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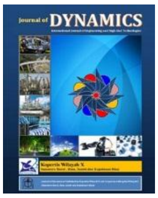

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Estimation of the Manufacturing Product Complexity Based on the Product Information on Turning Process Product

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Abstract

Product complexity index was an indicator of a manufacturing product that describes the products designed and manufactured by a level of complexity. In this study, assesment of product complexity conducted on milling processing product. Assesment conducted on the variable of turning processing product complexity based on features of the products and specifications of materials, shapes, geometry, tolerance, general surface finish and hardness. ElMaraghy introduced the method in this study and Urbanic based on information product were absolute quantity information, diversity of information, and content of product information. The results of product complexity assesment indicated that the product of original External Thread Bearing Housing had product complexity index of 6.28. While the results of product complexity assesment indicated that, the product of redesign External Thread Bearing Housing had product complexity index of 8.96.

Keywords: Information Product, Weighted Value, Turning Processing Product, Product Complexity Index

1. Introduction

The development and improvement of the manufacturing industry will continue to go along with the development and advancement of technology. In the manufacturing industry, there are three types of complexity to be considered in the manufacturing environment: product complexity, process complexity and operational complexity, and each complexity mutually supportive of each other [1].

The quality of products in the manufacturing industry in addition to emphasize the products produced, also need to be considered quality in the production process. Even the best is if the attention to quality is not on the final product, but the process of production or products that are still in the process (work in process), so that if known there are defects or errors can still be fixed. Thus, the final product produced is a defect-free product and no more expensive waste has to be paid which resulted in the product being discarded or reworked.

A product produced from a manufacturing industry of a predetermined quality, has an index of product complexity which illustrates that the product is made with some complexity or complexity. Thus, product complexity is one indicator of the assessment of the quality of manufactured products. According to ElMaraghy and Urbanic [1] that the complexity of a product is a function of the feature and the specification of a product. Feature is a form to be produced while the specification is the desired quality associated with the features that want to be produced. To assess the complexity of manufactured products, ElMaraghy and Urbanic have developed a method of assessing the complexity of product-based manufacturing products. The product information consists of an absolute amount of information / entropy of information, various information and content / content of the product information.

The complexity of the product is represented by the product complexity index ($CI_{product}$) and is an information / entropy product function

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($H_{product}$), product diversity ratio ($DR_{product}$) and the product complexity coefficient ($c_{j,product}$). The value of the relative product complexity coefficient is based on general manufacturing principles and depends on the type of process or volume. The value is increasing with the effort required to produce the final component of the product. An example of product complexity is illustrated in Figure 3.

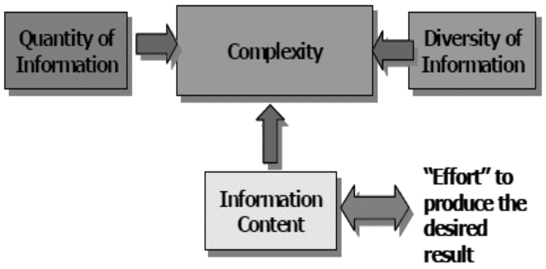

Figure 1. Basic elements of manufacturing complexity [1]

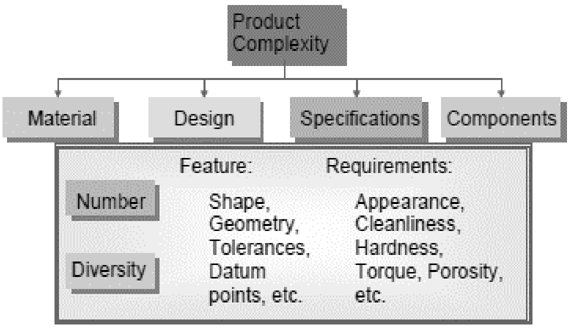

Figure 2. Elemen Kompleksitas Produk [1]

Product complexity index ($CI_{product}$) can be calculated by using the equation below [1]:

$$\boldsymbol{CI_{product}} = \left(\boldsymbol{D_{R_{product}}} + \boldsymbol{c_{j,product}}\right) * \boldsymbol{H_{product}} \quad (1)$$

Where $CI_{product}$ is the product complexity index, $DR_{product}$ is ratio of information variation, $c_{j,product}$ is coefficient of relative complexity, and $H_{product}$ adalah compression/entropy factor of information.

Ratio of information variation ($DR_{product}$), coefficient of relative complexity ($c_{j,product}$), compression/entropy factor of information ($H_{product}$), respectively, are defined as:

$$D_{R_{product}} = \frac{n}{N} \quad (2)$$

Where n is number of information variations that considered unique and N is total amount of information,

$$H = \log_2(N+1) \quad (3)$$

$$c_{j,product} = \sum_{f=1}^{F} x_f * c_{f,feature} \quad (4)$$

Where c_f adalah relative coefficient of feature complexity and x_f is the percentage of x^{th} form is not the same.

The coefficient of relative complexity is the average associated with the relative complexity of various aspects of the given specification and features, and is represented by:

$$c_{f,feature} = \frac{F_N * F_{CF} + S_N * S_{CF}}{F_N + S_N} \quad (5)$$

Where F_N is feature number, F_{CF} adalah factor of feature complexity, S_N adalah number of aspects that affect the specification and S_{CF} is specification factor of complexity.

$$F_{CF} = \frac{\sum_{j=1}^{J} \text{factor\_level}_j}{J} \quad (6)$$

Where J is number of aspects that affect the feature, and $factor\_level_j$ is factors for the category to j that so (j^{th}).

$$S_{CF} = \frac{\sum_{k=1}^{K} factor\_level_k}{K} \quad (7)$$

Where K is e number of aspects that affect the specifications and $factors\_level_k$ is factors for the category of k that is so (k^{th}).

In manufacturing industry, machining process is one way to produce the product in large quantities with a relatively short time. Machining process is one of the complex manufacturing process because it must consider many factors for the products produced in accordance with the specified quality specifications. The process of turning is the process of forming workpieces by reducing the material (material removal). Material reduction is performed on rotary workpieces with cutting tools (chisels) that move linearly (transverse, elongated, or angular), so that the resulting workpiece generally has a circular cross section. The principle of work or the main movements to perform pemakanan in the process of turning include the movement of rotating workpiece, the movement of insert/depth of depth (cut depth) and chiseling motion of workpieces or also called the feeding motion.

In a previous study there has been a study that discusses the complexity of product-based manufacturing manufacturing products developed by ElMaraghy [1]. Budiono, et. al. [2] have conducted research on the complexity of manufactured products by combining the ElMaraghy method with DFMA parameters on Sand Casting and Injection Mold products. Budiono, et. al. [3] re-examined the complexity of the product by comparing the multitier weighting method to the normalization method in weighting the complexity of the product to the panel roof dies product. Furthermore, Romiyadi [4] also conducts research on the measurement of product complexity index, especially the pressed part product, namely Bracket Air Box Component using product-based information method that has been developed by ElMaraghy [1].

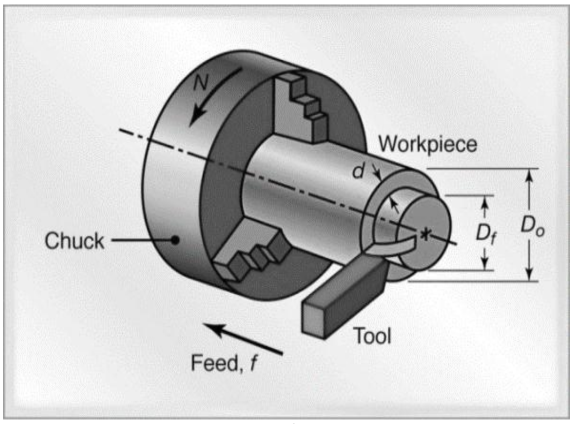

Figure 3. Principle of Lathe Machine [5].

This study aims to assess the complexity of product-based manufacturing products to the product of machining process, especially the lathe process, namely External Thread Bearing Housing. To assist in assessing the complexity of the product, it is necessary to identify the product complexity variables and weighting values of the product complexity for the lathe products to assist the researcher in assessing or scoring for each of the product complexity variables. Therefore, in this research, identification of product complexity of lathe process and development value of product complexity for product of lathe.

2. Material and Method

The research method used in this study consists of 3 stages are as follows:

A. Identification of Product Length Lathe Process Complexity

At this stage the researchers conducted a study of literature to determine the parameters that affect the complexity of manufacturing products, especially the product of lathe process based on the features and product specifications.

B. Development of Parameters Weight Value of Product Complexity Process of Lathe

The weight value of the product complexity parameter aims to enable researchers to assess or score for each product complexity variable. The result of the scoring is used to calculate the coefficient of relative complexity ($c_{j,product}$). The steps to make the weighting value are as follows [4]:

1. Identify the value of product weight of process of lathe.
2. Conduct an assessment of the product of the lathe process based on aspects of the product complexity variables.
3. Creating range from assessment result from the lowest value to the highest value of each product complexity paremeter
4. From the results of the range will be verified by several experts who are competent (expert) to give weighting.
5. The desired weighted value is low with value 0, medium with value 0.5 and high with value 1
6. The results of such verification, processed and analyzed to obtain the value of the desired weight
7. The result of weighting is made in a table based on aspects of the complexity parameters of machining products.

C. Measurement of Product Complexity Index

The steps to measure the index of product complexity, especially the product resulting from the lathe process are as follows:

1. Selecting the product of the lathe process to measure the complexity index of the product.
2. Identify the pressed products to determine:
   - Amount of information (N)
   - The amount of information that is considered unique (n)
3. Calculate the value of the compression factor / entropy product (H)
4. Calculate the ratio value of information variation ($DR_{product}$)
5. Weighing the product complexity variables based on the weighted tables that were made earlier to calculate the coefficient value of relative complexity ($c_{j,product}$)
6. Calculate the product complexity index ($CI_{product}$)

3. Results and Discussion

A. Product Complexity Parameter

Researchers conducted a literature study to determine the parameters that affect the complexity of the product of machining process lathe and frais. From the study literature it is found that the parameters that affect the complexity of the lathe process products are as follows:

1. Material includes the type of material used to be a product.

2. Shape includes the general form of a product that includes the shape type.
3. Geometry includes the size of a product produced.
4. Tolerance is a permissible measure for producing a product.
5. General Surface finish is the surface condition of a product after the product is manufactured which includes surface roughness.
6. Hardness is the material hardness of a product after the product is produced

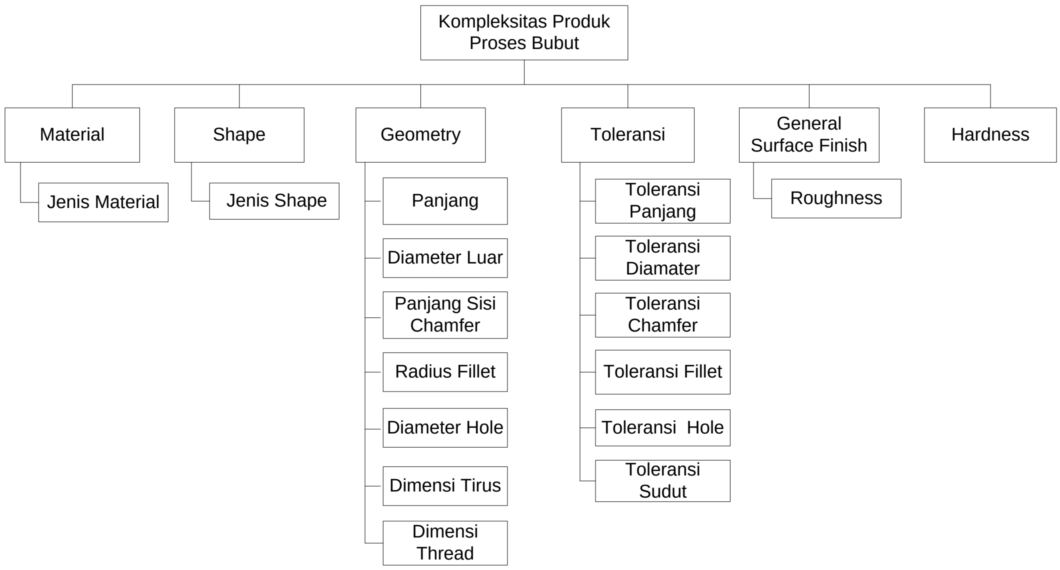

Figure 4. Parameter of Product Complexity of Lathe Process

B. Weighted Value of Product Complexity Parameters

The creation of a weighted value of product complexity aims to enable researchers to rate or score for each product complexity variable. The results of the scoring are used to calculate the coefficients of relative complexity ($c_{j,product}$).

Data processing is done by looking at the result of observation and questionnaire result of assessment of product complexity level. From the results of questionnaires seen the tendency of each product complexity variables. After that, continued by giving the weight of the level of complexity of each variable with reference to the results of observation. If the results of questionnaires on one variable shows the number 1 means the level of difficulty variable is high and if the results of questionnaires on one variable showed the value of 0.5 means the level of difficulty of these variables is moderate and the results of questionnaires on one variable shows the value 0 means the difficulty level The variable is low. To determine the interval between low and moderate to high values, the researcher determined by questionnaire.

Based on the results of data processing, it can be made table weighted value of the complexity level of pressed parts products. The weighted value table of product complexity for lathe process is as follows.

Table 1. Value weighting factor complexity product process material lathe

Material Type	Complexity Level
Aluminium	0
Brass	0
Thermo Plastic / Polymer	0
Composite	0
Cooper Alloy	0,5
Mild Stell / Low Carbon Steel	0,5
Medium-Carbon Steel	0,5
Bronze	0,5
Tungsten Alloy	0,5
High Carbon Steel	1
Stainless Steel	1
Gray Cast Iron	1
Titanium Alloy	1

Table 2. The weighted value of the product complexity factor of the shape shape lathe

Shape Type	Complexity Level
Under Cut	0
Chamfer	0
Fillet	0
Knurling	0
Cylinder	0,5
Hole	0,5
Grove	0,5
Plane Surface (Facing)	0,5
Cone (Tirus)	1
Excentric	1
Thread	1
Curved Surfaces	1

Table 3. The weighting value of the product complexity factor of the geometry variable lathe process

Length	**Complexity Level**
(0 < Length $\leq$ 120) mm	0
(120 < Length $\leq$ 1000) mm	0,5
LEngth > 1000 mm	1
Outside Diameter	**Complexity Level**
(0 < Outside Diameter $\leq$ 50) mm	0
(50 < Outside Diameter $\leq$ 120) mm	0,5
Outside Diameter > 120 mm	1
Chamfer Side Length	**Complexity Level**
(0 < Chamfer Side Length $\leq$ 6) mm	0
(30 < Chamfer Side Length $\leq$ 30 mm	0,5
Chamfer Side Length > 30 mm	1
Fillet Radius	**Complexity Level**
(0 < Fillet Radius $\leq$ 6 mm	0
(6 < Fillet Radius $\leq$ 30 mm	0,5
Fillet Radius > 30 mm	1
Hole Diameter	**Complexity Level**
(0 < Hole Diameter $\leq$ 30) mm	0
(30 < Hole Diameter $\leq$ 100 mm	0,5
Hole Diameter > 100 mm	1
Tapered Dimensions (Shortest Side Length)	**Complexity Level**
(0 < Shortest Side Length $\leq$ 10) mm	0
(10 < Shortest Side Length $\leq$ 50 mm	0,5
Shortest Side Length > 50 mm	1
Thread Dimension (Nominal Diameter)	**Complexity Level**
(0 < Thread Nominal Diameter $\leq$ 30) mm	0
(30 < Thread Nominal Diameter $\leq$ 100) mm	0,5
Thread Nominal Diameter > 100 mm	1

Table 4. The value of the factor weighting of the product complexity of the variable tolerance lathe process

Length Tolerance	**Complexity Level**
A. Nominal Length 0 -120 mm	
(± 0,3 $\leq$ Length Tolerance $\leq$ ± 0,8) mm	0
(± 0,15 $\leq$ Length Tolerance $\leq$ ± 0,3) mm	0,5
(± 0 < Length Tolerance $\leq$ ± 0,15) mm	1
B. Nominal Length 120 - 1000 mm	
(± 0,8 $\leq$ Length Tolerance $\leq$ ± 2) mm	0
(± 0,3 $\leq$ Length Tolerance $\leq$ ± 0,8) mm	0,5
(± 0,15 < Length Tolerance $\leq$ ± 0,3) mm	1
C. Nominal Length Large than 1000 mm	
(± 0,3 < Length Tolerance $\leq$ ± 0,5) mm	0
(± 0,5 $\leq$ Length Tolerance $\leq$ ± 1,2) mm	0,5
(± 1,2 $\leq$ Length Tolerance $\leq$ ± 3) mm	1
Diameter Tolerance	**Complexity Level**
Toleransi Diameter Luar > 0,1 mm	0
(± 0,01 $\leq$ Toleransi Diameter Luar $\leq$ ± 0,1) mm	0,5
(± 0 $\leq$ Toleransi Diameter Luar $\leq$ ± 0,01) mm	1

Chamfer Tolerance	Complexity Level
A. Nominal Length 0 - 6 mm	
(0,5 < Chamfer Tolerance ≤ 1) mm	0
(0,2 < Chamfer Tolerance ≤ 0,5) mm	0,5
(0 < Chamfer Tolerance ≤ 0,2) mm	1
B. Nominal Length 6 -30 mm	
(1 < Chamfer Tolerance ≤ 2) mm	0
(0,5 < Chamfer Tolerance ≤ 1) mm	0,5
(0,2 < Chamfer Tolerance ≤ 0,5) mm	1
C. Nominal Length Large Than 30 mm	
(4 < Chamfer Tolerance ≤ 8) mm	0
(2 < Chamfer Tolerance ≤ 4) mm	0,5
(1 < Chamfer Tolerance ≤ 2) mm	1
Toleransi Radius Fillet	**Complexity Level**
A. Nominal Radius 0 - 6 mm	
(0,5 < Fillet Tolerance ≤ 1) mm	0
(0,2 < Fillet Tolerance ≤ 0,5) mm	0,5
(0 < Fillet Tolerance ≤ 0,2) mm	1
B. Nominal Length 6 -30 mm	
(1 < Fillet Tolerance ≤ 2) mm	0
(0,5 < Fillet Tolerance ≤ 1) mm	0,5
(0,2 < Fillet Tolerance ≤ 0,5) mm	1
C. Nominal Length Large Than 30 mm	
(4 < Fillet Tolerance ≤ 8) mm	0
(2 < Fillet Tolerance ≤ 4) mm	0,5
(1 < Fillet Tolerance ≤ 2) mm	1
Hole Diameter Tolerance	**Complexity Level**
Hole Diameter Tolerance > 0,1 mm	0
(± 0,01 ≤ Hole Diameter Tolerance ≤ ± 0,1) mm	0,5
(± 0 ≤ Hole Diameter Tolerance ≤ ± 0,01) mm	1
Tire Tolerance	**Complexity Level**
0° < Tire Angle Tole≤rance ± 1°	0
± 1° < Tire Dimension ≤ 1° 30'	0,5
Tire Dimension > 1° 30'	1

Table 5. The weighted value of the product complexity factor of the general surface finish lathe process

Roughness	Complexity Level
N 10 (12,5 µm)	0
N 9 (6,3 µm)	0
N 8 (3,2 µm)	0
N 7 (1,6 µm)	0,5
N 6 (0,8 µm)	0,5
N 5 (0,4 µm)	0,5
N 4 (0,2 µm)	1
N 3 (0,1 µm)	1
N 2 (0,05 µm)	1
N 1 (0,025 µm)	1

Table 6. The weighting value of the product complexity factor of variable lathe variable process

Hardness	Complexity Level
No Hardening Process	0
With Hardening Process	1

C. Measurement of Product Complexity Index

The measurement of product complexity index toward lathe product is done to External Thread Bearing Housing product. This product is one that serves as a bearing housing in a coconut casting machine.

Based on the identification of information on External Thread Bearing Housing product, the amount of information (N) is 65, and the amount of information that is considered unique (n) is 49. So from the amount of information obtained, it can be calculated the product entropy value (H) Of 6.04 and the value of information variation *($DR_{product}$)* of 0.75. We then weighted the product complexity variables of the frais process to the V - Block product to calculate the relative complexity ($c_{j,product}$)

coefficient value and the relative complexity coefficient ($c_{j,product}$) value was 0.28. From the above calculation, it can be calculated value of product complexity index ($CI_{product}$) as follows:

$$CI_{product} = \left(D_{R_{product}} + c_{j,product}\right) * H_{product}$$

$$CI_{product} = (0{,}75 + 0{,}28) * 6{,}04$$

$$CI_{product} = 6{,}28$$

Figure 5. External thread bearing housing

The results of the weighting and value of the External Thread Bearing Housing product complexity index can be seen in Table 7 and Table 8.

The value of the External Thread Bearing Housing product complexity index is influenced by the amount of information that diangogap unique (n) is high despite the total amount of information (N) of the product resulting in a very high ratio of information variation. The total amount of information (N) obtained from the product is 65 information and the amount of information that is considered unique (n) is 49 and the ratio of information variation ($DR_{product}$) is 0.75. While the value of relative complexity coefficient ($c_{j,product}$) obtained is relatively low at 0.28. This indicates that the level of complexity / difficulty of the product is low or not too difficult. The value of the relative complexity coefficient (Cj, product) also affects the high value of product complexity index ($CI_{product}$).

If the External Thread Bearing Housing product is designed and regenerated by adding polishing process and hardening process to product finishing process, it will affect the value of complexity index of External Thread Bearing Housing product. The polishing process will produce a surface roughness level of 0.1 μm (Kalpakjian, 2006) so that based on Table 5, the weight value of general surface finish parameters is 1. While with the hardening process, the hardness parameter value also changed to 1, So the value of the relative complexity coefficient ($c_{j,product}$) changes to 0.73. Thus, it can be calculated value of product complexity index ($DR_{product}$) as follows:

$$CI_{product} = \left(D_{R_{product}} + c_{j,product}\right) * H_{product}$$

$$CI_{product} = (0{,}75 + 0{,}73) * 6{,}04$$

$$CI_{product} = 8{,}96$$

The redesigned results and index values of redesigned External Thread Bearing Housing product complexity can be seen in Table 9 and Table 10.

Table. 7 Weighting of product complexity variables to external thread bearing housing products

Description	J = 4						
	Number	**Aspects**				**SUM**	**Sum/J**
		Material	Shape	Geometry	Tolerance		
Bearing Housing	2	0,5	0,5	0,5	1	2,5	0,63
External Thread	1	0,5	1	1	1	3,5	0,88
Outside Cilindrical Surface	1	0,5	0,5	0,5	0,5	2	0,50
Chamfer	3	0,5	0	0	0,5	1	0,25
Plane Surface	2	0,5	0,5	0	0,5	1,5	0,38

Description	K = 2				
	Number	**Aspects**		**SUM**	**Sum/K**
		General Surface Finish	Hardness		
Bearing Housing	2	0,5	0	0,5	0,25
External Thread	1	0,5	0	0,5	0,25
Outside Cilindrical Surface	1	0,5	0	0,5	0,25
Chamfer	3	0	0	0	0,00
Plane Surface	2	0	0	0	0,00

Table 8. Calculation of the index of product complexity of external thread bearing housing

	Feature Complexity	Weighted Feature Complexity
Bearing Housing	0,44	0,10
External Thread	0,56	0,06
Outside Cilindrical Surface	0,38	0,04
Chamfer	0,13	0,04
Plane Surface	0,19	0,04
Relative Product Complexity Coeficient, c_j		**0,28**
CI Product		**6,28**

Table. 9 Weighting of product complexity variables to external thread bearing housing redesign products

Description	**J = 4**						
	Number	**Aspects**				**SUM**	**Sum/J**
		Material	Shape	Geometry	Tolerance		
Bearing Housing	2	0,5	0,5	0,5	1	2,5	0,63
External Thread	1	0,5	1	1	1	3,5	0,88
Outside Cilindrical Surface	1	0,5	0,5	0,5	0,5	2	0,50
Chamfer	3	0,5	0	0	0,5	1	0,25
Plane Surface	2	0,5	0,5	0	0,5	1,5	0,38

Description	**K = 2**				
	Number	**Aspects**		**SUM**	**Sum/K**
		General Surface Finish	Hardness		
Bearing Housing	2	1	1	2	1,00
External Thread	1	1	1	2	1,00
Outside Cilindrical Surface	1	1	1	2	1,00
Chamfer	3	1	1	2	1,00
Plane Surface	2	1	1	2	1,00

Table 10. Calculation of product complexity index redesign external thread bearing housing

	Feature Complexity	Weighted Feature Complexity
Bearing Housing	0,81	0,18
External Thread	0,94	0,10
Outside Cilindrical Surface	0,75	0,08
Chamfer	0,63	0,21
Plane Surface	0,69	0,15
Relative Product Complexity Coeficient, c_j		**0,73**
CI Product		**8,96**

From the calculation of product complexity index ($CI_{product}$) to the original External Thread Bearing Housing product and the redesigned External Thread Bearing Housing product, there is a difference in the complexity index value of the product. This happens because with the addition of polishing process and hardening process, making the information obtained especially related to the content / information content will change so that will change the coefficient value of relative complexity ($C_{j,product}$). Consequently the product complexity index value ($CI_{product}$) for the redesigned External Thread Bearing Housing product will differ from the product complexity index value ($CI_{product}$) for the original External Thread Bearing Housing product.

4. Conclusion

The measurement of the complexity index of the product can be done based on the product information itself which includes the amount of information, the variety of information and the content of the information. In this research, measurement of product complexity index on External Thread Bearing Housing product. To assist in the assessment of product complexity, we developed a value of parameter weights that affect the complexity of the product, especially the product of the lathe. The weight value is used to determine the value of the relative complexity coefficient ($C_{j,product}$). The result of assessment of product complexity to External Thread Bearing Housing product got value of product complexity index ($CI_{product}$) equal to 6,28. Furthermore, the product is redesigned by adding polishing process and hardening process on final product completion process, then produced value of complexity index of product ($CI_{product}$) equal to 8,96.

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