Multi Response Optimization of Turning Parameter Power Screw Hospital Bed Using Taguchi-Hybrid Method

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Abstract. Power screw is the driving part of a hospital bed which functions to raise and lower the bed. Power screw is an important part of hospital bed products that requires precision and accuracy, then in the manufacturing process by using CNC Turning machine with steady rest. Based on the observations, the defect of power screw caused by worn out tools. It causes chatter on CNC Turning machine. The aim of this study is to reduce the variation of power screw product by conducting experiments in the manufacturing process of power screw. The experiment was done by determining some factors such as spindle speed, depth of cut, coolant and usage time of tool. The specific purpose of this experiment is to reduce variation and simultance optimize are major diameter, minor diameter, pitch diameter, and cycle time. Taguchi multi response method was used for experiment to get simultance optimize process. Multi response case was done by using Grey Relational Analysis (GRA) and Principal Component Analysis (PCA). Experiment based on the orthogonal array of L9 with 3 replications. The results show that by using Taguchi-hybrid method, the optimum condition occurred at spindle speed is 1200 mm/min, depth of cut is 0.1 mm, coolant is 1:30, and usage time of tool is 70%. The result of the experiments carried out showed a decrease in the response variance in diameter and the cycle time faster.

Keywords: Turning process, optimization, grey relational analysis (GRA), principal component analysis (PCA).

1. Introduction

The function of a hospital bed is different from a bed in general because it must give comfort and convenience for the patient. Bed hospitals have the ability to raise and lower the front and rear with a power screw. The power screw is the main part of hospital bed products that require precision and accuracy, thus in the manufacturing process uses CNC turning machine of TC 20 type with Takisawa brand.

Based on observations, the occurrence of defect is caused by worn out tools. It causes chatter on the machine. Chatter causes defects in the workpiece because the unequal cutting force [1]. Anayet U Patwari et al have observed that mutual interaction of vibrations due to serrated elements of the chip is cause chatter on machine. [2-3]. This is a major problem in the manufacturing of power screw where major diameter, minor diameter, and pitch diameter are not in accordance with the desired size standard which causes the power screw to drag. The problem of unequal screw product that is produced, one of them is caused by the tool used has been worn out because the usage of the tool does not pay attention to the optimal time of tool usage. Based on the problems that arise from the power screw making process can be minimized with several parameters, namely spindle speed, depth of cut, coolant, and usage time of tool.
Quality Improvement can be used to reduce defects in the production process. Taguchi design uses a matrix of orthogonal array to study all parameter with a small number of experiments only [4-7]. Experiment is carried out with more than one response, namely to reduce screw variation consisting of major diameter, minor diameter, pitch diameter, and cycle time, so that uses Taguchi multi response method. Based on the multi response criteria used, the PCR-TOPSIS method has not considered the determination of the weight, while the PCA method considers the determination of the weight is principal component. In this study want to use weighting method to determine criteria based on priority, then the PCA method is selected. The response in this study there are various performance characteristics so that PCA must be combined with other methods. The other Taguchi multi response method is Grey Relational Analysis. Based on grey system theory, the grey relational analysis was developed and can be implemented to solve the complicated interrelationships among multiple performance characteristics or response effectively [8].

Through GRA, grey relational grade (GRG) will be obtained to evaluate more than one response and to estimate the appropriate weighting value is used PCA, so that some characteristics can be explained objectively and precisely [9]. The relation between machining parameters and performance can be found out with Grey Relational Analysis. Moreover, Grey Relational Grade will utilize the discrete [10]. Principal component in PCA can change the correlation between responses into the quality index that is uncorrelated and eliminate multicollinearity between responses [11]. Thus, this study uses a combination of Grey Relational Analysis and Principal Component Analysis methods.

The specific purpose of this experiment is to reduce variation and optimize some quality responses such as major diameter, minor diameter, pitch diameter, and cycle time. This study is conducted to determine the characteristics of the production process of power screw and the effect of cutting speed, depth of cut, coolant, and usage time of tool to optimize the response by using a combination of GRA and PCA methods. The limitation in this study is that the part under study is a hi low supramax type of power screw by using carbide tools on CNC Turning TC 20 machine.

2. Methodology

2.1 Experimental Planning Method

The concept of Taguchi method, the parameter design was performed to reach a target of process robustness [12]. This experiment used 4 controlled factors with 3 levels for each factor. The selected orthogonal array matrix was a matrix which had a df value > 6 and was able to condition the experiment for 4 factors with 3 levels. Thus, the design of the selected Taguchi experiment was L9(3^4) orthogonal matrix. In the selection of factor level designs, Taguchi suggested by using SN ratio as a parameter selection, parameter that minimized "error variance". Signal to noise ratio (S/N Ratio or SNR) was the logarithm of a quadratic loss function. S/N ratio and orthogonal array were two major tools used in this process. S/N ratio characteristics could be divided into three categories, there were Nominal is best, Smaller the better and Larger the better [13-15]. According to research response used quality character of Nominal was best and Smaller the better. In this research, the calculations used Microsoft Excel and Minitab. According to [9] the steps to analyze using GRA and PCA were as follows:

- Calculating the S/N ratio of each response.
- Calculating normalization of S/N ratios.
- Calculating Grey Relational Coefficient (GRC) value.
- Calculating Grey Relational Grade (GRG) using PCA.
- ANOVA for statistical analysis of data.
- Selecting the optimal level of process parameters.
2.2 Experimental Set-Up & Procedures

The experimental design consisted of determining the response, factors, levels for each factor, determining the total degree and determining the OA combination. The responses in this study were the major diameter, minor diameter, pitch diameter, and cycle time. The factors in this study were spindle speed, depth of cut, coolant, and usage time of tool. Spindle speed and depth of cut also affected the quality of the final threading process because it affected the rate of worn out tool. This factor also affected the cycle time because the higher of the cutting speed and thickness in the depth of cut used, then the faster of the turning process would be done.

Coolant factor was the amount of comparison between water and coolant used or the level of liquidity from coolant. Based on observations, the product had a defect when the tool used had begun to worn out and was marked with a buzzing CNC Turning machine sound. Worn out tool was influenced by heat conversion process to the level of liquidity from coolant. The factor of tool usage time was taken based on the average product defects that occurred after the tool usage for making 5 m of screw. This factor identified the presence of worn out tool which caused a measure of variance in the power screw. Based on the observations, 100% of tool use is the same as the use of a tool for turning 40 pieces of hi low screw threads or threads along 1080 mm.

The selection of the number of levels was important for the accuracy of the results of the experiment and the cost of carrying out the experiment. The more levels studied, then the research result would be more accurate because more data was gained. However, the number of levels would increase the number of observations, thus increasing the cost of the experiment. This experiment used 3 levels for each factor. Determination of the number of levels as much as 3, so that the costs incurred during the experiment were not too much and the accuracy of the results of the experiment remains. This study used factors, each of these factors had three levels as shown in Table 1.

| Factors            | Levels  |
|--------------------|---------|
| Spindle Speed (A)  | 1200 rpm| 1250 rpm| 1300 rpm|
| Depth of Cut (B)   | 0.05 mm | 0.075 mm| 0.1 mm  |
| Coolant (C)        | 1:20    | 1:30    | 1:40    |
| Usage time of tool (D) | 50% | 70% | 100% |

Experiments were carried out as many as 9 experiments with 3 replications to the number of experiments. The phases of conducting the experiment were as follows:

- Preparing several parts of power screw that had gone through several production processes as shown in Fig 1.
- CNC Turning Machine for threading process in readiness condition of running (there was no problem/problem).
- Setting the level before doing the experiment shown in Fig 2.
- Threading process with 3 replications for each experiment as shown in Fig 3.
- Recording cycle time parameters and measuring the magnitude of the major diameter, minor diameter, pitch diameter, and cycle time.
3. Result and Discussion

The size of power screw geometry is very influential on the quality of the power screw. This is a major problem in the manufacturing of power screw where the size of screw geometry does not match with the desired standard size, then causing the power screw jammed up or even stop at a certain point. In this study, the size tolerance was ± 0.2 mm. So, if the diameter of the thread is more or less than 0.2 mm is categorized as a defect. This is illustrated in Fig. 4.
The response in this experiment is major diameter, minor diameter, pitch diameter, and cycle time. The standard size of screw diameter for power screw of hi low supramax type namely major diameter is 18.70 mm, minor diameter is 15.4 mm, pitch diameter is 17.06 mm.

**Figure 5.** Geometry of power screw

Major diameter measurements are performed by using a micrometer screw shown in Fig. 6, minor diameter uses a vernier calliper shown in Fig. 7, pitch diameter uses a three-wire method shown in Fig. 8 and cycle time uses data on CNC turning machines shown in Fig. 9.

**Figure 6.** Measurement of major diameter

**Figure 7.** Measurement of minor diameter
Figure 8. Measurement of pitch diameter

Figure 9. Measurement of cycle time

The calculation of Taguchi multi response in this research uses a combination of Grey Relational Analysis (GRA) and Principal Component Analysis (PCA) methods. The initial step in processing the combination of the two methods is to find the signal to noise ratio (SNR) shown in Table 2.

Table 2. The sequence of S/N Ratio

| Exp no. | Major Diameter | Minor Diameter | Pitch Diameter | Cycle Time |
|---------|----------------|----------------|----------------|------------|
| 1       | -33.310        | -18.004        | -30.792        | -50.955    |
| 2       | -27.869        | -13.632        | -24.903        | -49.610    |
| 3       | -34.357        | 0.043          | -26.320        | -50.211    |
| 4       | -33.632        | -6.320         | -25.040        | -50.501    |
| 5       | -37.782        | -13.979        | -29.720        | -50.344    |
| 6       | -41.761        | -7.803         | -15.607        | -49.855    |
| 7       | -38.751        | -16.990        | -15.133        | -51.270    |
| 8       | -30.969        | -1.591         | -33.310        | -50.449    |
| 9       | -29.720        | -7.959         | -33.310        | -50.466    |

The next step after calculating SNR in the combination of the two methods is to scale the data in the range between zero and one by normalizing. Normalization is carried out in the overall experimental response is listed in Table 3.
Table 3. Normalised S/N Ratio

| Exp no. | Major Diameter | Minor Diameter | Pitch Diameter | Cycle Time |
|---------|----------------|----------------|----------------|------------|
| 1       | 0.608          | 0.000          | 0.139          | 0.189      |
| 2       | 1.000          | 0.242          | 0.462          | 1.000      |
| 3       | 0.533          | 1.000          | 0.385          | 0.638      |
| 4       | 0.585          | 0.647          | 0.455          | 0.463      |
| 5       | 0.286          | 0.223          | 0.198          | 0.558      |
| 6       | 0.000          | 0.565          | 0.974          | 0.852      |
| 7       | 0.217          | 0.056          | 1.000          | 0.000      |
| 8       | 0.777          | 0.909          | 0.000          | 0.494      |
| 9       | 0.867          | 0.557          | 0.000          | 0.484      |

In case of all turning parameters have equal weights, the distinguishing coefficient $\zeta = 0.5$ [14] to calculate grey relational coefficient (GRC). The value of GRC for each experiment is listed in Table 4.

Table 4. Grey relational coefficients

| Exp no. | Major Diameter | Minor Diameter | Pitch Diameter | Cycle Time |
|---------|----------------|----------------|----------------|------------|
| 1       | 0.5802816      | 0.3512715      | 0.3859585      | 0.4004322  |
| 2       | 1              | 0.4167773      | 0.5018367      | 1          |
| 3       | 0.5369013      | 1              | 0.4680279      | 0.5992103  |
| 4       | 0.566223       | 0.6056305      | 0.4983697      | 0.5020438  |
| 5       | 0.4314497      | 0.4106886      | 0.4028971      | 0.5504004  |
| 6       | 0.3512715      | 0.5546519      | 0.954114       | 0.785473   |
| 7       | 0.4087301      | 0.3645671      | 1              | 0.3512715  |
| 8       | 0.7081633      | 0.8567614      | 0.3512715      | 0.5171578  |
| 9       | 0.8025643      | 0.5497989      | 0.3512715      | 0.5119993  |

Calculation of the principal component weight value is done after getting the value of Grey Relational Coefficient. Before conducting the principal component calculation, looking for eigenvalue and eigenvector values of the correlation matrix by using Principal Component Analysis as a result of normalization in each response by using Minitab software. Principal Component calculation results are shown in Table 5.
Table 5. Principal component

|       | PC1     | PC2     | PC3     | PC4     |
|-------|---------|---------|---------|---------|
| Eigen Value | 1.7399  | 1.1566  | 0.8771  | 0.2264  |
|       | 0.677   | 0.217   | 0.234   | 0.663   |
|       | 0.255   | -0.571  | -0.756  | 0.193   |
|       | -0.574  | 0.441   | -0.379  | 0.576   |
| Eigen Vector | 0.383   | 0.657   | -0.48   | -0.437  |
| AP    | 0.435   | 0.289   | 0.219   | 0.057   |
| CAP   | 0.435   | 0.724   | 0.943   | 1       |

PCA value that fulfills the selection requirements of the principal component is PC2 where eigenvalue = 1.1566 > 1, cumulative variance between 70% to 80% is 72.4%, and the angle on scree plot shows the biggest eigenvalue change is PC1 as shown in Fig 10.

Figure 10. Scree plot diagram of response

Then, calculating GRG to evaluate the response with the large amount obtained. GRG calculation results for all experiments and responses are shown in Table 6. After gaining GRG value, the next step is to determine the significant factors with ANOVA. The results of ANOVA calculations performed for each factor by using Minitab software are presented in Table 7.

Table 6. Grey relational grade

| Exp no. | γ       |
|---------|---------|
| 1       | 0.3898  |
| 2       | 0.7122  |
| 3       | 0.7010  |
| 4       | 0.5378  |
| 5       | 0.4702  |
| 6       | 0.7220  |
| 7       | 0.4842  |
| 8       | 0.6042  |
| 9       | 0.5064  |
Table 7. Results of ANOVA

|                  | Spindle Speed | Depth of Cut | Coolant | Usage time of tool |
|------------------|---------------|--------------|---------|-------------------|
| P-Value          | 0.188         | 0.035        | 0.812   | 0.028             |

| Explanation      | Insignificant | Significant | Insignificant | Significant       |

According to ANOVA calculation results, it can be concluded that the depth of cut and usage time of tool have a significant effect on the response because the p-value is less than 0.05. The factors of spindle speed and coolant have no significant effect on the response because the p-value is more than 0.05.

In addition, mean analysis of Taguchi method is used to gain optimal combination of the parameters which mean of GRG values at different levels. The average sum of these GRG values is the corresponding response grade. The optimal level design of factors experiment are used to predict and verify the improvement of the quality characteristic [17]. Based on Table 8, it is found that optimum conditions can be achieved at a combination of levels that have the highest GRG values. A factor (spindle speed) has an optimal condition at level 1, which is 1200 rpm. B factor (depth of cut) has an optimal condition at level 3 which is 0.1 mm. C factor (coolant) has optimal conditions at level 2, which is 1:30. D factor (usage time of tool) has an optimal condition at level 2 which is 70% usage. Thus, it can be concluded that the optimal level combination obtained is A1-B3-C2-D2 with a sequence of factors that have the greatest influence, as follows: usage time of tool, depth of cut, spindle speed, and coolant.

Table 8. Optimal condition for each factor

| Level | Spindle Speed | Depth of Cut | Coolant | Usage time of tool |
|-------|---------------|--------------|---------|-------------------|
| 1     | 0.6009927     | 0.4705775    | 0.5719933 | 0.4554279         |
| 2     | 0.5766309     | 0.595536     | 0.585448 | 0.6394752         |
| 3     | 0.5316061     | 0.6431162    | 0.5517884 | 0.6143266         |
| max-min | 0.0693865     | 0.1725388   | 0.0336596 | 0.1840474         |
| Rank  | 3             | 2            | 4       | 1                 |

Optimal conditions are not found in one of the experiments, then do the confirmation experiment. This aims to confirm the optimal conditions of the experimental results. The confirmation experiment is performed by conducting a test uses a specific combination of the parameters previously evaluated [18]. The optimum conditions are set for the significant factors [19]. The confirmation experiments are carried out with a combination of factors and optimal levels, namely A1-B3-C2-D2 by taking 5 samples for the entire response.

Table 9. Confirmation experiment

| Sample | Major Diameter | Minor Diameter | Pitch Diameter | Cycle Time |
|--------|----------------|----------------|----------------|------------|
| 1      | 18.67          | 15.45          | 17.04          | 320        |
| 2      | 18.67          | 15.5           | 17.05          | 320        |
| 3      | 18.7           | 15.55          | 17.06          | 320        |
| 4      | 18.7           | 15.4           | 17.08          | 320        |
| 5      | 18.68          | 15.4           | 17.04          | 320        |
At the verification phase, a confirmation experiment is carried out which is run on a combination of optimal level settings. Based on the comparison of confidence intervals with a confidence level of 95% the results are acceptable. This is because the results of the confirmation value are still included in the optimal value confidence interval.

Based on the comparison of the results of the experimental confirmation with the existing product, it is known that the product size variance has decreased and the cycle time becomes faster. Average cycle time in the manufacture of power screw is 440 s and in the confirmation experiment is obtained 320 s. This shows that the optimal level setting obtained can reduce the response variance and the cycle time becomes faster. This result is shown in the Table 10.

| Response          | Existing Product | Confirmation Experiment |
|-------------------|------------------|-------------------------|
| Major Diamater    | 0.0004           | 0.0002                  |
| Minor Diameter    | 0.0403           | 0.0043                  |
| Pitch Diameter    | 0.0032           | 0.0003                  |

Based on calculations using a combination of Grey Relational Analysis method and Principal Component Analysis the contribution errors is 1.48%, while using the PCR-TOPSIS method obtained an error contribution of 2.16%. So it can be seen that the combination GRA and PCA method is better than the PCR-TOPSIS method.

4. Conclusions

Taguchi multi response uses a combination of Grey Relational Analysis method and Principal Component Analysis which aims to convert several responses into one response, so that the experimental design has a low error contribution value. Response variables in making experiment of power screw are major diameter, minor diameter, pitch diameter and cycle time. The combination of multi response method is used to get optimal level setting in power screw type of hi low supramax making process. The problem of deceptiveness produced is that one of them is caused by the tool used has been worn out because the usage of the tool does not pay attention to the optimal time of using the tool.

From ANOVA result, it is concluded that depth of cut and usage time of tool have a significant effect on response. It is found that usage time of tool is more significant factor followed by depth of cut. The optimum parameter has been found which is spindle speed at level 1 (1200 rpm), depth of cut at level 3 (0.1 mm), coolant at level 2 (1:30), and usage time of tool at level 2 (70%). The result of the experiments carried out showed a decrease in the response variance in diameter with average 0.0146 to 0.0016 and the cycle time was faster for 440 s to 320 s.

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