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Design of the Vertical Roundness Tester Machine Using the AHP Method (Analytical Hierarchy Process) Through the DFM Approach (Design for Manufacturing)

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ABSTRACT

The Roundness Tester Machine is a tool used to take measurements that are shown to check the Roundness of an object or to find out whether an object is really round or not when viewed carefully using a measuring instrument. DFM (Design for Manufacturing) is a method for reducing production costs by estimating production costs through reducing component costs, assembly costs, and other production supporting costs based on design submission data without reducing product quality. AHP (Analytical Hierarchy Process) method was chosen as a method to determine the optimal Vertical Roundness Tester Machine design based on a questionnaire given to the expert, to choose the best alternative decision. The questionnaire was created to get priority customer needs which was then used for the initial design. The next stage is selecting the optimal design using AHP which involves experts based on indicators of a product. The highest indicator value obtained on the Vertical Roundness Tester Machine is the accuracy indicator with a value of 48.52%. Then in choosing the optimal design in the DFM analysis, namely in alternative 3, where alternative 3 is the design with the lowest cost so as to minimize the cost of making a Vertical Roundness Tester Machine. The manufacturing cost for alternative design 3 is Rp. 4,173,000.

KEY WORDS: *Roundness Tester Machine, Design for Manufacturing, Analytical Hierarchy Process.*

NOMENCLATURE

CR	*Consistency Ratio*
CI	*Consistency Index*
RI	*Index Ratio*
λmax	*Eigen Value*
W	*Weight*

1.0 INTRODUCTION

Measurement is the process of collecting data through empirical observations that are used to collect information relevant to predetermined objectives [1]. Meanwhile, according to [2] Measurement is basically an activity to determine the numbers on an object systematically.

The Roundness Tester machine is a measuring tool that uses the principle of two centers as a clamp for the workpiece to be measured and is equipped with a workpiece driving motor and a sensor drive (dial indicator) [3].

Roundness Tester Machine is a tool used to make measurements that are shown to check the roundness of an object or to find out whether an object is really round or not when viewed carefully using a measuring instrument. Roundness Measuring has an important role in the engineering world, therefore it is necessary to develop Round Measuring Instruments.

Roundness is the uniformity of the distance between the center point and the outermost point (radius). A Roundness Tester Machine is a measurement that is shown to check the roundness of an object, or in other words to find out whether an object is really round or not, when viewed carefully using a measuring instrument [4].

Roundness is very basic and very important, the value of the roundness of the shaft greatly determines the performance and stability of the rotary motion of the shaft. Roundness can be measured in a very simple way, namely by using a dial indicator, but currently it is still difficult to determine roundness so that very high accuracy is needed to measure roundness.

Components with ideal sphericity are very difficult to produce, therefore non-roundness must be tolerated within a point limit according to the purpose and function of the component. Roundness has an important role in distributing the load evenly, determining component life, determining adjustment conditions, determining rotation accuracy, and

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smoothing lubrication. In producing the desired product, especially cylindrical products [5].

Many machines or other technical equipment are found with components that have a spherical cross-section, either in the form of shafts, bearings, gear parts with small dimensions such as mechanical watches, to components with large dimensions such as machines. megawatt-powered engine [5].

One method that can be used in assisting the design of the product is the AHP (Analytical Hierarchy Process) method. AHP was chosen as a method to determine the optimal design of the Roundness Tester Machine based on a questionnaire given to the expert, to choose the best decision alternative. AHP can provide a decision with a questionable level of confidence by ranking decision alternatives and selecting the best for complex problems by combining factors in the overall evaluation of alternatives [6]. Therefore, the AHP method is very suitable to be used in decision making so that the results of the design of the Vertical Roundness Tester Machine get the most optimal design choice based on expert judgment.

In addition to using the AHP method in determining the design of the Vertical Roundness Tester Machine, the DFM approach is used in the design process. DFM is a method used to ensure a manufacturing process can produce high quality products. This method is used to consider the ease of design so that the finished Vertical Roundness Tester Machine can be more easily used in the roundness data collection process.

With the above explanation, the author wants to conduct research on the Design of Vertical Roundness Tester Machine using the AHP method through the DFM approach, which aims to consider the ease of manufacture process of the Vertical Roundness Tester Machine.

2.0 LITERATURE REVIEW

2.1 Product Design

Design can be expressed as a decision-making process that can be used to develop an engineering system that involves functional, aesthetic, comfort, and safety aspects [7].

According to the type of design, it is divided into three, namely [8]:

1. Original Design, which is a new design or has never existed before. In searching for an original design, the designer should think as broadly as possible all the possible solutions and he should choose them.
2. Adaptive or Developmental Design, which is looking for better or more optimal changes in the performance of the designed tool through improving working principles. This type of design allows the development of materials designed for the tool.
3. Variant Design, namely the design process in which the dimensions or detailed scale of a designed tool are changed without changing the function or workings of the tool.

Product design includes a very broad process called product development. The development itself consists of developing new products in conjunction with production, distribution, and sales plans. This very broad process is called new business development. Product development does not stand alone, it is part of the industrial innovation process. Industrial innovation applies many activities in its implementation, which include the use of new products on the market (how to implement new products), sales planning, production, distribution, sales and after-sales service. Thus, innovation covers a wider range of development. The implementation of a development plan is the realization of a new product or production process by a company, and this is part of an innovation [8].

2.2 DFM (Design for Manufacturing)

DFM is an approach to estimating production costs in the initial design process. The wide choice of process technologies for the manufacture of a component and various types of materials make it impossible for the designer to know all the information. For this reason, DFM helps estimate costs in advance to be able to decide on alternative processes and appropriate materials without having to practice directly. DFM is also part of DFMA which provides manufacturing information into cost reduction analysis in DFA [9].

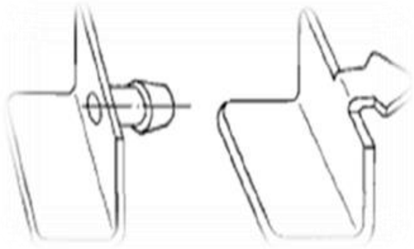

Figure 1: DFM Application [9]

Figure 1 above describes the application of DFM to a key that was previously shaped like a shaft and changed to simplify the manufacturing process [9].

When product specifications are finalized, the team makes a trade-off between the desired performance characteristics. For example, reducing weight will increase manufacturing costs. The DFM method consists of 5 steps and can be done several times until the team considers the design to be good enough:

1. Estimating production costs.
   Production costs are the sum of all costs for inputs from the manufacturing system as well as for the process of making outputs produced by the system. The schematic shows how to group the elements of production costs.

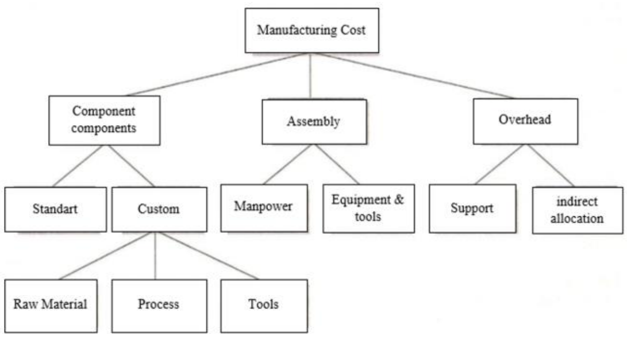

Figure 2: Product Manufacturing Cost Element [10]

2. Reduce assembly costs.
   Assembly costs are costs used to assemble several components into a product. The cost of this assembly process arises from the costs to pay the operator and the use of equipment to assemble. The way that can be done to reduce assembly costs is to create an integrated one, increase the ease of assembly, and consider consumer expectations for product assembly.

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3. Reduced component costs.
   Component costs are costs associated with all components used in product design, both standard components and new components. These new components are manufactured from intact materials depending on the required manufacturing design. Some strategies that can be used to reduce component costs are:
   a. Understanding process bottlenecks
   b. Redesign of components to eliminate stages of the manufacturing process
   c. Choosing the right economies of scale to process components
   d. Standardize all components and processes
   e. Procurement of components
4. Reducing production support costs.
   Cost reduction in this sector is carried out by using standard components on the market, reducing system complexity in the company, and preventing errors in the production system.
5. Consider the effect of the DFM decision on other factors.

In Figure 3 above are the stages of the DFM process into a product. DFM design uses CAD (Computer Aided Design) applications, other expert computer systems and equipment to design and develop products that are relatively easy to manufacture. DFM is a process that aims to reduce time to market, improve quality, improve process performance, increase profits, and finally to increase the competitiveness of manufacturing companies by addressing problems at the early concept design and prototype stages of product design and development. So assembly efficiency is the ratio of the ideal assembly time to the actual assembly time. References for these measurements are given based on the minimum number of components.

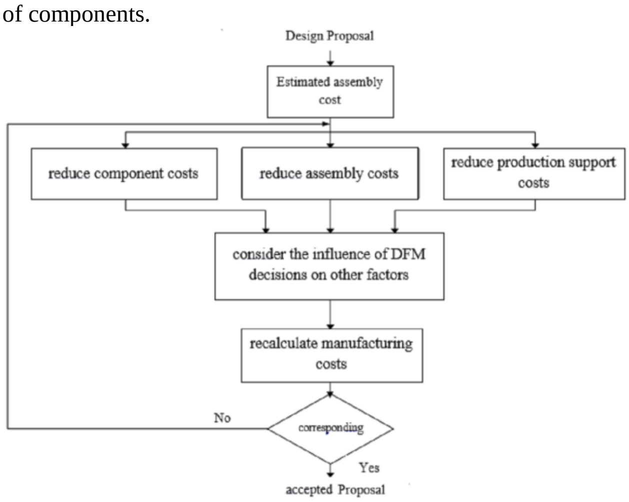

Figure 3: Design Method for Manufacturing Process [11]

2.3 AHP Method (Analytical Hierarchy Process)

AHP is a process of systematic rationality. With AHP, it is possible to consider a problem as a whole and examine the simultaneous interaction of various components arranged hierarchically so that they are easy to understand and analyze. According to [12] AHP is a structured method related to decision making on complex problems, which consists of many alternatives such as projects, actions and scenarios. AHP is developed according to the hierarchical structure of several alternative combinations in decision making. According to [13] AHP is a measurement theory through pairwise comparisons and relies on expert judgment to get a priority scale. Meanwhile, according to [14] AHP can solve complex multi-criteria problems into a hierarchy. Complex problems can be interpreted that there are so many problem criteria (multi-criteria), unclear problem structure, uncertainty of opinion from decision making, decision making by more than one person, and inaccuracies of available data.

AHP can be used to stimulate the emergence of ideas for creative actions, and to evaluate the effectiveness of those actions. In addition, to help leaders determine what information should be collected to evaluate the influence of relevant factors in complex situations. AHP can also track inconsistencies in participants' judgments and preferences, so that leaders can assess the quality of their assistants' knowledge and reinforce solutions [15].

2.4 Roundness

Roundness has an important role in terms of dividing the load equally, determining the life of components, determining the conditions of the suit, determining the accuracy of the rotation, smoothing lubrication in producing the desired product, especially products that are round [16].

Roundness is the uniformity of the distance between the center point and the outermost point (radius). Roundness Tester Machine is a measurement that is shown to check the roundness of an object, or in other words to find out whether an object is really round or not, if viewed carefully with a measuring instrument [5].

To be able to express the level of roundness of a measuring object, it is necessary to establish a roundness parameter. Roundness parameters can be calculated based on the roundness profile, relative to the reference circle. In this case, four types of reference circles can be used in determining the value of roundness parameters:

a. Minimum circumscribed circle; Non-rotation is the same as the radial distance from the circle to the deepest curve.
b. Maximum inscribed circle; The roundness is equal to the radial distance from the circle to the highest protrusion.
c. Minimum zone circleInaction; the difference in the radius of the two circles.
d. Least square circle; The radial distance of the absolute average price between the roundness profile and the smallest square circle is called the mean line average (MLA).

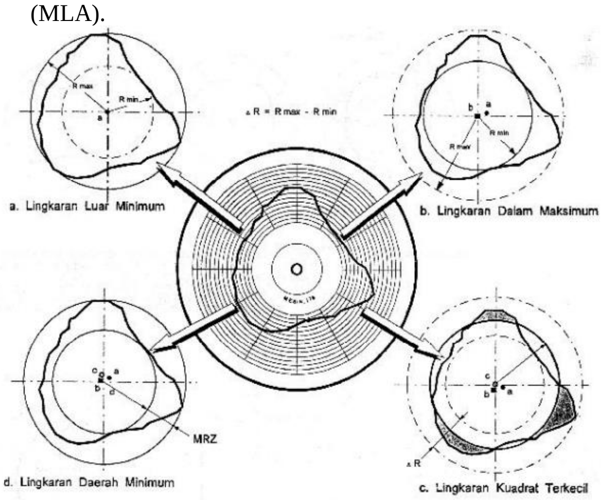

Figure 4: Polar Graph of the four types of reference circles [5]

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According to JIS (B0651-1984), "Roundness is defined as the sum of the deviations in the shape of a circle from a definite geometric circle." Here the shape of a circle is a form that is specified to be a circle as a shape of a field or cross-section of a surface that rotates [4].

Components with ideal roundness are very difficult to make, and thus must be tolerated by non-roundness within the boundaries of the point according to the purpose and function of the component. Roundness has an important role in terms of dividing the load equally, determining the life of components, determining the conditions of the suit, determining the accuracy of the rotation, smoothing lubrication [5], in producing the desired product, especially cylindrical products.

To determine the accuracy of the measuring instrument and measurement results, of course, there must be a basic reference that is used as a clear reference to the source. A mandrel is a standard measuring instrument that has been calibrated and certified for roundness quality by a calibration institution, namely PT. Global Quality Indonesia; this data will be used as a basic reference to determine the accuracy of making roundness applications [3,17].

Roundness can be measured in a simple way using the Dial Indicator, but currently, it is still difficult to determine the roundness so a program can be analyzed directly on a computer (PC), and the roundness program is currently still difficult to obtain because the program has a price selling high in the market. Roundness programs are usually sold separately from the measuring instrument with the program. So we need an application that can determine the price of roundness [18].

3.0 EXPERIMENTAL METHOD

Methods are steps taken by researchers in order to gather information. The research method provides an overview of the research design which includes procedures and steps that must be taken, research time, data sources, and problem solving methods.

3.1 Research Method

The research method used is an experimental method. The flow chart in this study can be seen in Figure 5.

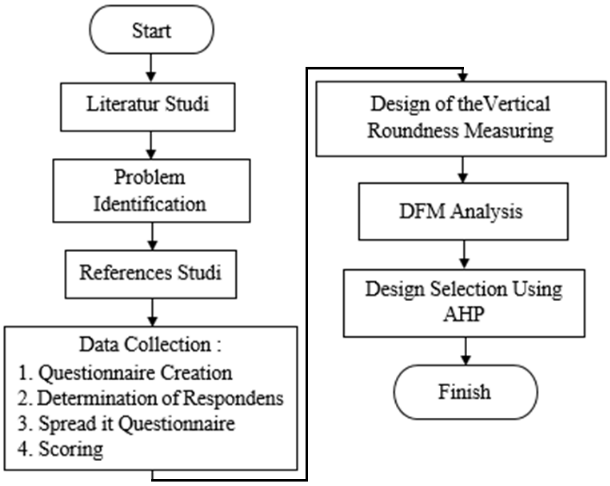

Figure 5: Research flow diagram

3.2 Research Method AHP

The AHP flow chart in this study can be seen in Figure 6.

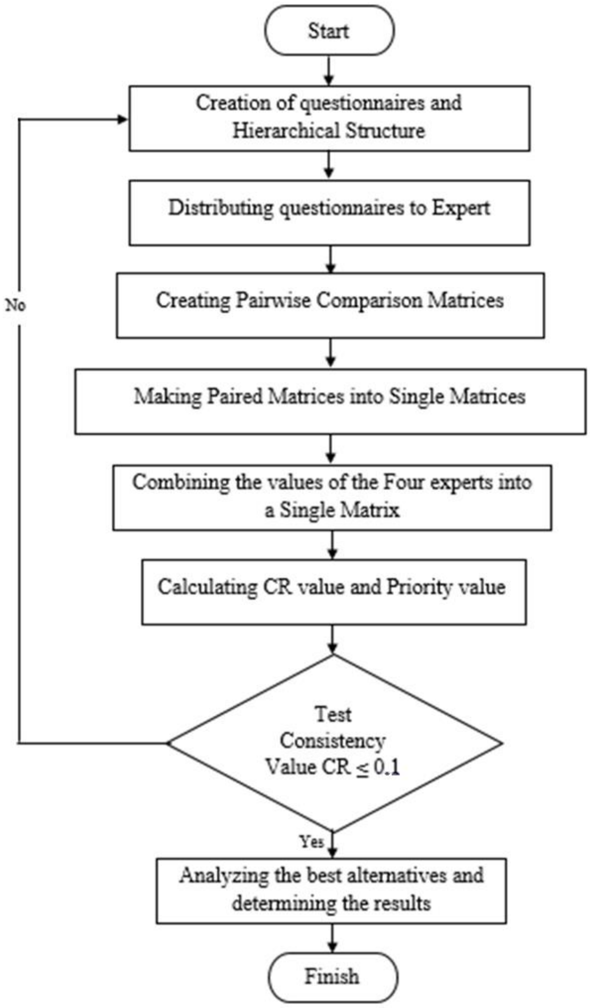

Figure 6: Research Flow Diagram AHP Method

3.3 Questionnaire Making and Data Collection

The data collection stage is in the form of questionnaires distributed to experts. Where the data that has been filled in by the experts is collected, then calculated using the formula in the AHP method and the calculation is done in excel. The stages of collecting data requirements are as follows:

1) Making a Questionnaire
   This initial questionnaire was made based on 4 aspects, namely:
   a) Aspects of Resolution
   b) Aspects of Precision
   c) Aspects of Accuracy
   d) Aspects of Serviceability
2) Determination of Expert Respondents and Distribution of Questionnaires In determining the number of expert respondents as many as 4 people and distributing questionnaires in Pekanbaru City and Bandung City.
   Respondents are divided into 2, namely:
   - 1 person who works as a lecturer in Mechanical Engineering, Universitas Riau.
   - 3 people who work at the Center for Materials and Technical Goods (B4T) Bandung.

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3.4 Vertical Roundness Tester Machine Design

At the design stage, the Vertical Roundness Tester Machine is designed using the Inventor 2017 application, based on the priority of each aspect that has been obtained, including the design of the components of the Vertical Roundness Tester Machine.

3.5 Design Selection Using the AHP Method

After getting the needs of the experts, then the most optimal alternative is selected using AHP which involves the Experts in the selection of alternatives.

1. The AHP method is used to determine the optimal design of the Vertical Roundness Tester Machine, the steps are as follows:
   Determination of criteria Vertical Roundness Tester Machine, with the result that there are 4 important criteria, namely:
   a) Resolution
   b) Precision
   c) Accuracy
   d) Serviceability
   The hierarchical structure of the Vertical Roundness Tester Machine can be seen in the following figure.

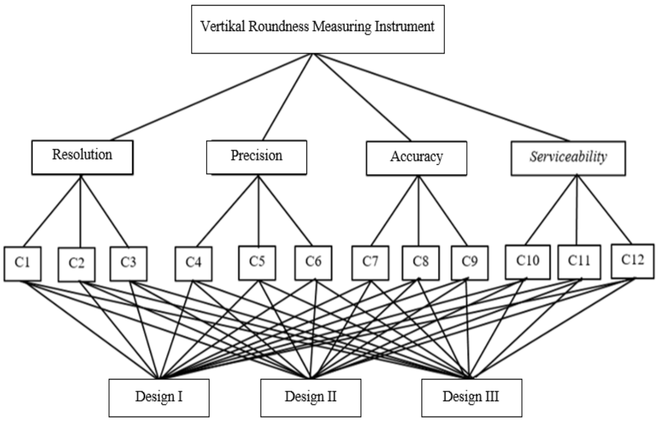

Figure 7: Hierarchical Structure of Vertical Roundness Tester Machine

Information;
C1 : Pupitas
C2 : Dial Indicator
C3 : Digital Indicator Dial
C4 : Shaft
C5 : Aluminum Profile
C6 : Linear Screw and Belt
C7 : Manual Control
C8 : Semi-Automatic Control
C9 : Automatic Control
C10 : Easy to clean
C11 : Easy to carry
C12 : Easy to disassemble

The hierarchical structure consists of 4 levels, level 1 is the main goal/objective, namely the optimal design, level 2 is the indicator/criterion that affects the optimal design, level 3 is the sub-indicator/criteria and level 4 is an alternative design.

Making a questionnaire based on the hierarchical structure that has been made previously, this questionnaire aims to obtain a level of importance in selecting designs by comparing interests 1 with other interests based on the comparison priority scale in Table 1.

Table 1: Comparison priority scale [6]

Importance Scale	Definition	Information
1	Just as important	The two elements have the same effect
3	A little bit more important	Experience and judgment are slightly in favor of one element
5	More important	Experience and judgment are very partial to one element
7	Very important	One element is very liked and practically very real dominance over his partner
9	Absolutes are more important	One element is shown to be absolutely preferable to its partner
2,4,6,8	Middle value	Awarded if there is doubt of assessment
The opposite	Aij = 1 / Aij	If an activity i gets a number when compared to activity j, then j has the opposite value when compared to i

2. Questionnaire distribution to experts
   In distributing the questionnaire, 4 experts were selected who would be respondents. Respondents were selected based on fields related to the research topic, namely the field of Measurement and Production, in this case the researcher gave questionnaires to lecturers of Mechanical Engineering at the Universitas Riau and employees in the Calibration section at the Center for Engineering Materials and Goods (B4T).

3. Create a pairwise comparison matrix
   After the questionnaire was filled in by the expert, a pairwise comparison matrix was made from the results of the questionnaire. An example of a pairwise comparison matrix can be seen in table 2.

Table 2: Comparison Matrix [6]

	A_1	A_2	…	A_n
A_1	a_{11}	a_{12}	…	A_{1n}
A_2	a_{21}	a_{22}	…	A_{2n}
.	.	.	.	.
A_n	a_{n1}	a_{n2}	…	a_{nn}

4. Create a matrix of normalization results
   After the pairwise comparison matrix for each Expert, a matrix of the normalization results of the three experts is created, each column is summed and then divided by the total required experts. An example of a matrix of normalization results can be seen in Table 3.

Table 3: Matrix of Normalization Result [6]

	A_1	A_2	A_3	A_n
A_1	$(a_{11}+b_{11}+c_n)/3$	$(a_{12}+b_{12}+c_n)/3$	$(a_{13}+b_{32}+c_n)/3$	A_{1n}
A_2	.	.	…	A_{2n}
.	.	.	.	.
.	.	.	.	.
A_n	a_{n1}	a_{n2}	…	a_{nn}

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5. Next, calculate the eigenvector and eigenvalues to get the weight and value max. With n = $4^{1/n}$

$$Eigenvector\ C\ (Weight) = \begin{Bmatrix} \frac{\frac{(C11*C12*C13*C14)1}{n}}{Sum\ C} \\ \frac{\frac{(C21*C22*C23*C24)1}{n}}{Sum\ C} \\ \frac{\frac{(C31*C32*C33*C34)1}{n}}{Sum\ C} \\ \frac{\frac{(C41*C42*C43*C44)1}{n}}{Sum\ C} \end{Bmatrix} \quad (1)$$

Where is the value "*Sum C* " is:

$$Sum\ C = \frac{(c11*c12*c13*c14)1}{n} + \frac{(c21*c22*c23*c24)1}{n} + \frac{(c31*c32*c33*c34)1}{n} + \frac{(c41*c42*c43*c44)1}{n} \quad (2)$$

6. Calculating value *weight* (W)
   Weight (W) is the weight of each criterion which can be obtained by the equation:

$$W = \frac{line\ average}{average\ number\ of\ rows} \quad (3)$$

7. Consistency Test
   The consistency test (CR) was carried out to assess the consistency of the answers *expert*, if the CR value is > 0.1 then the distribution of the questionnaires must be repeated, the consistency test is obtained by the equation:

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (4)$$

$$\lambda\text{max} = [(c_{11} + c_{21} + c_{n1})(c_{12} + c_{22} + c_{n2})(c_{13} + c_{23} + c_{n3}) \ldots] \begin{Bmatrix} W1 \\ W2 \\ W3 \\ W4 \\ W5 \\ W6 \end{Bmatrix} \quad (5)$$

$$CR = \frac{CI}{IR} \quad (6)$$

Information:
n = *Number of Elements*
CR = *Consistency Ratio*
CI = *Consistency Index*
IR = *Random Index*

Score *random index* can be seen in Table 4

Table 4: Score *Random Index* [6]

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

8. The best alternative is chosen based on value *weigh* t (W) which has been obtained from the calculation result.

3.6 DFM analysis on Vertical Roundness Tester Machine.

1) Alternative design 1
   In alternative design 1, it consists of 15 components and the total production cost is Rp. 11.062.000

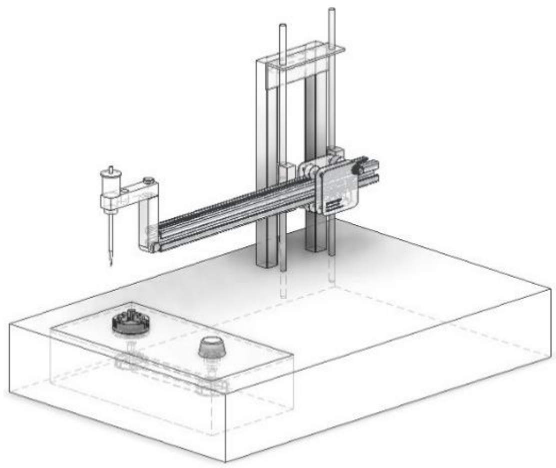

Figure 8. Alternative Design I

2) Alternative design 2
   In alternative design 2, it consists of 24 components and the total production cost is Rp. 4.927.000

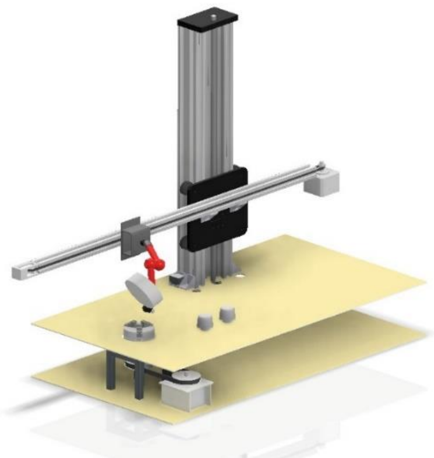

Figure 9: Alternative Design II

3) Alternative design 3
   In alternative design 3, it consists of 21 components and the total production cost is Rp. 4.468.000

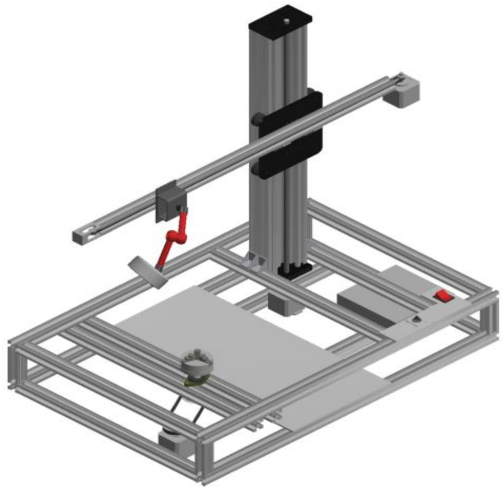

Figure 10: Alternative Design III

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4.0 RESULTS AND DISCUSSION

4.1 Calculation of AHP (Analytical Hierarchy Process)

4.1.1 Weight of Expert Assessment Against Criteria with Criteria

After processing the data, the value is obtained weight as in Table 5.

Table 5: The value of the weight of the criteria for Vertical Roundness Tester Machine

Criteria	*Weight*
Resolution	0.49
Precision	0.18
Accuracy	0.27
Serviceability	0.06

From the weight gain in Table 6, it can be seen that the highest criterion weight of the Vertical Roundness Tester Machine is Accuracy (0.49) and the lowest is Serviceability (0.06).

4.1.2 The weight of the Expert's assessment of the Criteria with Sub-criteria

At this stage, data processing is carried out to obtain the weight value of the sub-criteria against the criteria. From the values obtained, it is known that the sub-criteria that most influence the criteria for Vertical Roundness Tester Machine using the AHP method. From data processing, the weight values can be seen in Table 6.

Table 6: Criteria VS Sub-Criteria Assessment Weight

Criteria vs Sub Criteria	***Weight***	**CR**
RESOLUTION		
Pupitas	0.403	
Dial Indicator	0.216	0.1
Dial Indicator Digital	0.381	
PRECISION		
Shaft	0.383	
Profile Aluminum	0.223	0.08
Linier Screw dan Belt	0.394	
ACCURACY		
Manual Control	0.242	
Semi – Automatic Control	0.373	0.08
Automatic Control	0.385	
SERVICEABILITY		
Easy to Clean	0.346	
Easy to Carry	0.266	0.08
Easy to disassemble	0.389	

4.1.3 Rating weight Expert against Sub criteria with alternatives design

At this stage, data processing is carried out to obtain alternative weight values against the sub-criteria. From the values obtained, it is known that the most influential alternative on the Vertical Roundness Tester Machine using the AHP method. From data processing, the weight values can be seen in Table 7.

Table 7. Weight of Sub-Criteria Assessment of Alternatives

Sub Criteria	*Weight*		
	Alternative 1	Alternative 2	Alternative 3
RESOLUTION			
Pupitas	0.370	0.236	0.394
Dial Indicator	0.313	0.378	0.309
Dial Indicator Digital	0.312	0.327	0.361
PRECISION			
Shaft	0.442	0.271	0.287
Profile Aluminum	0.276	0.377	0.347
Linier Screw dan Belt	0.346	0.266	0.389
ACCURACY			
Manual Control	0.328	0.402	0.270
Semi – Automatic Control	0.328	0.402	0.270
Automatic Control	0.291	0.346	0.364
SERVICEABILITY			
Easy to Clean	0.442	0.287	0.271
Easy to Carry	0.304	0.350	0.346
Easy to disassemble	0.270	0.328	0.402

4.1.4 Alternative Options

From the results of data processing, the alternative value of the percentage weight of the Vertical Roundness Tester Machine can be seen in Figure 7.

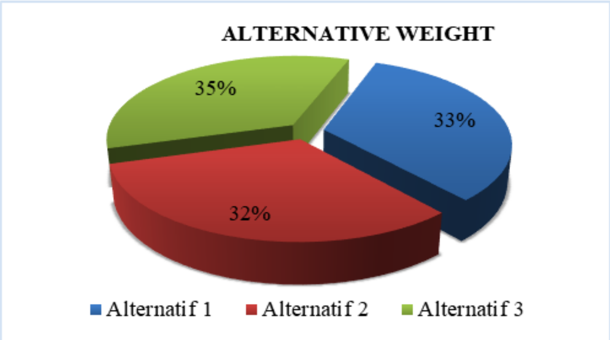

Figure 11: Alternative Diagram of Vertical Roundness Tester Machine

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The diagram above shows that the highest percentage value is in alternative 3 of 35%, this value is influenced by the first highest criterion, namely the accuracy criterion with a value of 48.52% where the accuracy criterion is also influenced by various sub-criteria, and the second highest on the accuracy criteria with a value of 27.18% where this criterion is also influenced by various sub-criteria. Therefore, the optimal alternative on the Vertical Roundness Tester Machine is won by design alternative 3.

4.2 DFM analysis on the alternative design of the Vertical Roundness Tester Machine

The lowest Manufacturing Cost for the components of the Vertical Roundness Tester Machine is in Alternative Design 3, which is Rp. 4,173,000 compared to Alternative Design 2 and Alternative Design 1. Therefore Design 3 can be manufactured with the aim of minimizing costs during the process of making the tool.

Table 8: Components of Alternative Design III

NO	MATERIAL	QYT	PRICE	TOTAL
1	Aluminium Profile 20x20	6 meter	Rp.850	Rp510.000
2	Aluminium Profile 20x80 c	50 cm	Rp4.500	Rp225.000
3	Dial Indikator Digital	1 pcs	Rp1.000.000	Rp1.000.000
4	*timing belt pulley*	1 pcs	Rp55.000	Rp55.000
5	*Corner Bracket*	50 pcs	Rp2.500	Rp125.000
6	V Slot Gantri Plate 20	1 pcs	Rp90.000	Rp90.000
7	C Beam Gantry Plate	1 pcs	Rp210.000	Rp210.000
8	V Slot Wheel	6 pcs	Rp19.000	Rp114.000
9	Spacer Aluminium	4 pcs	Rp6.000	Rp24.000
10	Baut L	50 pcs	Rp2.000	Rp100.000
11	*Gear Pulley*	2 pcs	Rp55.000	Rp110.000
12	*Open Builds C beam*	2 pcs	Rp120.000	Rp240.000
13	Lengan Dial Indikator	1 pcs	Rp100.000	Rp100.000
14	*Spacer Pulley*	4 pcs	Rp15.000	Rp60.000
15	*Eccentric Spacer*	4 pcs	Rp10.000	Rp40.000
16	Open Builds End Mount	2 pcs	Rp120.000	Rp240.000
17	Motor Stapper	3 pcs	Rp150.000	Rp450.000
18	T Sliding Nut	50 pcs	Rp2.000	Rp100.000
19	*Chuck*	1 pcs	Rp380.000	Rp380.000
20	*Screw Shaft*	1 pcs	Rp280.000	Rp280.000
21	Saklar On/Off	1 pcs	Rp15.000	Rp 15.000
			Amount	Rp4.468.000

5.0 CONCLUSION

The conclusions obtained from the research conducted are as follows:

1. Based on the results of the questionnaire, the indicators that influence the selection of the Vertical Roundness Tester Machine design from the highest to the lowest are 48.52% accuracy, 27.18% accuracy, 18.16% accuracy and 6.14% serviceability.
2. Based on the results of the DFM calculation, the manufacturing costs for the components of the lowest Vertical Roundness Tester Machine are in Alternative Design 3 of Rp. 4,468,000, compared to Alternative Design 2 and Alternative Design 1. Therefore Design 3 can be created with the aim of minimizing costs during the tool manufacturing process
3. From the data obtained by the weight of the design alternatives, it can be seen that the most optimal design alternative for the Vertical Roundness Tester Machine is Design Alternative 3, which is 35%.

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