RESEARCH ON DEVELOPMENT OF HYDRAULIC FIXING MODULES OF PARTS IN INDUSTRIAL CNC TECHNOLOGICAL SYSTEMS

COCOLOŞ Ana-Maria-Nicoleta[1], Marian GHEORGHE[2] and Nasim GANNAM[2, 3]

[1] Faculty of Industrial Engineering and Robotics, Specialization: Industrial Economic Engineering, 4th study year, e-mail: anamarianicoleta11092015@gmail.com
[2] University POLITEHNICA of Bucharest, IIR Faculty, Manufacturing Eng. Department (TCM)
[3] Dr. Köcher S.R.L.

ABSTRACT: For fixing large-sized and complex parts within technological machining systems, it is necessary to determine solutions after analyzing multiple possible variants. There are several significant advantages of using hydraulic clamping modules for parts in industrial CNC technological systems, especially for fixing parts with complex geometries. Additionally, this article presents data and the main results of experimental research regarding fixing parts using these modules within complex machining processes and systems that include milling, drilling, and threading.

KEYWORDS: part, hydraulic clamping, clamping mechanism, technological system

1. Introduction

The way of fixing parts within technological machining systems is influenced by the constructive characteristics of the parts, as general shape, wall thicknesses, possible space dimensions for fixing, etc. The hydraulic clamping system has higher efficiency compared to other clamping systems with lower energy consumption. In computer numerical control (CNC) systems, the hydraulic clamping system is generally used to maintain the part in the desired position. Compared to manual tightening, the use of hydraulic clamping in the system ensures a constant clamping force on the workpiece, makes the tightening process faster, and allows for automatic or robotic loading of workpieces.

2. General considerations

2.1. Types of manual-mechanical technological fixing mechanisms

The clamping mechanisms in the structure of technological machining systems can be pin-type, eccentric, screw-nut, pneumatic motor, hydraulic motor, and clamp (lever), plunger, pressure foot, vacuum, magnetic, etc., while orientation-clamping mechanisms can be with bushings, with elastic bushings, with levers, prisms, etc. [5, 16].

A series of manually-operated clamping mechanisms are shown in Fig. 1.

(a) Clamping with force elements type of screw - threaded hole within lathe tool holder

(b) Clamping with force elements type of nut - washer – screw - clamp at various devices

(c) Clamping with force elements type of screw - fixed nut -jaws, at vises and other devices

Fig. 1. Mechanisms for manual-mechanical clamping (adapted from [6])

2.2. Types of technological fixing mechanisms with magnetic actuation

Magnetic actuation represents a mechanized mode of operation characterized by the fact that the actuation force is generated, for example, by permanent magnets, properly oriented and isolated from each other with the help of non-magnetic isolatorss. Magnetically actuated devices have a number of advantages: low cost; uniform magnetic field distributed over the surface, with fixation without deformations, etc. [13].

Magnetically driven devices are built in the form of magnetic tables/plates. Such a magnetic table used in CNC milling machines is shown in Fig. 2. For holding small and thin parts, the most suitable devices are magnetic fixtures with neodymium magnetic systems [11] (Fig. 3). Neodymium magnets (NdFeB) are smaller and stronger than other permanent magnets.

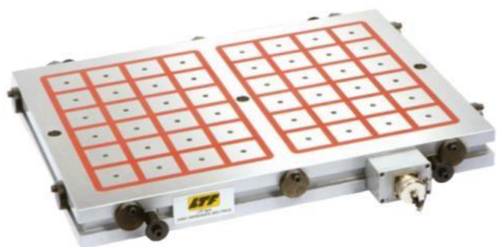


Fig. 2. Electropermanent magnetic table [12]

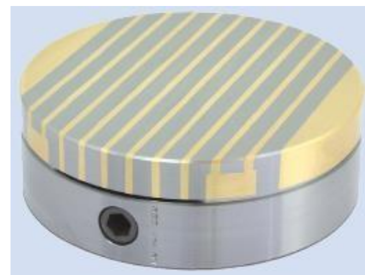


Fig. 3. Permanent magnetic device [11]

2.3. Types of technological fixtures with hydraulic actuation

The hydraulic clamping system has a higher efficiency compared to other clamping systems, with a lower energy consumption, and is driven by a pump that operates at a constant speed. In CNC machines, the hydraulic clamping system is generally used to hold the workpiece in the desired position [3].

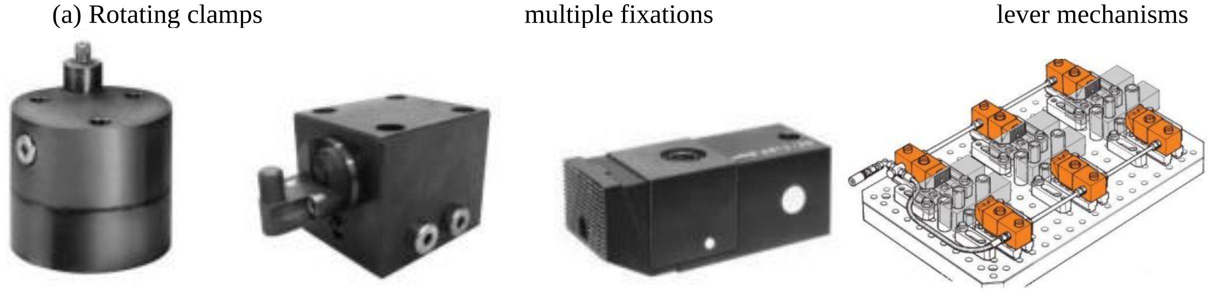
Compared to manual clamping, the use of hydraulic clamping systems ensures a constant clamping force on the workpiece, makes the clamping process faster, and allows for automatic or robotic loading of the workpieces [2].

A series of hydraulic clamping mechanisms are shown in Fig. 4.

(a) Rotating clamps

(b) Hydraulic clamp for multiple fixations

(c) Hydraulic cylinders with lever mechanisms



(d) Side clamps

Fig. 4. Hydraulic clamping mechanisms (adapted from [9])

2.4. Clamping System

From a mechanical point of view, the purpose of clamping a workpiece is to keep it in a rigid position so that various actions which can be performed on it. From another point of view, the clamping system is used to overcome the maximum forces that act on the workpiece. A clamping diagram of a hydraulic clamping system in a CNC system is shown in Fig, 5. In the case where a clamp is used to fix a workpiece for machining, the efficiency of the clamp depends on the action type [1]. Some of the main functions that an ideal clamp should fulfill are: reducing the maximum possible stresses acting on the workpiece during machining, eliminating the possibility of deformation due to clamping force, and maintaining adhesion to the workpiece surface during machining despite vibrations caused by cutting tools.

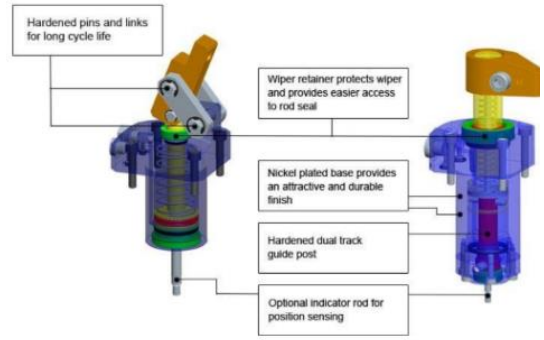


Fig. 5. Hydraulic Clamping System used for CNC machines [1]

2.5. Clamping rules

There are many rules for applying clamp on any work piece, e.g. [1, 5]:

• the clamping force should always be applied toward the locating surface;

• the clamp should be at a safe distance from the tool;

• tlamps should be arranged in such a way that clamping force acts on rigid part of the work. For example, if an I section is to be clamped, the clamp should be adjusted in such a way that clamping force acts on the flanges and not on the web of the I section;

• the design of the clamping device should be done based on the work it has to handle. With the advancement in technology, there are many types of clamping system. Mostly used systems are mechanical clamping systems and hydraulic clamping systems. However, due to greater efficiency and ease of application hydraulic clamping systems. has dominated in the rapidly growing industries.

2.6. Hydraulic clamping systems

The hydraulic clamping system is a fastening system that uses a pressurized liquid such as oil, water, etc. to hold a workpiece in a fixed position during processing. This system is more efficient than other clamping systems due to the reduced friction surfaces. The hydraulic system usually consists of a single or double-acting cylinder and a piston. On the hollow side of the piston, there is a hole for the flow of pressurized liquid. On the opposite side, namely on the rod side, there is a rocker-type, vertical, linked, or other type of clamp that exerts force on the workpiece to achieve the clamping action (Fig. 6).

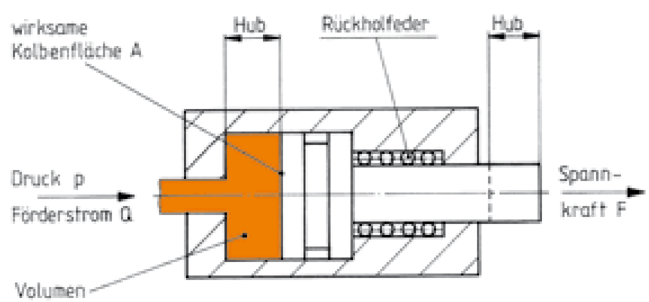


Fig. 6. Illustration of Hydraulic Clamping System [1]

In general, the power source for the hydraulic clamping system is a so-called hydraulic power unit. Its main components include the oil tank, pump, motor, pressure relief valve, pressure gauge, etc. A schematic diagram of such an industrial hydraulic power unit [1] is shown in Fig. 7. An example of such a hydraulic power unit is presented in Fig. 8.

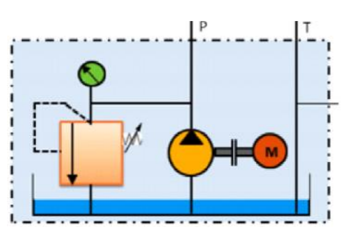


Fig. 7. Hydraulic Power Pack Circuit [1]

Fig. 8. Hydraulic Power Pack Bosch [8]

When high pressure is required, the hydraulic system plays an important role in performing various operations. The necessary pressure in the CNC machine is developed by the hydraulic power pack of several hydraulic components.

The structure of a hydraulic module circuit used in CNC machines is presented in Fig. 9. The most typical applications are shown in Fig. 10.

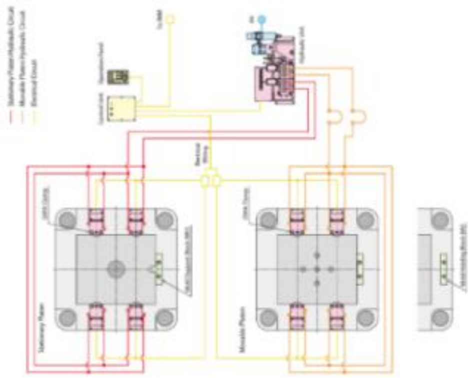
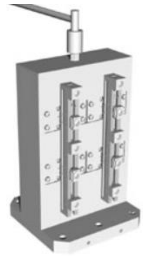


Fig. 9. The structure of a hydraulic module circuit [7]



(a) Continuous hydraulic connection with horizontal machining center

(b) Continuous hydraulic connection with vertical machining center

(c) The hydraulic connection is disconnected after loading (in FMS systems)

Fig. 10. Applications of hydraulic system in CNC centers [2]

2.7. The calculation of hydraulic clamping force

To calculate the necessary clamping force for a workpiece using a hydraulic clamping system, one must take into account the geometry and characteristics of the workpiece as well as the contact surface between the workpiece and the hydraulic module. This calculation is carried out using Eq. (1),

$$F = pA\eta \quad (1)$$

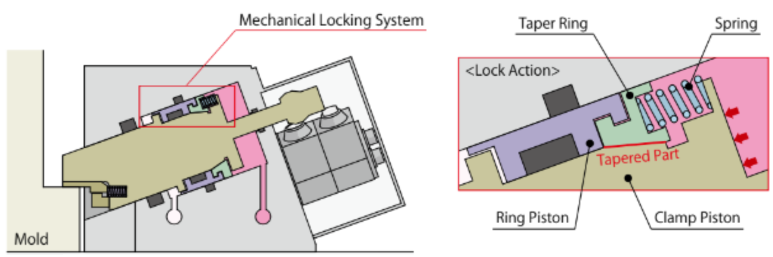
where: p is the hydraulic pressure, A - the active surface area of the piston, η - the transmission efficiency of force.

For example, at a hydraulic module with a diameter of d = 50 mm, hydraulic pressure of p = 65 bar, and transmission efficiency of η = 0.95 [18], the resulting force is F = 1212.5 daN.

3. Modules of parts in industrial CNC technological systems

A hydraulic module [14] used in industrial CNC technological systems for clamping workpieces is shown in Fig. 11.

Fixare hidraulică.mp4



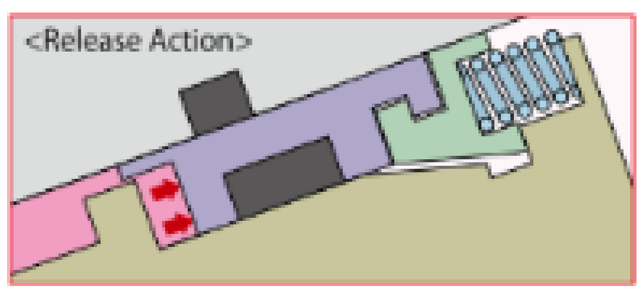


Fig. 11. Hydraulic clamping module [14]

The mechanical locking system prevents the hydraulic device from detaching during the workpiece is fixed and keeps it in the desired position [7].

The part shown in Fig. 12 is a complex model due to its geometric shape. The surfaces to be machined are highlighted in colors. In order to allow machining on all sides, the fixation must be made on surfaces that do not require machining. Therefore, it can be done in two ways, either on the large surfaces in the middle or on the sides. Fixation in the middle of the part can cause significant ovalization due to the lack of material, so the sides are the best option, although their geometry is more complex [10]. Point fixing of the part reduces the contact area (Fig. 13).

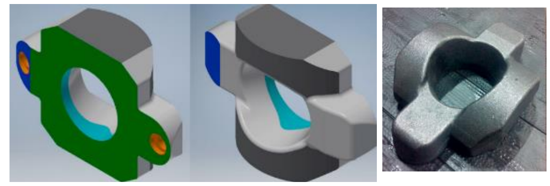


Fig. 12. 3D model of the part and the physical part [10]

Based on previous experiences with hydraulic clamping, several issues have been identified and ways to mitigate or prevent them have been studied. The identified issues and proposed solutions are presented in Table 1.

Fig. 13. Fixing the part with dog point screws for reducing the contact area and the appearance of deformations [10]

Table 1. Analysis of potential issues that may arise [10]

Possible problems detected	Possible solutions/ corrections
Part instability due to irregular clamping area or clamping over parting line	Use of “V” shaped clamps both on top and bottom to compensate for torsion
Excessive vibration during machining	Adding a hydraulic support clamp on the free side of the part increasing support area
Need for calculations during setup increasing human error probability	Adding centring spheres on the tool for the probe to measure and calibrate

4. Case study

The case study refers to the introduction of hydraulic clamping in a complex technological operation, which includes milling, drilling, threading, associated with a complex geometric shape part (Fig. 14).

The elements of the development regarding the application of hydraulic clamping are presented in Fig. 15: (a) an extended sketch of the technological operation; (b) a simplified 3D model of the device.

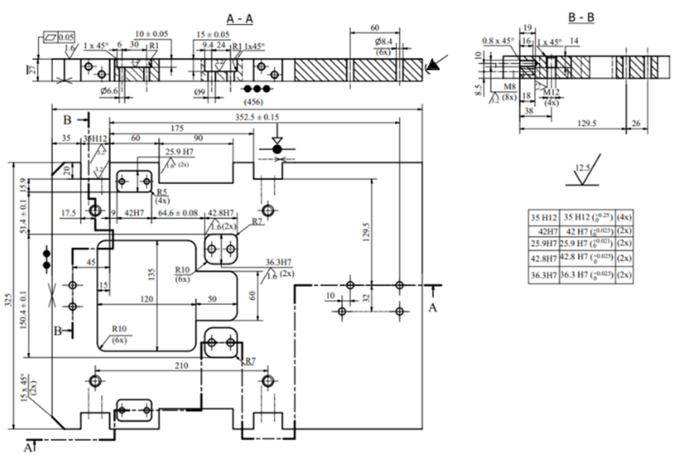
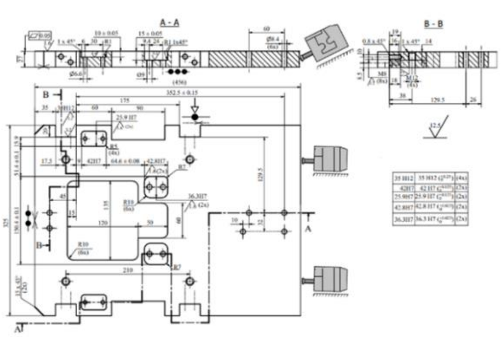
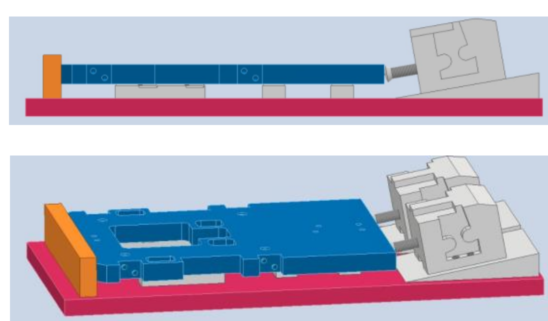


Fig. 14. Technological operation sketch [5]



(a) Extented technological operation sketch



(b) A 3D model of the device in a simplified form

Fig. 15. Elements of development regarding the application of hydraulic clamping

5. Conclusions

In order to fix large-sized parts within machining systems, various fastening schemes and mechanisms need to be analyzed, taking into account specific characteristics of the parts such as the overall shape, wall thickness, etc.

Experimental research on fixing parts with hydraulic modules during complex machining processes shows that technological conditions for using hydraulic devices in CNC machining systems can be determined for complex machining operations.

Developing theoretical and experimental research on hydraulic fixation of parts in machining operations will lead to a reduction in physical effort required for fixing and, correspondingly, to production cost reduction.

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