Cam – clamping device with variable eccentricity and pneumatic actuation

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Abstract. Modern manufacturing companies prioritize productivity and quality growth while reducing costs. To achieve these objectives, fixture devices play a crucial role in the production process. These devices are designed to facilitate rapid workpiece changes, feature simple construction, and minimize positioning and installation errors, all while remaining cost-effective. In the field of device design, key requirements focus on rapid workpiece fixing, simultaneous fixing of multiple workpieces, and reducing operator effort. The continuous advancement of computing technology, along with design and manufacturing software applications, has significantly contributed to improving clamping devices used in manufacturing processes. This technological progress has led to an increase in the quality of cut parts. This paper presents research on a novel fixture device featuring a pneumatically actuated variable eccentricity circular cam. This innovative design addresses the industry's need for flexible, efficient, and precise clamping solutions. By incorporating a variable eccentricity mechanism, the device offers adaptability to different workpiece sizes and shapes, potentially improving production efficiency and part quality. The study explores the design, construction, and performance of this circular cam-based fixture, contributing to the ongoing evolution of manufacturing technology.

Keywords: cam clamping device, eccentric, actuator

1. Introduction

The use of fixture devices aims to minimize auxiliary time for workpiece securing, employing rapid fastening mechanisms and often allowing for multiple workpiece fixation Fixture devices apply clamping forces to the workpiece after it has been properly oriented through adjusting forces.

Fixtures are integral components of the machine-device-tool-workpiece system, primarily orienting the workpiece and occasionally the tools during manufacturing. The design phase considers numerous parameters, including required strokes and forces, operation time, and construction simplicity, all of which influencing the cost of the device. In the field of specialized literature, there are many researches exploring various aspects of technological devices.

A relevant scientific paper [1] proposes an innovative method for computer-aided design of a device intended for parts with complex, irregular surfaces. The algorithm presented in this study primarily aims to determine the minimum number of clamping elements required to ensure optimal stability of the workpiece during the manufacturing process.

Another interesting scientific research describes the conception and development of mechanical clamping devices, characterized by extra-long wedge grips [2]. These innovative devices are specially designed to perform static and fatigue tests on composite materials, both in tension and compression modes. Their particular design allows for a comprehensive evaluation of the mechanical behavior of these advanced materials under various loading conditions.

In article [3], the configuration of the clamping device and the clamping force for a disk processed on a numerically controlled vertical lathe were analyzed. The study was based on factorial experiments to determine the optimal shape (configuration) of the clamping device. Using the finite element method, displacements were calculated for different values of the applied clamping force. This combined approach, using both practical experiments and numerical simulations, allowed for the optimization of the clamping system for an efficient processing of the disk on the vertical lathe.

In the study [4], researchers applied the finite element method in order to conduct a detailed dynamic analysis of the workpiece clamping system. The main objective of this analysis was to optimize the clamping force. By using this numerical simulation technique, they succeeded in determining the optimal value of the clamping force that leads to minimal deformation of the workpiece during the machining process. This innovative approach allows for significant improvement in the precision and quality of the processed parts by minimizing distortions induced by the fixturing system.

Another study of interest [5] in the field uses the finite element method to examine a specialized device designed for processing thin-walled parts with curved surfaces. The research focuses on a detailed analysis of the deformations which occur in these delicate parts when they are secured in the clamping device. By applying this advanced numerical simulation technique, the authors manage to provide a deep understanding of the mechanical behavior of parts with complex geometry and reduced thickness during the fixturing process, thus contributing to the optimization of clamping device designs for such sensitive components.

Research [6] explores advancements in the field of computer-aided design of technological devices. This innovative study proposes a design solution that incorporates artificial intelligence techniques. The presented approach aims to integrate various stages of the design process into a coherent and optimized workflow. The main objective of this methodology is to facilitate the creation of more efficient devices which are better adapted to specific requirements. By combining computer processing power with advanced artificial intelligence algorithms, researchers open up new possibilities for significantly improving the design process of technological devices.

Throughout the manufacturing process, these forces must maintain the orientation of the workpiece. The fixing force should be perpendicular to the workpiece orientation base, thereby eliminating the maximum number of degrees of freedom [7].

The field of manufacturing processes has seen diverse studies and approaches to fixture device design. The study [8] examines geometrical calculations for cams, fixing force and torque calculations, auto-blocking conditions, and contact resistance conditions. It proposes replacing the eccentric with a variable-curve cam designed to meet auto-blocking requirements.

A patent [9] presents an alternative model featuring an eccentric drive cam with variable stroke. Other researchers assess manipulation system efficiency by examining recent product developments and formulating new requirements for future systems. Some studies focus on integrated computerized manufacturing development, device design automation, and fixing force optimization. Additionally, paper explores fixture performance adjusted to advanced production, presenting design methodologies, finite element method studies, optimization techniques, simulation models, fixing force analyses, and both numerical research and experiments related to device performance.

2. The design of the clamping device

In the process of designing the fixturing device, several critical factors were considered to optimize performance and efficiency. These include facilitating the insertion of the workpiece, maximizing the amplitude of working movements, reducing the time required for activating the clamping mechanism, ensuring comfortable operation, and minimizing energy consumption

Taking these aspects into account, the implementation of an innovative clamping mechanism was chosen. This mechanism uses a circular eccentric with variable eccentricity, a solution that falls into the category of quick-clamping systems. The performance of this mechanism is reflected in its short actuation time, which ranges between 0.6 and 1.7 seconds. This feature contributes to the efficiency of the production process, allowing for rapid and precise clamping of workpieces.

The device illustrated in Figure 1 is designed with two workstations, allowing simultaneous clamping of two workpieces. Its structure consists of a base plate (1) on which bodies (2) and (3) are mounted, which are used for positioning the parts.

The workpiece (4) is positioned on support plates (5) and is secured using levers (6). These levers are activated by an eccentric (11), which in turn is controlled through the rack (8) - gear wheel (9) mechanism, ensuring firm and precise clamping.

To release the workpiece, the process involves manually retracting the actuator piston (14). Once the eccentric is disengaged, the spring (12) exerts a force on the rod (13), which in turn moves the levers (6) away, thus facilitating the rapid release of the machined parts.

Adjusting the eccentricity involves a process of disassembly and repositioning. First, the central screw (7) is loosened and the unit composed of the disc (11) and the toothed eccentric (10) is disassembled. Then, the disc (11) is lifted and repositioned in relation to the toothed coupling (10), rotating it by a number of teeth around the central axis. This operation allows obtaining the desired eccentricity and working stroke.

These adjustment features provide flexibility in adapting the device to various operational requirements, thus ensuring efficiency and precision in use.

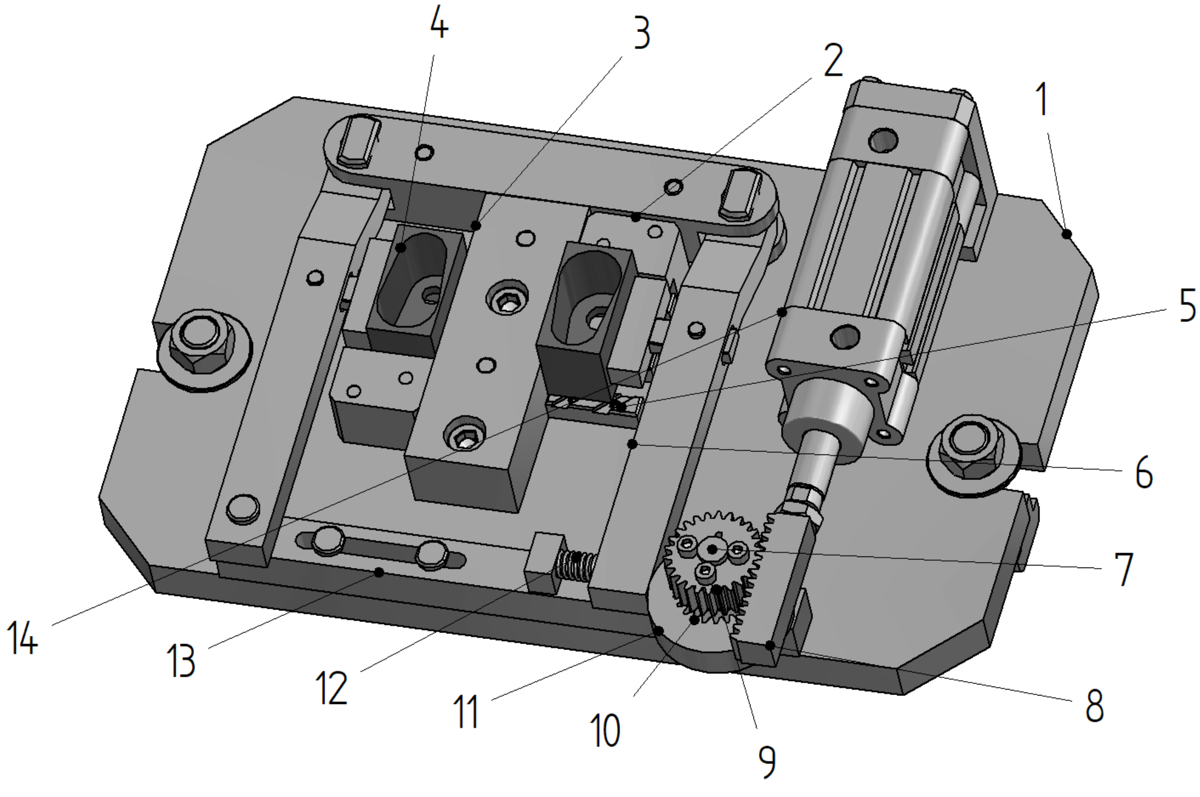


Figure 1. Clamping device with variable eccentricity and pneumatic actuation

Figure 2 shows a detail of the eccentric assembly consisting of the drive gear, eccentric gear, and eccentric disc, and Table 1 presents the design specifications for the engineered variable-eccentricity cam mechanism.

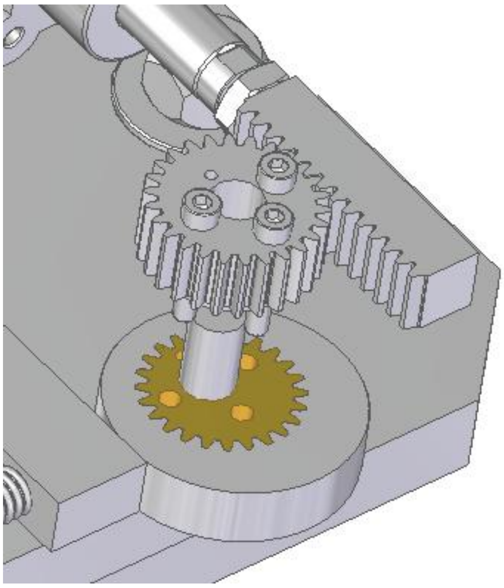
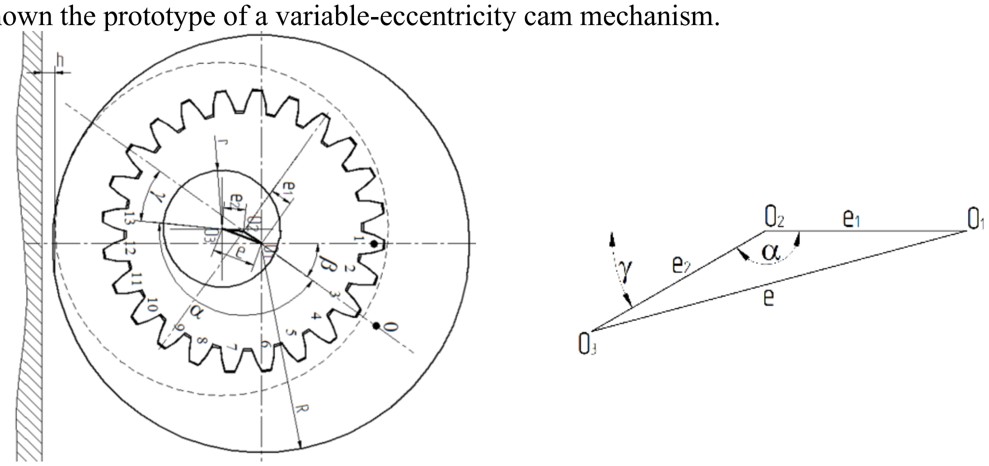


Figure 2. Detail of the eccentric actuation.

Table 1. Design specifications for the engineered variable-eccentricity cam mechanism**.**

Parameters	Symbol
Disk radius, mm	R
Rotation axis radius, mm	r
Stroke, mm	h
Toothed coupling eccentricity compared to disk, mm	e_1
Axis eccentricity compared to toothed coupling, mm	e_2
Total eccentricity of the disk compared to axis, mm	e
Actuation arm length, mm	L

Figure 3 presents the sketch used for calculus of eccentric cam with variable eccentricity, and in figure 4 is shown the prototype of a variable-eccentricity cam mechanism.



a) b)

Figure 3. Variable-eccentricity cam mechanism.

a. structural and operational components; b. eccentricity calculation diagram

Figure 4. Prototype of a variable-eccentricity cam mechanism

Knowing the number of teeth z of the toothed coupling, we can calculate the angle δ between two consecutive teeth. This angle represents an important parameter in the design and operation of the mechanism and for precise adjustments of eccentricity, or for other calculations related to the device performance.

$$\delta = \frac{2\pi}{z} \tag{1}$$

The adjustment of the total eccentricity e is achieved by loosening the central locking screw and rotating the eccentric disc over a certain number of teeth in relation to the toothed coupling. The angle corresponding to this rotation is designated by the symbol γ, as illustrated in Figure 2, b. This adjustment technique allows for precise calibration of the eccentricity, thus providing flexibility in adapting the device to various operational requirements and dimensions of the workpieces.

$$\gamma = \frac{2\pi}{z} z_i \tag{2}$$

The determination of the total eccentricity e is based on a detailed geometric analysis, using the configuration illustrated in Figure 2,b. This analysis considers two components: e_1, which represents the eccentricity of the eccentric disc, and e_2, which describes the eccentricity of the axis in relation to the toothed coupling. By examining the geometric relationships presented in the diagram, a mathematical expression can be deduced to calculate the total eccentricity e.

$$e = \sqrt{e^2 = e_1^2 + e_2^2 - 2e_1 e_2 \cos\left(\frac{2\pi}{z}(z - z_i)\right)} \tag{3}$$

The stroke *"h"* of the eccentric can be calculated based on its rotation by an angle β. This relationship allows for the precise determination of the linear displacement generated by the rotational movement of the eccentric. Knowing this stroke, is important for precise control of the mechanism movement and for ensuring proper clamping of the workpiece. The calculation of this value takes into account the geometry of the eccentric and the relationship between the angle of rotation and the resulting linear displacement.

$$h = e(1 - \cos\beta) \tag{4}$$

The self-locking characteristic of the eccentric is essential for the safety and efficiency of the device. This property ensures that the mechanism remains fixed in the desired position, regardless of the point chosen on the eccentric surface. To guarantee this functionality, a specific relationship between the geometric and friction parameters of the system must be met. Verifying this relationship ensures the correct design and operation of the eccentric mechanism, ensuring the stability and reliability of the clamping device under various operating conditions.

$$e \leq \mu R + \mu r \tag{5}$$

μ – coefficient of friction between the disk and lever and between the coupling and bolt, μ=0.16.

Determining the actuating force of the mechanism is based on a direct relationship with the clamping force Q generated by the eccentric. This relationship takes into account the pitch circle radius of the gear fixed on the eccentric, the eccentricity, and considers the friction conditions between the disk surface and the clamping lever, as well as between the bolt which the eccentric and the toothed coupling are rotated on.

This relationship allows for the optimization of the clamping force achieved by the device, ensuring that the force required for operation remains within appropriate and safe limits for both the user and the workpiece so that it results in minimal deformations after the machining process.

$$F_a = \frac{Q(e \sin \beta - \varphi) + \mu R + \mu r}{L} \tag{6}$$

φ – friction angle tgφ=μ.

3. Conclusions

Nowadays competitive market economy, manufacturing companies are driven by three primary goals: enhancing productivity, elevating product quality, and minimizing production expenses. For enterprises specializing in machined parts production, the achievement of these objectives is significantly impacted by the fixturing systems employed during the manufacturing process. Optimal fixturing devices should possess several key characteristics:

- Rapid workpiece clamping capability to reduce setup times
- Straightforward and uncomplicated design
- Cost-effectiveness in both production and maintenance
- Precision in positioning and minimal installation errors

These features ensure that the manufactured parts adhere strictly to the specifications outlined in the production documentation. By incorporating such efficient and accurate fixturing systems, companies can significantly improve their operational efficiency, maintain high-quality standards, and ultimately strengthen their competitive edge in the marketplace.

An innovative clamping device has been engineered, featuring a mechanism with a variable-eccentricity cam. This design falls within the category of rapid clamping systems, offering enhanced efficiency in manufacturing processes. To expand the devices versatility, the team developed a circular eccentric with adjustable stroke and eccentricity capabilities. Key features of the design include:

- variable-eccentricity cam mechanism;
- quick clamping functionality;
- adjustable stroke and eccentricity for increased adaptability.

The research process involved mathematical relationships governing the mechanism behavior. Comprehensive numerical studies are focusing on:

- eccentricity variation;
- stroke length dynamics;
- clamping force analysis;
- the rotational angle of the disk relative to the toothed coupling.

These investigations provide a thorough understanding of the device performance characteristics, enabling optimization for various manufacturing applications. The adjustable nature of the eccentric cam significantly enhances the device applicability across a wide range of workpiece sizes and clamping requirements.

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