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Design and Development of a Low-Power Motorcycle Camshaft Copying Machine: Feasibility and Accuracy Evaluation

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ABSTRACT

This research aims to design, develop, and evaluate the feasibility and accuracy of a motorcycle camshaft copy machine as an alternative to protect the privacy of modified camshafts from copying or duplication. This research used the ADDIE development model, involving: (1) problem analysis and needs analysis, which then produced a motorcycle camshaft copy machine; (2) the design phase, resulting in a Safety Factor of 1.23 with a load of 22.046 lb force or 10 kg; (3) the development phase, including the process of cutting the frame steel, welding to make the frame, drilling to make holes in the frame steel, assembling the motorcycle camshaft copy machine components, and painting; (4) the implementation phase, consisting of a feasibility test with a result of "very feasible," suggesting that the motorcycle camshaft copy machine can be used in workshops; and (5) the evaluation phase, which resulted in good accuracy of the camshaft copy machine. The results of this study indicate that: (1) the motorcycle camshaft copy machine has dimensions of 60 cm in length, 50 cm in width, and 75 cm in height, weighs 26.5 kg, and has a power of 245 watts. (2) The motorcycle camshaft copy machine is declared "very feasible", with a value of 89.23%. (3) The motorcycle camshaft copy machine has good accuracy with an accuracy of ± 0.13 mm.

1. Introduction

Indonesia has a very high rate of motor vehicle ownership. Based on data from the Indonesian National Police Traffic Corps on August 29, 2024, the number of motorcycles in Indonesia reached 137,350,299 units, with a population of 275 million. This figure shows that more than half of Indonesia's population uses motorcycles as their primary mode of transportation. East Java is recorded as the province with the highest number of motorcycles, followed by DKI Jakarta, Central Java, and West Java [1]. This data reflects the dominance of motorcycles as the most preferred means of transportation in Indonesia.

Technological developments and high demand for motorcycles in Indonesia have encouraged automotive companies to continue competing to deliver innovative technology in their latest products [2]. These innovations aim to offer motorcycles that appeal to consumers, with a focus on fuel efficiency and the lowest possible exhaust emissions. This forces manufacturers to develop more efficient, environmentally friendly engines, even though this often comes at the expense of performance [3]. Therefore, modification has become a common alternative for motorcycle users to increase power.

Modifications are usually made by replacing standard components with aftermarket or other-vehicle components. The area most often modified is the cylinder head component, which has an important role: first, it closes the cylinder block to form a tight combustion chamber and assists in the compression process; second, it houses components such as valves, camshafts, and valve springs; and third, it acts as an inlet for fuel and an outlet for combustion products [4].

The camshaft is one of the components that greatly affect engine performance because it regulates the movement of the intake and exhaust valves and influences the flow of the fuel-air mixture in the combustion chamber [3]. In the world of motorcycle racing, many workshops modify the camshaft to match the track's characteristics and improve engine performance.

Camshaft modifications must be carried out with a high degree of precision in order to meet engine specifications and competition requirements [5]. The main challenge for a workshop duplicating modified camshafts is privacy. Not all workshops or racing teams have direct access to expensive precision machines such as CNC (Computer Numerical Control) machines. Some workshops duplicate modified camshafts at partner workshops or other workshops, which, unfortunately, still offer low privacy protection for those camshafts.

This problem requires the development of a motorcycle camshaft copying machine that meets the needs of workshops and offers the advantages of space efficiency, light weight, and energy efficiency, without sacrificing functionality. A solution is needed through the research and design of a motorcycle camshaft copying machine with more compact dimensions and lower power consumption, to meet the needs of small workshops and medium-sized industries.

2. RESEARCH METHOD

This research uses the ADDIE development model to facilitate the development of the camshaft copying machine. ADDIE consists of five main stages, namely Analysis, Design, Development, Implementation, and Evaluation [6].

2.1 Analysis

The first stage of the ADDIE model, namely needs analysis, involves the researcher conducting a needs analysis through direct observation to determine the requirements for a motorcycle camshaft copying machine to solve existing problems. At this analysis stage, the following needs analysis will be carried out:

2.1.1. Needs analysis

A needs analysis is conducted to determine the requirements for a motorcycle camshaft copy machine.

2.1.2. Analysis of the camshaft copy machine specification plan.

The purpose is to determine the specification plan required to operate the motorcycle camshaft copy machine.

2.2 Design

After conducting a needs analysis for a camshaft copying machine, the next step is to design it in Autodesk Inventor.

2.3 Development

The third process is the development of the motorcycle camshaft copy machine. In this development stage, the first method used is welding to join two pieces of metal to form a strong structure. The second method is grinding, which is used to cut the iron on the camshaft of the copying machine frame. The third method is drilling, which creates holes in the iron so the components of the camshaft copying machine can be bolted together properly.

2.4 Implementation

After realizing the product from a design into a finished product, namely a motorcycle camshaft copy machine, the next step is to test the machine used to assess the feasibility of the motorcycle camshaft copy machine that has been made. By collecting data related to setup time and the accuracy level of the motorcycle camshaft copy machine.

2.5 Evaluation

The fifth stage is the assessment stage, after the assessment process on the motorcycle camshaft copy machine. The research data is analyzed to determine the accuracy and feasibility of the motorcycle camshaft copy machine. Based on the analysis results, it can be concluded whether the motorcycle camshaft copy machine is feasible.

3. Result and Discussion

3.1. Result

3.1.1. Analysis

This stage involves the analysis process and information related to the motorcycle camshaft copy machine. There are two analyses in this stage: problem analysis and needs analysis, which are used to solve problems.

3.1.2. Design

This stage involves designing the motorcycle camshaft copy machine based on the requirements analysis.

a. Camshaft copy machine design

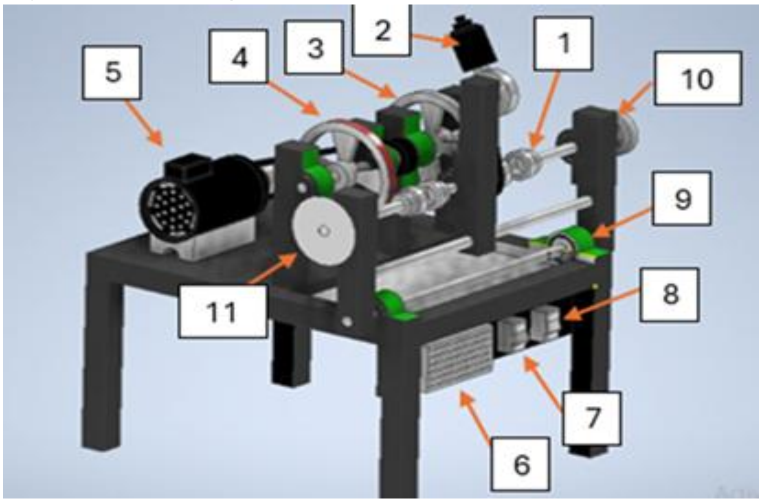

Figure 1. Camshaft Copy Machine Design

1. Clamp
2. Turning machine
3. Master pulley
4. Grinding pulley
5. Grinding machine
6. Power Supply Clamping
7. Machine power button
8. Grinding machine power button
9. Seat bearing
10. Manual clamping pulley
11. Camshaft degree arc

The camshaft copying machine design shown in the figure above has dimensions of 60 cm in length, 50 cm in width, and 75 cm in height. A 125-watt electric motor is mounted on the copying machine's camshaft to rotate the grinding pulley. Then, a 120-watt electric motor is added to rotate the clamp (Fig. 1). The selection of electric motors with these power ratings was made to ensure that the camshaft copying machine has low electrical power consumption.

b. Test results of the motorcycle camshaft copying machine design

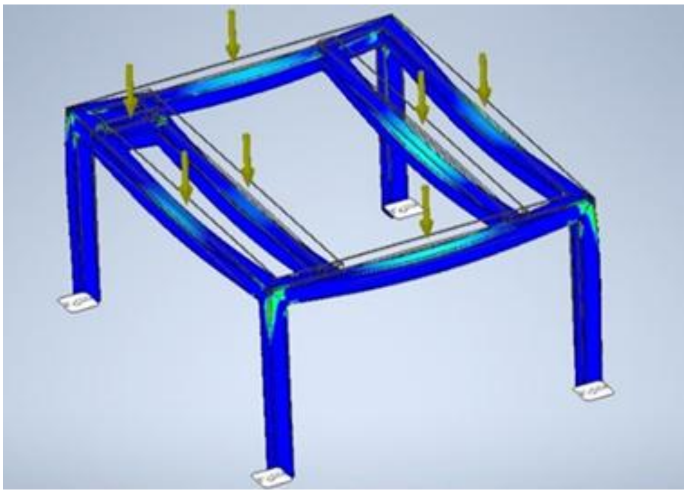

Figure 2. Frame Design Testing of the Camshaft Copying Machine

The safety factor obtained from the simulation results in Autodesk Inventor is 1.23, with a load of 22.046 lb-force (10 kg). This means that the copy camshaft engine frame is above the yield load and is capable of withstanding the permitted load of 10 kg, as can be seen in the Fig. 2, where most parts of the copy camshaft engine frame are blue, meaning that most parts of the copy camshaft engine frame have a safety factor above the permitted load.

3.1.3. Development

The development of the motorcycle camshaft copy machine resulted in specifications that can be seen in the table below:

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Table 1. Camshaft Copy Machine Specifications

No	Feature	Description
1	Product	Motorcycle camshaft copying machine
2	Developer	Raynaldi Prima Kurnia Putra
3	Electricity	AC (245 Watts)
4	Dimensions	a. Width: 50 cm b. Length: 60 cm c. Height: 75 cm
5	Total Weight	26.5 kg
6	Electric motor speed	11.2 RPM
7	Grinding pulley RPM	2,767 RPM
8	Key features	a. Adjustable clamping length Camshaft length b. Lighter machine weight c. Compact dimensions d. Lower power consumption

3.1.4. Implementation

a. Feasibility of the motorcycle copy camshaft engine.

Feasibility testing of the motorcycle camshaft copying machine was conducted by users and mechanics who use it. The summary of the feasibility testing results for the motorcycle camshaft copying machine is as follows:

Table 2. Feasibility Results of the Motorcycle Camshaft Copy Machine

Criteria						
Respondents	Strongly Agree (5)	Agree (4)	Disagree (3)	Don't Agree (2)	Strongly Disagree (1)	Total
1	5	8				13
2	7	6				13
3	6	7				13
Konversi Skor	**90**	**84**				**174**

After the test results are compiled, the next step is to calculate the feasibility percentage using the formula below.

Calculating the maximum score:

$$Eligibility = \frac{Obtained\ score}{max\ score} \times 100\%$$

Notes:

Feasibility = Feasibility value in percentage (%)

Maximum score = (number of questions) x (maximum score) x (number of respondents)

$$Eligibility\ (\%) \frac{174}{13 \times 5 \times 3} \times 100\%$$

$$Eligibility\ (\%) \frac{174}{195} \times 100\%$$

$$Eligibility\ (\%) = 0{,}8923 \times 100\%$$

$$Eligibility\ (\%) = 89{,}23\%$$

The eligibility calculation result for the motorcycle camshaft copy machine is 89.23%

b. Accuracy of motorcycle camshaft copying machines.

Table 3. Camshaft Accuracy 1

Parameter	Degree		Accuracy (mm)
Camshaft 1	**0-45**	IN	0.07
		EX	0.01
	46-90	IN	0.12
		EX	0.02
	91-135	IN	0.13
		EX	0.02
	136-180	IN	0.12
		EX	0.11
	181-225	IN	0.09
		EX	0.09
	226-270	IN	0.04
		EX	0.09
	271-315	IN	0.01
		EX	0.09
	316-360	IN	0.01
		EX	0.01

Table 4. Camshaft Accuracy 2

Parameter	Degree		Accuracy (mm)
Camshaft 2	**0-45**	IN	0.06
		EX	0.02
	46-90	IN	0.09
		EX	0.02
	91-135	IN	0.1
		EX	0.01
	136-180	IN	0.08
		EX	0.1
	181-225	IN	0.07
		EX	0.11
	226-270	IN	0.01
		EX	0.08
	271-315	IN	0.01
		EX	0.08
	316-360	IN	0
		EX	0

Table 5. Camshaft Accuracy 3

Parameter	Degree		Accuracy (mm)
Camshaft 3	**0-45**	IN	0.06
		EX	0.01
	46-90	IN	0.09
		EX	0.02
	91-135	IN	0.08
		EX	0.02
	136-180	IN	0.06
		EX	0.12
	181-225	IN	0.07
		EX	0.07
	226-270	IN	0.04
		EX	0.06
	271-315	IN	0.01
		EX	0.07
	316-360	IN	0.01
		EX	0.01

c. Time analysis

This stage involves taking data three times, followed by calculating the average time for the camshaft copying process. Below is a summary table of the camshaft copying process time:

Table 6. Recap of Camshaft Copy Process Time

No	Parameter	Setup Time (minutes)	Camshaft Copy Processing Time (minutes) - Stage 1	Camshaft Copy Processing Time (minutes) - Stage 2	Total (minutes)
1	Camshaft 1	13.47	34.43	38.20	86.1
2	Camshaft 2	15.28	37.50	41.40	94.18
3	Camshaft 3	14.12	33.51	39.55	87.18

Notes:
1. Camshaft 1: the first camshaft copy result
2. Camshaft 2: the second camshaft copy result
3. Camshaft 3: the third camshaft copy result

Once the time is known, the average calculation process for the camshaft copy process is carried out using the formula below:

$$\underline{T} = \frac{T_1 + T_2 + T_3}{3}$$

Explanation:
T1, T2, T3: represent the times of the first, second, and third tests.

$$\underline{T} = \frac{86{,}1 + 94{,}18 + 87{,}18}{3} = 89{,}15$$

Based on the above calculation, the average time for the motorcycle camshaft copying process is 89.15 minutes.

3.2. Discussion

3.2.1. Development of the motorcycle camshaft copying machine.

The process of manufacturing a motorcycle camshaft copying machine was developed through the ADDIE stages (analysis, design, development, implementation, and evaluation). The first step in the ADDIE stage is analysis, which identifies problems in motorcycle camshaft copying machines and helps find the right solution. The results of the needs analysis form the basis for designing the motorcycle camshaft copy machine. This finding aligns with the literature, which states that tools are developed based on their needs and limitations of use. Sudheer & Reddy state that good design is not only about technology, but also how technology integrates with needs and usage [7]. Designing a motorcycle camshaft copy machine according to needs is not only technically efficient.

The second step in the ADDIE model is design, which is carried out using Autodesk Inventor. The design stage has produced a motorcycle camshaft copy machine design that meets the needs identified in the analysis stage. The motorcycle camshaft copy machine design needs to undergo a frame-strength test to ensure the frame can properly support the camshaft copy machine. The strength test results from the Autodesk Inventor application, using stress analysis simulation, focused on the safety factor. The safety factor obtained from the simulation in Autodesk Inventor was 1.23, with a load of 22.046 lb-force (10 kg). This means that the copy camshaft engine frame is above the yield load and can withstand the permissible load of 10 kg. This is in line with the research by Toding Bunga, which states that a value above 1 is safe for static loads [8].

The third step of the ADDIE stage is development, which covers the process of cutting the iron frame, welding the frame, drilling holes in the iron frame, assembling the components of the motorcycle camshaft copy machine, and painting the motorcycle camshaft copy machine. This stage ultimately produces a complete copy of the camshaft. The fourth step is implementation, the process of copying motorcycle camshafts using a camshaft copying machine. This process produces copies of camshafts intended to be close in size to the originals.

The design of the motorcycle camshaft copy machine produces a machine capable of copying camshafts. This camshaft copy machine requires 245 watts of AC power, making it suitable for use in small workshops and medium-sized industries with low power capacity. This supports the research by Rahman, which states that small-scale workshops have relatively low electrical power, namely 400-900 watts [9].

The motorcycle camshaft copying machine has dimensions of 50 cm wide, 60 cm long, and 75 cm high. The weight of this motorcycle camshaft copying machine is 26.5 kg, and the RPM of the copying process is 2,767 RPM for grinding and 11.2 RPM for clamping rotation. The advantages of this motorcycle camshaft copying machine are that the clamping length can be adjusted to fit the camshaft shaft, it has compact dimensions, it is lighter than other camshaft copying machines on the market, and it requires less electrical power to operate.

3.2.2. The suitability of the motorcycle camshaft copy machine.

The feasibility validation test conducted by mechanics or users involving three respondents examined several aspects, including ease of operation, ease of storage, visual appeal, suitability for workshop needs, and safety. Based on testing conducted using Google Forms as the validation tool, a score of 89.23% was obtained. Based on this score, the motorcycle camshaft copy machine falls into the "Highly Suitable" category. This is in line with Yanthi's research, which states that a validation success rate of 81%-100% falls into the highly suitable category [10].

3.2.3. Product accuracy of the motorcycle camshaft performance.

Accuracy copying level machine testing was conducted to determine the precision level of the motorcycle camshaft copy machine. The testing was conducted three times on three different camshafts, after which the measurement process was carried out using a dial gauge and a protractor at 45-degree intervals. After the measurement was completed, the calculation was performed to find the largest difference between the copied camshaft and the original camshaft.

This motorcycle camshaft copying machine had the largest difference of ± 0.13 in the first camshaft test. The value of ±0.13 was due to significant changes in the profile shape during the camshaft copying process. This supports the findings of Girawan in their study on "the design and performance testing of a duplicate camshaft grinding machine for motorcycle racing applications" that the highest value in camshaft testing can occur when the camshaft copying process involves significant profile changes but is not followed by a reduction in engine speed, resulting in a significant deviation [11].

4. Conclusion

The design and fabrication of the Motorcycle Camshaft Copying Machine was successful, resulting in a device optimized explicitly for small workshops and medium-sized industries. The final unit is compact and energy-efficient, weighing 26.5 kg, measuring 60 cm (W) x 50 cm (L) x 75 cm (H), and requiring only 245 watts of AC power. In terms of performance, the machine has proven to be highly viable and precise. Feasibility testing yielded a suitability rating of 89.23%, indicating the device is "highly suitable" for practical application. Operational tests confirmed the machine's capability to produce high-quality components with a precision accuracy of ± 0.13 mm. Furthermore, the machine balances precision with efficiency, achieving an average copying process time of 89.15 minutes.

Conflict of interest

The authors declare no conflict of interest.

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