

Flexible Fixture Design for the Top and End Surface Processing of NP2_NP4 Cylinder Heads

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Abstract: This paper focuses on the design of fixtures for NP2 and NP4 cylinder heads on a horizontal machining center of flexible machining automatic lines. It began with an analysis of the diagrams of part processing and working procedure which formed the basis for the design of the processing technology scheme, a selection of suitable machine tools, and the setting of processing parameters. Fixtures tailored to the chosen machine tools were then designed to meet the processing requirements. Additional aspects of the project included the design of part drawings, calculation of working time quota, design of auxiliary guides, support clamping, and hydraulic circuits, all aimed at fulfilling practical production requirements.

Keywords: Part processing technology analysis; Calculation of working time quota; Fixture design

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1. Introduction

This project focuses on the design of flexible fixtures for processing the top and end surfaces of NP2 and NP4 cylinder heads. With the rapid development of modern science and technology and the diversification of social demands, multi-variety and small and medium batch production gradually become dominant. Consequently, specialized fixtures, which have long been advantageous in mass production, are gradually revealing their limitations^[1]. Therefore, to adapt to the characteristics of multi-variety and small and medium batch production, combined fixtures, universally adjustable fixtures, and grouped fixtures have been developed. With the advancement of computer numerical control (CNC) technology, CNC machine tools have been increasingly used in the mechanical manufacturing industry, with a parallel growth in their fixtures. The digitization and flexibility of equipment pose higher requirements for the rapid locating and clamping of fixtures. In this regard, fixtures suitable for the production of processing parts are developed, enabling the completion of the top surface processing of NP2_NP4 cylinder heads and the semi-precision processing of camshaft holes in a horizontal machining center, thus improving production efficiency^[2,3].

2. Design criteria

According to the diagrams of the working procedure and processing of workpieces, we propose the following design requirements:

- (1) Fixtures for NP2 and NP4 cylinder heads should be designed, and the processing of the top surface milling, top Holes 180, 181, and 151, and end Hole 760 should be completed.
- (2) Production efficiency needs to be improved to meet production requirements and expand the range of machine tool utilization.
- (3) The machine tool adopts a hydraulic system.
- (4) The clamping and unloading of fixtures should be reasonable, ensuring safe, stable, and reliable clamping, with sufficient space for loading and unloading.
- (5) The structure is simple and reasonable, being convenient for processing, assembly, replacement, and maintenance ^[4-6].

With the production program of 50,000 pieces per year, the allowable maximum production cycle time can be calculated by using relevant formulas. Based on a working time of 250 days/year and 8 hours/day, we the maximum allowable production cycle time is calculated to be as follows:

$$m = \frac{3600H}{N} = \frac{3600 \times 250 \times 8}{50000} = 144s / \text{pieces}$$

According to the calculation above, the maximum processing time of each part after design should be 144 seconds ^[7].

3. Technology analysis

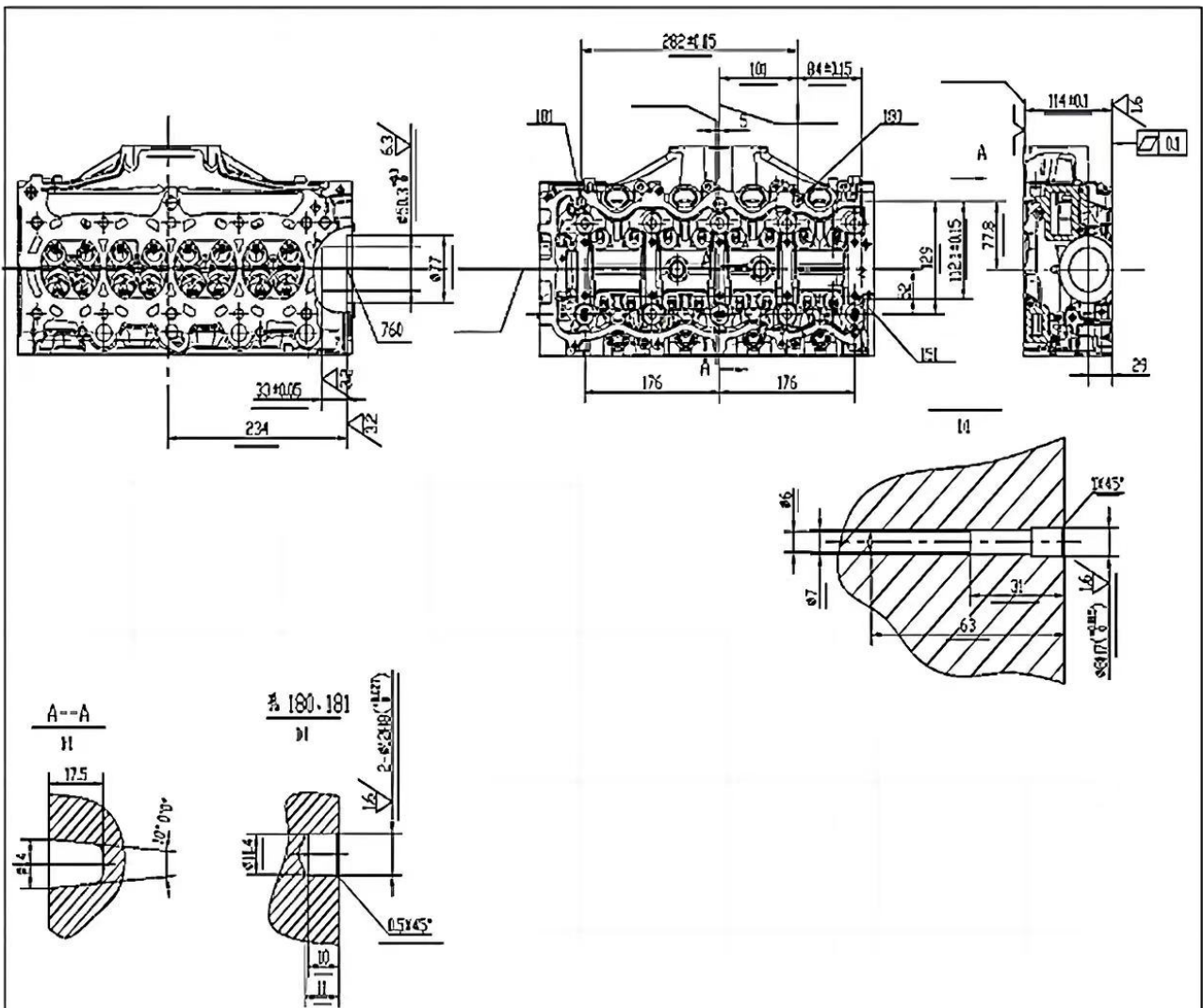
3.1. Technology analysis of parts

Through the analysis of the working procedure diagram of processed parts, this study primarily focuses on designing fixtures for processing the top and end surfaces of NP2_NP4 cylinder heads. In this paper, the fixture design for the NP4 cylinder head at Operation 10 (OP10) is mainly discussed. **Figure 1** depicts the working procedure diagram for the NP4 cylinder head, and the following requirements during processing can be obtained by analyzing this figure ^[8].

- (1) An end milling cutter is used to process the top surface of the cylinder head, ensuring that the locating dimension between the processed top surface and the locating bottom surface is 114 ± 0.05 , the flatness requirement for the processed surface is 0.1, and the roughness is Ra1.6.
- (2) Shallow mating hole processing: shallow Hole 180 is processed on the top surface. The positional accuracy requirement for Hole 180 is not high, but the position of Hole 180 serves as the reference for the subsequent Holes 181 and 151. The two positional dimension references of Hole 180 are the transverse centerline and the longitudinal centerline of the part, respectively. The transverse locating dimension is 101, while the longitudinal locating dimension is 77.8. The final dimension of the hole should be $\phi 12H8^{+0.027}_0$, the hole depth is 10 mm, the hole chamfer is $0.5 \times 45^\circ$, and the surface roughness of the inner wall is Ra1.6 ^[9].
- (3) Shallow mating hole processing
Hole 181 is parallel to Hole 180 in the longitudinal direction. The transverse dimension reference is the centerline of Hole 180, with a locating dimension of 282 ± 0.05 . The dimensional requirements for the hold are $\phi 12H8^{+0.027}_0$, with a depth of 10 mm, a chamfer of $0.5 \times 45^\circ$, and the surface roughness of the inner wall of Ra1.6 (same as Hole 180).
- (4) Deep multi-step mating hole processing: the positional reference of Hole 151 is based on the centerline

of Hole 180. Specifically, the transverse locating dimension is 84 ± 0.15 , and the longitudinal locating dimension is 112.1 ± 0.15 . Hole 151 is divided into three sections, and the final dimensional requirements for the hole are determined, with the radical dimensions decreasing from large to small being $\phi 8H7(^{+0.0}_{0})$, $\phi 7$, and $\phi 6$. The axial dimension takes the top surface for reference, specifically, the dimension of the Hole $\phi 6$ is 63 mm, the dimension of the Hole $\phi 7$ is 31 mm, the dimension of $\phi 8H7(^{+0.0}_{0})$ is 11 mm, the hole chamfer is $1 \times 45^\circ$, and the surface roughness of the inner wall is Ra6.3.

- (5) Enlarging and counterboring holes on the end surface 760, with locating references on the transverse center surface and bottom surface of the part. In terms of position dimensions, the hole axis is located on the transverse center surface of the part and parallel to the bottom surface, and the locating dimension relative to the top surface is 29. Finally, we ensure the radial dimensions from large to small are $\phi 77$ and $\phi 50^{+0.3}$, whose axial dimensions are somewhat complicated: the axial dimension of Hole $\phi 77$ is based on the longitudinal center surface of the part, with a dimension of 234; the axial dimension of Hole $\phi 50^{+0.3}$ is based on the end surface of hole $\phi 77$, with a dimension of 33 ± 0.05 . For both holes, the surface roughness of the inner wall is Ra6.3, and the surface roughness of the end surface is Ra3.2^[10].



Translations of figure contents:

零件中心线	Part centerline
夹具中心线	Fixture centerline
零件三点定位面	Three-point locating surface of the part
孔 151	Hole 151
孔 180、181	Holes 180 and 181
说明	Explanation
一、被加工零件	1. Processed parts
名称	Name
缸盖	Cylinder head
材料	Materials
图号	Figure number
硬度	Hardness
重量	Weight
二、图中背景：定位基准	2. Background in the diagram: locating the basis
定位基面	Locating base
三、凡尺寸下方有“—”者及相应的粗糙度，形位公差为本机床保证，其余尺寸及精度由前工序保证	3. For dimensions with a “—” below and corresponding roughness, the form and location tolerances are guaranteed by the machine tool, while other dimensions and accuracies are ensured by the previous process.

Figure 1. Working procedure of processed parts

3.2. Design of processing technology scheme

This process completes the fixtures for NP2_NP4 cylinder heads, as well as the processing operations of top surface milling, top Holes 180, 181, and 151, and end Hole 760. Workpieces with similar features are processed centrally, accompanied by composite tools for processing (stepped drilling for Hole 151 and enlarging-counterboring integrated tool for Hole 760). This process adheres to the principle of process concentration and adopts a composite processing method to improve processing efficiency. Moreover, it ensures coaxiality for the processing of coaxial holes, thereby enhancing hole processing accuracy. The following processing scheme, as shown in **Table 1**, is adopted ^[11].

Table 1. Processing technology scheme

Processing steps	Processing content
Step 1	Precision milling the top surface of the cylinder head cover
Step 2	Drill Hole 180 and Hole 181 (with identical dimensions) are sized to $\phi 11.6$
Step 3	Ream Hole 180 and Hole 181 are sized to $\phi 12H8^{+0.027}_0$
Step 4	The dimension of step drilling Hole 151 is up to $\phi 6$ and $\phi 7$ by using step drills (special tools)
Step 5	The mating hole of the reaming Hole 151 is sized to $\phi 8H7^{+0.01}_0$
Step 6	The dimension of enlarged and counterbore Hole 760 is up to $\phi 50^{+0.3}_0$ and $\phi 77$ by using an integrated counterbore tool (special tool)

4. Fixture design

4.1. Fixture dimension and locating design

Based on the analysis of **Figure 2**, considering the maximum spatial dimensions of the machining center, the workpiece is suspended on the fixture to complete all the machining operations on the machining center. The dimension of the fixture base plate should be consistent with the workbench, utilizing a 500 mm × 500 mm square base plate, with specific dimensional parameters designed during part design. The height can be less than 800 mm, ensuring smooth installation of the workpiece and a more compact structure. Since the part processing involves two adjacent vertical planes, both with blind hole processing, complete restriction of all six degrees of freedom is necessary to ensure the accuracy and correctness of processing on the workpiece. The locating reference for the workpiece is the bottom plane of the cylinder head, so the locating elements should be set at the contact position with the bottom surface of the cylinder head. To facilitate different fixture designs, the design of flexible fixtures is also considered ^[12].

4.2. Design of flexible fixture

As for the fixture design of NP2_NP4 cylinder heads, the general structure of both cylinder heads is similar, but the distances between location pin holes are different due to the inherent construction of the parts, so it is necessary to design a locating pin scheme with adjustable distance of the pin holes ^[13]. To this end, a part as shown in **Figure 2(a)** is designed. Specifically, the hole for the conical diamond pin placed in the middle of the part is eccentric, and its axis does not coincide with the center of the part itself, as illustrated more intuitively in **Figure 2(b)**.



Figure 2. Front and back views of conical diamond pin base

By rotating the position of the conical diamond pin support, the position of the conical diamond pin can be changed, thus solving the problem of variable pinhole positions. To address clamping issues resulting from changes in workpieces, another indenter is designed for resolution. The position of the oil cylinder remains constant, and varying indenter shapes are employed to tackle the challenge of changing clamping points. A partial scenario diagram of the clamping device is shown in **Figure 3**.

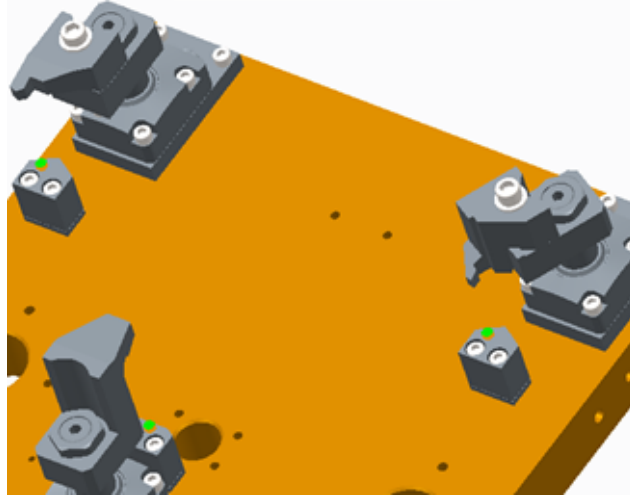


Figure 3. Partial scenario diagram of the clamping device

4.3. Fixture design

The design of flexible fixtures for NP2_NP4 cylinder heads in the automatic flexible machining line in this paper is to meet the requirements of diversified products and mass production. The fixture is required to ensure the locating accuracy of workpieces, ease of operation, safety, reliability, sufficient loading and unloading space, and convenience of adjustment and maintenance. The fixture body adopts a welded structure, combined with a suspension mode for workpiece placement, and reinforced ribs are added to enhance rigidity. The relationship between the fixture body and the directly contacted parts should be emphasized, as well as the mode of connection between the fixture and the machine tool. Consideration is given to the influence of different clamping methods (such as manual, pneumatic, and hydraulic clamping) on fixture design, as well as the specific layout of the tool setting device, connecting elements, and guiding elements. Additionally, the design of the fixture base plate also considers the convenience of chip removal, in which the key aspects are listed below.

- (1) Workpiece processing: The workpiece should be of moderate weight and equipped with auxiliary mechanical arms and guiding devices to facilitate workpiece loading and locating.
- (2) Fixture operation: The fixture operation should be simple, the clamping device should be easy to adjust and maintain, and the device should be safe to use.
- (3) Chip disposal: Chip removal should be easy without interfering with the processing process.
- (4) Locating accuracy: The perpendicularity between the locating surface and the bottom surface should be ensured, thereby guaranteeing the processing quality.
- (5) Form and location tolerance: The form and location tolerance of the fixture body during design should be considered, ensuring the accurate locating and processing of workpieces^[14].
- (6) Material selection: 45 steel is selected according to the processing properties and cost factors of the fixture itself.

Several auxiliary devices are set: limit support plates, auxiliary clamping rotary plates, protective plates, lifting screws, pressure gauges, etc. The cylinder head fixture is shown in **Figures 4 and 5**.

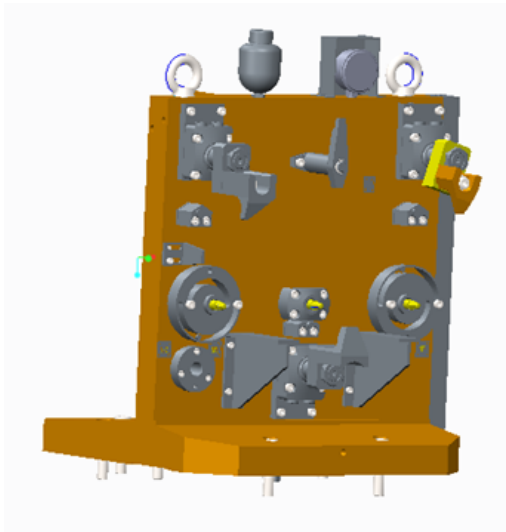


Figure 4. NP4 cylinder head fixture

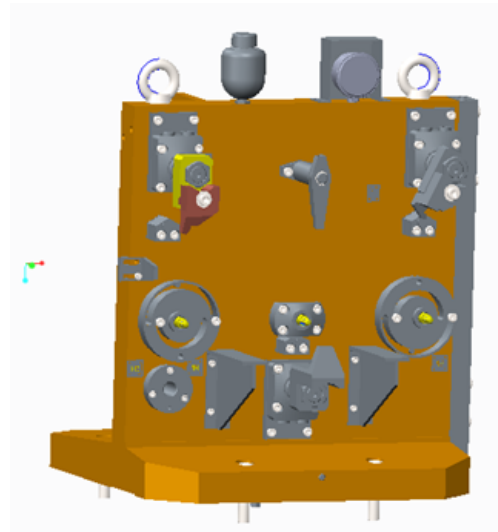


Figure 5. NP2 cylinder head fixture

5. Conclusion

This study establishes a rational and effective regulation for processing technology in mechanical parts, alongside proposing a methodology and steps for fixture design. This contribution provides fresh perspectives, enhances the application of theoretical knowledge in practical problem-solving, nurtures expertise in compiling processing technology regulations and fixture design, and fosters critical thinking and innovation in addressing challenges.

Disclosure statement

The authors declare no conflict of interest.

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