RESEARCH ON FIXTURING SMALL PARTS IN MACHINING SYSTEMS

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ABSTRACT: The fixturing of small parts, within machining technological systems, requires solutions which should be determined by extensive analysis of the interacting factors. There is evidenced a series of relevant elements regarding the small displacement torsor produced by fixturing, fastening mechanisms, as well fixturing of thin-walled parts. Moreover, there are presented data and main results of an experimental research regarding the fixturing of the workpieces on magnetic table, within milling and drilling systems.

KEYWORDS: fixturing, workpiece, fixturing mechanism, error, technological system.

1. Introduction

The small parts include some constructive features – general form, wall thicknesses, sizes of the possible spaces for fixturing elements, etc. - which can influence how they are fixed within the machining technological systems. Thus, it is necessary that the type and position of fixturing elements associated with technological operations to be determined through extensive technical-economic analysis on the interacting factors – position and dimensions of possible spaces for fixturing elements, structure and dimensions of the fixturing mechanisms, the characteristics of the specific errors, time and cost associated with the clamping-releasing process.

2. General considerations

2.1. Parameters of the small displacement torsor produced by fixturing

Geometric workpiece errors, locators geometric errors, and clamping errors are factors which influence the workpiece fixturing [1]. These errors accumulate, propagate during fixturing and may be the reason why a machined characteristic is outside the tolerance range. In the modeling and analysis of the combined effect of these errors (Fig. 1), the deviation of a machined characteristic is expressed by parameters of the Small displacement torsor, SDT.

Due to the geometric errors of the part and of the fasteners, the moment M, $M = Qd$ can be created by the action of the clamping force Q [1], which generates a rotation/ angular displacement, α, of the workpiece (Fig. 2) and, accordingly, angular fixturing errors. A flat surface that nominal is parallel to a reference plane (xy), Sp, may suffer fixturing errors (Fig. 1, 2) of type: geometric, error / variation Δz, in mm, of surface position after normal direction at (xy); errors/ variations $\Delta\theta_x$ and $\Delta\theta_y$, in rad, of the angular position of the surface around the reference axes x and y, respectively. Thus, to the Sp considered surface, a SDT (Sp) torsor can be associated consisting of the small displacements Δz, $\Delta\theta_x$ and $\Delta\theta_y$, as:

$$SDT\ (Sp): \{\Delta z, \Delta\theta_x, \Delta\theta_y\} \quad (1)$$

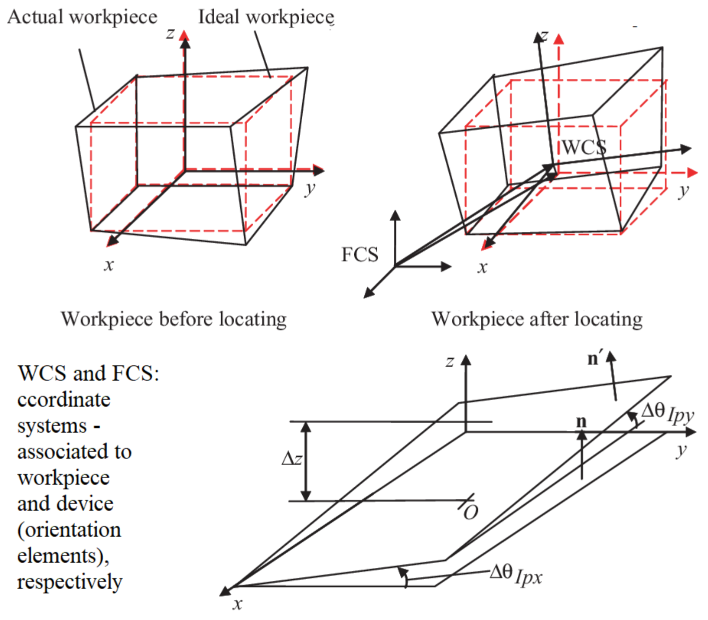


Fig. 1. Workpiece and primary plane of workpiece surface deviation (before and after locating) [1]

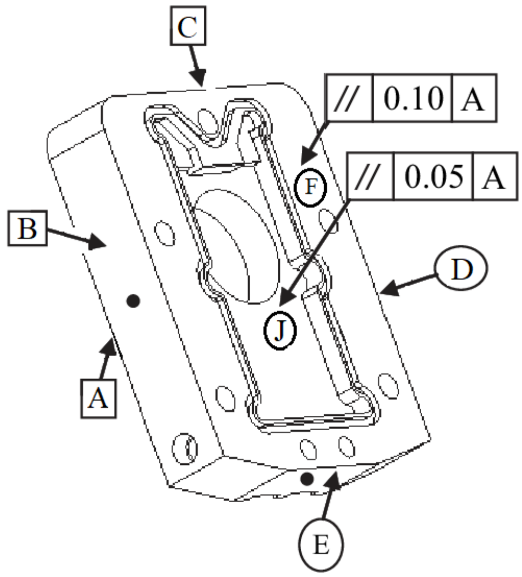


Fig. 3. Test-piece machined in the experiment (after [1])

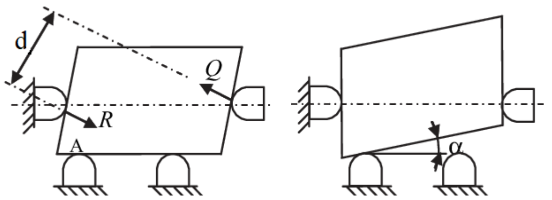


Fig. 2. Clamping error (example) [1]

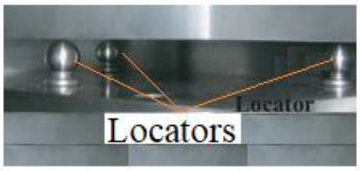


Fig. 4. Part locators from device structure (after [1])

A test-workpiece [1] (Fig. 3, 4) was oriented by contacting the A-B-C reference flat surfaces on six orientation elements type of the spherical pin, in a 3-2-1 structure and fixed on the flat surfaces D and E, respectively, by action of two fixturing elements, each with a fixturing force of 500 N (to prevent intense deformation). Thus, e.g., for the F and J surfaces of the test-piece machined by milling in the considered experiment (Fig. 3), SDT (F) and SDT (J) are:

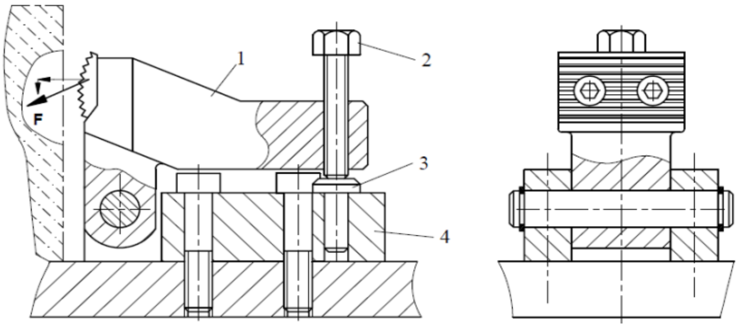
Prescribed SDT (F): (0.1, 0.00125, 0.00096} and Effective SDT (F): {0.0541, - 0.00067, - 0.00067} (2)

Prescribed SDT (J): (0.05, 0.0021, 0.0013} and Effective SDT (J): {0.0039, - 0.00067, - 0.00067} (3)

2.2. Technological fixturing mechanisms and technological machining devices

The fixturing mechanisms in the structure of technological machining systems may be with wedge, eccentric, screw-nut, pneumatic motor, hydraulic motor and clamp strap, plunger, oscillating plate or with vacuum, magnetic, etc., and the orientation-fixing mechanisms can be with jaws, elastic bushing(s), levers, prisms, etc. [2].

For fixturing according to a predetermined direction, two variants of screw/nut-clamp mechanisms are shown in Fig. 5.



1- Clamp, 2 – Bolt, 3 – Pressure pin, 4 - Support

a.

b.

Fig. 5. Fixing mechanisms: bolt – hinged clamp (a); bolt – nut - clamp (b) [3]

For clamping small parts within automated systems, an innovative solution consists of creating hydraulic actuators and solving the problem of extreme clamping forces in a small space combined with creating the precision of these fixing forces [4]. These mechanisms operate on a relatively simple principle, respectively, the hydraulic pressure (p) is first converted to the downwards force (F) and by means of a wedge-plungers mechanism, clamping forces (F) are created (Fig. 6). The easiest way to create a hydraulic device is to use a single-acting hydraulic actuator. In the case of a double-acting hydraulic actuator, the clamping force is stronger than the return force.

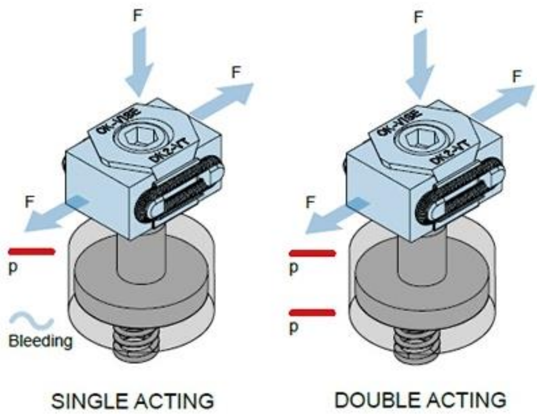


Fig. 6. Hydraulically operated fasteners in automated systems [4]

Magnetic action is a mechanized mode of action that is characterized by the fact that the actting force is achieved, e.g., with permanent magnets, which are properly oriented and insulated each - other by means of non-magnetic insulators. Magnetically operated fixtures have a number of advantages: low cost, uniformly distributed magnetic field on the surface, fixturing with no deformation, etc. [5].

Magnetically operated fixtures are built in the form of magnetic table/ plateau. A such of magnetic table that is used at CNC milling machines is shown in Fig. 7. For clamping smaller and thinner parts, the most suitable are magnetic fixtures with neodymium magnetic system [6] (Fig. 8). Neodymium (NdFeB) magnets are smaller and stronger than other permanent magnets.

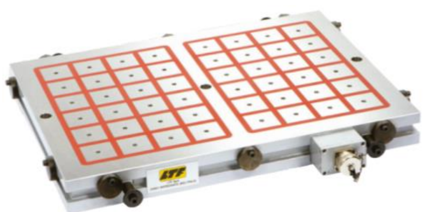


Fig. 7. Electropermanent magnetic table [7]

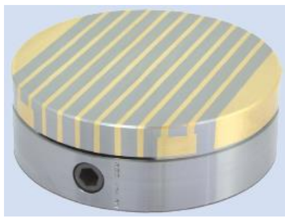


Fig. 8. Permanent magnetic chuck [6]

The fixturing force of the part is determined by the equal number of north and south poles with which is in contact. The short distances between the poles produce shorter magnetic lines of force and are therefore used for thin or small parts [8].

Vacuum fasteners are among the newest ways of fixturing workpieces in technological machining systems and have the important feature that the fixturing efficiency does not depend on the size of the fixed part. Such a fastening mechanism is a technology to fix the part by vacuum and to allow its machining from different directions, easily and quickly. Thanks to this special grip, the parts are protected against damage [9] (Fig. 9).

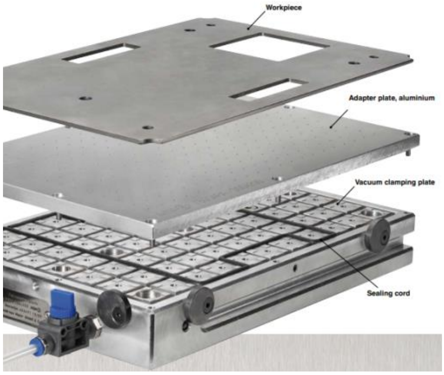


Fig. 9. Vacuum clamping system [9]

2.3. Clamping schemes of thin-walled parts

Thin-walled parts have widespread applications in the fields of aeronautics, astronauts, medicine, etc. The quality of the part (Fig. 10) is affected by several factors and the clamping scheme is a main influencing element. "Researchers mainly study from three directions: fixture design evaluation, finite element simulation, mathematical model establishment, and algorithm optimization". In one particular case, six fixturing schemes were proposed, from which a variant was chosen based on the finite element study in the ABAQUS software [10].

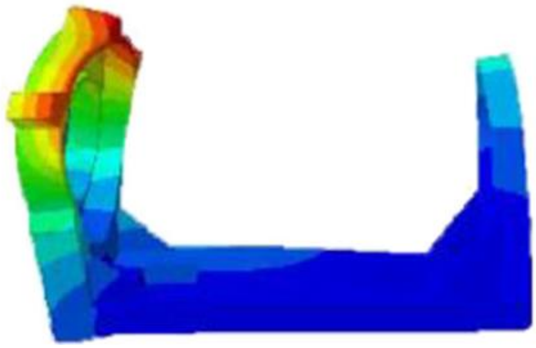


Fig. 10. Thin-walled part loaded by fixturing force, analyzed with finite element [10]

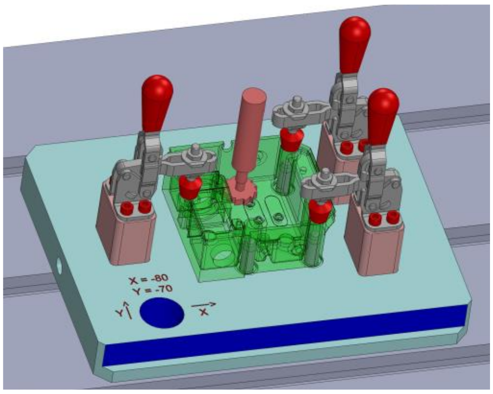


Fig. 11. Special fixture [11]

For a milling, drilling, etc. operation of a complex thin-walled workpiece, in a CNC technological system, the special fixture, that was designed, produced and used in industrial conditions, ensures the fixturing of the part in its maximum rigidity zones (Fig. 11) [11].

3. Experimental research on magnetic fixturing in machining processes

At the fixturing on the magnetic table, it is possible to apply the fixturing force after the normal direction to a main flat orientation surface, without the need to apply fixturing forces after other directions.

In the literature there are summary data on the technological conditions of use of magnetic devices in cutting operations with high cutting forces.

In relation to the above, an experiment was carried out under real machining conditions, by milling and, respectively, by drilling, in a laboratory of the Manufacturing Engineering Department, as follows.

● Test-piece: Prismatic body, made of C45 steel/ normal state, with overall sizes of 150 x 38 x 25 mm, and a flat settlement surface of 150 x 38 mm.

● Fixture: *ECLIPSE* magnetic table with permanent magnets, and overall sizes of 290 x 130 x 50 mm.

3.1. Machining by semi-finishing face milling

- Machine tool: TOS FN 32 universal milling machine.
- Fixture: *ECLIPSE* magnetic table - with settlement on the machine-tool table and fixing with bolt-clamp (2x).
- Cutting tool: Face mill, with z = 6 cutting tips – material P25, main angle of attack $\chi = 60^{o}$, active diameter d = Ø70 mm.
- Cutting parameters: cutting depth a = 0.2, 0.4, 0.6, 0.8 mm; cutting feed f_z = 0.021 and 0.027 mm/tooth; cutting speed v = 109.95 m/min, respectively, rotational speed n = 500 rpm; feed rate F = 63 and 80 mm/min, according to the following relationships:

$$n = 1000v/\pi d, \; F = nzf_z \tag{4}$$

- Lubricant coolant: without.

A series of elements regarding the unrolling of considered machining is presented in Fig. 12.

a.

b.

c.

Fig. 12. Elements regarding the unrolling of machining by milling:
a – preparation of the technological system; b, c - machining

3.2. Machining by drilling

- Machine tool: Drilling machine G 25.
- Fixture: *ECLIPSE* magnetic table - with settlement on the machine tool table, without fixing.
- Cutting tool: Twist drill, with diameter d = Ø9 mm, made of HS18-0-1 SR EN ISO 4957:2022.
- Cutting parameters: cutting feed f = 0.1 mm/rev, cutting speed v = 12.7 m/min, respectively, rotational speed n = 450 rot/min (n = 1000v/πd).
- Lubricant coolant: without.

A series of elements regarding the unrolling of the considered machining is presented in Fig. 13.

a.

b.

Fig. 13. Elements regarding the unrolling of machining by drilling (a, b)

4. Case studies

The case studies refer to the introduction of magnetic fixturing in machining operations, associated with the manufacture of a workpiece with a complex geometric shape (Fig. 14), and with thin walls (Fig. 15), respectively.

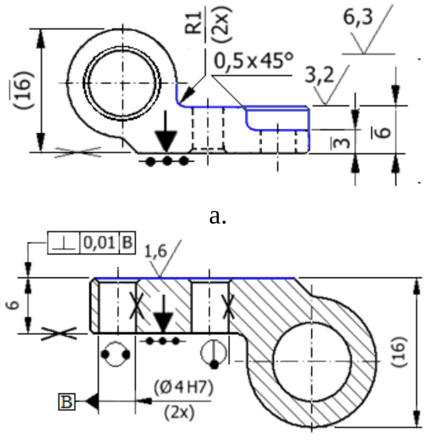


Fig. 14. Sketches of two operations including machining by milling – a, grinding – b, with magnetic fixturing of the part

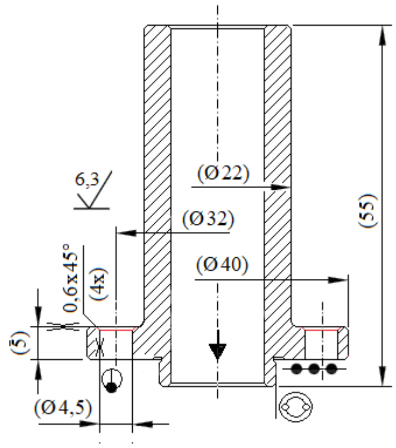


Fig. 15. Sketch of an operation including machining by countersinking, with magnetic fixturing of the part

5. Conclusions

For fixturing small parts in technological machining systems, it is necessary to analyze various fixturing schemes and mechanisms, with respect to a number of specific characteristics of the parts - general shape, wall thickness, etc.

Experimental research on the fixturing of the part on a magnetic table, in operations including milling or drilling, shows that technological conditions can be determined for the use of magnetic devices in milling, drilling, etc.

The development of theoretical and experimental research on magnetic fixturing of parts in technological operations will lead to the simplification of certain orientation-fixing systems and, consequently, to the reduction of production costs.

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