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DESIGN AND MANUFACTURE OF AUTOMATIC COLLET CLAMPING SYSTEMS FOR SPROCKET-CAM HANDLING ON CNC LATHES

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ABSTRACT

A proper clamping system reduces clamping time, enhances process repeatability, and increases flexibility in product replacement, significantly improving a company's competitiveness in terms of time and cost. The chamfering process for the KN-00XX series sprocket-cam product at PT. Toshin Prima Fine Blanking faced challenges due to the absence of a clamping device capable of quickly, securely, and automatically accommodating the contour clamping process while ensuring a long service life. To address this, optimizing existing spare parts, such as collets and pneumatic mechanisms, was essential to minimize manufacturing costs. This research aimed to design and evaluate a chuck tool that reduces product installation time and optimizes component stock to lower manufacturing costs. The study applied the VDI 2221-QFD method, where VDI 2221 identified functional requirements and user needs, while QFD assessed these needs and prioritized them for cost-effective design. Finite Element Analysis (FEA) was used to evaluate the design's strength and performance. The resulting pneumatic collet clamping design showed an actual von Mises stress value of 1,044,029 kN/m², safely below the maximum allowable value of 1,080,000 kN/m². FEA analysis indicated a collet displacement of 0.37 mm, close to the actual measured value of 0.42 mm, meeting clamping requirements. The estimated manufacturing cost of the pneumatic collet clamping system was Rp. 1,472,769. Actual trials demonstrated an average cycle time of 9.8 seconds, confirming that the pneumatic collet clamping design is safe, efficient, and fulfills specified requirements.

Keywords: clamping system; pneumatic collet; VDI 2221; FEA; cost optimization

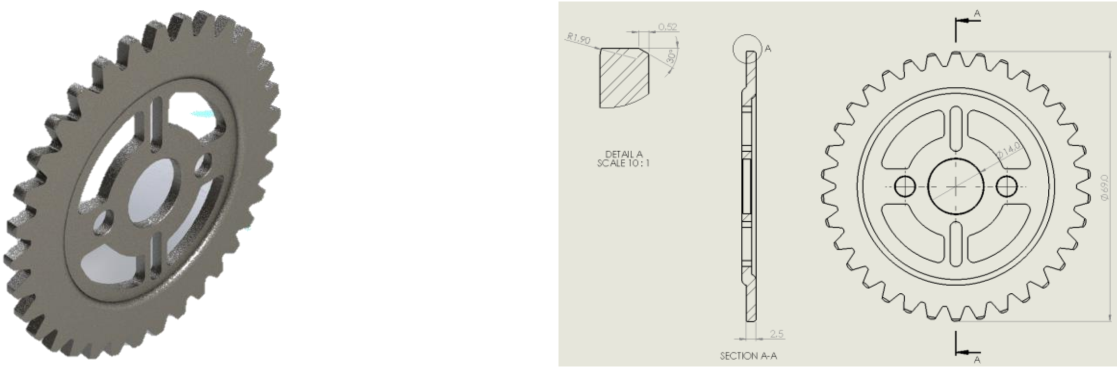
ABSTRAK

Sistem pencekaman yang tepat mengurangi waktu pencekaman, meningkatkan pengulangan proses, dan meningkatkan fleksibilitas dalam penggantian produk, sehingga secara signifikan meningkatkan daya saing perusahaan dalam hal waktu dan biaya. Proses chamfering untuk produk sprocket-cam seri KN-00XX di PT. Toshin Prima Fine Blanking menghadapi tantangan karena ketiadaan alat penjepit yang mampu mengakomodasi proses pencekaman kontur dengan cepat, aman, dan otomatis sekaligus memastikan masa pakai yang lama. Untuk mengatasi hal ini, mengoptimalkan suku cadang yang ada, seperti collet dan mekanisme pneumatik, sangat penting untuk meminimalkan biaya produksi. Penelitian ini bertujuan untuk merancang dan mengevaluasi alat pencekam yang dapat mengurangi waktu pemasangan produk dan mengoptimalkan stok komponen untuk menurunkan biaya produksi. Penelitian ini menerapkan metode VDI 2221-QFD, di mana VDI 2221 mengidentifikasi persyaratan fungsional dan kebutuhan pengguna, sementara QFD menilai kebutuhan ini dan memprioritaskannya untuk desain yang hemat biaya. Analisis Elemen Hingga (FEA) digunakan untuk mengevaluasi kekuatan dan kinerja desain. Desain pencekaman collet pneumatik yang dihasilkan menunjukkan nilai tegangan von Mises aktual sebesar 1.044.029 kN/m², jauh di bawah nilai maksimum yang diijinkan yaitu 1.080.000 kN/m². Analisis FEA menunjukkan perpindahan collet sebesar 0,37 mm, mendekati nilai pengukuran aktual 0,42 mm, memenuhi persyaratan pencekaman. Perkiraan biaya produksi sistem pencekaman collet pneumatik adalah Rp. 1,472,769. Uji coba aktual menunjukkan waktu siklus rata-rata 9,8 detik, yang menegaskan bahwa desain pencekaman collet pneumatik aman, efisien, dan memenuhi persyaratan yang ditentukan.

***Kata Kunci**: sistem pencekaman; collet pneumatik; VDI 2221; FEA; optimalisasi biaya*

1. Introduction

PT. Toshin Prima Fine Blanking is an automotive component manufacturing company that produces spare parts for cars and motorbikes. PT. Toshin Prima Fine Blanking produces engine parts, muffler/exhaust system parts, brake parts, heat cover parts, etc. PT. Toshin Prima Fine Blanking also produces the KN-00XX series sprocket-cam, shown in Figure 1a. After blanking process, KN-00XX series sprocket-cam products require a further chamfering process on the outer diameter profile. The chamfering process is carried out on a CNC lathe. Lathe operations are the most commonly used machining operations to produce cylindrical parts [1]. Lathe machining is the most widely used industrial manufacturing process due to its high flexibility and the quality that can be achieved [2]. Figure 1b shows a visualization of the sprocket-cam and parts that require a chamfering process on a lathe.



(a) (b)

Figure 1. KN-00XX series sprocket-cam (a) Product Illustration and (b) Product Dimensions
(Source: research documentation, 2024)

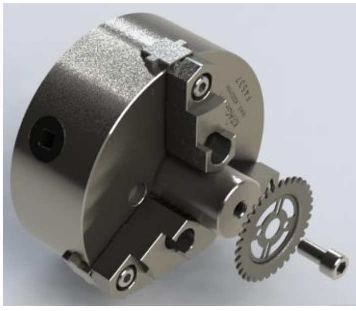


Figure 2. Illustration of CNC Lathe Chuck and Additional Attachments
(Source: research documentation, 2024)

At this stage, there were difficulties in the gripping process of KN-00XX series sprocket-cam products due to a lack of gripping area. Figure 1b shows the product contour with a material thickness of 2.5 mm, an external diameter of 69 mm, and an internal hole diameter of 14 mm, as well as the embossed contour in the middle. These dimensions and contours make it challenging to clamp using a three-jaw chuck, necessitating a clamping attachment to simplify the machining process [3,4]. Chavan et al., 2018 [1] emphasized the importance of clamps for stabilizing workpieces during machining. A three-jaw chuck, a common component for gripping workpieces in various turning applications, is frequently used on CNC lathes [3,5]. Engineers at PT. Toshin Prima Fine Blanking identified the internal hole diameter of 14 mm as a safe area suitable for gripping. To address this, the production department created additional attachments in the form of shafts with threaded holes (see Figure 2). The clamping process involves attaching the product to the shaft and manually locking it with an M14 bolt, while the release process is performed in reverse.

However, this clamping method has several limitations. Observations reveal that the average time required for product installation and removal is 37 seconds, which constitutes 86% of the total chamfering process time of 43 seconds. The use of inappropriate tools hampers operators, making the process inefficient [6]. Additionally, the threaded holes in the attachment wear out quickly, rendering the tool unsuitable for the long-term production demands of KN-00XX series sprocket-cam products, which reach 40,000 pieces per month. Consistent quality requires uniform treatment during manufacturing [4]. Furthermore, bolts frequently loosen during lathe machining due to worn threads, compromising the grip and increasing the likelihood of loose and defective products [5]. This also poses a safety hazard to operators [3].

It is necessary to develop a clamping device design for KN-00XX series sprocket-cam chamfering process. Clamping devices are required to grip product perfectly, have efficient installation and removal times, and have a long service life. PT. Toshin Prima Fine Blanking determines the use of pneumatic systems in clamping devices design to support the implementation of automation systems in production. Company needs development to increase productivity and process efficiency. This has a significant effect on competitiveness and operational costs. The time necessary to properly clamp, align, and set up the stock can significantly affect production especially for parts with short cycle times [7]. Time efficiency in the product clamping process on the machine is expected to reduce the overall process time significantly. Continuous process improvement requires preparation and realization so that the production cycle runs with short time and minimal costs [8]. Engineering division tries to optimize existing component stock to reduce manufacturing cost of clamping devices. This research was carried out on a CNC lathe - CK 6132/500 series - which has supporting components for clamping process with pneumatic system. They are collets (Figure 3a), pneumatic valves, and rotary joints (Figure 3b) to transmit wind pressure. Many lathes are equipped with a collet clamping mechanism [9]. In general, there is no commercially available off-the-shelf clamping system that is compatible with this machine tool and product dimension, therefore it was necessary to design a custom clamping system [7]. On the market there is no piston rod that has a diameter that matches the stock collet components used in this design. The demands of automatic working mechanisms, the obligation to utilize stock components, and unavailability of clamp components on the market are limitations in clamping devices design.

(a)

(b)

Figure 3. Component: (a) Collet Clamp; and (b) Pneumatic Valve and Rotary Joint Set
(Source: PT. Toshin Prima Fine Blanking document, 2024)

This research employs a design approach tailored to industrial demands and the availability of supporting components at PT. Toshin Prima Fine Blanking. The design process utilizes Computer-Aided Design (CAD), which enables precise planning, modeling, and evaluation of product models before production [10]. CAD enhances design efficiency and ensures consistent 3D modeling [5]. Subsequently, Computer-Aided Engineering (CAE) analysis was performed to simulate the design, validating the strength and functionality of the clamping device [11]. By integrating CAD and CAE, the design process minimizes errors, accelerates development, and delivers accurate analytical outcomes [10].

According to Kolte and Salunke [3], collet chucks with pneumatic systems offer an alternative clamping solution by employing mechanical force to secure parts during machining. Pneumatic clamps are widely used in air-actuated mechanisms for quick and economical operations [1]. Several studies highlight advancements in collet-based clamping systems. Kolte and Salunke [3] redesigned collet chucks, achieving improvements in cycle time, production speed, and rejection costs. Redko et al. [9] explored the manufacturing process of collet clamps, while Soriano et al. [12] analyzed the impact of clamping force on collet deformation. Rață et al. [13] evaluated collet functionality using Model-Based Engineering (MBE), and Alquraan et al. [14] examined gripping mechanisms for high-speed cutting. These studies emphasize the versatility and efficiency of pneumatic collet clamps, particularly for small or uniquely contoured workpieces [7].

Pneumatic clamps are expected to streamline product installation and removal, enabling efficient and safe production of up to 40,000 units per month. Automation offers additional benefits, such as flexible clamping options, improved repeatability, and faster production switchover [7]. Although hydraulic clamping systems are available, they are incompatible with the machinery at PT. Toshin Prima Fine Blanking due to higher production and maintenance costs [2]. Pneumatic systems remain a viable solution, delivering quick-action clamping mechanisms suited to the company's operational needs and cost efficiency.

Several studies use Verein Deutscher Ingenieure method (VDI 2222, VDI 2221, etc.) such as research conducted by Widodo and Putri [4], Komara and Rinaldy [15], Heras et al. [16], Syaripa et al. [17], Rido and Upara [18], Saeppudin and Fadillah [19], Dermawan and Wibowo [20], and Priyanggalaa et al. [21]. According to Rido and Upara [18], designing using VDI method solves design problems by optimizing the system, materials, technology, and prioritizing economic factors. One method used to analyze product quality improvement is Quality Function Deployment (QFD) [22]. Design using QFD was carried out by Dian and Sucipto [22], Ginting et al. [23], and Ginting et al. [24]. QFD is applied in many studies because of its effectiveness in quality management and product development [23].

Finite Element Analysis (FEA) simulation is used to analyze design quality. FEA research conducted by Croccolo et al.[2], Simanjuntak and Sinaga [6], Komara and Rinaldy [15], Heras et al. [16], and Rido and Upara [18]. FEA evaluation is useful for knowing product functionality and the product's ability to withstand loads based on the material it is made of [6]. With the finite element method, the displacement for a range of clamp force variations can be determined [8].

The research aims to produce a new clamping device design for clamping the KN-00XX series cam sprocket in order to: 1) shorten the product installation time on the clamping device; and 2) optimize the use of existing component stock to minimize manufacturing costs. This research is important for the development of automatic clamping technology in the industrial sector. This research is expected to become an additional reference in the design of new pneumatic collet clamping systems for the manufacturing industry, by validating the design through simulations in engineering software. The novelty of this research is 1) applying a combination of VDI and QFD methods in the design process; 2) using the FEA method to test the strength and displacement of clamping device components; and 3) apply internal clamping using collets.

2. Methods

The engineering process in this research encompasses product identification, layout design, machining analysis, strength analysis, and economic evaluation [21]. The research methodology is illustrated in Figure 4. The study begins by identifying user needs and work system requirements, which are then transformed into a functional structure following the VDI 2221 method. VDI 2221 is employed to address design challenges and optimize raw material usage and production processes [20].

Subsequently, the QFD method is utilized to evaluate user needs and prioritize their importance, ensuring the resulting work system design aligns with actual conditions and production demands. FEA using SolidWorks 2023 software is then applied to examine the mechanical behavior of the structure under load. FEA effectively predicts and optimizes the performance of lattice structures prior to their physical realization [25].

The next phase involves cost calculations for machining, material procurement, and the purchase of standard components. Finally, validation testing is conducted using a CNC lathe machine (CK 6132/500 series) to assess the chuck tool's compatibility with the machine, its gripping capability on the KN-00XX series sprocket-cam, and the actual time required for the product clamping process.

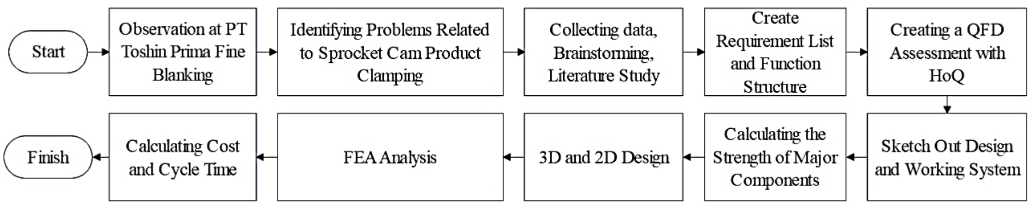


Figure 4. Research Methodology
(Source: research documentation, 2024)

Materials

The collet clamping design incorporates S45C and SUP9 materials, each selected for its specific properties and suitability in different components of the system. S45C, a medium-carbon steel, is commonly utilized as a raw material for manufacturing general-purpose components due to its excellent machinability, moderate strength, and cost-effectiveness. On the other hand, SUP9, categorized as a spring steel, is specifically chosen for components requiring superior elastic resistance and durability. This material is applied to the collet and spring components in the design, ensuring reliable performance under repeated mechanical stress and maintaining the precision required for clamping operations. Detailed mechanical characteristics of these materials, including tensile strength, hardness, and elasticity, are provided in Table 1 for reference.

Table 1. Strength of SUP9 and S45C Materials

Properties	Value (N/m2)	
	SUP9	S45C
Yield strength	1,08 x 109	0,53 x 109
Tensile strength	1,225 x 109	0,63 x 109
Elastic modulus	1,9 x 1011	2,05 x 1011

Requirement List and Functional Structure

The requirement list, developed through observations and user interviews, is categorized into two levels: Demand (*D*), which are essential components, and Wish (*W*), which are desirable but not mandatory. This list, along with component availability and desired work systems, is organized into a functional structure to model the product's work process. The functional structure identifies subfunctions and their tasks based on the flow of energy, material, and signals, ensuring the system operates effectively [20]. By accounting for machining conditions, the clamping system enhances quality, reduces time, and minimizes costs [26]. The functional structure is illustrated in Figure 5.

Table 2. Requirement List for Clamping Device

	Requirement List
	Geometry
D	Capable to clamp the product with spesification : 69 mm of external Diameter, 14 mm of internal diameter, 2.5 mm of thickness, 0.056 kg of product weight.
D	Space available for clamping device : L x W x H : 500 mm x 300 mm x 400 mm.
	Energy
D	5-6 bar of air pressure.
	Material
D	S50C/S45C material for clamping device (company requirement). Spring type material for collet.
	Production
D	Adapt spare parts that are already available in the company.
	Operation
D	Minimize product defects due to clamping.
W	The setting process can be carried out independently by the operator.
D	Overall process cycle time is less than 25 seconds.
	Cost
W	Minimum manufacturing and maintenance cost.

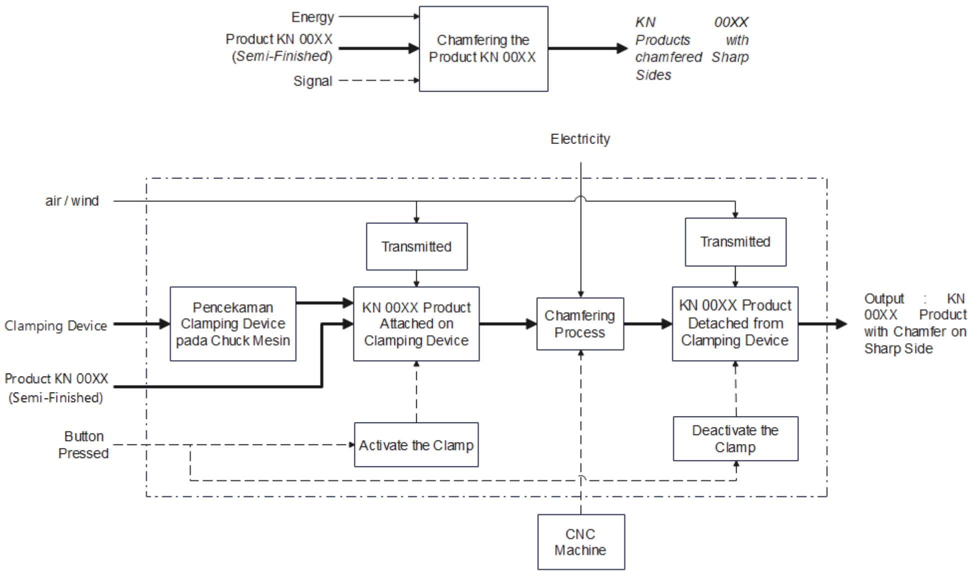
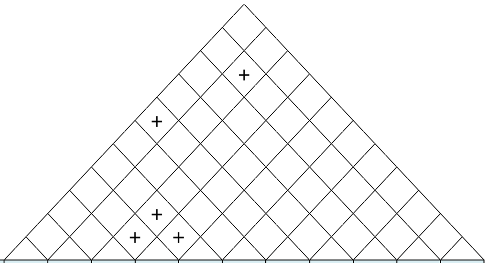


Figure 5. Functional Structure of Collet Clamping
(Source: research documentation, 2024)

Quality Function Deployment (QFD)

Quality Function Deployment (QFD) is an effective methodology for enhancing product quality by systematically understanding user needs and translating them into technical characteristics that guide the production process [22,24]. The Kano-QFD model is particularly useful in this context, as it facilitates the identification and prioritization of user requirements by categorizing them into basic, performance, and excitement attributes. These needs are then converted into technical specifications, aiding in the development of function structures and the identification of critical components within functional areas [23]. By aligning user expectations with design features, the QFD process ensures that the product not only meets but often exceeds customer satisfaction.

In the collet clamping design process, the planning phase involves constructing a House of Quality (HoQ), a central tool in QFD. The HoQ is a structured matrix that maps user quality attributes against design constraints, revealing the interrelationships between user needs and technical solutions [22,24]. This mapping helps designers identify priority areas for improvement while ensuring a balanced approach to cost, functionality, and performance. The use of HoQ in this research highlights its role in translating user-centric attributes into actionable design specifications, ensuring that the resulting clamping system aligns with both user requirements and operational objectives. The HoQ developed for the collet clamping design is illustrated in Figure 6, showcasing how user feedback is systematically incorporated into the design framework to produce high-quality, reliable products.



Row #	Relative Weight	Customer Importance	Maximum Relationship	Customer Requirements (Explicit and Implicit) / Functional Requirements	Air pressure on pneumatic	Flexibility of collet with spring steel material	Manufacturing cost	Standart part cost	Material cost	There is a pneumatic system activation button	Cross-sectional diameter dimension of wind at the piston pin	Dimension length of piston pin	Maximum tool space	Diameter of collet	Tool weight
				Column #	1	2	3	4	5	6	7	8	9	10	11
1	15,79%	9	9	Capable of gripping KN 00XX products with dimensions: ⌀ external 69 mm; ⌀ internal 14 mm;		●								○	
2	15,79%	9	9	Capable of gripping KN 00XX products with product weight: 0.056 kg	●	●									
3	15,79%	9	9	Capable of gripping KN 00XX products with JSC 270C material without any defects	●	○								○	
4	15,79%	9	9	Smooth gripping process	●	○					●	○	▽		
5	5,26%	3	9	Using spare parts that are already available in the company				●							
6	5,26%	3	9	Minimum manufacturing cost			●	●	●						
7	15,79%	9	9	Cycle time < 25 second	○					●					
8	10,53%	6	9	Operations are conducted independently						●					○
				Target	6 bar	0,32 - 0,40 mm	< Rp. 3.000.000	< Rp. 200.000	< Rp. 500.000	✓	Minimum ⌀ 31 mm	Maximum 40 mm	Maximum 500 x 300 x 400 (mm)	⌀ 13,7 mm	4 - 5 kg
				Max Relationship	9	9	9	9	9	9	9	3	1	3	3
				Technical Importance Rating	4,74	3,79	0,47	0,95	0,47	2,37	1,42	0,47	0,16	0,95	0,32
				Relative Weight	29%	24%	3%	6%	3%	15%	9%	3%	1%	6%	2%

Figure 6. House of Quality for Collet Clamping
(Source: research documentation, 2024)

Design Calculation

This calculation formula is used to calculate critical components in the design that will be used. Calculations are carried out to ensure the mechanical strength of design and the fulfillment of user needs.

Clamping Force

Clamping force (*F*) is the force required by the clamp to grip an object. Clamping force affects to accuracy of the workpiece position, deformation potential of workpiece, and increases production speed [26]. The clamping force is measured in Newtons (N). The clamping force is calculated using Equation 1. Diameter (d_1) refers to the cross-sectional size of the cylinder. Pressure (*P*) refers to the amount of force per unit area. The value of *R* is the magnitude of the friction force that occurs between the piston wall and the pneumatic cylinder. This is in accordance with Tocut et al., 2021 [8] which states that the clamping force calculation is influenced by the cylinder construction and air pressure in the system.

$$F = ({d_1}^2 \times P \times 7{,}86) - R \quad (1)$$

Cross-Sectional Area of Pneumatic Cylinder

A pneumatic cylinder is a mechanical device that uses air pressure to produce linear (back-and-forth) movement. The optimal design of the pneumatic cylinder geometry in the clamping collet will increase the durability of the clamping collet, improve the contact conditions of the collet with the spindle and rod, and reduce the stress concentration at the collet tip [9]. The Cross-Sectional Area of the pneumatic cylinder determines the amount of clamping force that must be adjusted to the product size and collet material properties to increase clamping accuracy [26]. Pneumatic cylinders certainly have a cross-sectional area which can be calculated using Equation 2.

$$A_{\text{cylinder}} = \frac{F}{P} \quad (2)$$

Pneumatic Cylinder Filling Speed

There is a close relationship between the cross-sectional area of the piston cylinder and the air pressure. It was shown that the clamping force increases when increasing the pressure and diameter of the pneumatic cylinder [8]. Filling speed of the pneumatic cylinder (*Q*) affects the performance of the pneumatic system. Filling speed of the piston cylinder varies depending on several factors, such as cylinder size, available air pressure, cross-sectional area of delivery medium (A_{pipe}), air velocity (v_{air}), etc. Filling speed of the pneumatic cylinder is calculated using Equation 3.

$$Q = A_{\text{pipe}} \times v_{\text{air}} \quad (3)$$

Cycle Time

Cycle time (*t*) is time that required to complete a process. Cycle time in pneumatics focuses on the time required for cylinder piston to move linearly (*h*) resulting from the wind pressure acting on the system. Cycle time can be calculated using Equation 4. One of the challenges of the machining process lies in re-clamping and repositioning components before resuming the machining process, which affects the overall production cycle time. Accurate re-clamping is a difficult task so requires a long time to reposition and adjust the grip force to avoid deflection of the object when rotating [26].

$$t = \frac{(A_{\text{cylinder}}.\,h)}{Q} \quad (4)$$

3. Result and Discussion

Figure 7 illustrates the initial concept of the collet clamping tool. The working system operates as follows: high-pressure air enters through the area marked by an arrow in Figure 7a, pushing the pneumatic cylinder piston forward. This movement causes the piston rod to advance, which in turn pushes the collet forward, resulting in displacement at the collet's end. This displacement allows the collet to grip the product securely at its internal diameter, as shown in Figure 7b.

Using a collet as a chuck offers several advantages. The clamping force is strong and rigid, ensuring a secure grip on the product due to minimal axial and radial forces exerted by the spindle [9]. Additionally, the collet chuck enables a fast, accurate, and efficient gripping process, making it highly suitable for specific applications [3]. The system also reduces risks to the operator while offering lower manufacturing and maintenance costs [2].

Design Calculation

Pneumatic cylinders are designed based on the force required in the working system. A large force is required to cause the collet to be displaced. In this section, collet dimensions are calculated to determine the dimensions of the pneumatic cylinder and the actual thrust force produced by the cylinder. The collet component stock has an inside diameter (d_1) of 10.1 mm (0.0101 m), shown in Figure 8. This size is used as a reference for calculating the thrust force (*F*) on the pneumatic cylinder shown in Figure 7b.

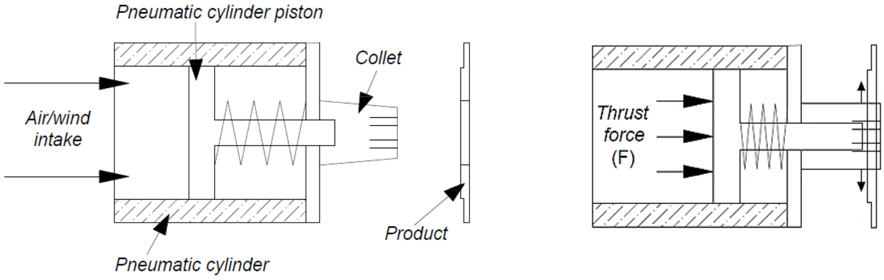


Figure 7. Sketches of (a) The Initial Concept and (b) How Collet Clamping Works
(Source: research documentation, 2024)

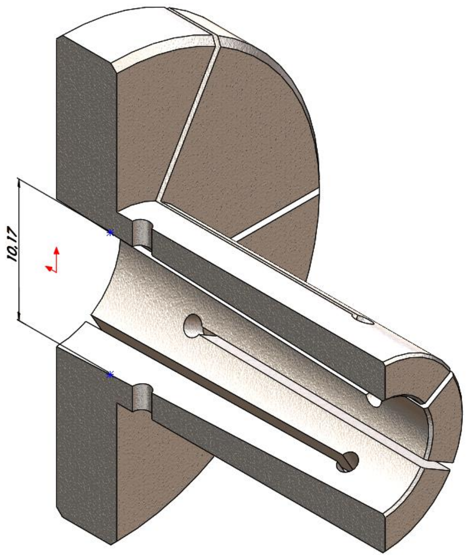


Figure 8. Internal diameter of the collet
(Source: research documentation, 2024)

The value of R in this study is 0.05 of F value. The constant air pressure (P) generated by the company's compressor is 6 bar (600000 N/m^2). The magnitude of pneumatic cylinder thrust force is calculated using Equation 1.

$$F = ({d_1}^2 \times P \times 7{,}86) - R$$
$$F = 0.0101^2 \times 600000 \times 7.86) - 0.05 \times F$$
$$F = 458.171 \text{ N}$$

The pneumatic cylinder thrust force (F) is used to determine the minimum piston cylinder diameter (d_2), which is directly facing high pressure air from compressor. The piston cylinder diameter (d_2) is calculated using Equation 2.

$$A_{\text{cylinder}} = \frac{F}{P}$$
$$\frac{1}{4}\pi \times {d_2}^2 = \frac{458.171}{600000}$$
$$d_2 = 0.03114 \text{ m}$$
$$d_2 = 31.14 \text{ mm}$$

Based on calculation results, the minimum piston cylinder diameter (d_2) is 31.14 mm. This minimum dimension of the piston cylinder required to produce a force (F) of 458.171 N. PT. Toshin Prima Fine Blanking has stock piston cylinders with a diameter of 51.2 mm. This stock can be used because its size is larger than the minimum requirement (31.14 mm), as well as saving costs. Thus, the design uses an actual piston cylinder (d_2) of 51.2 mm, which has a cylinder cross-sectional area ($A_{\text{actual cylinder}}$) of 0.002057 m^2. This actual cylinder cross-sectional area is used to calculate the actual (F_{actual}) thrust force on pneumatic cylinder.

$$F_{\text{actual}} = A_{\text{actual cylinder}} \times P$$
$$F_{\text{actual}} = 0{,}002057 \times 600000$$
$$F_{\text{actual}} = 1234.698 \text{ N}$$

Furthermore, the actual thrust force (F_{actual}) was used for collet strength analysis with FEA. Theoretical calculations were carried out to support and strengthen the results of CAE simulations [11]. CAE simulation in this study used FEA. Simulation with general engineer software was conducted to validate the functional design [21].

The filling speed of pneumatic cylinder determines the cycle time of gripping process. The faster the air fills the cylinder, the minimum cycle time will be. Diameter of connecting pipe between compressor and pneumatic cylinder affects the air flow speed. In this section, the cycle time of product grip-release process is calculated based on available pipe size. The connecting pipe used has an inner diameter of 0.5 inch, or a pipe cross-sectional area (A_{pipe}) of 0.000127 m^2. The compressor pressure of 6 bar produces a high pressure air speed (v_{air}) of 0.72 m/s [19]. The amount of filling speed (Q) of the pneumatic cylinder is calculated using Equation 3.

$$Q = A_{\text{pipe}} \times v_{\text{air}}$$
$$Q = 0.000127 \times 0.72$$
$$Q = 0.0000912\ \text{m}^3/\text{s}$$

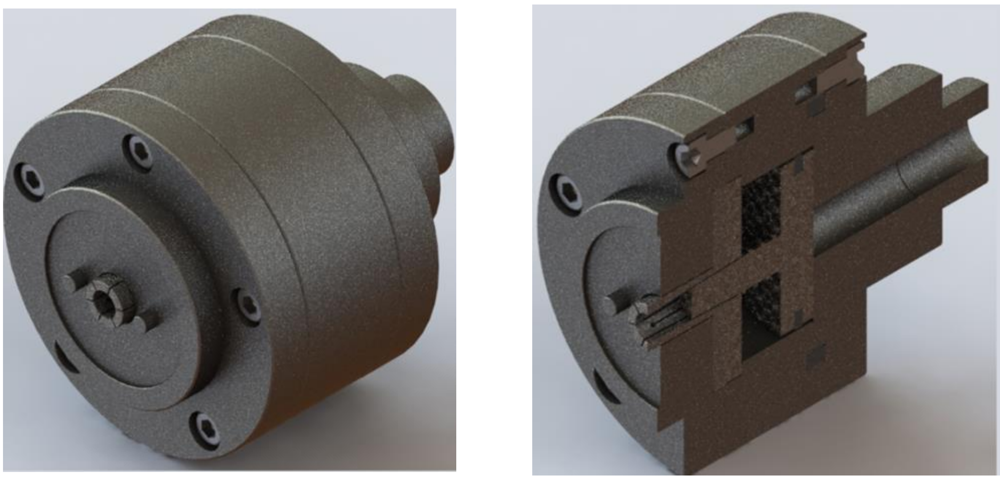
Furthermore, cycle time (t) of gripping process is calculated according to cross-sectional area of pneumatic cylinder ($A_{\text{actual cylinder}}$) and the piston stroke length (h) versus the filling speed (Q). Cycle time is calculated with Equation 4. Thus, the cycle time of grip-release process is 0.226 seconds each.

$$t = \frac{(A_{\text{actual cylinder}} \times h)}{Q}$$
$$t = \frac{(0.002059 \times 0.01)}{0.0000912}$$
$$t = 0.226\ \text{second}$$

Design Results

The functional structure analysis, House of Quality, and main component dimension calculations led to the design of the collet clamping tool, shown in Figures 9a and 9b. The design was created using SolidWorks software, which enables the presentation of a 3D model as a functional product [25]. Figure 9a presents the complete 3D visualization of the collet clamping design, while Figure 9b shows a section cut, providing a detailed view of the tool's composition. Figure 10 depicts a 2D section view with component identification.

The clamping mechanism operates by air pressure pushing the pneumatic cylinder piston towards the collet, causing the collet tip to expand and grip the product. When air pressure is released, the spring provides back pressure, retracting the piston and causing the collet tip to shrink, releasing the product. O-rings are used to prevent air leakage between the cylinder piston and middle chuck, with the P46 series O-ring (46 mm diameter) and a square-ring-seal (334 series, 66.04 mm inner diameter) ensuring an airtight seal between the bottom and middle chuck. An M14 threaded hole in the bottom chuck connects the collet clamping tool to the lathe machine's pneumatic valve system, which is linked to the CNC lathe machine spindle - CK 6132/500 series. The air is supplied through a high-pressure air pipe connected to the machine by a compressor hose. The upper chuck limits the piston stroke and features a pin to assist in product positioning.



(a) (b)

Figure 9. Design Results (a) Overall Isometric View and (b) Section Isometric View
(Source: research documentation, 2024)

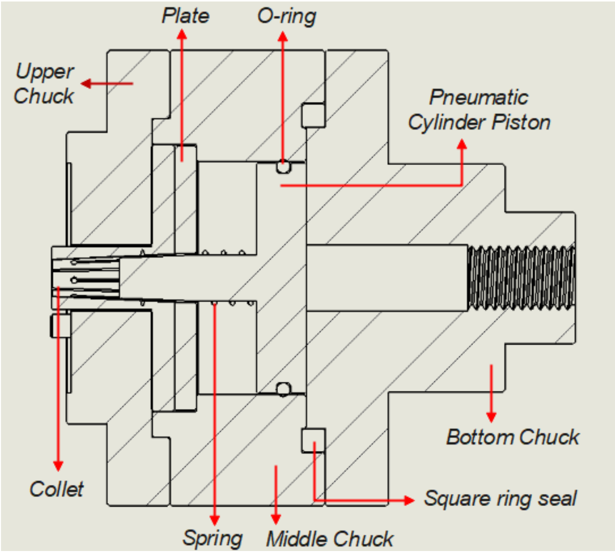


Figure 10. Section View of the Collet Clamping Parts
(Source: research documentation, 2024)

Finite Element Analysis (FEA)

Simulation analysis is used to determine the von Mises stress and static strain displacement to assess the strength of components [18]. FEA was conducted to test the stress limits experienced by the collet during loading. FEA was applied to the spring steel (SUP 9) collet component, with external dimensions of 51.2 mm in diameter and an internal diameter of 13.7 mm. The FEA process is shown in Figure 11.

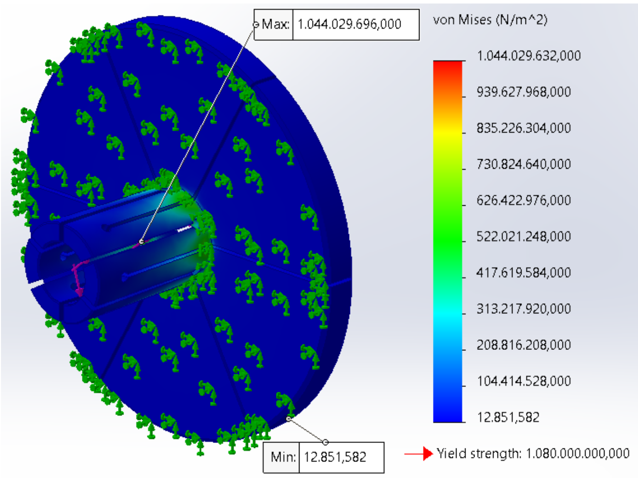


Figure 11. Collet Stress Analysis
(Source: research documentation, 2024)

The actual (F_{actual}) thrust force of 1234.698 N was used in FEA analysis as a loading reference on the collet. The stress analysis results show that the maximum stress received by collet is 1,044,029 kN/m^2, with a maximum allowable tensile stress value of 1,080,000 kN/m2. Thus, the collet design is safe to use because it has a safety factor value of 1.03. The safety factor value is small because the collet is required to be flexible. Flexibility is needed so that the collet can be displaced during the product clamping process. FEA is also used to test collet flexibility to determine the displacement value that occurs during loading. The design is analyzed and validated using engineering software (FEA) to ensure the deflection capability that occurs [15]. External diameter of collet is 13.7 mm, while the internal diameter of product to be clamped is 14 mm. In this way, it is hoped that the collet tip can be displaced by 0.32 mm to 0.4 mm, so it can grip perfectly. Collet chucks are suitable for gripping workpieces with a diameter smaller than 3 inches [3]. FEA analysis for collet displacement shown in Figure 12. The results of displacement analysis show that actual thrust force (F_{actual}) exerted on collet produces a displacement at collet tip of 0.37 mm which is indicated by red colored part.

The displacement of the collet meets the specified requirements, with values ranging from 0.32 mm to

0.40 mm. FEA results confirm that the design parameters, including a pneumatic cylinder with a diameter of 51.2 mm and an air pressure of 6 bar, are sufficient for the intended application. Additionally, the use of a SUP9 collet with an external diameter of 13.7 mm proves to be viable for the collet clamping construction. These findings demonstrate that the selected components provide the necessary performance and reliability for the clamping system, ensuring the required displacement and strength during operation. The successful simulation results validate the design and confirm its suitability for practical use in the specified application.

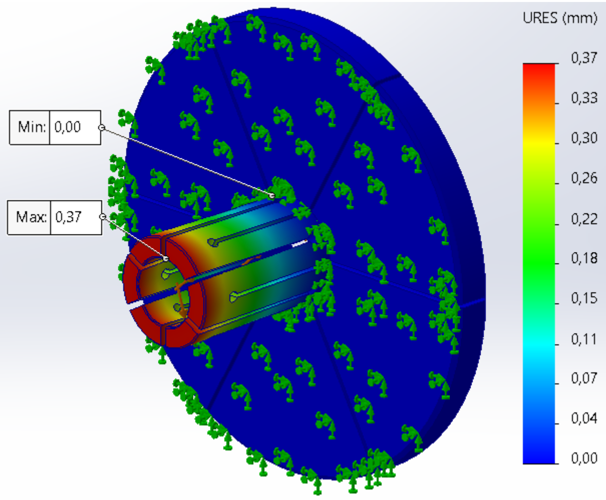


Figure 12. Collet Displacement Analysis
(Source: research documentation, 2024)

Manufacturing Cost

The design plan components are detailed in bill of materials (BOM), as shown in Figure 13. Bill of materials consists of part name, material type, and quantity required. Bill of materials for designing collet clamping is presented in Table 3. In Table 3 there are 5 parts that are not included in company stock so machining processes are required. All collet clamp manufacturing costs are shown in Table 4.

Table 3. Details of Bill of Materials Table

Item	Part	Material	Qty.
1	Upper Chuck	S50C	1
2	Plate	S45C	1
3	Piston Silinder	S45C	1
4	Middle Chuck	S50C	1
5	Bottom Chuck	S50C	1
6	Collet	SUP9	1 (stock)
7	Spring	SUP9	1 (stock)
8	Square Ring Seal	Rubber P56	1 (stock)
9	O-Ring	Rubber 334	1 (stock)
10	Screw	M6 x 35 mm	10 (stock)

Table 4. Calculation of Collet Clamping Cost

Part	Process	Cost
Upper Chuck	Turning Milling Hardening	Rp. 291,416,-
Plate	Turning Hardening	Rp. 27,275,-
Piston Silinder	Turning Hardening	Rp. 125,331,-
Middle Chuck	Turning Milling Hardening Hardchrome	Rp. 633,272,-

Bottom Chuck	Plating Turning Milling Hardening	Rp. 395,475,-
TOTAL		Rp. 1,472,769,-

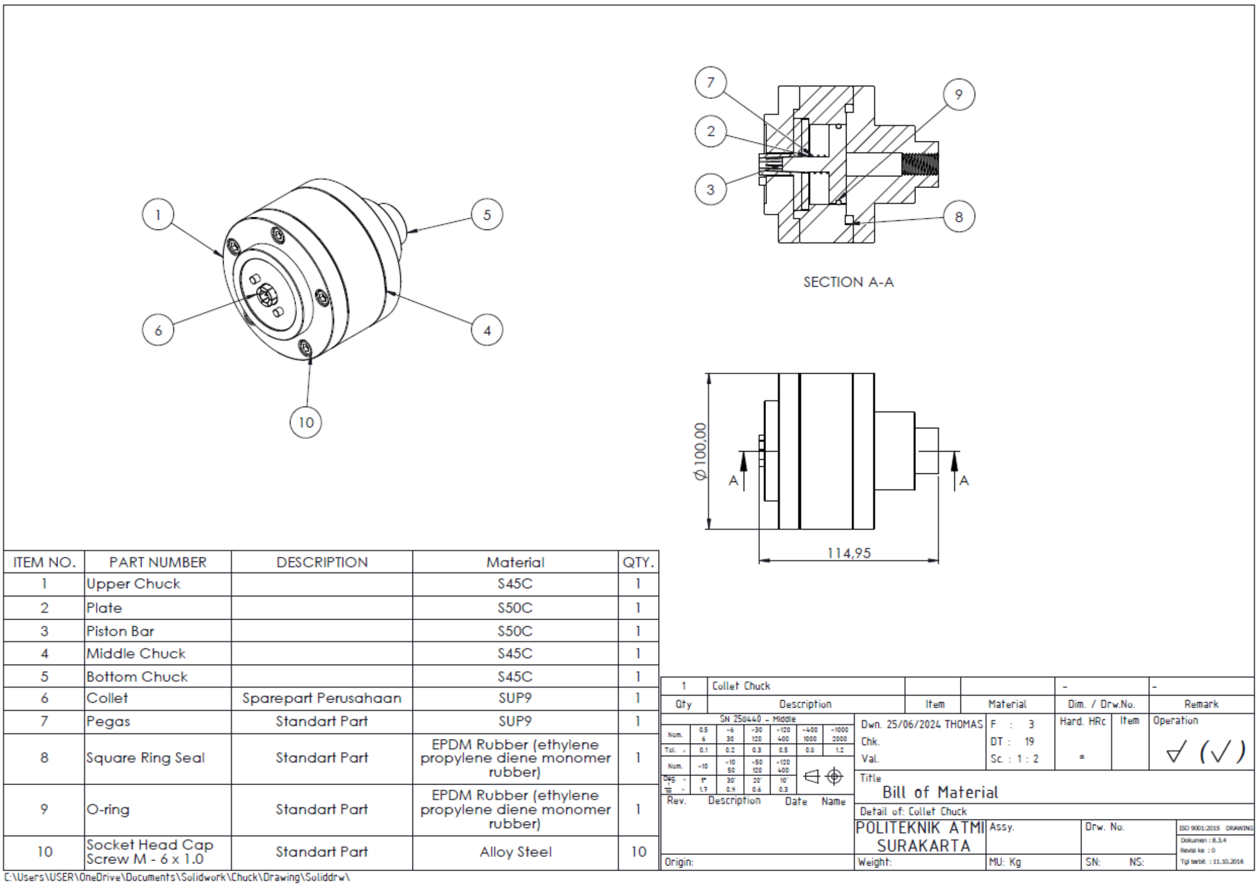


Figure 13. Bill of Material Collet Clamping
(Source: research documentation, 2024)

The calculation shows that the collet clamp manufacturing costs is Rp. 1,472,769. Manufacturing costs are calculated to give the company an idea of the value that needs to be invested in this clamp tool. Figure 14 shows the collet clamping components that have been realized and are ready to be assembled. However, the picture of collet clamping that has been assembled and applied to the machine cannot be shown due to the company's confidentiality factor.

Figure 14. Collet Clamping Components After Machining
(Source: research documentation, 2024)

Confirmation Test Results

The research ended with actual testing of collet clamp on CNC lathe machine - CK 6132/500 series for the KN-00XX series sprocket-cam product. Bottom chuck, as the basic component of collet clamp, can be attached to the machine spindle. Pneumatic system can work perfectly when the collet clamp rotates without any indication of leakage. The collet can expand to a diameter of 14.16 mm (maximum) when the pneumatic system is turned on, and shrink again to a diameter of 13.74 mm (minimum) when the pneumatic system is turned off. Collet can grip the inner diameter of product (14 mm) perfectly, while the gripping strength and product stability are maintained during the chamfering process. However, product confidentiality is a barrier in test documentation process.

The confirmation test also evaluates cycle time calculation, which is consists of: 1) the time required by operator to grip-release the product; and 2) operational time of chamfer program. The running time of chamfer program on CNC lathe machine is 5.5 seconds, and the actual program runs for 6 seconds. According to theoretical calculations, the collet clamp movement for grip-release is 0.226 seconds each, so theoretically the total cycle time calculation is 5.95 seconds. The actual product grip-release process is carried out manually by the operator, which takes between 3 and 5 seconds. Repeated data collection on different work shifts shows that the average total machining cycle time for the KN-00XX product is 9.8 seconds. The actual use of collet clamping saves up to 33.2 seconds (77.21% faster) compared to the bolt clamping method. The existence of a clamping device on production machines helps complete products quickly and safely, thereby reducing production cycle time and costs [18].

4. Conclusion

The collet clamping design, developed using the VDI 2221-QFD method, was successfully implemented and is capable of securely gripping KN-00XX series sprocket-cam products with an internal diameter of 14 mm and a thickness of 2.5 mm. The collet clamping system was tested at PT. Toshin Prima Fine Blanking, and FEA indicates that the collet withstands a von Mises stress of 1,044,029 kN/m² with a safety factor of 1.03, confirming its strength and safety. FEA also shows that the collet can achieve a displacement of 0.37 mm, which is within the required range, though actual tests revealed a maximum displacement of 0.42 mm. This variation is acceptable to the users, as the clamping process does not cause any damage to either the product or the collet.

The actual trials demonstrated a significant improvement in efficiency, with pneumatic collet clamps reducing processing time by up to 77.21% compared to the manual clamping method using bolts. This outcome aligns with the company's goal to streamline production time and presents an opportunity to implement the system on other similar machines, even for different products. The manufacturing cost of the collet clamp is Rp. 1,472,769. Additionally, integrating a robotic arm for the product installation and removal process would further eliminate time fluctuations caused by human operators, enhancing the overall efficiency and consistency of the clamping process.

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