SURAT KETERANGAN

No.: 002/PA-LP2/SKet/IX/2023

Dengan hormat,

Yang bertanda tangan di bawah ini, menerangkan bahwa:

1. Nama : Yohanes Tri Joko Wibowo
   NIDN : 0309027603
   Program Studi : Pembuatan Peralatan dan Perkakas Produksi, Politeknik Astra

adalah dosen yang sedang melakukan penelitian di lingkungan Program Studi Pembuatan Peralatan dan Perkakas Produksi Politeknik Astra dengan judul

"***RSM-based Modeling to Restrain the Dimension Deviation in CNC Milling Operation.***"

Surat keterangan ini dibuat untuk keperluan administrasi laporan kinerja dosen di lingkungan Kopertis III. Demikian surat ini dibuat dengan sebenar-benarnya agar dapat digunakan sebagaimana mestinya.

Jakarta, 4 September 2023
Kepala Lembaga Penelitian & Pengabdian Masyarakat

Dr.Eng Syahril Ardi, S.T, M.T

The 9th International Conference on Science and Technology
UGM Central Building, 3rd Floor, Room S3-15, Bulaksumur, Yogyakarta, 55281 Indonesia
Phone: + 62 274 649 2619 *Email:* icst@ugm.ac.id *Web:* icst.ugm.ac.id *Twitter:* @icstugm

October 23, 2023

Ref. : 035/UGM/ICST-2023/2023

Subject : Notification of Paper Acceptance

Dear Yohanes Tri Joko Wibowo,

On behalf of the Organizing Committee, we would like to inform that your manuscript with the details:

name of the authors : Yohanes T. Wibowo, Nurhadi Siswanto, and Mokh. Suef

symposium : Mechanical and Industrial Engineering Symposium

paper title : RSM-Based Modeling to Restrain the Dimension Deviation in CNC Milling Operation

has been **refereed and accepted for presentation**.

For the most updated information at the ICST 2023, please check the conference website at https://icst.ugm.ac.id/2023. Should you have any questions regarding the registration, submission of the final manuscript and the conference technical, please do not hesitate to contact us. We look forward to seeing you at the ICST 2023 on November 1-2, 2023 in Yogyakarta, Indonesia.

Thank you for your attention.

Yours sincerely,

Dr.Eng. Ir. Wawan Budianta, S.T., M.Sc. IPM.
Conference Chair

YOHANES TRI JOKO WIBOWO

From:	EDAS Conference Manager <help@edas.info> on behalf of ICST UGM 2023 (icst@ugm.ac.id) <icst=ugm.ac.id@edas.info>
Sent:	04 October 2023 12:22
To:	YOHANES TRI JOKO WIBOWO
Subject:	[ICST UGM 2023] Your paper #1570948501 ('RSM-Based Modeling to Restrain the Dimension Deviation in CNC Milling Operation') has been accepted for presentation

Dear Mr. Yohanes Wibowo,

We are pleased to inform you that your paper #1570948501 ('RSM-Based Modeling to Restrain the Dimension Deviation in CNC Milling Operation') has been selected for presentation in 2023 9th International Conference on Science and Technology (ICST).

Please revise your final manuscript according to the reviewers' feedback. You can find the detailed reviews at 1570948501, using your EDAS login name wibowo.207010@mhs.its.ac.id. Please also note that you are responsible for (English) proofreading your final paper to ensure that it meets the publication standards of the related publisher.

Please consider four mandatory steps for the author in preparing the presentation for this conference:

1. Register your presenter

Payments cannot be made in cash; they must be via credit card (for international participants) or bank transfer to the ICST UGM 2023 account below:

- *Payment via credit card (USD)*
  The international presenter who submits their manuscript in the EDAS system. We do not recommend the local presenter pay the conference fee via credit card because the EDAS payment currency is USD.
- *Payment via bank transfer (IDR)*
  The local presenter can transfer the payment to:
  - Account name: UGM ICST
  - Account number: 9888-8002-2411-1453
  - Bank name: BNI 46

Please make sure not to miss the date. The deadline for the payment confirmation is on **October 18**, but you will get an early-bird discount if you pay before October 15, 23:59 GMT+7. For further information, you can refer to https://icst.ugm.ac.id/fee/

2. Revised manuscript preparation

Papers should be written in English (US) and use the AIP Conference Proceedings template. Please note that AIP Conference Proceedings is indexed in Scopus, which means that your paper will be visible to a large audience. For further information about the author guidelines, you can refer to https://pubs.aip.org/aip/acp/pages/preppapers

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While preparing the revised manuscript, the corresponding author should sign the copyright transfer from the related publisher:
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4. Copyright transfer and revised manuscript submission

The copyright transfer and revised manuscript should be submitted in the same manner as the review manuscript using EDAS before October 23. We encourage all participants to submit the documents 1 or 2 days before the deadline to avoid overcrowded conditions.

5. Presentation document preparation

The symposia will be moderated by experts in the field, and each session will have one or more committee members present. The oral presentations for the symposia should be no longer than 20 minutes, including time for questions and answers. Please note that each paper can only be presented by one person, but the co-authors can register as non-presenters and take part in the discussions. To fit within the time limit, we recommend that you prepare 10–12 slides for your PowerPoint presentation. The content of your presentation should be clear, concise, and relevant to the symposium theme.

For your convenience, we will supply the following equipment for your presentation:

- A laptop with a USB port and an HDMI/VGA cable. You will not be able to use your own computer for your presentation;
- A projector and a screen;
- A microphone and a speaker system; and
- A laser pointer.

As part of the conference materials, you are **required to upload a presentation document** of your paper before the conference day. You also need to attend the conference and interact with the attendees for questions and answers.

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The deadline for uploading your presentation document is **October 23**. Please do not miss this date, as it is essential for the technical program committee to verify your document.

Guidelines for preparing your presentation

- Duration of presentation: 10-15 minutes.
- File size: 100MB max.
- File format: ppt / pptx / pdf.
- Dimensions: Aspect ratio 16:9
- Please be sure the presentation includes the title of the paper, the authors, and mention ICST UGM 2023.
- Please note the final specifications will be checked at the time of submission, and files not compliant may not be uploaded.

Tips for preparing

- Your presentation file should be compatible with Microsoft PowerPoint 2007 (or earlier).

- Use simple (Arial, Calibri) and large (30+) fonts.
- Avoid using hi-res images.
- Have no embedded videos.

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In the EDAS dashboard page, click your paper title and upload the PPT or PPTX or PDF documents by clicking the cloud icon in **Presentation**.

If you have any issues with uploading your presentation, please contact us. As a reminder, document that are not received by the deadline will be considered no-shows in accordance with the non-presented paper policy.

For further information about the revised manuscript submission, you can refer to https://icst.ugm.ac.id/mie . Please be informed that only PRESENTED PAPERS will be submitted to the publisher.

If you still require further assistance, please feel free to contact us at icst@ugm.ac.id. We look forward to seeing you at the conference.

Regards,

ICST 2023 Committee
Secretary,

Muhammad Rafieiy

Organized by Universitas Gadjah Mada
Bulaksumur, Yogyakarta, 55281, Indonesia

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Review 1

Relevance and timeliness: Rate the importance and timeliness of the topic addressed in the paper within its area of research.

Acceptable (3)

Technical content and scientific rigour: Rate the technical content of the paper (e.g.: completeness of the analysis or simulation study, thoroughness of the treatise, accuracy of the models, etc.), its soundness and scientific rigour.

Valid work but limited contribution. (3)

Novelty and originality: Rate the novelty and originality of the ideas or results presented in the paper.

Minor variations on a well investigated subject. (2)

Quality of presentation: Rate the paper organization, the clearness of text and figures, the completeness and accuracy of references.

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Please check the comments in the manuscript.

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Solid work of notable importance. (4)

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- Pada bagian introduction, saya belum menemukan bagian yang menjelaskan signifikansi riset ini dan apa impact yang bisa diberikan riset ini pada bidang yang dikerjakan.
- Figure 7, figure 8, dan figure 9 bisa dibuat lebih berdekatan agar lebih mudah dibandingkan.
- Sudah baik. Tapi clarity Bahasa inggris perlu ditingkatkan agar lebih mudah dipahami terutama oleh orang yang tidak berbahasa Indonesia. Beberapa kalimat yang ambigu sudah saya tandai di manuscript review.

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Novelty and originality: Rate the novelty and originality of the ideas or results presented in the paper.

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This paper decribe a nice improvement for cnc machine. However there are few things that needs to be clarified.

1. The paper is too long, please check the template and maximum pages of the paper.
2. Figure 1 has no any detailed information in it. There is alsomno scale. Please check all figure.
3. Figure 3 only shows the operator not the testing process. Please clarify this. And check for all the figure

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RSM-based Modeling to Restrain the Dimension Deviation in CNC Milling Operation

Yohanes T. Wibowo[1, 2, b)], Nurhadi Siswanto[1, a)], and Mokh. Suef [1)]

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Abstract. The problem of dimension deviation still happens in CNC milling operation, although using a modern machine completed with many advanced features. This study aims to get a prediction model for calculating the dimension deviation using selected machine parameters such as feed rate, cutting speed, axial depth of cut, and radial depth of cut. The study is to find the best solution for machine parameter configuration to restrain the dimension deviation so that the dimension deviation can be controlled. The method in this study is response surface methodology. Analyzing data collected from the experiment, the prediction model of dimension deviation based on response surface methodology is very accurate, with a coefficient correlation of 0.89, RMSE 5.52%, MAPE 0.938%, and R-Square 0.8. The 89% of the prediction model lies in the range of 0.20 µm. The dimension deviation can be restrained to 0.1 µm. The objective to find the value of parameters that can restrain the dimension deviation using the response surface methodology approach has been shown. The delay as an effect of dimension deviation can be eliminated. Finally, this study can trigger an adoption study on another manufacturing CNC milling machine.

INTRODUCTION

The CNC milling machine is a state-of-the-art machine tool with the largest population used in the manufacturing sector, especially in machining (1). Precise CNC milling settings significantly impact machining results (2). Thus, The significance of milling machines as a central component in machining should not be underestimated (1,3). Modern CNC milling makes achieving product dimension targets easier. However, this convenience has not ensured dimensional achievement. There is still uncertainty in achieving dimension, and dimension deviation still occurs. Dimension deviation consists of several conditions, namely undercut and overcut. In this study, undercut deviation is the condition in question.

From the technical aspect, dimension deviations result in no potential for not being able to be assembled, unable to work, decreased product performance, loss of compatibility and interoperability aspects, potential decline in safety aspects, non-achievement of standards and regulations, and delays (4). On the economic aspect, the impact is the potential for a decrease in sales, the potential for customer loss, the emergence of costs for recovery (rework), the emergence of potential reputation decline, and the emergence of additional production costs, to the risk of facing lawsuits and legal sanctions. Dimensions in the product have a dominant role. Considering the importance of dimension, dimensional deviations are essential things to be studied and avoided (5).

In machining CNC milling machines, various factors cause dimensional deviations ranging from the material characteristics of the workpiece, the properties of cutting tools, and the machines used to the machining parameters. Machine behavior is directed by controlling the parameters so that the product's shape follows the requested technical specifications, such as the dimension of the product, which is one of the intended technical specifications (6,7). The process will run well, the product will function accordingly, and the associated economic aspects will be positive when the dimensions meet the specifications.

Parameter settings are used as input to produce a response following the request for technical specifications (8). One response that becomes the manufacturing need is to get product dimensions that meet the technical drawing (9). Dimension deviation is a distortion from the technical specifications used as responses in this study. Dimension deviation is the last response of the product, which is an advanced response of material removal rate, processing time, and cutting tool wear. Previous studies found that the increase in cutting speed, feed rate, and depth of cut initiates material removal rate (10). Tsao's research revealed that increased cutting tool wear increased the dimension deviation to 0.117 mm (11). The findings of Hricova show that dimensional accuracy is associated with a decrease in cutting speed when machining aluminum alloy (12). The increased cutting tool wear due to increased spindle speed causes dimensional deviation. Previous research found that dimensional deviation is influenced by feed rate, axial depth of cut, and spindle speed (13–15). Lin also found that dimensional accuracy is affected by spindle speed, feed rate, cutting depth, tool geometry, and vibration (16,17).

A study comparing prediction results using a multi-linear regression approach with an artificial neural network concludes that the artificial neural network approach provides more accurate results characterized by a 17% increase in R-value compared to the multiple regression approach. However, it is essential to note that the use of artificial neural networks has limitations, including the need for large data sets for good predictions, as well as non-adaptivity to data outside the training set, which can result in inappropriate predictions for new data (18). Several aspects of uncertainty in CNC milling machining influence the dimension of non-achievement. Uncertainty conditions can occur because of material element heterogeneity, cutting tool wear, and machining parameters (19).

Cheng et al. emphasized the importance of dimensional accuracy related to product function and aesthetics (20). Maximizing dimensional accuracy will reduce uncertainty. The additional processes to revise the dimensional deviation are lower. Therefore, through a back propagation neural network approach, dimensional accuracy is analyzed and predicted by considering the input variables of spindle speed, feed rate, and width of cut. The RMSE result of BPNN is much smaller, 0.008, compared to the linear regression method, which reaches 0.021. Response surface methodology (RSM) and artificial neural network (ANN) are applied to compare prediction performance with dimensions such as the response and spindle speed, feed rate, and axial cutting depth as inputs (21). The findings showed that the ANN produced more accurate predictions than the RSM model. However, RSM has limitations in the case of non-linear interactions.

Fountas et al. reported research on optimization with single and multiple objective functions through ANN-based approaches, genetic algorithms (GA), evolutionary algorithms (EA), and hybrid approaches in the use of CNC milling machines (22). This study proved that the ANN-based method has a more optimal performance in terms of functionality. Meanwhile, Burhanudin confirmed that the helix angle significantly contributes to achieving dimensional aspects in CNC milling operations (23). However, given that the helix angle of each cutting tool is unique to the cutting tool manufacturer, including the helix angle as one of the input variables is impractical and difficult to implement in CNC milling machine operations. The previous studies still leave space for further research using CNC milling for uncertainty minimization, namely dimensional deviation minimization. This research aims to obtain a prediction model of dimensional deviation in CNC milling and then optimize it to diminish the impact of dimensional deviation.

The research on dimensional accuracy is just a few because CNC milling machines offer features to fix deviations quickly. However, with these features, the essence of green machining, where machining time is kept lower, becomes unbiased. With this research, the extra time to make corrections due to dimensional discrepancies will decrease, so the benefits of time-saving and cost-saving increase.

In this study, an RSM is used to make predictions, study the phenomenon of dimensional deviation, and optimize the process. RSM has the flexibility to model the relationship efficiently (24–26). Making predictions is to obtain the response value as accurately as possible by minimizing the difference between the prediction and the actual response value as the basis for determining the optimal machining parameters.

METHOD

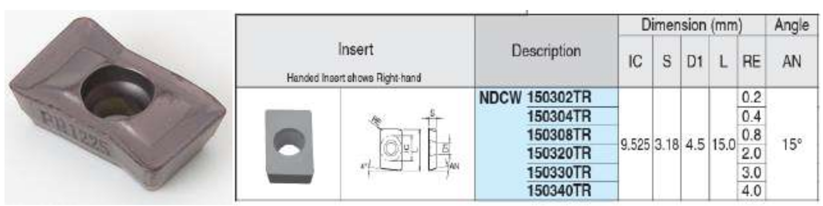
Materials

In this CNC milling process, the specimen selected is PAC5000 from Daido Steel Co., Ltd., used in the automotive industry. PAC 5000-type material belongs to the general-purpose plastic mold steel group. This type of material is an improvement from the P20 series in the aspects of wear resistance and mirror-quality polish for products that require a smooth or mirror-quality surface, such as lampshades or speedometer covers. This material has a hardness of about 36-40 HRc. Due to patent restrictions, the mineral composition of PAC 5000 is concealed. It is equivalent to DIN 2311 or JIS14A, with mechanical properties at room temperature, as shown in Table 1.

TABLE 1. Mechanical properties of material PAC500

Hardness (HRc)	Tensile Strength (MPa)	0.2% Yield (MPa)	Elongation (%)	Reduction in Area (%)
40	1244	1127	15.9	61.7

The cutting tools used in this study are End Mill Inserts NDCW150302TR-TN100M series with DMC-316SXT holder made by Kyocera, as shown in Figure 1. The tool diameter is 16mm, with a cutting edge of 14mm, with a total length of 90mm. The tolerance for the diameter is 0~0.03mm, while the radius tolerance is ±0.01mm. The new cutting tools apply to each specimen. The spindle speed used was 2900 rpm.



Insert (Handed Insert shows Right-hand)	Description	Dimension (mm) IC	S	D1	L	RE	Angle AN
	NDCW 150302TR	9.525	3.18	4.5	15.0	0.2	15°
	150304TR					0.4	
	150308TR					0.8	
	150320TR					2.0	
	150330TR					3.0	
	150340TR					4.0	

Figure 1. Insert Carbide of End Mill DMC-316SXT used to cut the specimen

Material Preparation

This study runs a homogeneity test on the surface hardness of the specimen material before machining to ensure the method's repeatability. The homogeneity test refers to the similarity of the specimen's material properties on all sides. In their research, Kumar et al. suggested that heterogeneity of material properties can cause differences in material deflection (19). Hardness measurement of the specimen is carried out at 5 different points on each machining line with the highest deviation of a maximum of 5% of the average measurement value (27), as shown in Figure 2. The specimen length is at least 10 times the diameter of the cutting tool, and at least one specimen is required for each test condition or variable. Considering there are 4 variables of interest, the homogeneity test will be conducted on 8 specimens or 2 specimens for each input variable. Hardness testing was conducted using a Mitutoyo Hardness Testing Machine (Wizhard HR-522 series, Japan, 2019).

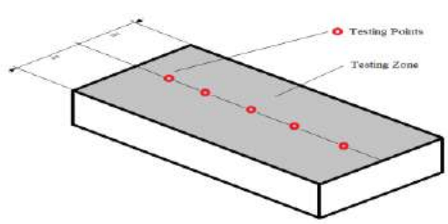


Figure 2. Hardness Testing Points of Specimen

Box Behnken

Using the RSM approach, the experimental design defines two variables: independent variable or input and dependent variable or response. Independent variables are subjects that can be controlled in an experiment. In RSM, the input must have a relationship with the response but not have a relationship with other inputs. Inputs have a contribution with a certain level of significance.

The experimental design used is Box-Behnken Design (BBD). The value of the independent variable in CNC milling is not extreme. There is no corner point of a value in the machining variable. It is a meeting point between the characteristics of BBD and the existing conditions on the machining variables. BBD is beneficial in conditions where a feasible solution is within an area in the design of the experiment. BBD has the advantages of providing optimal results with high accuracy under minimal conditions, namely having three levels of factorial design, requiring a smaller number of experiments, and having a minimum of 3 factors. The design of experiment used in this study is L27(3^4), where 27 experiments with 3 levels and 4 factors are observed. The replication of the dataset was carried out 3 times with consideration of cost and result precision (28,29). The inputs selected in this study are feed rate (F), cutting speed (CS), axial depth of cut (Ap), and radial depth of cut (Ae). The number of parameter levels is three per the BBD criteria. Detailed information on the independent variables, level values, and units used are shown in Table 2 below.

Dimension deviation is the dependent variable or response. Dimension deviation was measured by comparing the initial dimension of the specimen with the final dimension after being measured using a coordinate measuring machine (CMM) (Duramax 5/5/5, Germany, 2023), as shown in Figure 3 and Figure 4. The Duramax CMM has a precision level of 0.01 µm or 0.00001 mm.

Table 2. Variabel Independent CNC Milling

Variable Independent	Code	Level			Units
		-1	0	1	
Feed rate	F	10	20	30	mm/sec
Cutting Speed	CS	100	120	140	m/min
Axial Depth of Cut	Ap	0.2	0.5	0.8	mm
Radial Depth of Cut	Ae	4	6	8	mm

Figure 3. Duramax CMM 5/5/5 and Mounted Specimen

Figure 4. Duramax CMM 5/5/5

Experimental Dataset

The mechanical properties of the PAC5000 specimen material are shown in Table 1, and Figure 1 shows the cutting tools' information. The preliminary test, namely the homogeneity test performed on the specimen, is also shown in Figure 2 and Table 3. The selected input levels and variables are shown in Table 4. Measurements were made on the dimension deviation response using a Duramax CMM. The CNC milling machine used is the Makino Machine (KE55, Singapore, 2010), as shown in Figure 5.

Figure 5. Machining Setup and CNC Milling Makino KE-55

Process Steps

This study uses the RSM method to see the interaction between machining parameters and dimensional deviation. The study began with the stages of machining operations on a CNC milling machine applied to specimens that have passed the homogeneity test using prepared cutting tools. The operation performs the sequences according to the orthogonal array L27(3^4). After all 81 specimens passed, the CMM measured the actual dimensions of the machining results and entered them into the table as the dependent variable. The following procedural step is to perform numerical simulations using RSM to see the predictions and end with the optimization of input variables for dimensional deviation minimization.

RESULT AND DISCUSSION

Experimental Dataset

The hardness test result is shown in Table 3. The deviation of the hardness level is in the range of 0.9-2.6%, which means that it is still within the limits of the measurement standard according to ISO 8688. The independent and dependent variables of the experimental results in the form of dimension deviation are shown in Table 4.

Table 3. Rockwell Hardness (ISO 8688-2) PAC 5000 Specimen

Specimen	Testing Point Position (HRc)					Deviation (%)
	1	2	3	4	5	
1	39,5	39,7	39,9	40	40,3	1,1
2	41,8	40,7	40,8	40,9	41,2	1,8
3	41,5	40,9	40,9	40,8	41,0	1,2
4	39,5	40,8	40,8	40,8	41,2	1,4
5	40,2	41,3	40,7	40,8	41,0	1,2
6	41,1	40,0	39,7	39,5	40,0	2,6
7	39,5	39,9	39,2	39,5	39,6	0,9
8	39,2	39,0	39,0	39,4	39,9	1,5

Table 4. Experimental Research Result

Run Order	Feedrate (mm/min)	Cutting speed (m/min)	Axial Depth of Cut (mm)	Radial Depth of Cut (mm)	Dimension Deviation (µm)
1	20	100	0,5	8	2,13
2	20	140	0,8	6	6,41
3	20	120	0,5	6	3,43
4	10	120	0,2	6	3,42
5	20	120	0,2	4	7,47
6	20	120	0,8	8	4,08
7	10	140	0,5	6	10,12
8	20	100	0,5	4	15,55
9	30	120	0,2	6	0,97
10	20	140	0,2	6	1,65
11	20	120	0,2	4	7,46
12	20	120	0,2	4	7,46
13	30	120	0,5	4	6,06
14	20	120	0,2	8	1,02
15	30	120	0,2	6	1,02
16	20	140	0,5	8	2,85

17	20	140	0,5	4	21,92
18	20	140	0,2	6	1,76
19	10	120	0,2	6	3,47
20	20	120	0,5	6	3,43
21	10	120	0,5	8	3,77
22	30	100	0,5	6	2,12
23	20	120	0,8	4	3,01
24	20	120	0,5	6	3,77
25	20	120	0,8	8	4,08
26	20	140	0,5	4	22,06
27	20	100	0,2	6	1,14
28	10	120	0,5	4	60,11
29	10	100	0,5	6	7,03
30	20	120	0,8	8	4,08
31	20	120	0,2	8	1,02
32	30	140	0,5	6	2,98
33	10	120	0,5	4	58,66
34	20	100	0,2	6	1,1
35	30	120	0,5	8	2,01
36	20	120	0,2	8	0,97
37	10	140	0,5	6	9,84
38	20	120	0,5	6	3,43
39	30	120	0,8	6	4,09
40	20	100	0,5	4	15,65
41	30	120	0,5	4	5,94
42	30	140	0,5	6	2,98
43	10	120	0,8	6	13,69
44	20	140	0,8	6	7,05
45	20	120	0,5	6	3,43
46	20	140	0,8	6	7,04
47	30	120	0,5	8	2,01
48	20	100	0,8	6	4,57
49	30	120	0,8	6	4,08
50	30	100	0,5	6	1,94
51	10	120	0,8	6	13,31
52	20	100	0,8	6	4,57
53	20	140	0,5	8	2,98
54	30	120	0,2	6	0,97
55	30	120	0,5	4	5,72
56	10	120	0,2	6	3,47
57	30	140	0,5	6	3,11
58	10	140	0,5	6	10,12

59	20	140	0,5	8	2,98
60	20	100	0,8	6	4,88
61	20	120	0,8	4	29,86
62	10	120	0,8	6	13,31
63	30	120	0,5	8	2,22
64	20	120	0,5	6	3,43
65	20	120	0,5	6	3,43
66	10	120	0,5	8	3,89
67	10	120	0,5	8	3,77
68	10	120	0,5	4	59,3
69	10	100	0,5	6	7,23
70	20	120	0,5	6	3,66
71	20	100	0,5	8	2,12
72	20	120	0,8	4	30,26
73	20	100	0,5	4	15,55
74	20	140	0,5	4	22,12
75	20	120	0,5	6	3,43
76	20	100	0,2	6	1,14
77	10	100	0,5	6	7,13
78	30	100	0,5	6	2,12
79	30	120	0,8	6	4,08
80	20	140	0,2	6	1,49
81	20	100	0,5	8	2,03

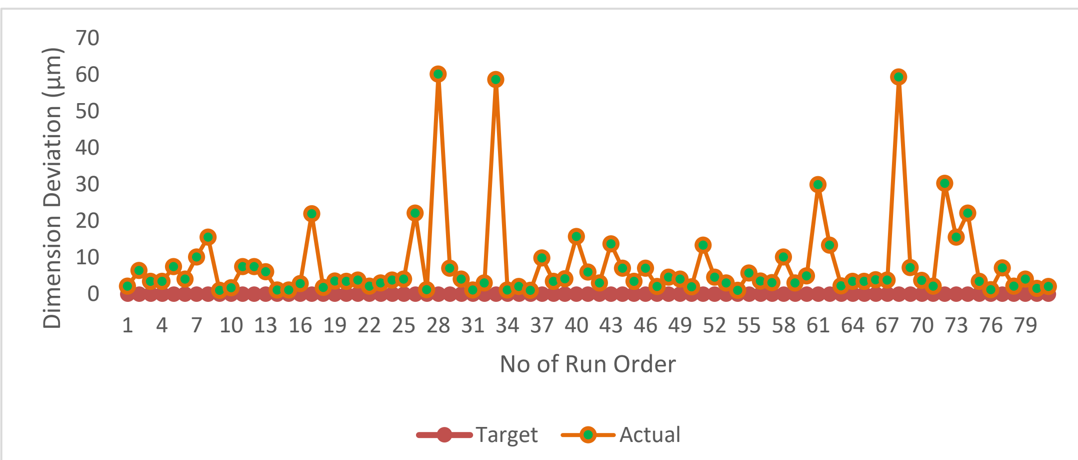


Figure 6. Dimension Deviation of CNC Milling Operation

Figure 6 shows the response data of the process. The red dots represent the requested dimensional targets, while the orange line graph with green markers shows the resulting dimensions of the process. The resulting dimensional variation ranges from 0.97-60.11 µm. 90% are between 0-20 µm, 6% are in the 20-40 µm range, and the rest are in the 40-61 µm range.

Numerical Simulation of Responses

The regression equation of the dependent variable of the dimension deviation is obtained from the numerical simulation, as shown in Equation 1 below.

$$D = 203{,}8904 - 6{,}3799 * F + 0{,}046 * F^2 + 0{,}2287 * CS * Ap - 43{,}5517 * Ae + 2{,}1512 * Ae^2 + 0{,}7155 * F * Ae - 0{,}0011 * F * CS * Ap * Ae \quad (1)$$

Figure 7 shows the results of the numerical simulation of dimension deviation values using regression equations based on response surface methodology.

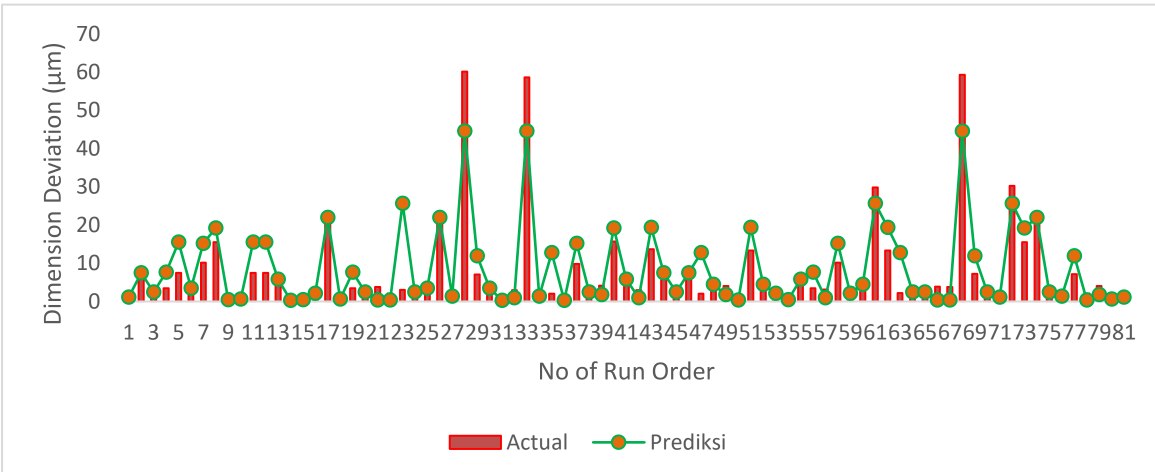


Figure 7. Prediction Data of Dimension Deviation Using RSM Approach

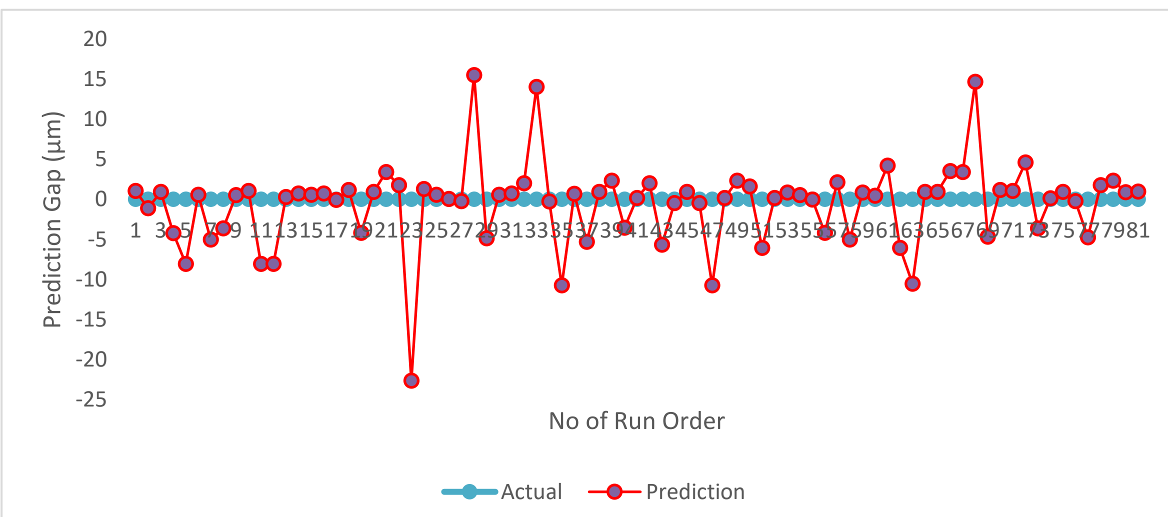


Figure 8. Gap Data between Actual and Prediction from Prediction Model

The red bar chart represents the actual dimension deviation, while the green line graph with orange markers shows the prediction results generated from the numerical simulation using regression equation 2. The resulting dimensional variation ranges from 0.3-44.61 µm. 89% are between 0-20 µm, 7% are in the range of 20-40 µm, and the rest are in the range of 40-44 µm. The width of the predicted dimension deviation range is narrower than the range of actual values.

Graphically, the deviation information of the numerical simulation results compared to the response values is presented in Figure 8.

Confirmation Criteria

The criteria of correlation coefficient (r), Mean Absolute Percentage Error (MAPE), Root Mean Square Error (RMSE), and coefficient of determination (R-squared) are selected to asses the prediction result. The correlation coefficient ranges from -1 to 1, where a value of 1 means the model can show a strong positive relationship between variables. MAPE measures the average percentage of the absolute difference between the prediction and the actual. A low MAPE value represents the model's accuracy in predicting data. RMSE measures the average deviation between the model's predicted value and the data's actual value. R-square measures how much variation in the dependent variable can be explained by the independent variable. Table 5 shows the prediction model calculation as a confirmation of performance.

Table 5. Confirmation Criteria Matrix of Prediction Model

	r	RMSE (%)	MAPE (%)	R-Square
RSM	0.89	5.52	0.938	0.80

Table 5 shows various information regarding the RSM-based prediction model. The r value of 0.89 means that the two variables used have a positive linear relationship close to perfect. The RMSE of 5.52% means that the prediction error is as significant as that number. MAPE 0.938% means that the prediction accuracy is close to 94%, and R-Square 0.8 means that this model better explains the variation in the relationship between the independent and the response variable.

Discussion

The research aims to reduce the negative impact of dimensional deviation. First, reviewing the criteria used to confirm the model's performance is necessary. The numerical simulation results are shown in Table 5. The correlation coefficient ranges between -1 and 1. The r value of 0.89 shows that the proposed regression model shows a strong and positive linear relationship pattern. Strong and linear are defined as when one variable increases, the other will also increase. The word positive indicates the right direction and not the opposite. The linearity and positive direction are around 89% of the relationship pattern and direction of the variables.

The RMSE criterion informs the model's accuracy in predicting. The RMSE of 5.52% indicates that the average model prediction error is around 5.52% of the dependent variable scale. The scale of the dependent variable used is a micron meter (µm). The numerical simulation results of dimension deviation are in the range of 0.3-44.61 µm. 5.52% of the deviation range is 2.46 µm. Considering the CNC milling operation ranges from 10-54 minutes, and the longest cutting tools path is 18400 mm or almost 19 m, the dimension deviation of 2.46 µm counts as a slight deviation. The figure of 2.46 µm is adequate and will be able to make a positive contribution in both technical and economic terms.

From Table 5, the MAPE value is 0.936%. MAPE is one of the evaluation metrics in regression and prediction models to measure the relative error rate of a model in predicting the value. The 0.936% figure indicates that the average difference between the model prediction and the actual value is around 0.936. The lower the MAPE value of a model, the more accurate it is. In this model, the average difference is less than 1%. In regression, the level of prediction accuracy seen from the MAPE criteria can be seen in Table 6 below.

Table 6. Prediction Accuracy based on MAPE Points

	Very Accurate	Good	Fair	Inaccurate
MAPE Points	<= 10 %	10 – 20 %	20 – 50 %	>= 50 %

The last performance criterion used is the coefficient of determination or R-squared, with a value of 0.8. The R-square value is 0 - 1, where 0 means the model produces a prediction value far from the actual value. In contrast, the number 1 means that the existing regression model produces a predicted value close to the actual value. The greater the R-Square value, the better the model. A value of 0.8 indicates that 80% of the variation in the value to be predicted (dependent variable) can be explained by variations in the independent or input variables. Based on the numerical simulation results' performance criteria values compared to the regression model's standard values, the proposed prediction model is accurate, has a strong relationship pattern, has the correct positive direction, and represents most of the variation in the data. The prediction error of the proposed model is 5% or 2.46 μm.

Other information obtained in the numerical simulation is the Pareto chart, as shown in Figure 9. The Pareto chart shows the factors from the most dominant variable to the least influential. Figure 9 shows the radial depth of cut variable, and the two dominant variables are the radial depth of cut and feed rate. The least influential is cutting speed.

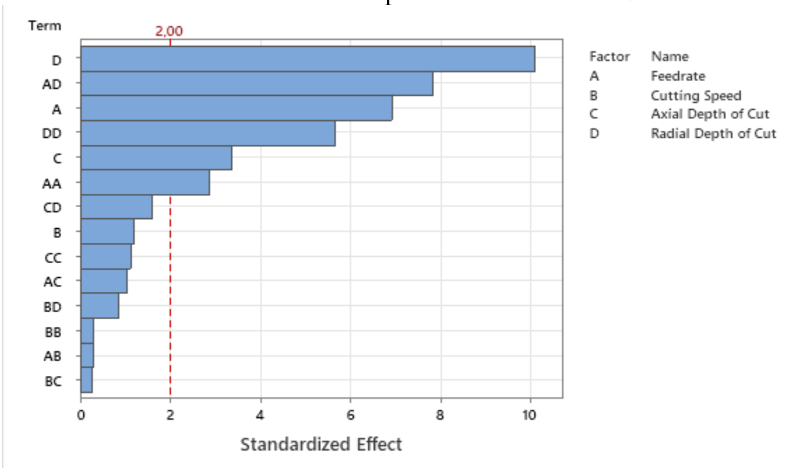


Figure 9. Pareto Chart of The Standardized Effects

The radial depth of cut and feed rate values are inversely proportional to the deviation. The contour plot shows that the greater the radial depth of cut, the greater the feed rate and the smaller the deviation value, as provided in Figure 10.

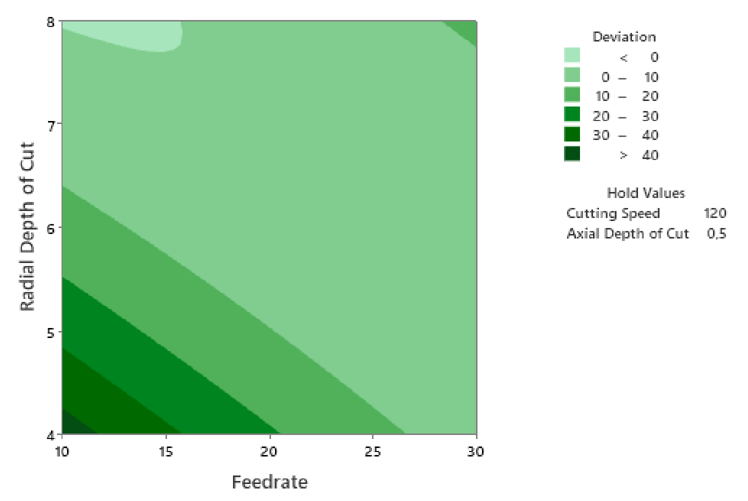


Figure 10. The Interaction Pattern of Input Variable and Dimension Deviation

Figure 11 informs the three-dimensional format of a more precise interaction pattern among a radial depth of cut, feed rate, and dimension deviation.

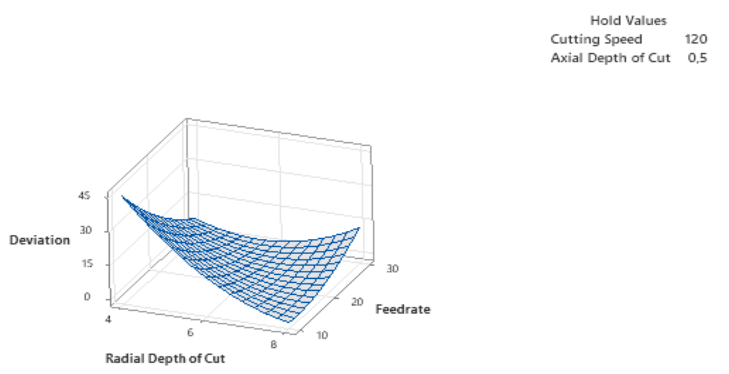


Figure 11. The Interaction Pattern of among Variables in Surface Plot Model

The resulting dimension deviation in the proposed prediction model is between 0.3-44.61 µm, with the 5% value being 2.46 µm. It means it is possible to optimize to less than 0.3 µm. Several optimization efforts were taken to achieve a dimensional deviation of 0.1 µm. In this optimization process, several parameters are chosen considering that these parameters are too rigid to be adjusted and by considering safety aspects. The parameters were cutting speed at 120 m/min and axial depth of cut at 0.2 mm. The optimization process provides the results as follows in Table 7. The dimensional deviation significantly impacts the delay or time aspect (4). To obtain the benefit of dimension deviation, choosing CNC milling parameters with the radial depth of cut and low feed rate is recommended because they have a linear relationship pattern. The results of the optimized parameters are tested and presented in Table 7 in the last column.

Table 7. Optimization Target and The Machine Parameters

Dimension Deviation (µm)	Radial Depth of Cut (mm)	Feedrate (mm/sec)	Cutting speed (m/min)	Axial Depth of Cut (mm)	Final Dimension Deviation (µm)
1.00	5.6	19	120	0.20	0.89
0.50	4.0	29	120	0.20	0.48
0.25	6.9	10	120	0.20	0.21
0.10	5.8	19	120	0.20	0.10

CONCLUSION

The study aims to find a good performance prediction model for the optimization process. Based on the results of the BBD-based design of experiments and numerical simulations, the proposed prediction model performs well according to the prediction performance criteria. Coefficient correlation of 0.89, RMSE 5.52%, MAPE 0.938%, and R-Square 0.8. 89% generated from the numerical simulation data produce a deviation range of 0.2 µm. The optimization process can reduce the dimension deviation to 0.1 µm while still considering safety aspects. The test results of the optimized parameters produce a slight dimension deviation. Related industries can use the selected parameters for CNC milling processes requiring a low dimension deviation. The prediction and optimization model can be adopted and tested for other machining models, such as turning or other subtractive machines, in other objectives, such as energy consumption optimization or surface roughness. Utilization for prediction in other areas and for multi-response prediction suggests further study.

ACKNOWLEDGMENTS

The authors are grateful to the civitas academics of Institut Teknologi Sepuluh Nopember, Astra Polytechnic, and the industrial partners, especially the silver experts, for rendering assistance towards this study.

FUNDING

This work was supported by the Directorate of Research, Technology, and Community Service; Ministry of Education, Culture, Research, and Technology; the Republic of Indonesia under Grant Number 1409/PKS/ITS/2022.

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Issued on November 2, 2023