PROSIDING SNTTM XXI 2023
Volume 21, Tahun 2023, 5 Oktober 2023
e-ISSN 2623-0313
p-ISSN 3032-1972

# Tolerance stack-up analysis of generator magnet permanent using worst-case method

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## ABSTRACT

Tolerances and dimensions play a key role in the manufacturing process as it is possible to have some deviations from the designed values, which significantly impact a product's functional quality. On the other hand, it is known that the correlation between cost and precision is that the more precise/tighter the tolerance value required, the more expensive it is. In a permanent magnet generator, the gap between the stator and the rotor/air gap is an important requirement for the permanent magnet generator to function optimally. The air gap is formed from a pile of components with certain dimensional values and tolerance values from a permanent magnet generator. This paper analyses the tolerance piles on generators and proposes reducing the contributing variables to the air gap tolerance piles to reduce the tight tolerance values on the components. The proposal is based on consideration of the ISO 2768-1 and 2768-2 standard approaches. The details of the nominal dimensions of the permanent magnet generator and the allowable gap range obtained from the electrical and mechanical design of LIPI (Indonesian Institute of Sciences) are used as input parameters for the tolerance analysis. The tolerance value resulting from the initial design is used as a comparison for the final tolerance value allocation. The worst-case method was chosen to carry out the tolerance stack analysis process. Referring to the allowable air gap distance range of 0.8 - 1.2 mm, the result of the air gap tolerance pile distance calculation is 0.81 - 1.18 mm. The smallest tolerance value obtained was found on the rotor shaft, 0.011 mm, in the initial design, which was 0.001 mm. A machining centre (CNC) can achieve this tolerance value during manufacturing.

**Keywords**: Dimension tolerance, geometry tolerance, stack tolerance, worst case, method, gap

**Received** 30 September 2023; **Presented** 5 October 2023; **Publication** 27 May 2024

## INTRODUCTION

Tolerances and dimensions play a key role in the manufacturing process because it is possible to have some deviations from the designed values , which have a very significant impact on the quality and functional requirements of the final product, as stated by [1]. This will involve different component shapes, as well as different component characteristics, such as component length, hole position, pins, etc. In several standards that refer to ASME Y14.5M and ISO 2768-1 and 2768-2 standards which explain product design, tolerance intervals are determined based on knowledge from company research and scientific analysis to determine acceptable dimensional variations and tolerances. From product development to the final phase of production, tolerance analysis is used to organize and manage efficient and profitable production processes and ensure safety and performance on both the production process line, operators, inspections, and the components themselves.

In these matters, tolerances and dimensions have a very important influence on the functioning of permanent magnet generator components, which is related to the gap between the stator and rotor that must be met. Because dimensions are very possible to have several deviations/variations from the initial design values , which have a very significant impact on the quality and functional requirements of the final product, the deviations or variations in dimensions and tolerances must be controlled, so from this it is very important to analyze the determination of dimensions and their tolerances. According to [2] who has researched tolerance analysis related to the production process of permanent magnet generators that will be mass-produced, states that tolerance allocation, tool selection, production process selection, generator design, and production time analysis will greatly affect the performance of the magnetic generator. In his research, the performance of the magnetic generator was analyzed using FEM including the measurement parameters of the gap between the stator and the rotor, the cogging torque, and the power generated by the generator.

The impact of manufacturing tolerances on the performance of permanent magnet synchronous generators has been investigated by [3]. The research was carried out by measuring the air gap magnetic flux density, air gap length, as well as the magnetization and size of the permanent magnet. The results of this research found that the remanence value of the permanent magnet used was below tolerance, the air gap distance was smaller than specified, and the resulting air gap magnetic flux density was lower than specified. From these results, it can be concluded that the design must consider tolerances and quality control of spare parts, especially the magnetization of permanent magnets, to obtain the expected machine performance.

At the same time, there is a relationship or correlation between cost and precision, where the looser the tolerance, the lower the manufacturing process costs, while the tighter the tolerance, the more expensive the manufacturing process and inspection process costs, as stated by [4]. The manufacturing process for making a feature will produce varying dimensions, shapes, and tolerances [5]. The machine operator influences the general manufacturing process method used. The machine operator is allowed to change the machining parameters, and by using the inspection process, the optimal tolerance value for the manufacturing process results can be determined. Based on this, if the manufacturing process is very complex, it will take much time so production costs will increase.

The tighter the tolerance, the higher the production cost [6]. However, when product quality is used as a reference other than just the manufacturing process capability, it requires not only operator capability but also all aspects of the manufacturing process for tolerance analysis so that production costs can be minimized.

Stack-up tolerance analysis is used to study the suitability of parts with tolerance zones [7]. Different dimensional and geometric tolerances are given to the various component parts. When these components are assembled, an accumulation or accumulation of tolerances will arise which plays a very important role in the assembly's functionality. The process of analyzing the accumulation of tolerance stacks requires a stack-up tolerance analysis to calculate the accumulation of tolerances on assembly dimensions, according to the dimensions and tolerances given to each component, along with the resulting consequences in relation to the assembly performance of the components before and after the assembly process.

According to [8], from the variations in dimensions and tolerances on each building component of a product from the results of the tolerance stack analysis, optimization of component and assembly tolerances in new designs will be obtained, a balance between precision, accuracy, and cost with manufacturing process capabilities, determination of component tolerances to guarantee the process assembly, determining the allowable component tolerance variations according to the assembly process, determining whether the tolerance stack analysis will work in the worst case or statistical conditions, determining whether the tolerance variations will affect the assembly process, finding problems that occur during the assembly process, finding alternative designs using different components or modified components, as well as determining how much influence changes in the assembly process have on variations between related component features.

This article discusses the process of stack-up tolerance analysis in the permanent magnet generator prototype design. The tolerance stack analysis method used in this study is the worst-case method, which guarantees a 100% assembly fit process, as stated by [9] in his book.

Furthermore, the tolerance value obtained will be compared with the tolerance value from previous research to obtain the optimal tolerance value.

## RESEARCH METHOD

Referring to previous research, the tolerance values obtained from the tolerance stack analysis process are very tight, so these tolerances are difficult to work with in general production processes. The component tolerance values from previous research are shown in Table 1.

### *1. Product Structure and Functionality Analysis*

Architectural products are the embodiment of component functions and physical components in a product because a product is built from components that are designed functionally and physically. The product architecture of the permanent magnet generator is shown in Figure 1, while Figure 2 depicts the assembly of permanent magnet generator component parts.

Tabel 1 Final Aloate tolerane value [10]

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e-ISSN 2623-0313
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Final tolerance allocation value

| Component | Features | Nominal dimension (mm) | Dimension tolerance (mm) (t) | | Geometry tolerance (mm) Coaxciality | Cylindricity | Profile | Runout | Total runout |
|---|---|---|---|---|---|---|---|---|---|
| | | | (t) | (t') | (coax) | (cyl) | (surf) | (ro) | (tro) |
| Stator | SOS | Ø400 | 0 | -0,02 | — | 0,02 | — | — | — |
| | SIS | Ø337 | 0,02 | -0,02 | 0,02 | 0,02 | — | — | — |
| Shaft | FSBS-SRBS | Ø75 | 0,02 | 0,01 | 0,001 | 0,001 | — | — | — |
| Rotor | RPMS | Ø323 | 0,02 | 0,02 | 0,001 | — | — | — | 0,001 |
| Magnet | MOS | R167,5 | 0,02 | 0,02 | — | — | 0,02 | | |
| | MBS | R161,5 | 0,02 | 0,02 | — | — | 0,02 | | |
| Bearing | OBS | Ø130 | 0 | -0,018 | — | — | — | 0,025 | — |
| | IBS | Ø75 | 0 | -0,015 | — | — | — | 0,015 | — |
| Frame | FSF | Ø412 | -0,014 | 0 | 0,004 | 0,004 | — | — | — |
| | SSF | Ø400 | 0,06 | -0,039 | 0,004 | 0,004 | — | — | — |
| End-Shield | FSE | Ø412 | 0 | -0,02 | 0,003 | 0,003 | — | — | — |
| | BSE | Ø130 | 0,02 | -0,02 | 0 | 0,005 | — | — | — |

## *2. Important Factors that Influence Component Functionality*

The permanent magnet generator will be able to function properly if the conditions are met, including the gap between the stator and the magnetic rotor must meet the specification value of 0.8 – 1.2 mm because this gap affects the coging torque which will affect the output power of the permanent magnet generator as shown in Figure 3 .The larger the gap, the coging torque will decrease, but the smaller the coging torque, the output power of the permanent magnet generator will also decrease. Meanwhile, if the gap is too small, the coging torque will increase, and the greater the coging torque, the lower the output power of the permanent magnet generator will be. The gap between the stator and rotor is formed from a pile of tolerances for the components that make up the permanent magnet generator. So variations in the dimensions and geometry of the constituent components will cause variations in the gap between the stator and rotor. The gap variation must remain within the allowable range of 0.8 -1.2 mm as shown in the figure so that the gap variation must be controlled.

## *3. Possible Component Relationships That Reduce Component Functionality*

Efforts to ensure the functioning of the harvesting magnetic generator components are to analyze and control possibilities that could reduce the functioning of the permanent magnetic generator.

Based on the relationship diagram between components in architectural products, the possible component relationships that contribute to reduced functioning of permanent magnet generators include: the position of the shaft is not on the same axis/tilt, which causes the rotor also to experience tilt and this affects the gap between the rotor and the stator (Figure 4),

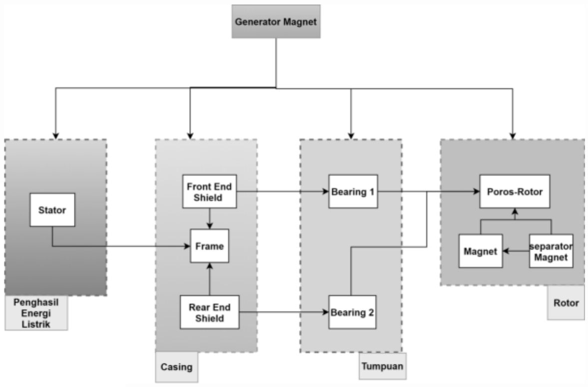


Figure 1 Permanent Magnet Generator Product Architecture

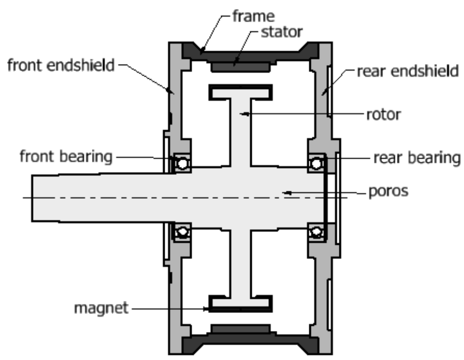


Figure 2 Half cut of Permanent Magnet Generator Component Assembly

the relationship between the shaft and the bearings is not correct  or tilted which is a result of the shaft geometry not being on the same axis as well as incorrect installation of the bearings which causes the shaft tilts and results in a wide gap between the stator and rotor, the relationship between the bearing and the endshield is incorrect/skewed which causes the position of the endshield to become tilted which will result in a gap between the stator and rotor because the endshied is the frame mount and the frame is the stator mount so if the connection between An endshield with an incorrect frame will result in a gap between the stator and rotor, an incorrect/tilted connection between the endshield and the frame will result in a gap between the stator and rotor because the frame is a stator mount, the connection between the frame and the stator is not on the same axis/tilt so that resulting in a gap between the stator and rotor (Figure 5)

Based on the features of the components that make up the permanent magnet generator in Figure 7, the relationship between the features can be realized. component functioning is shown in the form of a Liason diagram in Figure 8

e-ISSN 2623-0313
p-ISSN 3032-1972

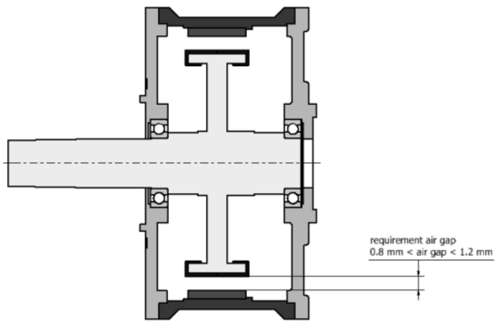


Figure 3 Requirement Gap to Ensure Component Functionality

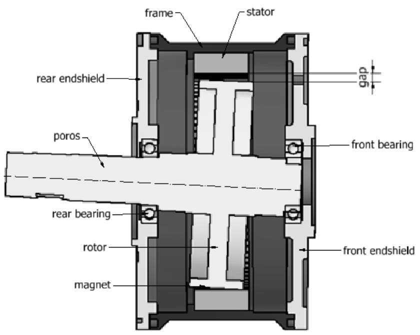


Figure 4 Illustration Of Faulty In The Connection Between Rotor Components And Bearings Resulting In Gaps

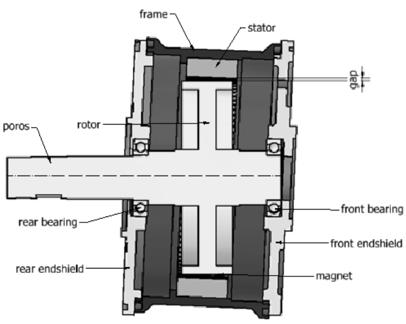


Figure 5 Illustration of Faulty Bearing-Endshield-Frame-Stator Component Relationships Resulting in Gaps

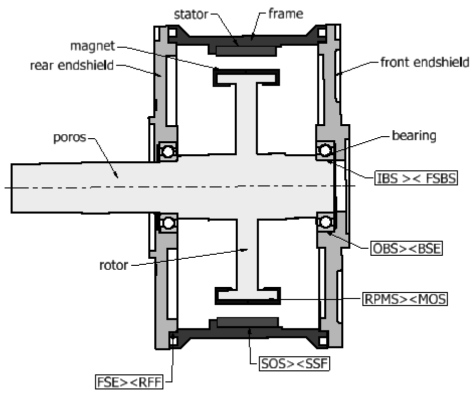


Figure 7 Relationship between Permanent Magnet Generator Component Features

## RESULTS AND DISCUSSION

Geometry Dimensional Tolerance (GDT) is very important in the product development process, especially at the detail design level which includes tolerance allocation and feature geometry.

*1. Initial Tolerance Allocation for Tolerance Stack Analysis*

Tolerance allocation is based on the ISO 2768-1 standard which is shown in Table 2 for dimensional tolerances and ISO 2768-2 for geometric straightness and flatness tolerances which are shown in Table 3

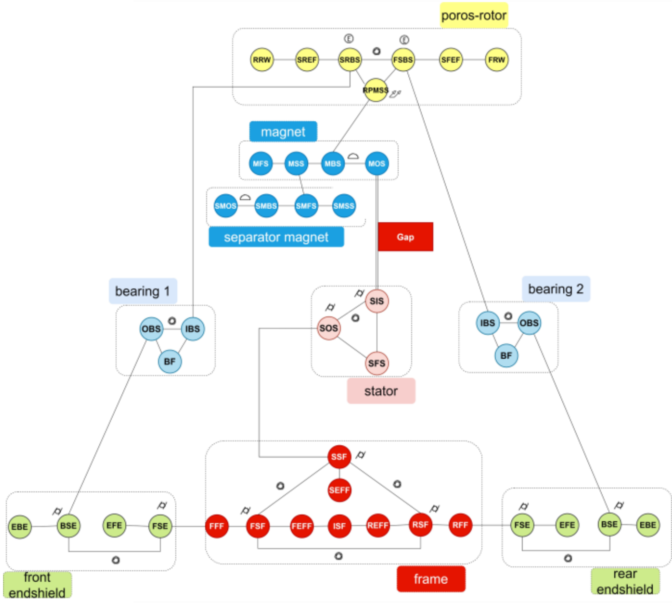


Figure 8 Liason Diagram of Permanent Magnet Generator Component Feature Relationships

The geometric run-out tolerance for shafts reference to SKF standard bearings which allocated according to standard bearings for normal conditions of tolerance (moderate speed and load) IT5/2 tolerance value of 13 µm [11].

The tolerance allocation considerations, both linear tolerances and geometrical tolerances, are as follows: Tolerances based on the precision that can be achieved in normal workshop processes (if general tolerances are applied to components, workmanship will be easier), Selection of grade tolerances in general tolerances based on the capabilities of the machine used, If the general tolerance has to be exceeded or resized, the decision making regarding the tolerance variation is rejected or accepted according to the function of the component. Any change in tolerance variations for each feature will affect the cost/economics of the entire component (if the tolerance

e-ISSN 2623-0313
p-ISSN 3032-1972

is tighter, the process and inspection costs will be more expensive, while if the tolerance is looser, the process and inspection costs will be cheaper). The initial allocation of tolerance values for permanent magnet generator components is shown in Table 4

Based on the ISO 2768-2 standard [12]: Circularity is not presented in tabular form however, the circularity tolerance value must not be allowed to exceed the dimensional tolerance value or at least be equal to the dimensional tolerance value.

Cylindricity is not presented in table form but the cylindricity value is not allowed to exceed the tolerance value parallel geometry, circularity and straightness because cylindricity is a combination of these three tolerances. In the case of limit and fit, cylindricity deviations are limited by Ⓔ Envelope conditions so there is no need to allocate a cylindricity tolerance or and even if a cylindricity tolerance is allocated then the cylindricity tolerance is usually ignored

Coaxiality or concnetricity is not represented in tabular form, but the value of concnetricity or coaxiality is not allowed to exceed the tolerance value.

Table 2 Permissible Deviation for Linear Dimension [13]

Values in millimetres

| Tolerance class | | Permissible deviations for basic size range | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Designation | Description | 0,5 1) up to 3 | over 3 up to 6 | over 6 up to 30 | over 30 up to 120 | over 120 up to 400 | over 400 up to 1 000 | over 1 000 up to 2 000 | over 2 000 up to 4 000 |
| f | fine | ±0,05 | ±0,05 | ±0,1 | ±0,15 | ±0,2 | ±0,3 | ±0,5 | – |
| m | medium | ±0,1 | ±0,1 | ±0,2 | ±0,3 | ±0,5 | ±0,8 | ±1,2 | ±2 |
| c | coarse | ±0,2 | ±0,3 | ±0,5 | ±0,8 | ±1,2 | ±2 | ±3 | ±4 |
| v | very coarse | | ±0,5 | ±1 | ±1,5 | ±2,5 | ±4 | ±6 | ±8 |

1) For nominal sizes below 0,5 mm, the deviations shall be indicated adjacent to the relevant nominal size(s).

Table 3 General Tolerance on Straightness and Flatness [12]

Values in millimetres

| Toler-ance class | Straightness and flatness tolerances for ranges of nominal lengths | | | | | |
|---|---|---|---|---|---|---|
| | up to 10 | over 10 up to 30 | over 30 up to 100 | over 100 up to 300 | over 300 up to 1 000 | over 1 000 up to 3 000 |
| H | 0,02 | 0,05 | 0,1 | 0,2 | 0,3 | 0,4 |
| K | 0,05 | 0,1 | 0,2 | 0,4 | 0,6 | 0,8 |
| L | 0,1 | 0,2 | 0,4 | 0,8 | 1,2 | 1,6 |

## *2. Tolerance Stack Analysis*

Description: A is the dimensional vector quantity of the stator component, B is the dimensional vector quantity of the magnetic component, C is the dimensional vector quantity of the rotor component, D is the dimensional vector quantity of the bearing component, E is the dimensional vector quantity of the shaft component, F is the dimensional vector quantity of the frame component, G is the vector dimension of the Endshield component. The loop diagram for tolerance analysis is shown in Figure 9.

Efforts to ensure that the gap value is within the required range, namely a minimum gap of 0.8 mm and a maximum gap of 1.2 mm, are necessary.

component dimensions are considered based on the material condition of each component which influences both minimum and maximum gaps.

Table 4 Initial Tolerance Allocation

| Lamb Komp | Nama Komp | Dimensi (mm) | Toleransi Linier (mm) | Toleransi Geometri (mm) | | | |
|---|---|---|---|---|---|---|---|
| | | | | ⌭ | ◎ | ⌰ | ⌓ |
| A | Stator | D out : 400<br>D in : 337 | D out : ± 0.5<br>D in : ± 0.5 | 0.5<br>0.5 | 0.5 | - | - |
| B | Magnet | Rout : 167.5<br>R in : 161.5 | D out : ± 0.5<br>D in : ± 0.5 | - | - | - | 0.5<br>0.5 |
| C | Rotor | D out : 323 | D out : ± 0.5 | - | - | 0.013 | - |
| D | Bearing | D out : 130<br>D in : 75 | ***D out***: $^{0}_{-0.018}$<br>***D in*** : $^{0}_{-0.015}$ | - | - | - | - |
| E | Poros | D: 75m6Ⓔ | ***D out***: $^{0.024}_{0.011}$ | | 0.013 | - | - |
| F | *Frame* | D out : 412<br>D in : 400 | D out : ± 0.8<br>D in : ± 0.5 | 0.6<br>0.6 | 0.6<br>0.6 | | |
| G | Endsield | D out : 412<br>D in : 130 | D out : ± 0.8<br>D in : ± 0.5 | 0.6 | 0.6 | | |

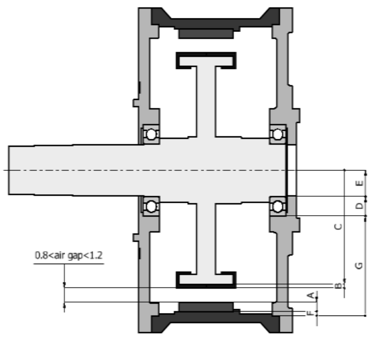


Figure 9 Loop Diagram of Permanent Magnet Generator

The effect of component material conditions on the maximum and minimum gaps as required is shown in Figure 9 and Table 5 for the minimum gap conditions and Figure 10 and Table 6 for the maximum gap conditions.

## 3. Calculating Gap Variations and the Results

Things that contribute to the variation in the gap include the variation in the gap obtained from the tolerance value both dimensional tolerance and geometric tolerance, the gap variation obtained from the presence of a shift assembly or a shift in component position related to the presence of clearance

e-ISSN 2623-0313
p-ISSN 3032-1972

between paired components, gap variation obtained from the existence of a datum shift on components.

The contribution of geometric tolerances to material requirement conditions, both at maximum and minimum conditions, is expressed as follows:

MMR = MMS + geometric tolerance (shaft)
MMR = MMS – geometric tolerance (hole)
LMR = LMS - geometric tolerance (shaft)
LMR = LMS + toleransi geometri (lubang)
MMR : maximum material requirement
LMR : least material requirement
MMS : maximum material size
LMS : least material size

The effect of geometric tolerances is analyzed using tolerance indicators as explained in Figure 11 for the stator component at maximum gap conditions, Figure 12 for the shift assembly which occurs due to looseness between the frame and stator at maximum gap conditions and Table 7 for the calculation of the stack tolerance analysis

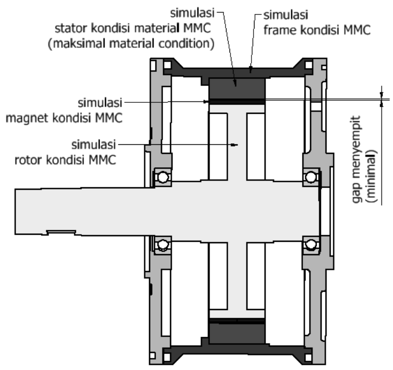


Figure 9 Material Requirement Minimum Gap Condition

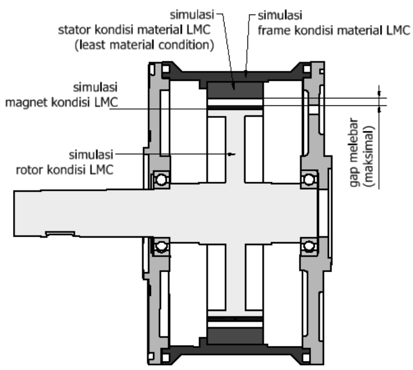


Figure 10 Material Requirement Maximum Gap Condition

Table 5 Material Requirements Minimum Gap Conditions

| Gap Minimal | Kondisi Material | |
|---|---|---|
| Stator | MMC (maksimal material condition) | Dout = MMC<br>Din = MMC |
| *Frame* | MMC (maksimal material condition) | Dout = MMC<br>Din = MMC |
| *Endshield* | LMC (least material condition) | Dout = LMC<br>Din= LMC |
| Bearing | MMC (maksimal material condition) | Dout = MMC<br>Din = MMC |
| Rotor | MMC (maksimal material condition) | Dout = MMC |
| Poros | MMC (maksimal material condition) | Dout = MMC |
| Magnet | MMC (maksimal material condition) | Dout = MMC<br>Din= MMC |

Using the same method, the results of the tolerance stack analysis on permanent magnet generator components are shown in Table 8

Table 6 Material Requirements Maximum Gap Condition

| Gap Maksimum | Kondisi Material | |
|---|---|---|
| Stator | LMC (least material condition) | Dout = LMC<br>Din = LMC |
| *Frame* | LMC (least material condition) | Dout = LMC<br>Din = LMC |
| *Endshield* | MMC (maksimal material condition) | Dout = MMC<br>Din= MMC |
| Bearing | LMC (least material condition) | Dout = LMC<br>Din = LMC |
| Rotor | LMC (least material condition) | Dout = LMC |
| Poros | LMC (least material condition) | Dout = LMS |
| Magnet | LMC (least material condition) | Dout = MMC<br>Din= MMC |

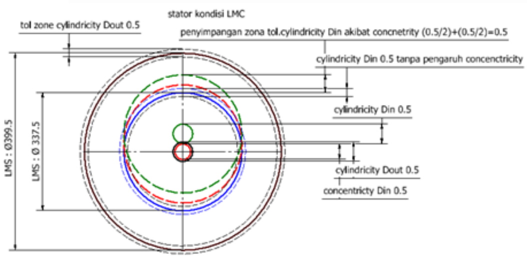


Figure 11 Effect of Geometry Tolerance on Stator components on Tolerance Stack Analysis

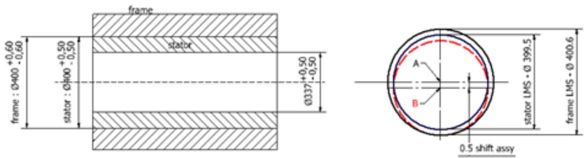


Figure 11 Shift assy on Stator Components against Tolerance Stack Analysis

Table 7. Stack Analysis of Stator Component Tolerances in Maximum Gap Conditions

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| ALOKASI TOLERANSI AWAL PADA ANALISA TUMPUKAN TOLERANSI KONDISI GAP MAKSIMUM | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Product** | : Assembly Generator Magnet Permanent | | | | | | | |
| **Problem** | : Stack Tolerance Arah radial dengan Memperhitungkan Effect Toleransi Geometri | | | | | | | |
| **Object** | : Menganalisa Jarak Gap antara Komponen Stator dan Magnet | | | | | | | |
| **Nama Komp.** | **Symbol Komp.** | **Nomor** | **Diskripsi** | **Dim Arah naik** | **Dim Arah Turun** | **toleransi geometri** | | **Sumber dan Perhitungan Stack Dimensi/Toleransi** |
| | | | | (+) | (-) | (+) | (-) | |
| **Stator (LMC)** | **A** | 1 | Dimensi | | 31 | | | (LMS Dout - LMS Din)/2 = (399.5 - 337.5)/2 = 31 |
| | | 2 | cylindricity Dout | | | | 0.25 | tol. cylindricity = 0.5/2 =0.25 |
| | | 3 | concentricty Din | | | 0.25 | | tol. Concentricty = 0.5/2 = 0.25 |
| | | 4 | cylindricity Din | | | 0.5 | | tol. Cylindricity Din karena dipengaruhi oleh tol.concentricity (0.25+0.25=0.5) |
| | | 5 | Shift assy | | | 0.5 | | pergeseran posisi stator terhadap *frame*; (LMS Din *frame* - LMS Dout stator) = (400.5 - 399.5)/2 = 0.5 |

Table 8 Gap between Stator and Rotor Component Tolerance Stack Analysis Results

| **Gap Maksimum Hasil Analisa Tumpukan Toleransi** | **Gap Minimum Hasil Analisa Tumpukan Toleransi** | **Keterangan** |
|---|---|---|
| 5.263 | 2.344 | *Requirement* gap belum terpenuhi |

Because the results of the initial tolerance stack allocation analysis did not meet the specified requirements, namely a gap of 0.8 – 1.2 mm, the resize process was carried out using the same method to obtain the gap values between the rotor and stator in Table 9 with the tolerance allocation

Table 9. Gap Stator And Rotor Resize Results

| **Gap Maksimum Hasil Resize Analisa Tumpukan Toleransi** | **Gap Minimum Hasil Resize Analisa Tumpukan Toleransi** | **Keterangan** |
|---|---|---|
| 1.179 | 0.812 | *Requirement* gap terpenuhi (0.8 – 1.2 mm) |

Table 10 Final Tolerance Values Resie Results

| Komp | Dimensi Toleransi | **Toleransi Geometri** | | | |
|---|---|---|---|---|---|
| | | ⌭ | ◎ | ⌰ | ⌓ |
| **Stator** | $Din = 337^{0}_{-0.1}$ $Dout = 400^{0}_{-0.1}$ | Din=0.05 Dout=0.05 | Din=0.05 | - | - |
| ***Frame*** | $Din = 400^{0.3}_{-0.3}$ $Dout = 412^{0}_{-0.1}$ | Din=0.05 Dout=0.05 | Din=0.05 Dout=0.05 | - | - |
| ***Endshield*** | $Din = 130^{0.1}_{0}$ $Dout = 412^{0}_{-0.1}$ | Dout=0.05 | Dout=0.05 | | |
| **Bearing (produk SKF)** | $Din = 75^{0}_{-0.015}$ $Dout = 130^{0}_{-0.018}$ | - | - | - | - |
| **Poros** | $Dout = 75^{0.024}_{0.011}$ | | Do=0.013 | | |
| **Rotor** | $Dout = 323^{0}_{-0.1}$ | - | - | Do=0.013 | |
| **Magnet** | $Rin = 167.5^{0.1}_{0}$ $Rout = 161.5^{0}_{-0.1}$ | - | - | - | Din=0.05 Do=0.05 |

## *4. Production Process Planning Based on Resize Results of Stack Tolerance Analysis*

The tolerance contribution to the selection of production processes is very large because it will affect production costs, tools, and inspection

Based on considerations of the tolerances that can be achieved by the machine, the shapes that can be produced by the machine, the MRR (material removal rate) that can be achieved by the machine and the batch size that can be achieved by the machine, the production process for permanent magnet generator components is shown in Table 12. Process selection EDM production on stator components because even though the CNC machining center can reach a tolerance of 1 µm, the CNC machining center cannot produce small shapes due to the limitations of the endmill tool or slot mill. The production process that can produce components with small dimensions (slots, holes, radii and chamfers, inner and outer threads) is wire EDM (wire electrical discharge machine).

Figure 12 is a detailed image of the stator components. Consideration of the stator production process using wire EDM according to the advance machining characteristics table in Table 12 MRR wire EDM 6 mm/minute, no surface damage due to exposure to electrical jumps (wire EDM uses wire as a tool cutter and not using spark) [14] on , the tolerance that can be achieved is 0.025 – 0.5 mm for the roughing process and 0.0125 – 0.025 mm for the finishing process, and the batch size that can be achieved is 1000 units [15]

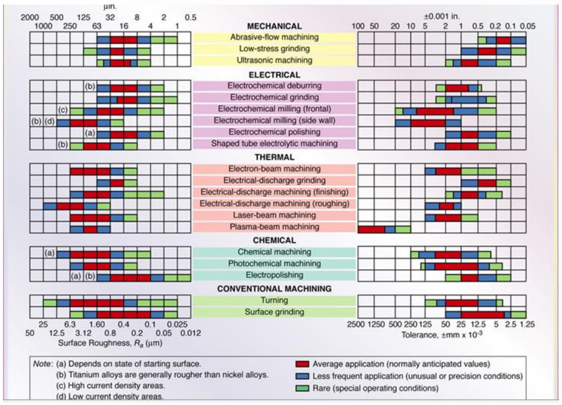


Figure 11 EDM Process And Tolerance Diagram [14]

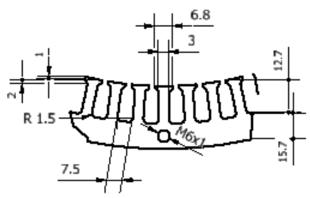


Figure 12 Stator Component Details

Table 11 Production Process of Permanent Magnet Generator Components

| **Nama Komp** | **Proses Produksi Yang Direkomendasikan** |
|---|---|
| Stator | EDM (wire EDM) |
| *Frame* | Universal machining center (CNC) |
| *Endshield* | Universal machining center (CNC) |
| Rotor | Universal machining center (CNC) |
| Magnet | Powder Metalurgy (roughing) Grinding (finishing) |
| Separator Magnet | Universal machining center (CNC) |

e-ISSN 2623-0313
p-ISSN 3032-1972

## CONCLUSION

Based on the results of the analysis of tolerance stack research on permanent magnet generators using the worst-case method, it was concluded that the allocation of tolerance values for each generator component in order to ensure the permanent generator components function properly has been obtained (complete results are shown in table 10) with tolerance values smallest on the shaft components of the FSBS and RSBS features with a tolerance value of 0.011 mm and run out geometric tolerance on the RPMS feature rotor and on-entry on the FSBS and RSBS features. easy and appropriate, namely using enter machining and EDM for the SIS features of the stator components

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