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DESIGN OF EXPERIMENT IN INVESTIGATION REGARDING MILLING MACHINERY

Abstract. *Design of experiment (DOE) is a systematic method used to determine the relationships between independent factors and dependent variables. This information can be used either to get deep knowledge of the existing problems or to explore new processes. The DOE is important because it can give more details about the processes with the minimum usage of resources, materials and time. In this paper, four methods of design of experiment and their applications in the field of milling machines (full factorial, fractional factorial, Taguchi method and response surface methodology) are argued. The aim of this paper is to give a comprehensive overview and classification of the use of these methods and present the current trends in investigation of milling technology.*
Keywords: *DOE; full factorial design; fractional factorial design; Taguchi method; response surface methodology; milling technology.*

1 INTRODUCTION

Design of Experiments is a statistical methodology used for analysing the data obtained by given experiments as well as planning and conducting these experiments. In other words, Design of Experiments used for applying scientific studies of a process, product or system in a way that manipulates one or more independent variables to investigate their effects on one or more dependent variable [1].

By choosing the design of experiments well, the information obtained by these experiments can be maximized, which is the aim of Design of Experiments. In manufacturing, studying all the parameters and their effects on the output is not possible in all cases. The time and cost are the main factors in any industrial process. That makes using Design of Experiments a necessary to investigate the output parameter and obtain the needed manufacturing information with few but appropriate experiments [2].

The milling technology is one of the most often used cutting method in case of non-axial-symmetrical machine pare. In case of milling, the chip removal is done by a multi-edge rotational cutting tool, and because of the several variations of feed direction, different shape of surfaces can be produced from a simple slot of the complex free form surfaces. Several parameters define the machining performance, the technical and financial proprieties of the process. The milling technology is widely used in machining industry including automotive, aeroplane, and mould and die making.

This paper argues three methods of Design of Experiments (full factorial, fractional factorial, Taguchi method and response surface methodology) and their applications in investigations regarding milling machinery. The purpose of this work is to study and present the recent literature on this topic.

2 DESIGN OF EXPERIMENTS

The first step to design the experiment is to define the objective. Choosing the key object helps to determine the outputs and inputs parameter, which the next step is. In the second step, it is important to define the levels of each factor. These factors can be divided into two groups: controllable factors, which can be adjusted easily during the experiment and play a key role in the process. Cutting speed, feed rate are two examples of these factors in the case milling technology. On the other hand, uncontrollable factors or noise factors are difficult to be controlled during the experiments, such as temperature and other environmental conditions. These factors could have a major effect on the product performance. From another point of view, these factors can be classified into two sets: quantitative factors which can be determined by specific number (e.g. depth of the cut, cutting speed, etc.). The second one is the qualitative factors such as kind of cutting tool [2][3].

Figure 1 depicts the factors and the output response of the process. Each factor has several levels. The number of levels depends on the purpose of the experiments, but it could be from 2 up to 5. On the other hand, the number of factors and their levels determine the Design of Experiments approach that should be used [2]. In the next chapters four approach of Design of Experiments will be discussed.

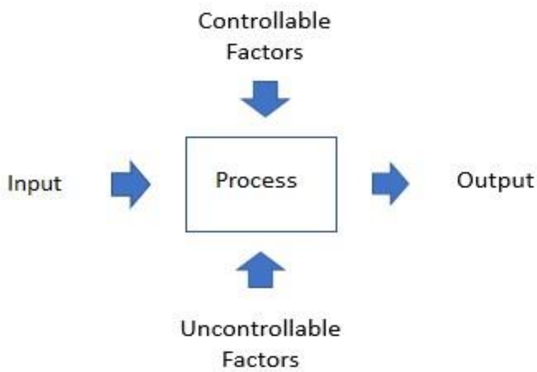

Figure 1 – Factors and output of process

2.1 Full factorial design

In case of full factorial design method, all the factors and their interactions are investigated. The number of levels usually is 2 and rarely 3. If the number of level equals to 2, the linear effect of the factors should be investigated. In case of 3 or more, not only the linear effects but also the quadratic effects of each factor should be studied.

The number of the experiments that should be done is determined by n^k, where k is the number of the factors, and n the number of level of each factor. As an example, if we have three factors at two levels then the number of experiment is 8. In this case, all the possible combinations of the factors at all levels are investigated. Full factorial design is suitable for the number of the factors is less or equal to four [3].

Many researchers depend on this method to determine the most important inputs those have a remarkable effect on the output. Noorani, Farooque and Ioi [4] studied the effect of four factors: spindle speed, depth of cut, feed rate and tool size on the surface roughness of the aluminium alloy 6061, and they found that feed rate and tool size are highly responsible for surface roughness. The least surface roughness is when the spindle speed and depth of cut are adjusted to the highest level and the feed rate is low.

Investigating the tool life using the same material of work-piece, M. Kasim et al. [5] found that the highly responsible factor for tool life is the cutting speed, In a way that increasing of the cutting speed will decrease the tool life. Maximum life of 97 minutes can be obtained by when cutting speed is 115 *m*/*min*, feed rate is 0.15 *mm*/*tooth* and depth of cut is 0.5 *mm*.

A Multi objective optimization was done by Kiran and Kumar [6]. They found that the least total cost is Rs = 12.22 and maximum tool life is 170.19 *min* and obtained when feed = 0.3 *mm*/*rev*, the cutting speed = 50 *m*/*min* and depth of cut = 0.3 *mm*.

Lakshmi and Subbaiah [7] studied the effect of the cutting speed, feed rate and depth of cut on surface roughness and they found that the feed has the main effect on surface roughness and then the cutting speed .Moreover, a multi objective optimization was conducted with the target of maximizing metal removal rate *MRR* and minimizing the surface roughness R_a the optimum conditions were when feed 800 *mm*/*min*, speed 160 *m*/*min* and depth of cut 0.5 *mm*.

Using the same factors but spindle speed instead of cutting speed Shahrajabian and Farahnakian [8] investigated the effect the same factors on the surface roughness and machining forces on CFRPs, the results were as follows: By increasing the feed rate the surface roughness will increase, while it decreases with the spindle speed. By increasing the feed rate the machining force will increase, while it decreases with the spindle speed.

Similar results were founded by Abbas et al. [9] when they investigated the effect of the same factors on surface roughness of the high strength steel. Besides they conducted a multi objective optimization withe the target of maximize metal removal rate and minimize the surface roughness R_a. The optimum parameters were: depth of cut1.0*mm*, spindle speed 1250 *rpm* and feed rate 67 *mm*/*min* with a composite desirability of 0.83, to give $R_a = 0.15\ \mu m$ and $MRR = 233\ 3 mm^3/min$.

Different results were found by Vipindas, Kuriachen and Mathew [10] when they did their experiments using 0.5 *mm* tool diameter, they found that depth of cut is the most significant factor on surface roughness followed by spindle speed and feed rate. Feed rate - spindle speed interaction has a significant effect, while the results were similar to other studies, when they used 1 *mm* tool diameter. However, for both tools, feed rate-spindle speed interaction has a significant effect on surface roughness. Vipindas et al. [10] studied the effect on top burr formation also and found that depth of cut is the most significant factor, on the other hand, the feed rate - depth of cut interaction is the most significant interaction.

For Deshmukh et al. [11] who studied material removal rate as well, the results were as follows: feed rate has the main effect over surface roughness, whereas the depth of cut is the most important factor in case of material removal rate. Material removal rate and surface roughness are proportional to each other. In their study, they found that the minimum surface roughness is $R_a = 1.2\ \mu m$, when feed rate 250 *m*/*min*, depth of cut 0.2 *mm* and spindle speed 600 *rpm*. Whereas maximum material removal 29.214 mm^3/s is when feed rate 300 *m*/*min*, depth of cut 0.6 *mm* and spindle speed 800 *rpm*. In addition, they found that the minimum time 13.03 *s* required for maximum material removal rate.

Bolar, Das and Joshi [12] investigated the effect of tool diameter, feed rate and axial and radial depth of cut on surface roughness. They found that:

- The best surface finish quality has been achieved by applying Lower values of feed rate, axial depth of cut and radial depth of cut with tool diameter of 8 *mm*.
- Tool diameter has a main effect on both surface roughness and cutting force.
- In cases of 4 *mm* diameter tool with high depth of cut and feed rate a tool breakage is noticed.

Mikó and Nagy [13] studied the effect of tool's corner radius as well as the feed rate and depth of cut over surface roughness and his results can be summarized as follows:

- The effect of the depth of cut and the feed rate are the same
- Higher feed has small effect on surface roughness but can improve the surface error a little bit.
- The higher depth of cut impairs both investigated input parameters.
- The larger tool corner radius decreases the surface roughness. But increases the surface error.

Table 1 is a summery to number of researches used full factorial design in their studies. In this table we can notice that the number of the input factors is three in eight studies only two studies have four in put factors. However, the number of the levels is not the same in all researches, some researches have 2 levels others have 3 levels only one study has 4 levels. From the Table 1 also, we can see the highest number of the needed experiments is $3^4 = 81$.

On the other hand, feed rate, depth of cut, spindle speed and cutting speed are the most important factors in the case of milling machine. Whereas the surface roughness R_a is the output in most of these studies.

Using full factorial design helps studying all the possibilities of the levels of the factors. It gives enough information about the output response of the process. However, the limitation of this method is that the number of the experiments is related with the number of the factors and their level, which makes applying this method impossible, because the limitation in the time and the cost. In such cases, another method could be chosen like fractional factorial design which will be discussed in the next chapter.

Table 1 – Full factorial design in milling machine experiments

Author/ year	Work piece Material	Input Factors	No. levels	No. Experiments	Response Variables
Noorani Farooque Ioi 2009 [4].	AL 6061	Spindle Speed Depth of Cut Feed Rate Tool Size	2	24 3 replications	Surface roughness *Ra*
Lakshmi Subbaiah 2012 [7]	EN24 alloy steel	Cutting speed Feed rate Depth of cut	3	33 no replication	Surface roughness *Ra* Material removal rate
Kiran Kumar 2013 [6]	AISI 304 Stainless Steel	Cutting speed Feed rate Depth of cut	3	33	Tool life Total cost
Kasim et al. 2015 [5]	AL 6061-T6	Cutting speed Feed rate Depth of cut	2	23 no replication	Tool life
Shahrajabian Farahnakian 2015 [8]	CRFP	Spindle speed Feed rate Depth of cut	3	33 no replication	Surface roughness *Ra* Machining force
Vipindas Kuriachen Mathew 2016 [10]	Titanium alloy Ti-6Al-4V	Spindle speed Feed rate Depth of cut Tool type	3 2	3^3*2 no replication	Surface roughness *Ra* Top burr formation
Abbas et al. 2016 [9]	High strength steel	Spindle speed Depth of cut Feed rate	4	33 no replicate	surface roughness *Ra* and *Rt* Material removal rate
Deshmukh et al. 2017 [11]	AISI 1020 Mild Steel	Cutting speed Depth of cut Feed rate	4 3	3^2*4 no replication	Surface roughness *Ra* Material removal rate
Bolar Das Joshi 2018 [12]	AL 2024-T35	Tool diameter Feed rate Axial depth of cut Radial depth of cut	3	34 no replication	Surface roughness *Ra* Cutting force
Mikó Nagy 2019 [13]	C45 steel	Tool's corner radius Feed rate Depth of cut	3 2	2^2*3 no replication	Surface roughness *Ra*

2.2 Fractional factorial

Time, resources and budget are very important in the industry. That makes running full factorial experiments is unavailable when the number of the factors is large. Instead fractional factorial design is implemented, in this approach a smaller number of experiments can be run to get the information of the main effects and desired interactions effects, in other ward some interactions are considered unimportant will not be investigated [3].

The number of the experiment in this method can be determined by n^{k-p}, where n is the number of the levels, k is the number of factors and $1/2^p$ is the fraction of full factorial that should be run [14]. When p=1, we got the half factorial design, in case of 3 factors with 2 levels, we need to run four experiments, which is the half what we need in case of full factorial.

In the following, a review of some researchers used fractional factorial design in milling machinery is provided:

Saini and Pradhan [15] used this method to study the effect of four machining parameters (speed, feed, depth of cut and coolant) For high carbon alloy steel. They found that: the depth of cut has the most significant effect on material removal rate, followed by feed, interaction effect of depth of cut and feed and finally on coolant. the optimum result of MRR is 52.1512 *gm*/*min*, that is when depth of cut 3.0 *mm* feed is 0.15 *mm*/*tooth* with coolant on.

On the other hand, Catherine, Ma'arof and Suresh [16] used five factors (depth of cut, feed rate, step over, spindle speed and plunge rate) to study the impact on surface roughness. They found that step over is the most significant factor on surface roughness.

Tseng et al. [17] used half fractional design to investigate the effect of five factors (cutting speed, feed rate, depth of cut, nose radius and cutting fluid) on surface roughness. According to their research the most important factors are feed rate, cutting speed and depth of cut.

El-Taybany et al. [18] studied 2 levels for six factors, the outputs of the experiments were the cutting forces and the moment. The results can be summarized in the following way:

- The cutting fluid has a big effect on the cutting forces. With application of cutting fluid, the moment de-creases while cutting forces increase. The case is the same with ultrasonic vibration which results in minimizing the moment and maximizing the cutting forces

- The feed rate, spindle speed and depth of cut have major effect on cutting forces which increase by increasing the depth of cut and feed rate and decreasing the spindle speed.

Table 2– Fractional factorial design in milling machine experiments

Author/ year	Work piece material	No. Fac-tors	Input Factors	No. levels	Fractional Design	Response Variables
Saini Pradhan 2014[15]	EN-31	4	Speed Feed Depth of cut Coolant	2	2^{4-1} no replication	Material removal rate
Catherine et al 2015 [16]	PE board	5	Depth of cut Feed rate Step-over Spindle speed Plunge rate	2	2^{5-1} no replication	Surface roughnes s *Ra*
Tseng Konada Kwon 2015 [17]	AL 6061 T6	5	Cutting Speed Feed rate Depth of cut Nose radius Cutting fluid	2	2^{5-1} 3 replications	Surface roughnes s *Ra*
El-Taybany Hossam El-Hofy 2017 [18]	Soda glass	6	Spindle speed Feed rate Depth of cut Ultrasonic vibration Grain structure Cutting Fluid	2	2^{6-1} 2 replications	Cutting forces and the moment

Table 2 shows five studies used fractional factorial design. It is clear that the number of factors here is higher than in table 1. Three studies used half fractional factorial where the number of factors was 5 in two of them and 6 in the other one.

Fractional factorial design is a very useful tool to investigate the most important factors which have the main effects on the output. When the time and cost are limited, using this approach would be a necessary to give a maximum amount of information in less number of experiments than full factorial. However, the information that can be received by this approach could be insufficient in some process and need a prior knowledge of the main factors that should be studied.

2.3 Taguchi method

It is a very widely used method, founded by Dr. Taguchi a Japanese engineer who introduced a new way of thinking of product quality in industry. The main idea in Taguchi's methodology is the "loss of society" which indicates that the whole society and individual firms suffer when the well-made products do not work as they could[14].

According to Taguchi view, the process of improving the quality of the product starts by taking the population distribution close to the target value. The next step is to reduce the variation around the target [19].

In his approach, Dr. Taguchi put a set of standard orthogonal arrays. These arrays determine the number of the experiments that should be implemented. Choosing the suitable array depends on the number of the factors and their levels [14]. Using these arrays, the linear effects of the factors and some relevant interactions between the factors can be investigated.

Noise or uncontrollable factors were part of Taguchi's method. These factors were usually ignored for an economic reason and because of the small effect that they have on the response of the process. By taking these factors in account, Taguchi was able to build a robust design [19]. In this robust design, an outer array represents the noise variables are added to an inner array which represents the main factors [14].

Here, we will go throw some researches where this approach was used in investigations in the field of milling machine.

Singh and Mall [20] studied the effect of cutting speed, feed rate and depth of cut in order to optimize the surface roughness of aluminium, they pointed out that the most important factor is the feed rate followed by cutting speed and depth of cut. Whereas Ramesh [21] studied the spindle speed, feed rate and depth of cut to minimize the cycle time in machining of stainless steel AISI 304, the results of this research was as follows:

- In case of cycle time, the most important factor is spindle speed followed by feed rate and depth of cut.
- In case of surface roughness, the most important factor is feed rate.

Malay et al. [22] studied the same factors to optimize the milling process in machining Al 6351. The results in this study were different from the previous one, they indicated that the most important factors in modelling surface roughness is spindle speed. However, in their research, Ghalme, Mankar and Bhalerao [23] pointed out that the optimal value of surface roughness can be achieved when: Speed= 200 *rpm*, depth of cut= 1.2 *mm* and feed= 40 *mm*/*min*.

Ratnam et al. [24] investigated in the effects of process factors on each of surface roughness, surface hardness and tool vibrations. The results of this study can be summarized in these three points:

- The most important factors on surface roughness are the feed rate and tool speed.
- While tool speed and depth of cut are the most important in case of surface hardness.
- In case of orthogonal turn-milling, depth of cut has a vital role on surface hardness and tool vibrations, whereas in tangential turn-milling, the most significant factor is tool speed.

In their research, Gupta, Krishna and Suresh [25] focused on the flatness of the work piece. From this research, it can be concluded that by increasing the spindle speed and feed rate the flatness decreases, while it increases with the increase of depth of cut. In their study Kumar et al [26] found that, the most important factor is spindle speed, then depth of cut and feed. Whereas, Sosa, Makwana and Acharya [27] did not focus only on surface roughness but also on material removal rate, they found that in case of material removal rate, feed rate has the most significant effect, while cutting speed has the main effect on surface roughness.

Kim and Lee [28] studied the cutting force and tool wear beside of the surface roughness. The results can be summarized as follows:

- In case of tool ware, spindle speed was the main factor.
- In case of cutting force, depth of cut has the most significant effect.
- Feed rate has the most significant effect on surface roughness.

In their study to minimize the energy consumption as well as the surface roughness, Ahmed and Arora [29] found that in case of surface roughness, spindle speed is the most important factor, while feed rate has the most significant effect on energy consumption.

Table 3 – Taguchi design in milling machine experiments

Author/ year	Work piece material	No. factors	Input factors	No. levels	Ortho-gonal matrix	Response variables
Singh Mall 2015 [20]	AL	3	Cutting speed Feed rate Depth of cut	3	L_9	Surface roughness
Ramesh 2015 [21]	AISI 304 Stainless steel	3	Spindle speed Feed rate Depth of Cut	3	L_9	Surface roughness Cycle time
Malay et al. 2016 [22]	AL 6351	3	Spindle speed Feed rate Depth of cut	3	L_9	Surface roughness
Ghalme1 Mankar Bhalerao 2016 [23]	GFRP	3	Spindle speed Feed rate Depth of cut	3	L_9	Surface roughness
Ratnam et al. 2016 [24]	Extruded brass (leaded)	3	Tool speed Feed rate Depth of cut	4	L_{16}	Surface roughness Surface hardness Tool vibrations
Gupta Krishna Suresh 2017 [25]	AL/Si alloy	4	Spindle speed Feed Rate Depth of Cut Step over ratio	3	L_9	Flatness
Kumar et al. 2017 [26]	Al2024-SiC	4	Spindle speed Feed Rate Depth of Cut Number of Flutes	3	L_{27}	Surface roughness
Sosa Makwana Acharya 2108 [27]	Medium carbon steel	3	Spindle speed Feed Rate Depth of Cut	5	L_{25}	Surface roughness Material removal rate
Kim Lee 2019 [28]	Inconel 718	3	Spindle speed Feed rate Depth of cut	3	L_9	Tool wear Cutting force Surface roughness
Ahmed Arora 2019 [29]	Low carbon steel A36 K02600	4	Spindle speed Feed rate Depth of cut Cutting speed	3	L_9	Surface roughness Energy consumption

As it is shown in the table 3 L_9 orthogonal array is the most used, the array is useful in case of 3 levels and four or three factors. Using this orthogonal array in investigating surface roughness is reasonable as the most important factors, in case of surface roughness, are spindle speed, depth of cut and feed rate as it is indicated in table 2. For higher number of factor's level, another orthogonal array should be used, as in case for 4 and 5 levels the L_{16} and L_{25} orthogonal arrays were used.

Taguchi method shed the lights on the target value rather than a value within specification limits which improved the quality of the products. In addition, it gives the ability to analyse many factors with a small number of experiments. In addition, it makes it possible to focus only on the key factors and ignore the unimportant factors.

2.4 Response surface methodology

Response surface methodology (RSM) is an integrate of mathematical and statistical techniques used to improve, develop and optimize the process. It also plays a vital rule in the formulation and design the new products [30]. In most of RSM problems, first and second order models are used. Linear terms are related with first order model, whereas, second order model has quadratic terms.

Depending on this method, many researches were done in order to optimize the cutting parameters in machining operations. Subramanian et al. [31] developed a second-order quadratic model to compute the vibration amplitude. In their research they found that: by increasing feed rate, the vibration amplitude increases. It increases also by decreasing the cutting speed. This increasing of vibration amplitude is noticed at low nose radius and low radial rake angle, whereas the decreasing of vibration amplitude took a place at high nose radius and high radial rake angle.

Jeyakumar et al. [32] investigated the influence of machining parameters on the cutting force, tool wear and surface roughness, their results were as follows:

- The z-component of the cutting force is the most dominant component and comparing to the other component in x direction, it shows a significantly higher magnitude.
- At low cutting speed, tool wear rate is high.
- At higher speed, the surface roughness was low, whereas, it was high at lower feed rate.
- When machining with high depth of cut, all of the tool wear, cutting force and surface roughness are high.

Patel et al. [33], showed, in their study the effect of cutting parameter on the temperature of the work piece, they found that: the temperature increases by increasing the depth of cut. In the same way increasing the feed and speed will increase the temperature. On another hand, the most important parameter is the depth of cut. Therefore, to minimize the temperature, lower depth of cut is desirable.

Kumar and Rajamohan [34] studied the effect of spindle speed, feed rate, axial depth of cut and radial depth over surface roughness and flatness. The research pointed out that in case of surface roughness, feed rate is the most significant factor on surface roughness. By increasing the feed rate or axial depth of cut surface roughness will increase, while by increasing the cutting speed or spindle speed, the surface roughness decreases. In case of flatness, axial and radial depth of cut can make significant changes on flatness.

In their study, Rao and Murthy [35] used a multi response optimization technique to optimize the cutting parameters in order to minimize the surface roughness and RSM of vibration velocity of the work piece. The optimum parameters were: 210 *m*/*min* of cutting speed, 0.6828 *mm* of nose radius and 0.10 *mm*/*min* of feed rate.

Khairusshima et al. [36] developed a statistical model to investigate the effect of cutting parameters on tool wear. He found that the most important factor on tool wear is the feed rate. The optimum parameters are: feed rate 200 *mm*/*min*, cutting speed 3510 *rpm* and depth of cut 0.5 *mm* to achieve tool wear 0.0267 *mm*.

On the other hand, Başar, Kahraman and Önder [37] investigated the effect of the cutting parameters on surface roughness and developed a model to estimate the surface roughness. They found that: the spindle speed and feed rate have the most significant effects on surface roughness. In their model, the minimum surface roughness achieved when spindle speed 5981 *rpm*, feed 3008 *mm*/*min* and depth of cut 0.54 *mm*.

Singh, Samad and Saraf [38] analysed the effects of the machining parameters on surface roughness in turning AL6061. The results of their model were close to the experimental values with a confidence level equals to 95 percent confidence. The minimum surface roughness parameters $R_a = 0.6943$ μm, $R_q = 1.0314$ μm, and $R_z = 4.1229$ μm have been achieved at feed = 73.37 *mm*/*min*, cutting speed = 187.84 *m*/*min* and depth of cut = 0.48 *mm*.

Based on the Table 4 we can say:

- Surface roughness was the response variable in many researches and the work has been done to reduce the roughness using various machining parameters.
- Besides the effect of conventional factors like cutting speed, feed rate and depth of cut, the effect of nose radius also has been studied.

- Other response variables have been studied like tool wear, vibration and cutting force.

Table 4 – Response surface methodology in milling machine experiments

Author/ year	Work piece material	No. factors	Input factors	No. levels	Type	Response Variables
Subramanian et al. 2013 [31]	Al 7075-T6	5	Radial rake angle Nose radius Cutting speed Cutting feed Axial depth of cut	5	CCD	vibration amplitude
Jeyakumar Marimuthu Ramachandran 2013 [32]	Al6061/SiC	4	Spindle speed Feed rate Depth of cut Nose radius	3	CCD	Cutting force Tool wear Surface roughness *Ra*
Patel et al. 2014 [33]	Mild steel	3	Speed Feed rate Depth of cut	3	CCD	Temperature of work piece
Kumar Rajamohan 2015 [34]	AL 6063-T6	4	Spindle speed Feed rate Axial depth of cut Radial depth	5	CCD	Surface roughness *Ra* Fatness
Rao; Murthy 2016 [35]	AISI 316	3	Nose radius Cutting speed Feed rate	2 3	CCD	Tool wear Vibration of work piece
Khairusshima et al. 2018 [36]	CFRP	3	Cutting speed Feed rate Depth of cut	5	CCD	Tool wear
Başar Kahraman Önder 2019 [37]	AL 5083	3	Feed rate Spindle speed depth of cut	3	FCD	Surface roughness *Ra*
Singh; Samad Sara; 2019 [38]	AL 6061	4	Feed Depth of cut Spindle speed Nose radius	2	CCD	Surfaceroughn

3 CONCLUSION

In this paper, a review of the recent literature for the use of design of experiments in investigations in the field of milling machinery has been done. From this review we found that design of experiment methods are widely used to determine the most important factors those have the remarkable effects during the operation done by the milling machine.

- Design of experiments approaches are found to be very useful and powerful tools for defining the factors those have the most significant effect in milling operation.
- The most important factors to be investigated in milling operations are spindle speed, axial and radial depth of cut and feed rate.
- Surface roughness is by far the most important output parameter to be considered in determining the quality of the component. In addition, cutting force and material removal rate are should be taken in account.
- Choosing the suitable approach of design of experiments depends on the number of the parameters those should be examined and the level of each parameter. On the other hand, time and cost play a vital role in preferring one approach over the other.
- For optimization problem RSM, full factorial and fractional factorial design are appropriate methods.

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ПЛАНУВАННЯ ЕКСПЕРИМЕНТУ ДЛЯ ДОСЛІДЖЕНЬ СТОСОВНО ФРЕЗЕРНОГО ОБЛАДНАННЯ

Анотація. *Планування експерименту (DOE) - це систематичний метод, який використовується для визначення взаємозв'язків між незалежними факторами і залежними змінними. Ця інформація може бути використана або для отримання глибоких знань про існуючі проблеми, або для вивчення нових процесів. DOE важливий, тому що він може дати більш детальну інформацію про процеси з мінімальним використанням ресурсів, матеріалів і часу. У даній статті обговорюються чотири методи планування експерименту і їх застосування в області фрезерних верстатів (повний факторіал, дробовий факторіал, метод Тагучі і методологія поверхні відгуку). Метою даної роботи є дати вичерпний огляд і класифікацію використання цих методів і представити сучасні тенденції в дослідженні технології фрезерування. З огляду зроблено висновок, що розробка методів планування експерименту широко використовується для визначення найбільш важливих факторів, що помітний вплив на роботу, виконувану фрезерним верстатом. Встановлено, що підходи до планування експериментів є дуже корисними і потужними інструментами для визначення факторів, які надають найбільш значний вплив на операції фрезерування. Найбільш важливими факторами, які необхідно досліджувати при фрезерних операціях, є швидкість шпинделя, осьова і радіальна глибина різання і швидкість подачі. Шорсткість поверхні - безумовно, найважливіший вихідний параметр, який слід враховувати при визначенні якості компонента. Крім того, сила різання і швидкість видалення матеріалу повинні бути прийняті до уваги. Вибір відповідного підходу до планування експериментів залежить від кількості параметрів, які необхідно вивчити, і рівня кожного параметра. З іншого боку, час і витрати відіграють життєво важливу роль в перевазі одного підходу іншому. Для завдання оптимізації поверхні відгуку (RSM) придатними є повний факторний і дробовий факторний дизайн.*

Ключові слова: *планування експерименту; повнофакторне планування; дробовий факторний план; метод Тагучі; методологія поверхні відгуку; фрезерні технології.*