thermal dilatation coefficients;
- materials have the same heat transfer coefficients.

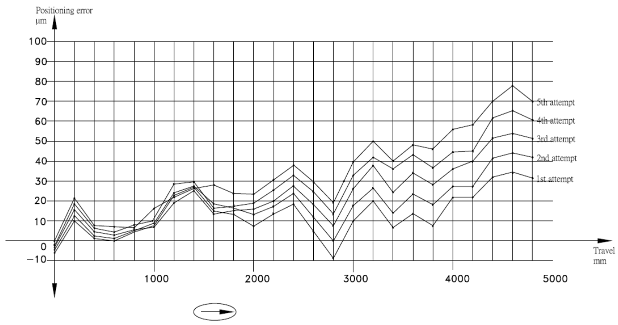
b. Uneven dilatations-deformations, which are due to non-observance of any of the above conditions;

c. Examples:

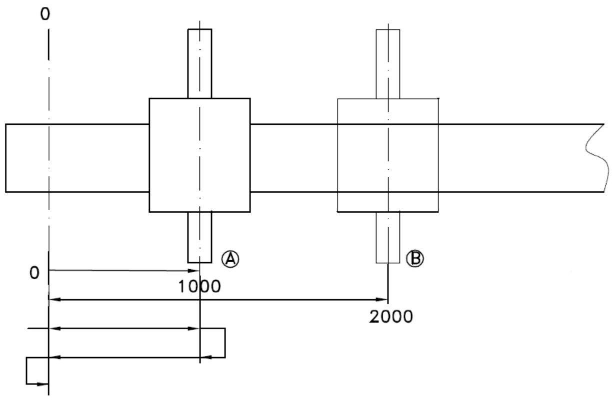
i. Positioning accuracy parameters variation due to encoder temperature variation (Fig. 1.a and b), and the deviation constancy (on the same controlled axis) in the condition of the minimum encoder temperature deviation (Tables 1 and 2);

ii. Boring spindle position variation at a jig boring machine machine, at constant speed (Fig. 2.a, b and c.);

iii. Concrete bed of a parallel lathe dilatation mode (Fig. 3).



a



b

Fig. 1. Positioning accuracy parameters variation due to encoder temperature variation: *a* – digrams; *b* – mesuring setup.

Table 1

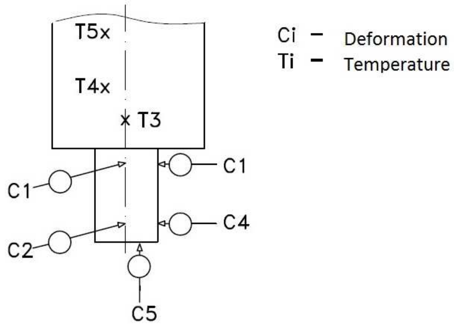
Deviation constancy (on the same controlled axis) at distace 1 000 mm.

	0		1000	
	↓	↑	↓	↑
1	0	–	+28	+41
2	+13	+4	+28	+39
3	+10	−2	+28	+41
4	+9	−1	+28	+41
5	+8	−3	+28	+40

Table 2

Deviation constancy (on the same controlled axis) at distace 2 000 mm.

	0		2000	
	↓	↑	↓	↑
1	0	–	+54	+52
2	+10	+6	+52	+50
3	+9	+6	+52	+50
4	+7	+6	+52	+48
5	+4	+11	+52	+47



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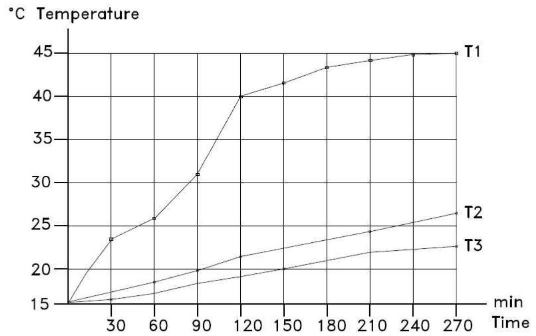

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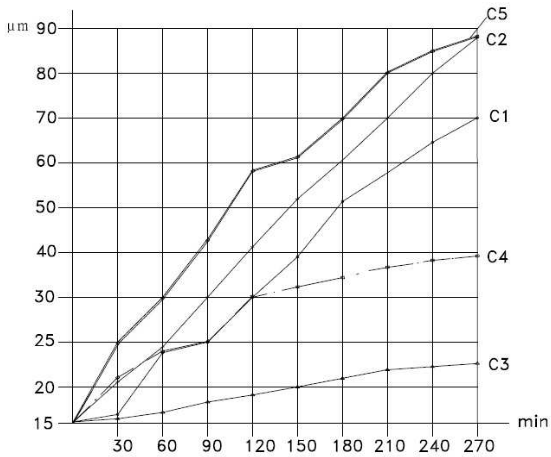


c

Fig. 2. Spindle deformation and temperature: *a* – boring spindle mesurement points; *b* – temperature variation; *c* – deformation.

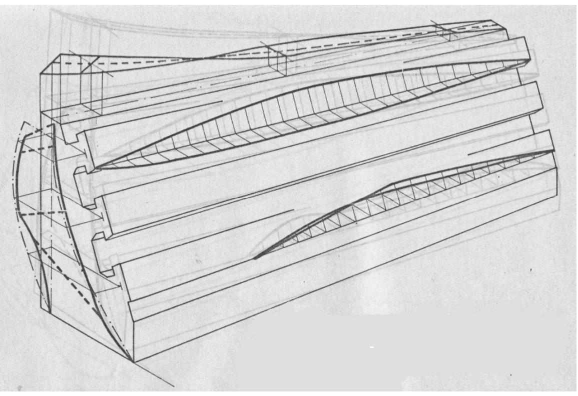


Fig. 3. Parallel lathe concrete bed dilatation mode.

2.2. Measures to be taken

2.2.1. Emitted heat amount diminishing and its equalization (constancy) by

a using components with high output (as low as possible friction coefficient): sliding friction to be replaced by rolling friction, replacement of the dry/semi-fluid contact with the wet (fluid) friction (hydrostatic/hydrodynamic) by the oil temperature control, the use of materials assuring a dry lubrication, magnetic sustentation. The use of hydrostatic gudeways has several advantages:

- much lower friction and, consequently, much lower heat generation;
- high stiffness and lower vibrations;
- no gideways/slider wear, so keeping the accuracy for a much longer period of time;
- higher response fidelity to the control signals and thus a higher positioning accuracy (Fig. 4) [4];

b diminishing of the forces heat generating (e.g. centrifugal forces in rolling bearings, in the bearing system), by:

α. Diminishing the mass of the rolling elements (balls, rolls) either by using lower density materials (e.g. ceramic rolling components instead of steel ones) (Fig. 5.a, b)[19,16](codes HCB,HCN,HS,XC, [19]), or by using bearings with a greater number of rolling elements, but with smaller dimensions (Fig. 6)[21, 19](series 719), with the same overall dimensions, or by using cave rolling elements (easier to be performed for cylindrical, taper, spherical rollers, but much more difficult for balls);

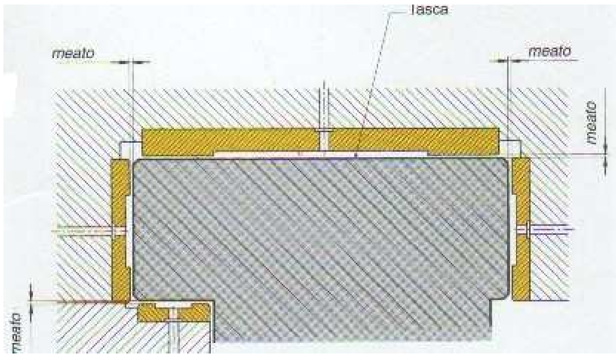
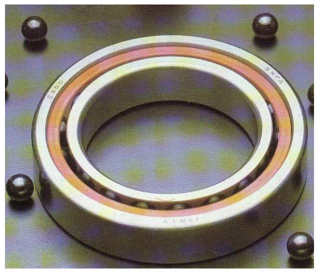


Fig. 4. Systems with higher positioning accuracy.



a b

Fig. 5. Ceramic rolling components with reduceed mass.

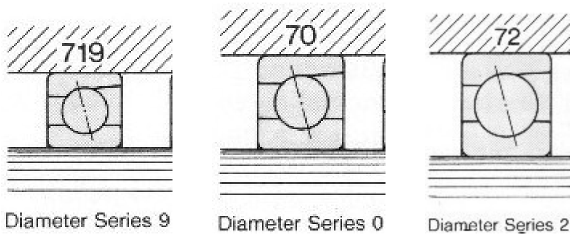
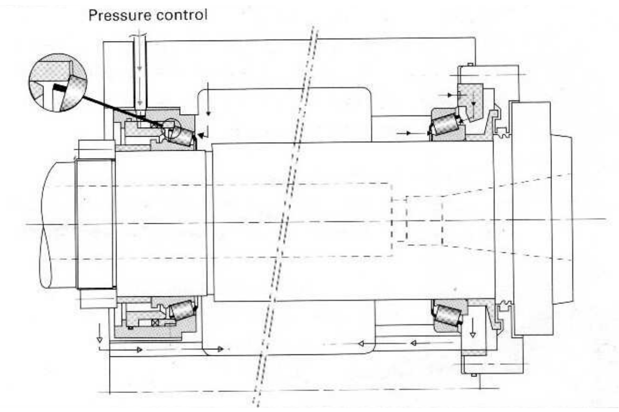
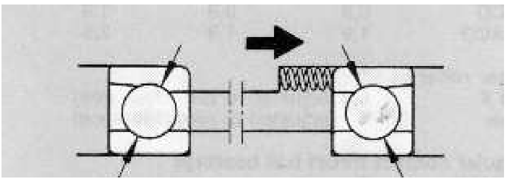


Fig. 6. Bearings with greater number of rolling elements and smaller dimensions.



a



b

Fig. 7. Proper assembling depinding on: *a* – speed/loading; *b* – constant preloading.

β. Providing proper fittings/assembling of the components (bearings, ball screws) and suitable (depending on speed or/and loading conditions) (Fig. 7.a) [6] or constant operating preloading (Fig.7.b) [21];

γ. Avoiding/removing the eccentric masses of the assemblies in rotation movement (static and /or dynamic balancing);

δ. Components machining with shape (roundness, cylindricity) and position (coaxiality, parallelism etc) errors as low as possible, taking into account the operating conditions and the movement accuracy.

2.2.2. Heat efficient removal/exhaust from the space it is generated. It is assumed [5, 20]:

- a ratio between the oil supply/oil exhaust areas of minimum 1:4;
- an independent oil removal from each bearing, but, finally, collected in a single duct, for preventing the appearance of the pressure variation.

2.2.3. Providing a constant temperature into the whole structure, in condition of operating and environment parameters variation, of the loading conditions[22].

Several methods have been used:

a. Hydraulic components heat generating(pumps, tanks, hydraulic blocks etc) have been removed from the structure components, to allow heat dissipation, without influencing the machine components accuracy (shape, dimensions) [4];

b. Some structure components of machine tools(universal round grinding machine bed, portal type milling machine, high accuracy machining center[10] etc) are "washed" by controlled temperature circulating oil, water or air flow. A very interesting (and efficient) synchronizing system is used to keep the temperature difference between the machine structure and the oil at constant level, even when the environment temperature varies. There are only light thermal variations and the accuracy is kept constant (Fig. 8) [4].

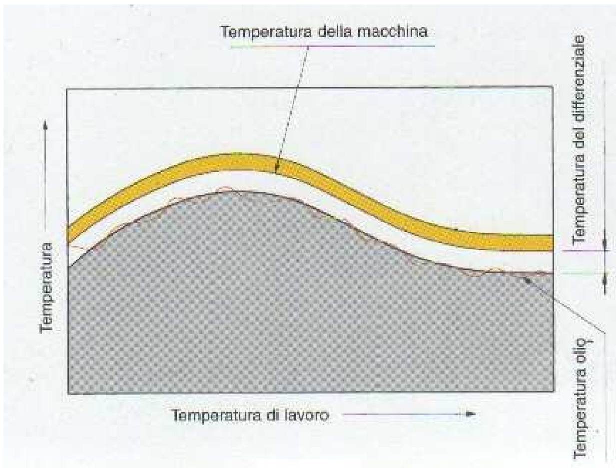


Fig. 8. Keeping the temperature difference between the machine structure and the oil at constant level.

c. Rolling bearings supplied with oil:

- heated, at the beginning of the operating period, up to the reaching the stabilized temperature of the bearings (rather quickly);
- later, oil cooling, for keeping the bearings stabilized temperature.

The following remarks must be done: after temperature inside a main spindle bearing system is stabilized (which, depending on the machine, bearings type, lubrication method, temperature control, operating conditions etc could last 0.5–6 hours), the dilatations/deformations produced by the generated temperature inside the bearings, could develop several hours. The goal of any design, technological measure is to control both the value and the evolution mode of the deformations, relative position between workpiece and the cutting tool, indifferent of the machine tool or workpiece type.

2.2.4. Designing [22]. The measures which could be taken in that stage include:

a. machine designing by thorough knowledge of the machine tool type thermal distortion;

b. by designing as simple as possible construction: structural components, mechanisms etc;

c. heat sources discharging/removal from the machine tool body;

d. assuring the thermal balance of the machine structure by properly placing of the heat sources.

2.2.5. Thermal distortion by specialized operating systems and temperature active stabilizing systems, which are taking into account [22]:

- workshop temperature changing (variation);
- machining process parameters variation (speed, especially);
- presence or absence of the coolant.

3. GUIDEWAYS ACCURACY

The movement of any rigid body or of a machine tool assembly on a guiding system implies six degrees of freedom (Fig. 9)[23]:

- along the movement direction (position error);
- two square each other on the movement direction (straightness error);
- three rotations around the reference system axes (roll, pitch, and yaw).

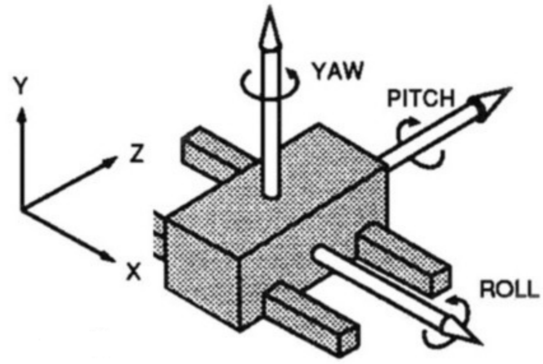


Fig. 9. Six degrees of freedom for a machine tool moving assemly.

At a machine tool with three coordinate axes, the freedom degree number is, at least, 21: 3x6=18 degrees, according to the above mentioned, to which it is added the squareness between the three axes (two by two), totally three. In case of a rotating spindle, other two degrees of freedom appear, at least: rotation around its own axis (CL) and dilatation along its own CL. Besides, owing to the variation of the relative position of the movable assemblies (e.g. at a horizontal boring and milling machine with movable column-floor type- with ram and boring spindle) elastic deformations appear both at the moving assembly, and at the supporting elements (bed, column etc). Those deformations are not linear and they are yielding the alteration, variation of the tool CL position to the machine tool coordinate axes.

By checks (sometimes very much time consuming, which need specialized instruments, specialists in measurements and results evaluation) it is possible to plot the errors of different types (straightness, squareness etc), which, by means of the present CNC equipments could be recorded, memorized. Depending on the moving assemblies position when machining, those diagrams could be used for compensation of the relative errors between tool and workpiece.

Other errors are compensated by machining of some components (e.g. the columns of the horizontal boring and milling machines) with an error of opposite direction to the deformation.

Some remarks must be done:

The error plots are ascertained when checking the machine tool "idle running", that is

- in the absence of the cutting and dynamic forces;
- in certain environment conditions;
- very seldom in a stabilized temperature conditions at the machine tool.

i- If the linear errors could be compensated without serious problems, the angular errors didn't, yet, found a practical compensation method.

In machining, when using a machine tool, the above mentioned errors represent just a part of the total error of the machine tool. On another side, the found error is in machine tool "idle running" could differ much enough to those in use, because of some external parameters to the machine tool (environment conditions, the workpiece mass/weight), and because of some internal factors (deformations owing to the relative position of the moving masses, owing to the thermal conditions variation, owing to dynamic loading, cutting forces).

A lot of errors of the assemblies with, theoretically, straight movement are due to the guideways manufacturing errors, and in the case of long beds, built from modules, because of their adjustment errors.

The typical guideways errors are:

- shape errors: straightness on two square directions; flatness; torsion;
- relative position errors: parallelism; squareness between the bearing (supporting) and the guiding surfaces.

The combination of all those errors could lead to:

a- Appearance of five error types at a linear displacement of a moving assembly, namely:
- straightness errors, in two square planes;
- angular errors, around the coordinate axes.

b- Torque variation at the driving motor and in the whole feed mechanism.

c- Early (premature) wear of the guideways or of the feed mechanism components.

d- Relative errors between the cutting tool and the workpiece amplifying, by moving assemblies rotation in movement, due to the moving tool or workpiece cantilever variation.

If some errors could be compensated, others could have unforeseeable evolutions (due to the above mentioned reasons, to which some environment factors could be added), which raise particular problems when machining some large and high accuracy workpieces, when machining batches of identical workpieces.

The measures the machine tool manufacturer has to take (machining accuracy of the structure components and the adjustments) must be completed by the user by:

- building a suitable foundation,
- avoidance of the influence of the disturbing factors external to the machine tool (external heat sources, air draughts).

I consider that it must be underlined the fact that the guideways torsion is one of the factors generating the most and more complex problems in assuring the mobile assemblies movement accuracy, and, implicitly, of the machining accuracy. That error type could be avoided by a proper guideways machining, only. In the case of the machine tool beds, even if the guideways were machined within the allowed (tolerated) limits, the errors could be increased by an unsuitable adjustment/assembling.

The guideways accuracy parameters variation has a peculiar effect in the case of hydrostatic guideways: any variation of the guideways geometry (errors) is leading to the oil film thickness variation, which, at its turn, arouses the stiffness variation of that assembly. A consequence of this phenomenon is the machined surface quality (accuracy), indifferently of its type, machining procedure.

4. ROUNDNESS, CYLINDRICITY, SHAPE ACCURACY

The great majority of the machine tools are using rotation movements either for the tool, or for the workpiece, sometimes the both. A rotation movement supposes a housing (bore), a spindle and the bearing system itself (indifferent of its type). If the main spindle has, theoretically, the same stiffness in all radial directions, the same is not valid in the case of the housings: usually, the wall thickness variation could lead to the radial stiffness variation.

That one is influencing the machined surface (internal or external) shape. From that point of view, the shape error of the machined surface-roundness-could be estimated, ascertained as value and orientation.

In the operation of such assembly, with rolling bearings, they are met the following elements, too:

i- Roundness and cylindricity errors of the housing bore and of the spindle journals (bearing seats)

ii- Coaxiality errors of the housing bores and/or of the spindle journals

iii- Parallelism errors of the bores and journals CLs

iv- Parallelism and squareness errors of the supporting surfaces of the bearing rings

v- Variation of the thickness *rolling surface/assembling surface* of the bearing

vi- Rolling elements and race dimensions and shape variation

vii-Lubrication method and in operation generated heat and its exhaust mode

The bearing operational fit (endplay/preload, when assembling or in operation)

The shape of the contact between the bearing rings and the bearing seats (Fig. 10) [19, 5].

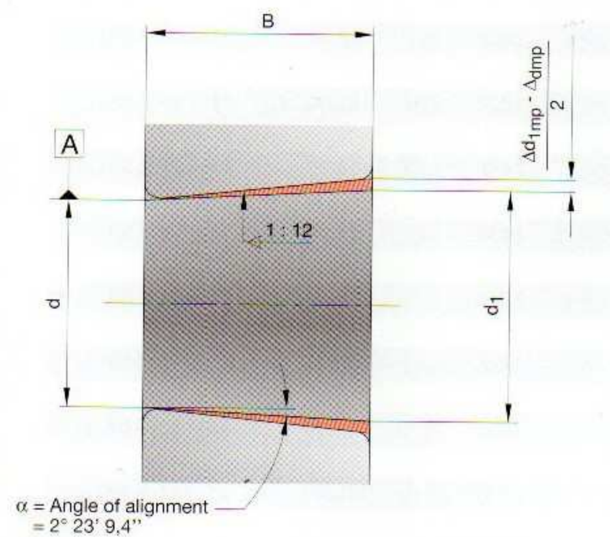


Fig. 10. Contact between bearing rings and seats.

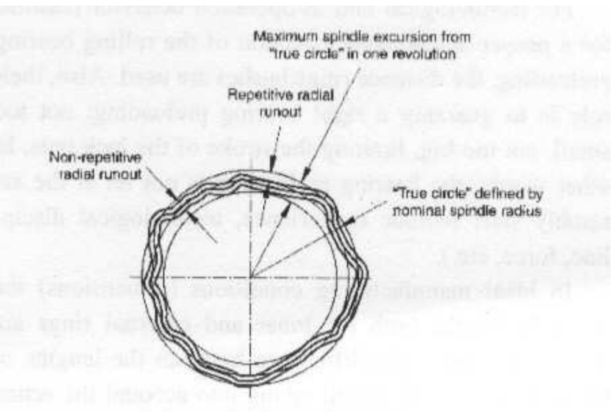


Fig. 11. Machined surface roundness error.

Roughness (micro-geometry) and waviness (macro-geometry) of the bearing seats

Bearing assembling procedure, checking technologies of the components, machining errors compensation etc.

Continuous, random combination of all those parameters is leading to a probable range of the machined surface roundness error (Fig. 11) [18]. If the machining requires a linear movement of the cutting tool or of the workpiece, to the above mentioned elements (i-xi) they are added the following error types:

a. movement straightness error (in two planes);
b. parallelism deviation (in two planes) between the linear movement direction and the rotation axis of the tool/workpiece;
c. the presence of at least one of the rotation error of the "straight" moving assembly (usually, the most unfavorable rotation is yaw);
d. a special case is shown by the machine tools at which the cutting tool could have, simultaneously, two movements: one around its own axes and a straight movement along its rotation axis (the case of the horizontal boring and milling machines). The variation of the boring spindle diameter (or of the ram dimensions), errors of coaxiality and parallelism of some surfaces (boring spindle guiding bushings, tool bore and external diameter of the spindle and/or ram cantilever variation, which is generating the sag/ deformation variation of the respective assembly and of the tool rotation axis position to the machine coordinate axes system), all of them are supplementary appearance sources of additional, random machining errors.

The machine tool manufacturers of a high reputation assert, any time they have the opportunity, that the main spindle assembly mounting (and the whole bearing system) is done in a "clean environment", defined by the number of the solid particles under 0,5μm dimensions in a cube with 300mm sides.

Let us suppose that the allowed radial run-out of a main spindle is 10μm. the presence, at a moment, between the (any) race and a rolling element of such a solid particle modifies the radial run-out with 1μm, that is with 10%! If the real deviation is smaller, the error introduced by such particles into the bearing increases even more the momentary deviation.

To the particles present in a bearing system because of

- a poor cleaning of the bearing components,
- an improper assembling environment,

they are added those from the lubricant and those resulting from the natural wear process. All those are generating an increase of the operating deviations (radial run-out, wobbling, if the phenomenon in the two supporting bearings is not "timed", that is the main spindle "movement" is not parallel with its own reference position), uncontrolled, random, which, at their turn, are causing dimensional, shape (roundness, cylindricity, flatness), position (squareness of the surfaces perpendicular to the tool/workpiece rotation axis) deviations of the machined surface.

Tool fastening low stiffness, closed connected to its bearing (supporting) surface (indifferent of that surface shape) is generating (see Fig. 10):

- Random dimensional, shape and position deviations of the machined surface(s);

- Appearance of vibrations, generating micro (roughness) and macro geometric (undulations, waviness) on the machined surface;
- Untimely tool wear, as an additional and random source of errors.

5. STIFFNESS OF THE STRUCTURE COMPONENTS AND OF THE JOINTS

The special/specialized machine tools are performing, practically, the same operation at the same workpiece type all their operating life. By a close cooperation between the machine tool manufacturer and its user very good results could be obtained concerning:

- the yield capacity;
- machining accuracy;
- repeatability of the machined surface parameters.

In the case the universal machine tools, which could machine workpieces of a large variety of shapes, dimensions, materials, conditions (specifications) etc the problems are more complicated. The user would be interested to use the machine tool in the same conditions (operating parameters), within the whole working space, and to get the same results (machining accuracy, repeatability of the parameters). In fact, that thing is impossible, because of some natural laws, of which effect we could know and, in certain extent, compensate. Once again, I want to specify: if the evolutions in time and space of some machine parameters are linear, there are, already compensating methods, within certain limits. The machine tool builder task is to ensure-in time and space-a linear variation of the parameters. Of those which could be controlled. But, it is compulsory to avoid sudden jumps of the parameters. A typical example is the ball screw: if in the same area it appears a small rolling diameter variation and of the pitch, it will appear a local variation of the boll screw-nut stiffness, having, sometimes, important influence on the machined surface accuracy (dimensions, shape, and/or position). Over those local errors they could be overlapped the ball screw alignment errors to the machine tool guideways. All those have as effect a supplementary worsening of the machine tool behavior and its machining accuracy.

Into a machine tool design there are both structure components, and joints of different types. Each of them has its own stiffness-static and dynamic-which could vary as a function of several parameters:

Structure components design (wall thickness, ribbing etc), contact pressure and its variation in joints;

Application point, direction and space orientation of the disturbing force;

Natural frequency and vibration modes etc.

For providing a movement (kinematic) accuracy within a certain limits (straightness, parallelism, squareness), some machine structural components (e.g. columns of the horizontal boring and milling machines, cross rail of the vertical turning and boring machines and of the portal type milling machines etc)- as supporting components- are machined with errors opposite to the deformations appearing when the moving assembly is displacing. But those imposed conditions are satisfied when checking the machine tool “idle running”, in the absence of external forces to that one. When using the machine tools, over those efforts (movable masses) they are superposed the cutting and dynamic forces. Their application point (cantilever), value and direction could vary much. In order that the machine tool user to be satisfied with it, to get machined surfaces within specified limits, the manufacturer must put at the user’s disposal (in the machine operating manual) loading diagrams (power consumption, loading torques) depending on the relative positions of the mobile assemblies in the working space (e.g. headstock position on the column at the horizontal boring and milling machines, the ram travel at the same machine type and at the vertical turning and boring mills). For several years that thing is easier done by modeling the machine/components behavior (static, dynamic and thermal, including overlapped fields, that is static and dynamic behavior in transitory thermal conditions) by the Finite Element Analysis (FEA).

The joints represent a particular case in the machine tool design. From detailed, laborious studies and research [8, 9], they were found a lot of factors influencing a joint behavior. Generally, it is compared with the “equivalent solid”, that is with a solid body having the same shape, dimensions but without joint.

One of the most important of those parameters influencing the joint (static, dynamic) behavior is (again!) the pressure constancy inside the joint. That constancy (or a value with an as small as possible variation) of the pressure could be obtained by a suitable joint design (number, position, dimensions of the tightening components, tightening force), and also by technological measures (the shape of the joined surfaces on two square directions, roughness and machining method, number of the preloading before the final assembling etc). Ideally, the joint should have a constant behavior, indifferently of the disturbing force (module, direction, frequency). Actually, that thing isn’t possible, for which reason the machine designer/manufacturer must take into consideration the most frequent/unfavorable loading configurations, providing a suitable joint(s) behavior.

6. THE MACHINE TOOL DYNAMICS

According to the second law of the mechanics:

$$F = m\,a.$$

For a body with a constant mass, the higher the imposed acceleration, the bigger is the applied force to that body. The phenomenon is identical both at acceleration, and at deceleration. The stiffness (rigidity) is defined as the ratio between the acting force on a body (system, assembly) and the resulting deformation:

$$R = F / \delta \text{ [N/mm]}.$$

In the world of the mechanical structures it does not exist bodies with an infinite stiffness, so that the bigger the force, the bigger the deformation, even the relationship is not always linear.

At the machine tools that fact has several consequences:

a- For avoiding large deformations, of using large inertia (Gd^2) moments motors the acceleration has to be limited and it could be calculated and experimentally found so that the machine tool user to get satisfactorily results in operation (a particular case is the machining by contouring, when the machining path could have various angles, when machining circular surfaces etc). the numerical control equipment manufacturers are showing the ways to adjust the acceleration of the driving system, depending on the machine tool actual design (the moving mass, the driving force application point etc)-the feed factor: k_v (in the case of SIEMENS CNC equipments).

For each machine tool there is a contouring speed allowing getting a suitable accuracy. That speed is closed connected with two parameters: mass and acceleration speed (jerk) [17]. Jerk ramps the acceleration to smooth the velocity (speed). Steps-sharp edges in command values-tend to excite mechanical systems to oscillate at their natural (resonant) frequencies. The bigger is the step, the greater this tendency. If a system does not meet the performance that is expected of it, the control over jerk can round the velocity corners. This reduces the amplitudes of the frequencies that excite resonance oscillations. As a result, acceleration factors can be set higher. Many big, heavy machine tools are inherently unstable, meaning that they shake at very low frequencies.

From my own experience it results that by a close cooperation between mechanical and electronic engineers it is possible to optimize the positioning, contouring accuracy by a suitable adjustment of the driving system, taking into account the actual design of the machine tool.

The wish, the desire of any machine tool manufacturer is to improve the performances of his products, and not in the last turn, from commercial point of view, this is leading to finding of methods to increase the dynamic performances (acceleration included). So, one arrives at the second consequence.

b- From the same law of mechanics, to keep the same acting force, the acceleration growth would be possible by diminishing the mass. If some massif components (e.g. saddles, cross rails etc) with translation movement would be achieved not from cast iron or steel (with density of about 7 800 kg/m^3), but from aluminum (with a density of about 2 700 kg/m^3, it results that for the same volume the mass is about three times lowered. Consequently, for the same driving system, the acceleration could be increased three times [10]. But, it appears another problem: the big difference between the dilatation coefficients of the cast iron/steel (of about 11µm/m, ^{o}C) and of the aluminum (of about 24 µm/m, ^{o}C). To render compatible the operation of such hybrid system it is necessary:

-to machine the components at 20^{o}C± (1-2)^{o}C;

-to assembly the components in the same conditions;

-the machine tools to be used in the same conditions.

Without entering into details, the proper operation of such machine tool implies measures for ensuring constant internal thermal conditions, especially that some of those types of machine tools are used in car building industry. The machining centers of that type are operating 24 hours x 7days/week. They are intended for machining the motor block, the gear box housing of well known cars. The environment and the machine structure itself temperature constancy keeping allows to get a space accuracy of 1.5–2 µm, with a repeatability of maximum half of the above mentioned value.

This is a clear prove of what it would mean to keep constant of, at least, one parameter.

c- There are another ways to tackle the driving system to avoid undesirable phenomenon, e.g.:
-the appearance of the "overturning" when driving a body in a point differing to its gravity center;
-heavy masses (for instance a portal made up of two massive columns, a cross beam and a cross rail).
The adopted, so far, solutions are:

d- The driving point to be as close as possible to the gravity center (for example the moving column of a planer type horizontal boring and milling machine), but it means to place the driving mechanism on a type of "wall", parallel to the mobile assembly movement direction (Fig. 12)[11];

e- The use of the "box-in-box" principle[11], the mobile elements being conceived as a closed frames, with driving on two sides (indifferently of the moving direction), what means the driving in the gravity center (Fig. 13);

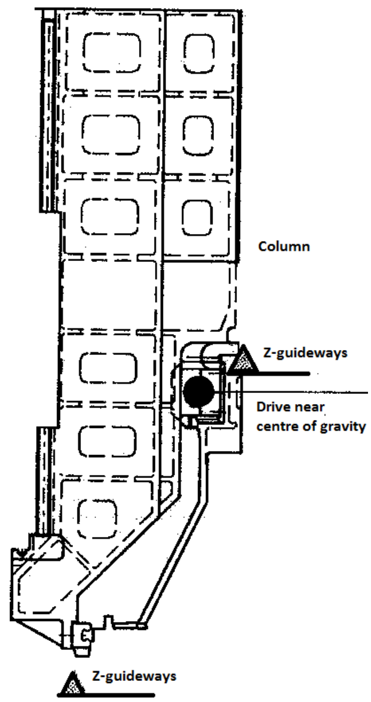


Fig. 12. Principle of driving point to be as close as possible to the gravity center.

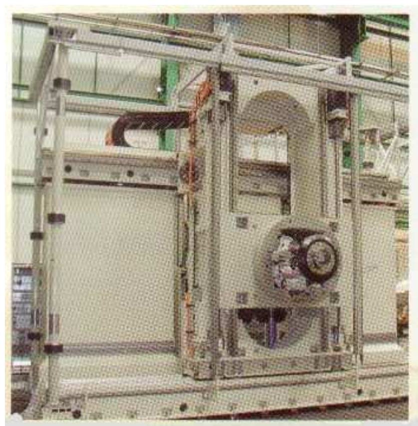


Fig. 13. The use of the "box-in-box" principle.

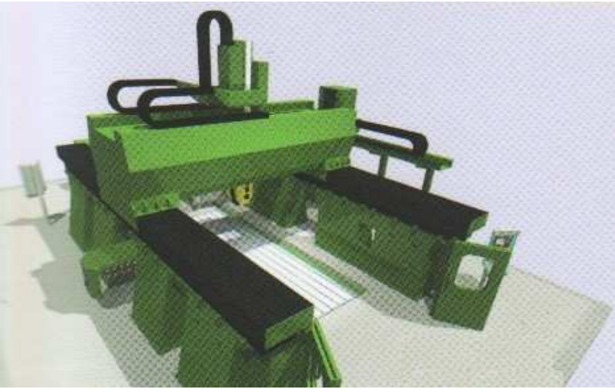


Fig. 14. Structure with crossrail sliding on a "high bed" replacing two colums.

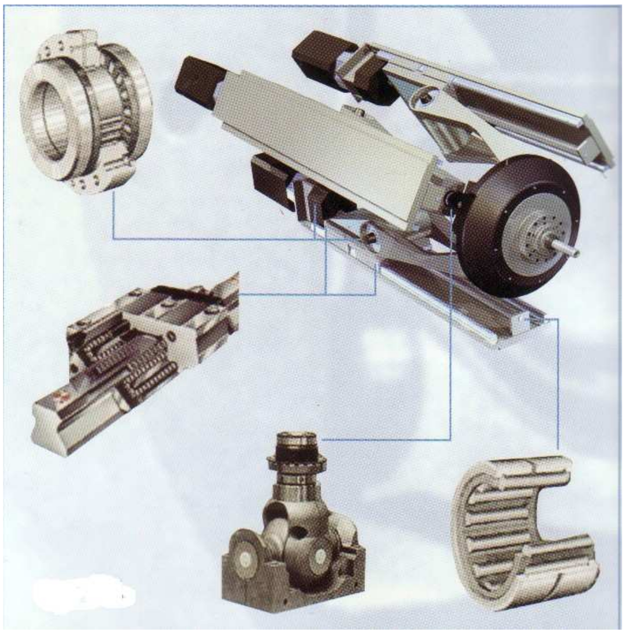


Fig. 15. Tool clamping in an electro-spindle.

i- Replacement of the portal with two heavy columns, with a cross rail, only, using a "high bed", made up of a (preloaded) concrete structure or a welded structure "stuffed" with (polymer or cement) concrete, for improving the static (stiffness) and dynamic (damping) performances (Fig. 14)[12].

The above mentioned design solution ensure:

- high accelerations (over 1g);

high moving speeds/feeds (sometimes over 80m/min), extremely useful for machining of light alloys components (aero-space industries), but for molds/dies, too;

ii- Tool clamping in an electro-spindle (direct drive system), the feed system being achieved with a (simplified) Steward platform ("*architecture parallel*"), ensuring (within certain limits) by three linear movements two additional rotation movements (Fig. 15) [14].

iii- Driving, guiding and measuring systems to be placed as close as possible (Fig. 16) [13].

It has been found that the driving in the gravity center of the mobile structure, or as close as possible to that one, is avoiding (diminishing) deformations, vibrations, wear and other undesirable phenomenon at the linear displacements.

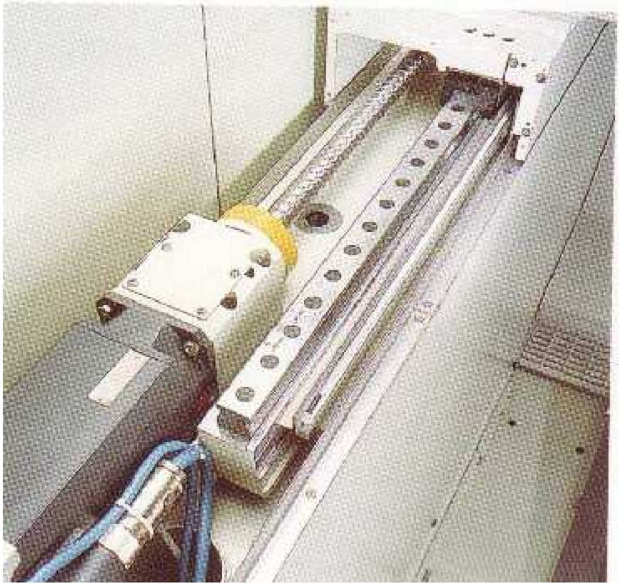


Fig. 16. Compact assembly of driving, guiding and measuring systems.

The machine tool architecture, structure alteration depends on the designer/manufacturer knowledge, skill, and courage and on the dialogue with the customer(s), on the latter one trust on the "builder's" skill. The current "working instruments" used in engineering (Computer Aided-Design, Engineering, Quality Control, testing etc) permit working out and virtual testing of several solutions, among which the most suitable to the proposed goal (output, accuracy, flexibility, price etc) could be chosen. The dialogue and the courage are needed at all involved levels in promoting the most performing solutions (including the hardware and software components suppliers).

The same importance has to be granted to the components/assemblies in rotation movement. The symmetry must be applied not only to the components with a linear movement, but to those in rotation movement, too. For avoiding some phenomenon with non-linear evolution it is recommended the symmetrical design

- from thermal point of view,
- from dynamic point of view.

It means, at least from dynamical point of view, that rotating components must not have eccentric masses. Even when machining workpieces of which shape, structure includes eccentric masses, they must be balanced statically and dynamically.

Let us suppose the designer took all measures avoiding the eccentric masses. Because of some material non-homogeneity, of machining errors, the dynamic balancing, in real (worse) operating conditions, is compulsory. For that reason, within the design of assemblies in rotation movement, they must be provided elements, components which allow the dynamic balancing (by mass adding, moving or subtracting).

Relative recent achievements are showing the presence in the machine tool structure of some hardware (acceleration transducers, eccentric masses) and software (vibration analysis, eccentric masses displacement control) components, which allow the automatic balancing of the eccentric mass fastened on the machine main spindle (cutting tool or workpiece)(Fig. 17)[15].

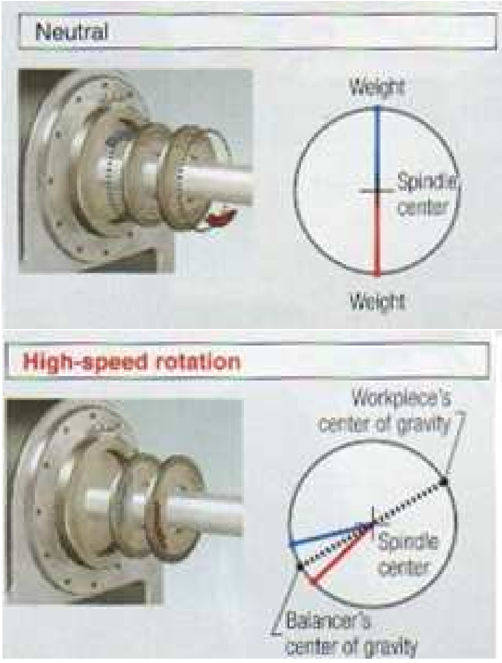


Fig. 17. Automatic balancing of the eccentric mass on the machine main spindle.

7. OTHER ELEMENTS

The machine tool is more and more a mechatronic system. The developments in the field of sensors, transducers and of the data acquisition and handling systems (software included) and programs for compensation of some parameters (deviations, errors) of the machine tool (deformations, temperatures, vibrations, loads, displacements etc) allow "to feel" the machine tool more and more complex, to be more and more complex monitored. All those are tending to the concept of "operating errors compensation". It will have as a result the growth of the machining accuracy (errors diminishing) several times, even at machine tools achieved with normal (actual) technologies and at the normal accuracy level. And, also, for those which are working in usual environmental (not-controlled) conditions in metal cutting workshops. I'm concerned with this type of problems for several years, and some early results are encouraging.

8. CONCLUSIONS

Any experience must be used:

- that one leading to unfavorable results –to be avoided, or, by solving the problems, to enrich the knowledge treasury;
- that one leading to positive results to be hoarded up, to be possible to use it in the future, too, to continuously enrich/develop it.

It is compulsory that the experience –of any nature/result-to be transmitted: either for avoiding mistakes, or to offer ways, means for success.

In any activity field the "technological discipline" must be observed (that is the positive experience earlier gained must be applied): the democracy must be stopped in the front of the company door (entrance): inside there is nothing but "technological discipline".

The continuous enrichment of the knowledge, at all levels of the hierarchy structures, its checking and application are needed ways for a development of the individuals, of the company and at the social level.

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