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Магістерська дисертація на здобуття ступеня магістра

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на тему: Оптимізація режимів різання в процесі точінння

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ЗАВДАННЯ

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4. Предмет дослідження Оптимізація процесу точіння

5. Перелік завдань, які потрібно розробити Розробити математичну

модель процесу різання, вибрати критерій сталості ТОС, розробити прикладну програму моделювання процесів, що відбуваються у пружній ТОС, розробити методику визначення оптимальних режимів різання.

6. Орієнтовний перелік ілюстративного матеріалу рисунки, таблиці, формули

формули

7. Орієнтовний перелік публікацій статті, тези конференцій, наукові роботи,

КАЛЕНДАРНИЙ ПЛАН

№ з/п	Назва етапів виконання магістерської дисертації	Термін виконання етапів магістерської дисертації	Примітка
1	Вивчення сучасного стану проблеми (огляд		
	літератури)		
2	Вибір та обгрунтування критерію для оцінки		
	сталості ТОС		
3	Розробка прикладної програми моделювання		
	процесів, що відбуваються у пружні ТОС		
4	Розробка методики визначення оптимальних Режимів різання при точінні		
5	Проведення експерименту на токарному верстаті		
6	Порівняння теоретичних та практичних результатів		

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РЕФЕРАТ

Оптимізація токарних операцій може стати ефективною лише тоді, коли продуктивність буде досягнута максимально, а собівартість продукції знижується до найнижчого мінімуму. Важливість вибору оптимальних умов різання не може бути занижена. Складний характер оптимізації процесів обробки послужив мотивацією інженерів шукати інші ефективні методи максимальної продуктивності. Це завдання ускладняються відсутністю досвіду операторів, яким доводиться працювати з сучасними верстатами з ЧПУ. Це дослідження зосереджено на розробці моделі оптимізації на основі відомих параметрів обробки та застосуванні їх до будь-якого процесу різання.

Після перегляду безлічі відповідної літератури про різні методи оптимізації, які застосовувалися в минулому, було визначено основу, на якій ця теза зосереджена. Основна ідея фокусується на виборі оптимальних режимів різання та умов, таких як глибина різання, поздовжня подача, швидкість шпинделя та інші параметри різання для процесу обточування. Він також зосереджується на сухому обточуванні деталі, виготовленої зі сталі 45 (ANSI 1045).

У минулому більшість експериментів з оптимізації процесів обробки були зосереджені на використанні методу оптимізації Тагучі. Цей метод, а також філософська робота в поєднанні з ANOVA-аналізом використовуються для оцінки впливу окремих параметрів.

Інші методи оптимізації включають модельований відпал (SA), звичайний та вдосконалений загальний алгоритм (GA), оптимізацію рою частинок (PSO). Ці методи застосовуються для оптимізації поворотного процесу у виробництві.

Інструмент, що використовується для цієї операції, також перевіряється для підтвердження впливу напружень на термін служби інструменту. Напруги на ріжучій грані включають пластичну деформацію ріжучої кромки внаслідок зусиль різання та моменту згинання деталі. Параметри ріжучого інструменту також включені в оптимізаційну модель.

Затискні пристрої також аналізуються для визначення жорсткості та пластичної деформації одно-масової системи. Сили компонентів, що діють на систему, аналізуються і також включаються в модель. Інші фактори, що сприяють, включають параметри обробки, рекомендовані виробником, а також обмеження параметрів обробки.

Для розгортання операцій на токарному верстаті зараз розроблена методика оптимізації, яка включає всі компоненти компонентів, які були включені в цю модель. Також була розроблена комп'ютерна програма для визначення всіх обмежень та ефективного прогнозування оптимальних умов. Приклад результатів, передбачених програмою, наведений у цій дипломній роботі. Також пропонуються пропозиції щодо подальших досліджень.

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Ключові слова: оптимізація, точіння, процес різання, оптимум, деталь, заготовка.

ABSTRACT

Optimization of turning operations can only become effective when the productivity is maximized and the cost of production is decreased to the barest minimum. The importance of selecting the optimum cutting conditions cannot be understated. The difficult nature of optimizing machining processes has served as motivation for engineers to seek other efficient techniques of maximizing productivity. This task is made more difficult with the lack of expertise of operators who have to handle modern CNC machines. This research focuses on developing an optimization model based on the known machining parameters and applying them to any cutting process.

After reviewing a host of relevant literature on the various techniques of optimization that have been used in the past, a framework was identified on which this thesis focuses. The core idea focuses on selecting the optimum cutting modes and conditions like depth of cut, longitudinal feed, spindle speed and other cutting parameters for a turning process. It also focuses on the dry turning of a work piece made of ANSI 1045 steel.

In the past, most of the experiments on the optimization of machining processes have focused on utilizing the Taguchi method of optimization. This method as well as the philosophy work in conjunction with ANOVA analysis are used to estimate the impact of individual parameters.

Other optimization techniques include Simulated Annealing (SA), conventional and improved General Algorithm (GA), Particle Swarm Optimization (PSO), These techniques are used to optimize the turning process in manufacturing.

The tool used for this operation is also checked to confirm the effects of the stresses on the tool life. The stresses on the cutting edge include the plastic deformation of the cutting edge due to cutting forces and bending moment of the work piece. The parameters of the cutting tool are also incorporated into the optimization model.

The clamping fixtures are also analyzed to determine the rigidity and the plastic deformation of the single-mass system. The component forces acting on the system are analyzed and also incorporated into the model. Other contributing factors include the machining parameters recommended by the manufacturer as well as the constraints on the machining parameters.

An optimization technique which incorporates all the component factors that have been incorporated into this model is now developed for turning operations on a lathe. A computer program has also been developed to determine all the constraints and effectively predict the optimum conditions. An example of the results provided be the program is provided in this thesis. Proposals for further research is also provided.

Publications – The core research of this dissertation was published in the journal of the XVIII International scientific-practical conference titled "MACHINE-BUILDING progressive ideas - science - production ", Kramatorsk, 2018 under the title " Determining the optimum cutting depth in rough turning".

Keywords: optimization, turning, cutting process, optimum, work piece.

MODELLING OF THE OPTIMIZATION OF TURNING OPERATIONS

THESIS

A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science in Production Engineering
in the Institute of Mechanical Engineering
at the National Technical University of Ukraine, Kiev.

By
Ezenduka Johnmary

Supervisor: Prof. Y.V. Petrakov, Professor of Mechanical Engineering.

Kiev, Ukraine

2019

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CHAPTER 1

INTRODUCTION AND OVERVIEW

1.1 Introduction

Machining is the center-piece of any production process in the manufacturing industry in this modern age. And just like every other industry, the main focus is increasing the level of productivity without compromising the quality of the final product. To this effect, optimization is a vital part of production which focuses primarily on maximizing the productivity of the manufacturing or production process. Consequently, optimization of cutting process has become some of the most analyzed and researched concepts in the field of industrial/production engineering.

However, when it comes to manufacturing of rough turning processes, the problem of optimization is compounded by a lot of factors which make it difficult to determine what criteria on which to focus. Unlike any other problem, you can only optimize a cutting process based on a given criterion. Therefore, most researchers focus on whatever criterion they believe will have the most impact in terms of increasing productivity to the maximum level possible.

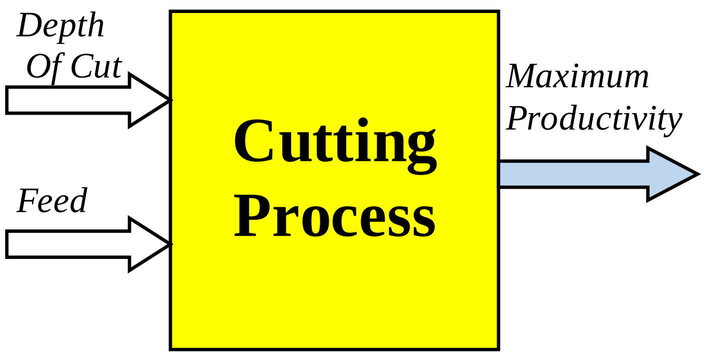

Figure 1.1 The expectations of the optimization process

Preferably, a good criterion to optimize is the amount of material being removed per pass. This criterion is called the Material Removal Rate (MRR).

It works by using a model developed by factoring in the cutting and machining parameters in a standard turning process. This model is them used to write a program which automatically calculates the necessary values with the use of the known variables and equation to produce a value – MRR.

Over the years, a lot of research has been carried out on the issue of optimization by different professionals. While some of these researches focus on the machining parameters and cutting parameters, the primary focus has been on increasing the cost of production. This is a problematic approach because reducing the cost of the production process might affect the quality of the final product. Moreover, it is more cost-effective to optimize a criterion which is part of the machining process because it helps in controlling the process efficiently.

In contrast to previous research, this paper will focus on the optimization of cutting process using two important criteria. The first criterion is the hardness of the cutting tool, and tool holder. The second criterion focuses on the rigidity of part-holding mechanism. In order to properly determine the important factors to note during the experiment, we consider the part-holding mechanism in two different setups – one with the only chuck and the other with the chuck and dead center.

1.2 Overview

The extent of the research covers the entire scope of the experimental work to develop a functioning model used to determine the optimum cutting parameters for a rough turning process with consideration of the stiffness of the work piece-holding setup and the toughness of the cutting tool. With the help of this functioning model, a program was then developed to calculate the predictive optimum cutting parameters under these specific conditions.

The main focus of this thesis include:

a. Evaluating the effects of the clamping mechanisms on a work piece mounted on a lathe of the cutting forces
b. Analyzing the effect of the tool toughness on the level of productivity in a rough turning operation
c. Creating a model for the material removal rate based on the machining and cutting parameters of a standard turning operation
d. Developing and optimization problem for roughing a work piece with the aim of achieving maximum productivity.
e. Make us of previous work by other professionals to improve on the results of the work presented in this thesis
f. Provide information to further future research on optimization of cutting operation.

Chapter 2 focuses on a review previous literature on the optimization of turning operations and other cutting processes. This chapter features a concise summary of important work on the optimization of cutting processes over the past few decades.

Chapter 3 focuses on introducing the material removal model for turning based on research by Petrakov (2003) and Agrawalla (2014). This chapter focuses on an in-depth description of the techniques used by both authors in their research.

Chapter 4 presents the process of optimization which has been developed for turning operations. The criteria for determining the productivity of the entire manufacturing process can be split into two. The first criterion focuses on the stiffness of the work holding under two conditions – with the chuck and dead center and with the chuck alone. An analysis based on the data obtained from the experiment help in predicting the material removal rate. This chapter also explains the effectiveness of the use of Material Removal Rate (MRR) as a reliable quantifier for maximized productivity in turning operations.

Chapter 5 discusses the programming and optimization of the turning process. It summarizes the previous research done in this area of manufacturing process optimization. Also, this chapter sheds more light on the principles of optimization used in this thesis.

Chapter 6 contains the summary of the experimental, modelling and research done in this evaluation. This chapter also highlights the importance of paying more attention to the improvement of sustainable machining process in the manufacturing industry for a better overall bottom-line.

CHAPTER 2

SUMMARY OF PREVIOUS WORK

2.1 Introduction

Over the past few decades, a lot of research has been carried out by researchers trying to determine a definite way of optimizing machining processes. The main focus of some of the research is on turning. This focus on turning is because it bears a huge impact on the entire turning process because of the amount of material removed. Today, most modernized equipment is constructed in such a way as to predict the most useful approach to maintaining the productivity at a maximum. The increase in demand for these kind of machines makes increases the necessity of a model that can predict with a high level of accuracy, the necessary cutting parameters for a given turning operation. When the predicted model has been developed and analyzed, it can then be used to write a program which automatically performs the optimization task with respect to the parameters provided. Subsequently, with the aid of the resulting parameters, the new machines can be integrated with programs which can perform the task of optimization with a high degree of accuracy.

Here are some the factors one has to consider before going about the task of optimizing turning operations:

a. Depth of cut
b. Cutting Speed
c. Feed
d. Tool Hardness
e. Tool toughness
f. Work piece holding mechanism

This chapter reviews a number of research over the past decades on the optimization of turning processes. Here is a brief description of some of these factors.

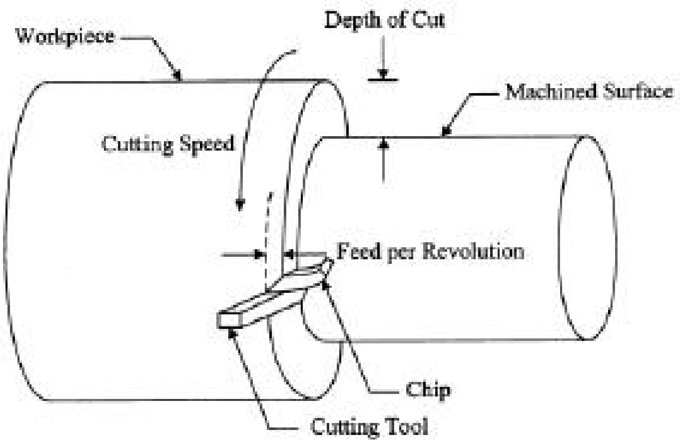

Figure 2.1 Machining parameters

- Depth of Cut – This is the distance between the already machined surface and the remaining part of the work piece. Another description of this parameter is the depth to which the cutting tool can penetrate into the surface of a work piece. The lathe operator has to set this parameter prior to the start of the rotation of the chuck.

$$H = \frac{D_1 - D_2}{2} \tag{2.1}$$

Where D_1 = Initial Diameter

D_2 = Final Diameter

- Cutting Speed – this is the rate at which the work piece is approaching the cutting tool. The unit of measurement is often expressed in m/min (meters per minute). The spindle speed is relative to the cutting speed because the spindle rotates together with the work piece.

Therefore;

$$V = \frac{\pi D n}{1000} \tag{2.1}$$

Where D = Diameter of work piece (mm)

n = Spindle speed

- Feed – this is the distance covered by the tool in a straight path for every revolution of the spindle and work piece. The unit of measurement is in mm/revolutions (mm/rev) or in mm/min (meters per minute).
- Tool toughness and hardness – the value of these depend of the materials of the cutting tool. Any material used for the cutting tool should be tougher than the material that is being cut (Schneider 1989). According to Dash (2012), the material of the cutting tool must be able to withstand vibrations during the cutting process without fracturing.
- Work piece holding mechanisms – The method of fixing the work piece to the lathe has a bearing on the productivity of the machining process. The work piece can be held in the place by the chuck alone or, at both ends by using the dead center.

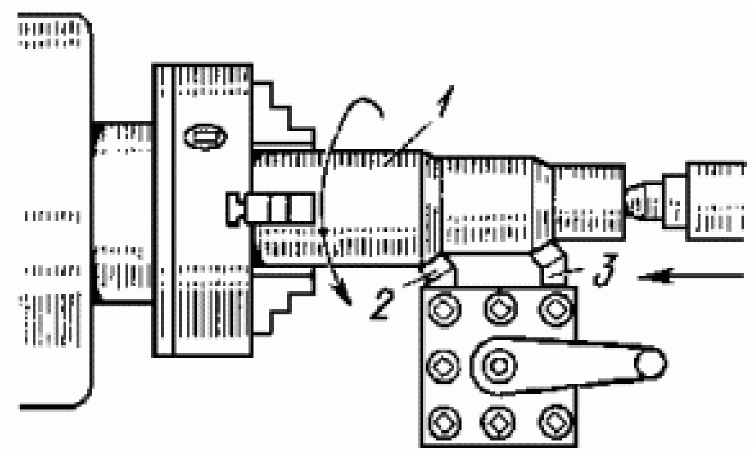

Figure 2.2 Work holding (clamping) using a chuck and dead center

2.2 Previous Work

In an experiment carried out to optimize a manufacturing process, the cost of production as well as the duration of the entire process were expressed as an objective function (Agapiou 1992). In his research, he gave preference to the optimization of the depth of cut, the number of passes as well as the cutting speed and the feed rate. All these values were part of the model and were developed using dramatic programming (Agapiou 1992). Also, some physical constraints were incorporated into the model with each individual pass of the multiple pass machining independent of each other.

Petty et al (1985) explained a process that can be used to determine the optimum cutting conditions for turning operations. This process focuses primarily on either minimalizing cost or maximizing productivity of a manufacturing process. For a given combination of tool and work material, determining the optimum was confined for a feed rate against the depth-of-cut plane defined by the chip-breaking constraint. Other constraints that can go into the process of optimization include the power, work holding mechanisms, and surface finish (Petty et al 1985).

Another research was conducted to evaluate the relationship between the multiple and single-pass machining of a carbon steel work piece using a carbide tool (Tsai 1986). He stipulated a point when a given value of the depth of cut where the single pass and multiple pass machining are effective to the same degree. This point of effective depth of cut can be referred to as the break-even point (Tsai 1986). When the value of the depth of cut is above this point, the single-pass becomes more economical than the double pass and vice versa.

An optimization module was also developed for turning operations as part of a PC-based generative CAPP system for steel, cast iron and aluminum materials (Prasad et al 1997). In his work, the tools used in this study were made of HSS and carbide tools. The objective function was the reduction of the production time of the machining process. Some of the constraints employed in the development of the module include the following parameters: power, surface finish, tolerance, work piece rigidity, range of cutting speed, and depth of cut (Prasad et al 1997). The models were also improved by changing the tolerance and work piece rigidity constraints for multi-pass operations.

2.2.1 Taguchi Method

This method of experimental design was introduced by the Japanese Genichi Taguchi. This method is very popular and effective, and as such, is used for experiment analysis and process optimization not only in manufacturing processes but also in other spheres. The Taguchi method is essential in optimizing high quality precision systems (Barker 1990). It is also essential for system and process which function within a wide scope of variable conditions.

Furthermore, the Taguchi method depends on a methodology and philosophy which massively depends on statistics (Taguchi 1989). This means that a lot of variables and factors are considered simultaneously during the course of planning and executing the experiment. As such, the Taguchi method involves the concatenation of engineering and statistical techniques with the aim of attaining massive cost and quality improvements through the process of optimizing the manufacturing design.

The Taguchi method has not only been implemented by Japanese companies, but also by other international corporations worldwide, including tech and manufacturing giants like AT & T, Ford, Xerox, UNIX, NEC and Fugitsu (Barker 1990, Chanin 1990).

The Taguchi method shows that quality should be part of the production design rather than quality being determined by inspection (Ribeiro et al 1999). To achieve this feat, a lot of attention should be paid to system, parameter and quality design. A good measure of the quality of a product is the signal-to-noise ratio (S/N ratio). This quality can be split into three categories according to the level of performance of the evaluation:

Nominal (Best) $$\frac{S}{N_t} = 10 * \log\left(\frac{\overline{y}^2}{s_y^2}\right) \qquad (1.1)$$

Larger (Better/Maximize) $$\frac{S}{N_L} = -10 * log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \qquad (1.1)$$

Smaller (Better/Minimize) $$\frac{S}{N_s} = -10 * log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \qquad (1.1)$$

where $\overline{y}$ is the average of observed data, $\overline{s_y^2}$ is the variance of y, n is the

number of observations and y is the observed data (Ribeiro et al 1999).

The core elements of the philosophy surrounding the application of the Taguchi method in the optimization process include:

- Off-line quality control
- Robust design of processes
- Innovations in the statistical design of experimental tests.

According to Melkote et al (2006), the Taguchi method works on a few methodologies and philosophies which include:

- Recognizing the main function, the failure mode and the side effects involved
- Identification of the noise factors (exigent factors), testing conditions and characteristics defining quality
- Identification of the core function to be optimized
- Creation of orthogonal arrays
- Carrying out the experiments according to the created arrays

- Evaluating the predicted data alongside the parameters suggested by the technique of optimization
- Confirmation experiment as a means of validating the optimization technique, and planning for future work

Oktem et al (2008) created a method for optimizing cutting processes involving low surface roughness when milling the mold surfaces of 7075-T6 aluminum. This optimization method is based on the Taguchi method. Some of the machining parameters take into account are feed, cutting speed, axial and radial depth of cut. With the use of these parameters they carried out a few milling experiments to measure the roughness data. With the use of a regression analysis, the experimental measurement was identified to represent a fitness characteristic for the process of optimization (Oktem et al 2008). To this effect, a Taguchi orthogonal array, the S/N ration, and an ANOVA were used.

The work of Palanikumar (2008) focuses on the use of the Taguchi method as well as the response surface methodologies for minimizing the surface roughness in machining glass fiber reinforced (GFRP) plastics with a polycrystalline diamond (PCD) tool. The conclusions of the research based on the Taguchi method was that in order to achieve a good surface finish on the GFRP work piece, high cutting speed, high depth of cut and lower feeds are preferable.

According to research by Tosun et al (2004), optimization of machining parameters massively affected the cutting width and material removal rate (MRR) in wire electrical discharge operations. The experiments were carried out under different conditions: varying pulse duration, open circuit voltage, wire speed and dielectric flushing pressure. Machining parameters were determined through the use of Taguchi techniques. The amount of impact of the machining parameters on the cutting width and MRR were deciphered through the use of ANOVA (analysis of variance). Subsequently, the optimum conditions and parameters for machining were obtained based on analysis of signal-to-noise (S/N) ratio.

Furthermore, a recent research covered a lot of ground in determining the necessary machining parameters for performance indicators such as MRR, SF and cutting width (kerf) as a separate entity in the WEDM process (Mahapatra & Patniak 2006). They made use if the Taguchi's experimental design method to obtain optimum parameter combination of MRR, SF and also the minimization of cutting width. To optimize for all three criteria, the researchers formulated mathematical models using the non-linear regression method.

The use of a robust design optimization technique was developed for improvement of multiple characteristic problems (Tsui 1999). Robust design is used to enhance manufacturing and machining processes by making the response insensitive to variations that are uncontrollable (Tsui 1999).

Manocha et al (2004) deciphered the optimal setting of the process parameters on the electro-discharge machining (EDM) machine while experimenting and studying carbon-carbon composites. Some of the parameters that were taken into consideration include pulse current, gap voltage and pulse-on-time. The responses and outputs were expressed in the form of electrode wear rate (EWR) and MRR. To determine the optimal indication of the parameters, the research made use of experiments planned and executed using the Taguchi method. Subsequently, the finding was that the electrode wear rate decreases massively within the region where the study is being carried out and also when the parameters are expressed at the lowest level possible (Manocha et al 2004). In contrast, the parameters set at their maximum increased the MRR immensely.

A process of optimizing Wire-EDM process parameters depending on the use of Non-Dominated Sorting Genetic Algorithm in to obtain a non-dominated solution set (Shunmugam & Kuriakose 2005). This particular process of sorting makes use of a fitness assignment scheme which takes preference of non-dominated solutions and also employs a sharing strategy which helps to keep the solution diversified (Shunmugam & Kuriakose 2005). The engineer who is in charge of the process can choose whatever combination of cutting parameters he deems optimal by making use of the Pareto optimal solution set, depending on what is required by the experiment.

Kackar & Shoemaker (1986) opined that parameter design decreases the level of performance variation by reducing the impact of the sources of the variation instead of trying to control them. This makes it a very productive and a cost-effective method of improving engineering design and manufacturing.

Ozel & Karpat (2006) presented a technique to develop and effectively decipher optimization problems for multiple and varying aims which can be seen in hard turning processes. These processes can be viewed in a neural network modeling together with dynamic neighborhood particle swarm optimization technique (Ozel & Karpat 2006). Through the results they obtained from their research, they signified that the proposed swarm intelligent approach necessary to solve the multi-objective optimization problem with conflicting objectives is both efficient and extremely effective (Ozel & Karpat 2006). This method also provides intelligence in production planning for multi-parameter turning processes.

The extensive application of the Taguchi method proves that it one of the most reliable methods of optimization. Despite the popularity of this method, it has come under a lot of scrutiny by purists who claim that it depends a lot on statistical methods which is not a proper reflection of reality. However, the consensus is that the Taguchi loss function concept is of great value to the manufacturing industry.

Also, the offline experiments during the manufacturing stage is off immense consequence. The methodology has its core principle in engineering values. The process of decreasing the loss of quality by designing the process to be resistant to variations is of ultimate importance not only to statisticians but also to quality engineers.

2.2.2 General Algorithm Technique

Generic algorithms (GA) are based on natural selection and natural genetics. These processes are more robust and have a higher probability of locating the global optimum. The solution space initiates from a group of point rather than a single point (Aggarwal and Singh 2005). Genes are used to represent the cutting conditions by binary encoding to apply GA to the optimization of machining parameters. These sets of genes form chromosomes to such as crossover and mutation.

Crossover means exchanging some part of the chromosomes to generate a new offspring while mutation id applied after crossover so as to randomize the new chromosomes. To evaluate each individual or chromosome, the encoded conditions of cutting are used to predict machining performance (Aggarwal and Singh 2005). To obtain the optimum results of cutting conditions, compare the values of functions among all individuals after a number of iterations.

Jawahir & Wang (2004) employed this method for the optimization of cutting processes especially parameters of milling machines. This method be randomly selecting individuals in the full scope of variables. Individuals that are out of constraint have a fitness level of zero. This is how a constraint is implemented in a GA technique.

Sardinas et al (2006) presented the idea that a posteriori multi-objective optimization offers the highest number of information to help in making a decision on choosing cutting parameters in turning operations. Using the

Pareto graphics, multiple situations can be put into consideration while making the choice of the right parameter possible for any condition. They also presented a micro-GA which had the ability to get many evenly distributed point, so as to arrange the Pareto front at a lower cost of computation. With the use of cost analysis, one can complement the Pareto front information (Sardinas et al 2006). This helps in improving the process of making decisions during a manufacturing process. However, the model proposed by this research had to be expanded to cover more constraints such as the cutting surface temperature.

Abido et al showed the importance of generic algorithms for the stabilization of multi-machine power systems over a large variety of operating conditions (1999). This process makes use of single-setting power system stabilizers (PSS). The power system is represented as a finite series of plants. With the use of a generic algorithm, the problem of choosing the parameters of PSS that can stabilize all the plants at the same time can be transcribed and converted into a single problem of optimization (Abido et al 1999). This problem is then solved through the use of an Eigen-value base objective function.

2.2.3 Other important work on optimization

Davim & Conceicao (2001) proposed a methodology which places a lot of emphasis on the choice of optimized values for cutting conditions in a machining process including drilling and turning of aluminum matrix composites. Their research considered a hybrid technique on the basis of a search across a design environment by means of experimentation. Parameters like the machining forces, tool wear and surface finish are obtained by the means of a controlled experiment. Other machining parameters like the feed and cutting speed are predefined by the operator of the machine or the manufacturers. Analysis of the results obtained from the research show that the turning and drilling of composite material which consist primarily of composite materials with metal matrices using a PCD tool is perfectly compatible with the cutting conditions for cutting time of industrial interest (Davim & Conceicao 2001). This also is in consonance with the pre-determined optimal machining parameters. They referenced the significance of optimization of machining parameters which make use of experimental models which depend on generic algorithms in large scale industrial applications.

A few decades ago, a detailed research focused on the robust design of multi-machine Power System Stabilizers by making the use of Simulated Annealing (SA) optimization technique (Davim & Conceicao 2001). This technique employs SA to search for optimal parameter settings of a universally acceptable conventional fixed-structure lead-lag PSS (CPSS). The parameters of the suggested simulated annealing based PSS are optimized in such a way so as to shift the system electrochemical modes at varying loading conditions and system configurations at the same time to the left in the s-plane (Davim & Conceicao 2001). By using SA as an optimization technique devoid of derivatives in PSS design significantly reduces the computational burden. A massive upside to this method is the robustness to the initial settings.

Chen & Chen (2003) presented an adaptive particle swarm optimization (APSO) method to optimize the sequence of component placements on a PCB and the assignment of component types to feeders at the same time for a pick-and-place machine with more than on head. The APSO suggested in the paper makes use of three principles: head assignment algorithm, reel grouping optimization and adaptive particle swarm optimization. In terms of the distance covered by the placement head determined by the research, they concluded that APSO is not an inferior technique to the other popular optimization techniques. The obtained results make it possible to decrease the total assembly time of assignment sequencing time of the placements of component on the PCB board to a minimum.

Further research on this methodology focused on a simulated annealing algorithm for optimizing machining parameters in turning operation for work pieces with cylindrical contours (Kolahan and Abachizadeh 2008). Analysis of the results of this research showed that the proposed procedure for optimization of the turning operations cut down the cost of production by determining the optimum machining parameters.

Reddy et al (2003) talked about the perks of dry machining over wet machining by choosing the appropriate conditions and parameters of cutting tools and cutting geometry from the manufacturer. The process of optimization covered in their work, provides a chance for the user to choose the most appropriate too geometry and the fitting cutting condition in order to get the required surface quality (Reddy et al 2003). From the conclusions from their work, a huge emphasis has made it clear that proper selection of parameters helps to cancel out the use of cutting fluids during a machining process thereby making it more environmentally friendly.

Salminen et al (2006) expressed a method of minimizing the time allocated for the optimization and application execution in mapping an application on Multiprocessor System-On-Chip (MPSoC) using simulated annealing. This technique is a universally accepted algorithm for very complicated optimization problems like the distribution of MPSoCs. The new method suggested of automatically choosing parameters for a simulated annealing logarithm to conserve the effort put into the optimization process. This optimization method determines a proper annealing schedule and transition probabilities for simulated annealing. This makes the algorithm scalable according to the size of the application and platform.

Zhou et al (2006) presented particle swarm optimization (PSO) technique in training a multi-layer feed-forward neural network (MFNN) which is necessary for implementing a prediction model of error in diameter in boring machining. During the course of the experiment, it was determined that in comparison to the back propagation (BP) algorithm, the current algorithm brought forth a better machining precision with a lesser number of iterations (Zhou et al 2006). The results obtained from their work displayed that the networks for predicting diameter error trained by the PSO algorithm or by the BP algorithm both make the precision of the boring mechanism better. However, the neural networks rained by the PSO algorithm perform better than those trained by the BP algorithm.

Conclusion

Ultimately, despite the extensive research that has been carried out in this field of machining, there still remains a need for continuous work on introducing newer and better methods of the optimization of cutting processes under given constraints. There has been just little work done as regards the optimization of turning with pre-determined machining parameters and the constraints as the work piece rigidity and tool hardness. Hence, an attempt is being made to provide a predictive model that will lead to the optimization of cutting conditions to ensure maximum productivity.

CHAPTER 3
EXPERIMENTAL WORK

3.1 Introduction

The rapid advances in the manufacturing industry, especially in the machining industry has prompted an increased demand for automated processes which can massively reduce the cost of production while maximizing the productivity. To this effect, the need for a functioning model which can be implemented into a program for cutting seemed to be the reasonable decision to address this pressing need. This program will then be incorporated into CNC machines to optimize the machining and cutting parameters thereby increasing the productivity to a maximum level.

This chapter covers a holistic experimental research in turning in order to establish a relationship between the machining and cutting parameters and the material removal rate. This relationship is narrowed down to constraints introduced into the cutting process like work-holding and tool toughness. Also, this chapter outlines the setup of the experiment and also the problems encountered as well as the observations during the research.

3.2 Experimental Setup

In his work in determining the optimum condition for cutting operations especially in rough and finishing turning, Petty et al (1985) employed a search procedure focused on the depth/feed plane. The focus area of the feed/rate sector was narrowed down to a 20 by 20 grid as displayed in Fig.3.1. By evaluating all the points on the virtual grid for the established constraints, starting from the origin (point O), we could determine the different regions of feasibility.

The changing thickness of the blank was considered during the machining process as it progressed from stage to stage. By doing so, the optimum cutting conditions for each pass of the multiple pass turning was determined. The constraints used to estimate the force component was the equivalent chip thickness. This technique is only appropriate for the cutting force component but not the feed and radial force components. The optimum point can be found lose to the border of the different regions of feasibility. Hence, this reduces the amount of calculation needed

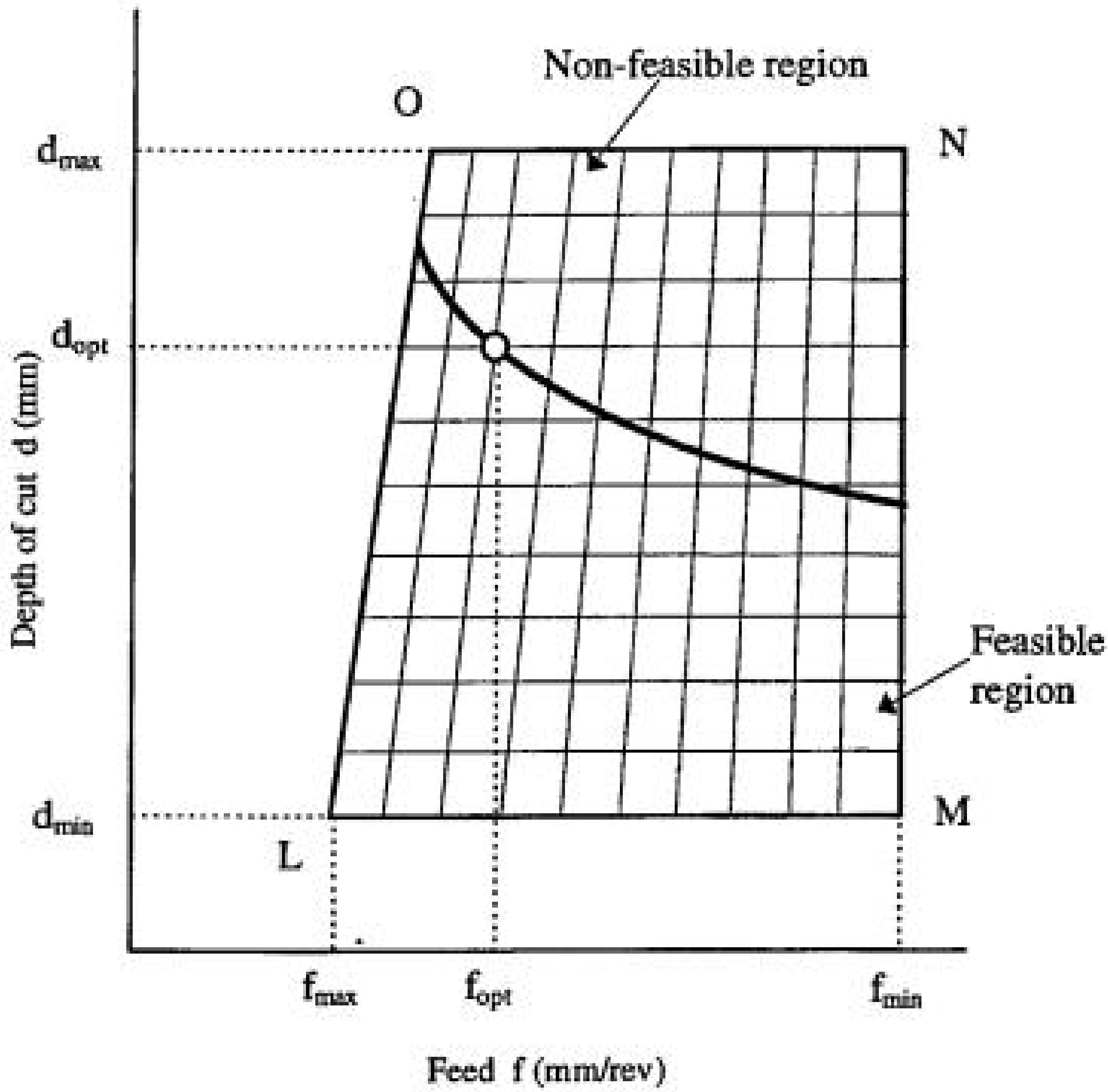

Figure 3.1 Sector showing d/f optimization plane (Petty et al, 1985).

3.3 Practical Application

While setting up the experiment a lot of factors were considered to achieve the expected result of optimization. Some of these factors include the machining conditions as well as internal and external constraints.

3.3.1 Blank and work piece material

3.3.1.1 Contour analysis and Tool-path generation

A close look at the desired contour from the in-process work piece helps in choosing a blank for the operation. Also, with the use of a CAM system, a toolpath for the turning operation was generated. This toolpath was also corrected to eliminated unnecessary rapid passes.

Also, during the process of generation the contour and toolpath for the turning operation, a blank was chosen. The choice of a blank to be used for this operation was aimed at reducing the amount of material to be removed. With the measurements in mind, a blank was chosen to match that which was generated in the CAM system. Since the manufacturing needed for this experiment is not a large production scale, the size of the blank will not affect the process massively. Nevertheless, the blank generated with consideration for minimum chip volume was selected. The material of the blank/work piece is Structural steel 1045 (AISI 1045).

Table 3.1 Chemical composition of AISI 1045

Element	C	Fe	Mn	P	S
Content	0.42 - 0.5 %	98.51 - 98.98 %	0.6 - 0.9 %	≤ 0.04 %	≤ 0.05 %

Table 3.2 Mechanical properties of AISI 1045

Mechanical Property	Value
Hardness, Brinell	163
Tensile Strength, Ultimate	565 MPa
Tensile Strength, Ultimate	310 MPa
Modulus of Elasticity (Typical for steel)	200 GPa
Poisson’s Ratio (Typical For Steel)	0.29
Shear Modulus (Typical for steel)	80 GPa

This material was chosen because of its ubiquity in many machining processes in the manufacturing industry.

3.3.2 Machining parameters

The choice of machining parameters is very important depending on the operation. Since it has been established that the operation is turning, the logical decision is the use of a lathe. Also, the need for an automated process helps to narrow the choice of lathes down to a CNC-based machine. The choice of the machine has to be guided by the measurements of the work piece as well as the power required to cut the blank. Therefore, proper analysis of the blank (work piece parameters), a HAAS lathe was chosen for this experiment.

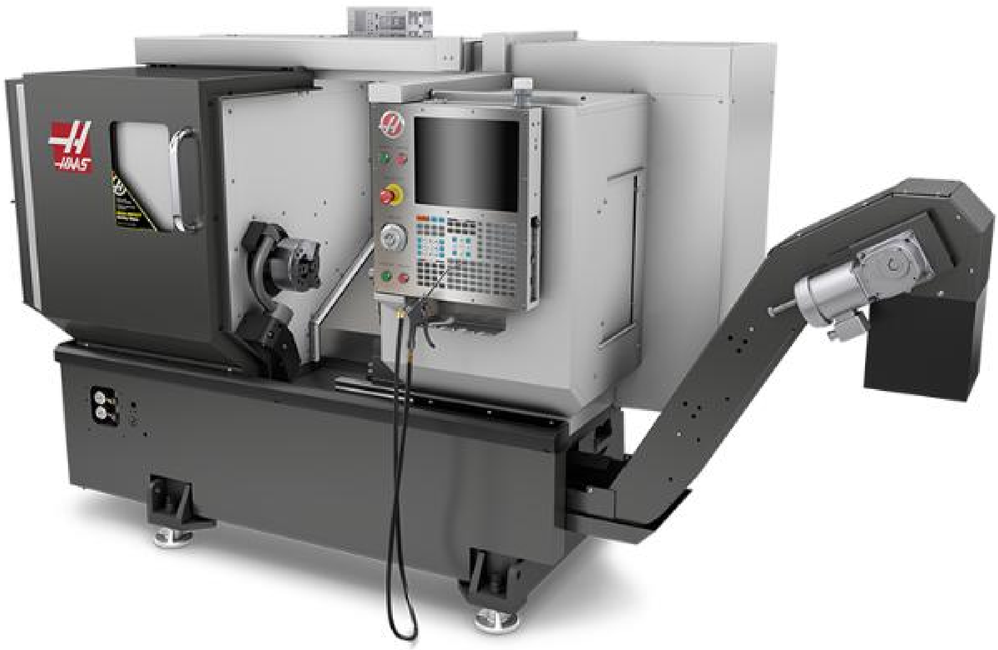

Figure 3.2 HAAS ST–10 lathe machine

Table 3.3 Characteristics of the HAAS ST–10 lathe

Max Part Diameter	419 mm		Chuck Size	165mm
Max Spindle Speed	6000 rpm		Full Load	3A
Weight	12 – Station		Spindle Power	11.2 kWatts
OD vs ID Tools	Any		Air Pressure Min	5.5 bar
Input AC Voltage	220-400 VAC		Bar Capacity	44 mm
Rapid feed on X	30.5 m/min		Rapid feed on Z	30.5 m/min

3.3.3 Cutting parameters

The cutting parameters for the turning operation have to be chosen from the standard recommendations of the companies providing the cutting tool. Also, you have to take into consideration the material of the work piece when choosing the cutting parameters. Since the material is **AISI 1045** steel, then we have to choose a cutting tool that is most adapted to machining this type of steel. Other variables like the radius of the insert and other geometric parameters are chosen from the catalogue (Sandvik 2019). The cutting tool chosen is Sandvik **CP-25BR-2020-11**. The cutting tool insert chosen is **CP-B1108-M5 4325**.

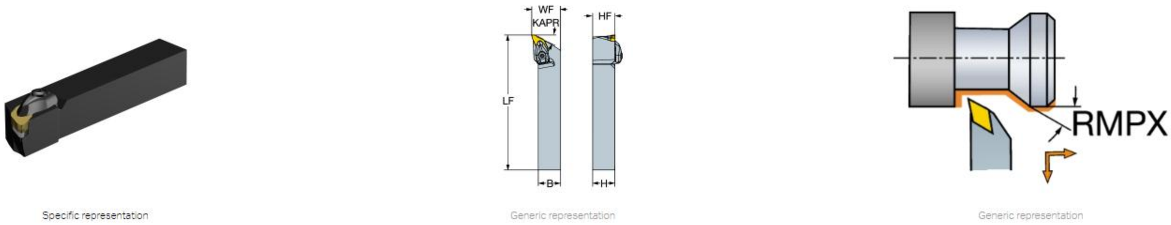

Figure 3.3 Cutting tool for the turning operation

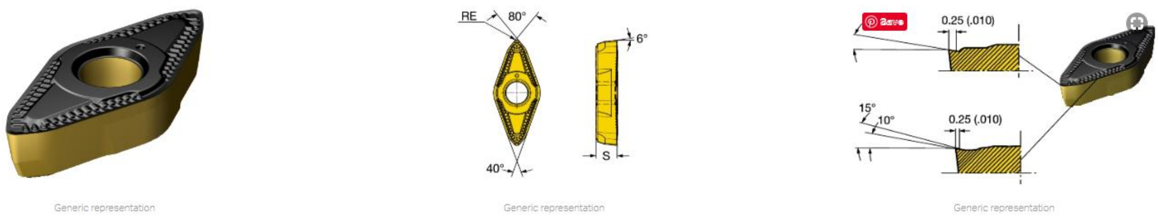

Figure 3.4 Cutting tool insert for the turning operation

Table 3.4 Characteristics of the cutting tool

Characteristic	Value
Edge Angle	95°
Shank Height	20mm
Shank Width	20mm
Functional length	125mm
Max Ramping angle	23°
Tool Lead Angle	-5°
Overhang	37.88- 40 mm

Table 3.5 Characteristics of the cutting tool insert

Characteristic	Value
Inscribed circle Diameter	11mm
Corner radius	0.794 mm
Insert Thickness	5 mm
Clearance Angle Major	6°
V_c – Recommended Cutting Speed	$380\, m/min$

3.3.4 Work-holding fixtures

The essence of a firm work holding fixture is to ensure the rigidity and stiffness of the work piece and to reduce the effects of external factors like chatter. The fundamental work-holding fixture for holding cylindrical work pieces on a lathe is the chuck. A standard **3-jaw chuck** was chosen for this setup because of its availability and economic advantage over a 4-jaw chuck. A dead center was also attached to the other end of the lathe to increase the rigidity of the work piece. This reduces the deviations in the geometry as far as positioning is concerned

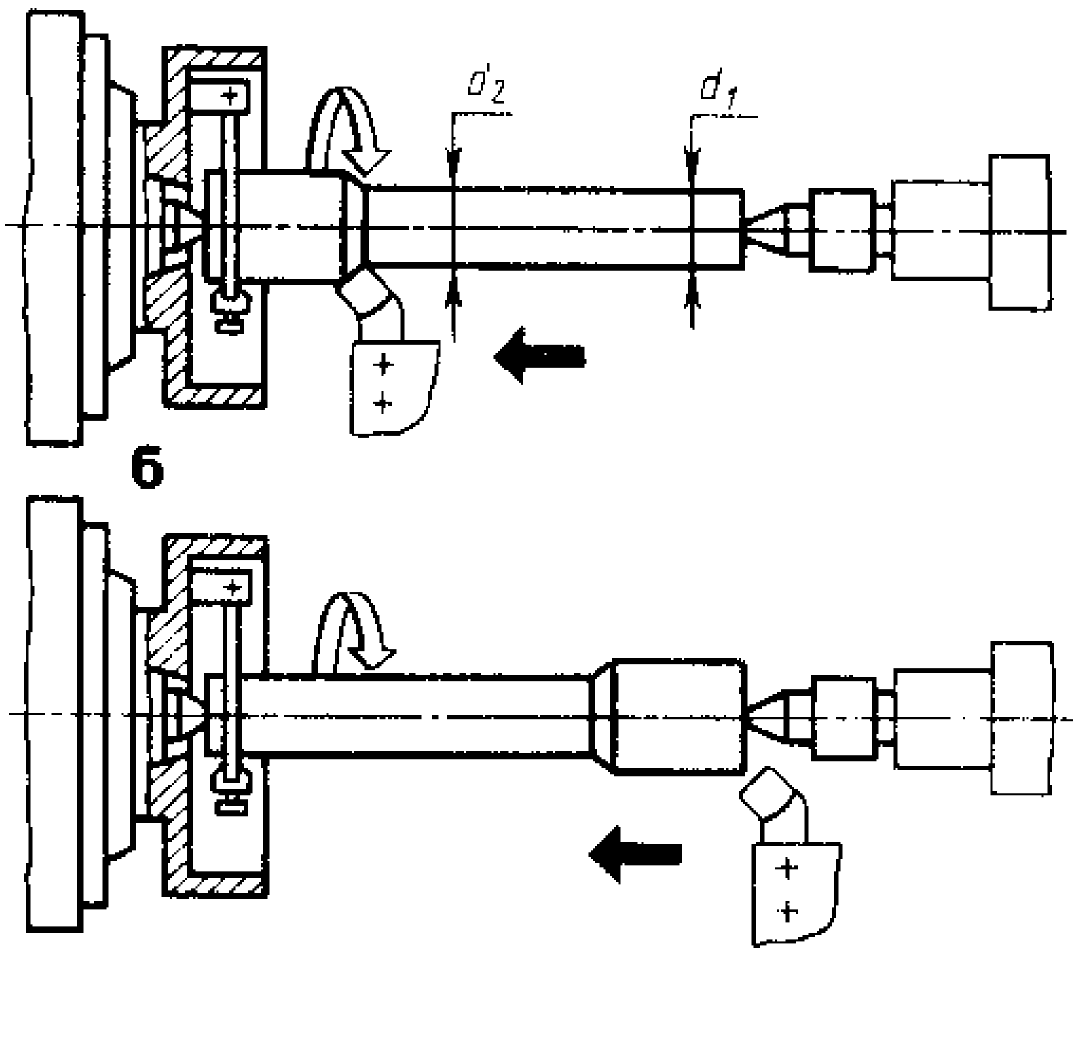

Figure 3.5 Work-Holding Fixture on a lathe

3.3.5 Constraints

All the constraints in the experiment are expressed in the form of an inequality. The constraints are applied so as to give an acceptable range of values for the turning operation. Some of these constraints include minimum and maximum spindle speed, minimum and maximum longitudinal feed, maximum cutting force and a lot of other cutting parameters.

Some of the other internal constraints considered include the displacement of the work piece as a result of the external forces of cutting. The displacement of the work piece is a direct consequence of the cutting force and the clamping mechanism in use. The second constraint is the stiffness and toughness of the cutting tool and other geometric parameters.

Spindle Speed Constraint	$s_{min} \leq s \leq s_{max}$	(3.1)
Longitudinal Feed Constraint	$n_{min} \leq n \leq n_{max}$	(3.2)

3.4 Methodology / Procedure

In this particular experiment, the cutting parameters like the cutting speed and the feed were kept constant while the depth of cut continued increasing. The effect of the coolant was neglected in this experiment and also the increase in temperature of the entire machining process.

A number of experiments were carried and the results were recorded. A total of 10 experiments for the work piece using the chosen cutting tool. 10 levels of depth of cut were chosen with increments of 1 mm for individual passes. The minimum and maximum spindle speeds were set according to the recommendations of the cutting tool manufacturers (Sandvik).

After the completion of the first 10 passes, the work piece is unclamped from the chuck and the measurements of the remaining work piece are taken to coincide with the predictions of the CAM system.

Table 3.6 Coefficients for cutting force and tool

Coefficients and exponents For cutting force				Coefficient and exponents for Tool stiffness				
C_{pz}	x_{pz}	y_{pz}	k_{pz}	C_v	x_v	y_v	k_v	m
2000	0.80	0.75	0.96	385	0.18	0.27	0.85	0.23

Table 3.7 Input data for machining parameters

Machining parameters						Cutting conditions			Cutting tool		
N, (kWatts)	P, (N)	n_{min} (rev/min)	n_{max} (rev/min)	f_{min} (mm/rev)	f_{max} (mm/rev)	T, (min)	Rz, (mkm)	D, (mm)	φ°	φ1°	r, (mm)
6	2600	196	2800	0.07	1.2	100	5	80	40	60	0.5

Conclusion

With the help of these results obtained from the experiment a proper analysis is performed to ascertain the optimum cutting conditions for the turning operation. The use of the developed model makes the calculation of the cutting values. The next chapter reviews the development of this model and the modelling techniques.

CHAPTER 4
MATHEMATICAL MODEL FOR TURNING OPERATIONS

4.1 Introduction

With the current demand on the optimization of production in the manufacturing industry, there is an increased necessity for providing a model for predicting the performance machines. This model is then used as a means of calculating the productivity and production cost.

The aspect of performance of the machine which is discussed in this chapter is both a technological and commercial aspect. This is expressed as the material removal rate of the turning operation. MRR has a direct correlation with the main operational conditions like the feed and speed. So, with the use of empirical equations a model for this machining performance can be effectively developed.

Figure 4.1 Major factors influencing machining performance (Da et al., 1997).

4.2 Development of a working model

First of all, it is imperative to develop a function which will express the maximum productivity as a product of the spindle speed and the feed of the lathe machine. This function will also gradually tend to its maximum value at the same time.

$$Q = nf \rightarrow max \qquad (4.1)$$

Where f = Feed; n = Spindle speed

The productivity function expressed in 4.1 is only effective if the time

$$t_c = \frac{L}{nf} \rightarrow min \qquad (4.2)$$

Where L = Cutting Length

equation in 4.2 is tending to minimum.

The above expressions in 4.1 and 4.2 form the basis of the optimization process in which the productivity increases and the time of cutting decreases. Here in lies the central idea of the development of the model.

4.2.1 Expression of the productivity function as a factor of cutting speed

In order to establish a relationship between the cutting speed and Q, it is imperative to express the cutting speed as a function of the tool life. This tool life equation is then compared arithmetically to the equivalent in order to establish an nf- relationship for the operation.

Cutting speed/velocity $$V = \frac{\pi D n}{1000}$$ (4.3)

where D = Diameter of work piece

Also, $$V = \frac{C_v k_v}{T^m H^{x_v} f^{y_v}}$$ (4.4)

where C_v, k_p, x_p, y_p, m – coefficients and exponents based on cutting force

H = Depth of cut; T = Tool life; f = feed

Combining 4.3 and 4.4, $$n f^{yv} = \frac{318 C_v k_v}{D H^{x_v} T^m}$$ (4.5)

Through simple algebra and the knowledge of basic empirical relationships between the cutting and machining parameters, we obtain the nf - relationship of as a function of the cutting speed.

4.2.2 Expression of the productivity function as a factor of cutting power

In order to establish a relationship between the cutting power (N_c) of the lathe machine and Q, it is imperative to express the cutting power as a function of the cutting speed. This tool life equation is then compared arithmetically to the equivalent in order to establish an nf relationship.

Cutting power, $$N_c = \frac{P_z \pi D n}{1000 * 6 * 10^4} \quad (4.6)$$

Also, $$N_m \eta \geq \frac{C_p H^{x_p} f^{y_p} k_p \pi D n}{6 * 10^7} \quad (4.7)$$

Since $N_c = N_m \eta$, we combine the two equations 4.7 and 4.6 to obtain the empirical relationship via the nf- function.

We obtain, $$n f^{y_p} \leq \frac{1.91 * 10^7 N_m \eta}{C_p H^{x_p} k_p \pi D} \quad (4.8)$$

Where N_m = Effective power of lathe in kiloWatts; C_p, k_p, x_p, y_p – coefficients and exponents based on cutting force.

4.3 Establishing the machining constraints

Constraints help in narrowing the scope of the values and the cutting parameters to a specific interval which is needed for the turning operation. These constraints are established on some of the necessary cutting parameters as a control method for the experiment.

4.3.1 Spindle speed and feed constraints

To calculate the feed as a result of the maximum cutting force generated by the transmission used in the lathe, you need to establish an

Acceptable feed interval,

$$[f_P] = \left(\frac{2P_t}{C_p k_p H^{x_p}}\right)^{\frac{1}{Y_p}} \quad (4.9)$$

empirical relationship between the cutting conditions.

To obtain the acceptable interval for the feed, we choose the minimum between the feed based on the cutting force or feed based on the tool le of the

Feed interval,

$$f \leq \min([f_P],[f_l]) \quad (4.10)$$

instrument.

$$f = [f_{min}, f_{max}] \quad (4.11)$$

After establishing the minimum value for the feed, we obtained

Spindle speed interval

$$n = [n_{min}, n_{max}] \quad (4.12)$$

Since the feed and spindle feed are inversely proportional according to 4.1

4.3.2 Work piece holding constraints

The standard clamping method used in this experiment is the chuck and the dead center. A proper analysis of the force system gives an insight into the rigidity of the work piece and the deformation.

First of all, the setup should be considered to be absolutely rigid. By doing this, we can assume that the deformation in the system at the start of the experiment. Then, we consider the entire work holding set-up as a single mass system.

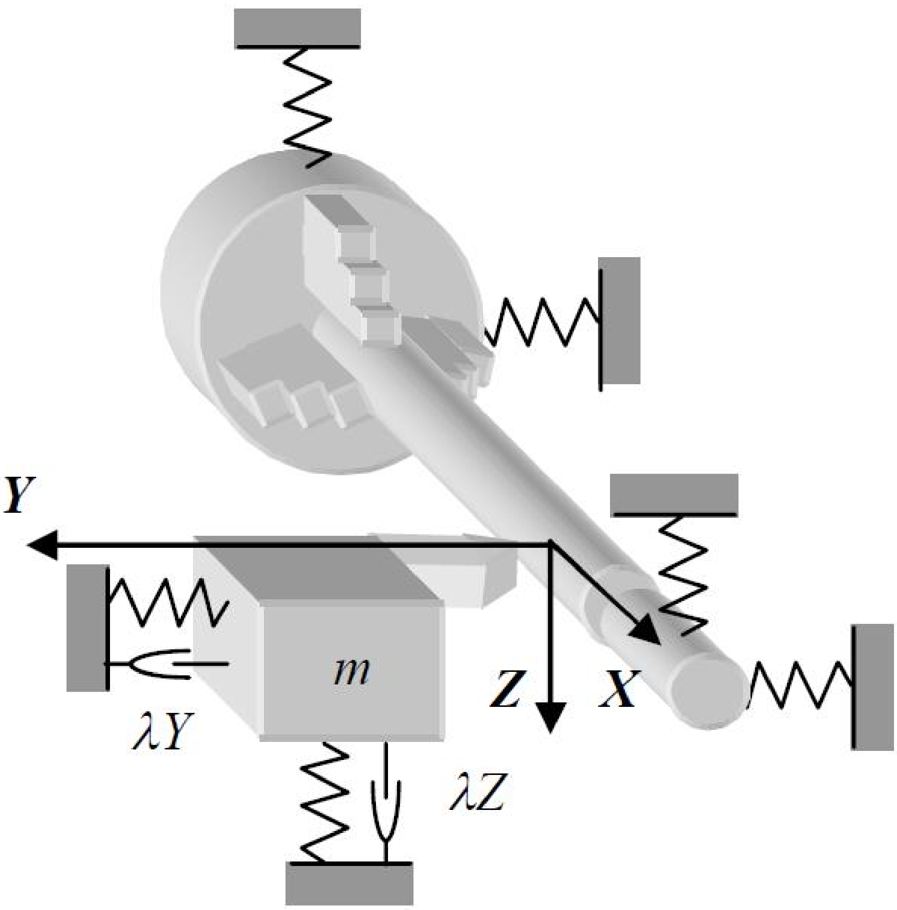

Figure 4.3 Work holding setup as a single mass system

4.3.2.1 Clamping with the chuck

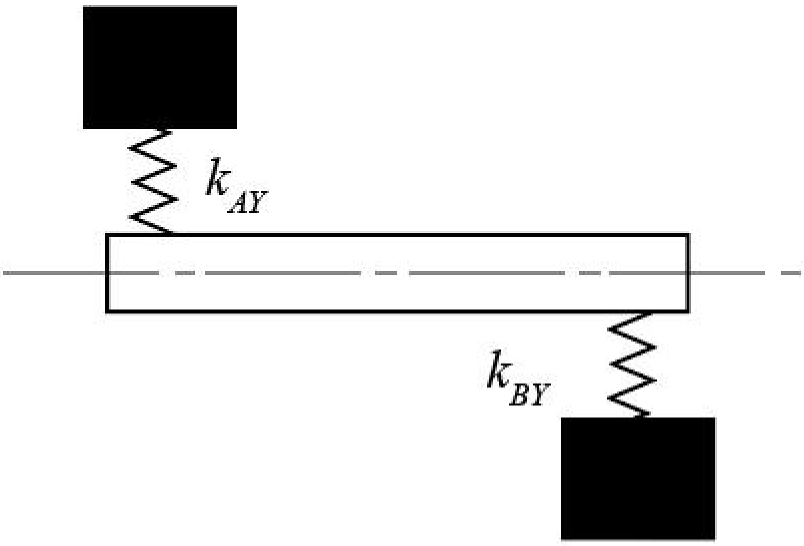

Figure 4.4 Force system for clamping with a chuck

This mass system is a closed mass system with a rigid body. Therefore, it can be evaluated based on the forces acting on it. To properly, evaluate this system, we need to establish the stiffness-compliance relationship and regard

Since compliance, $$c = \frac{1}{k} \tag{4.13}$$

the system as a spring.

We obtain, $$c_{s1} - \frac{1}{k_{Ay}} + \frac{1}{k_{By}} - \frac{k_{By} + k_{Ay}}{k_{By}k_{Ay}} \tag{4.14}$$

Where $k_{Ay}, k_{By} = \text{stiffness } (Y - \text{coordinate})$

{A – spindle, B – Rest}

where *k* is the stiffness.

Also, by considering the compliance of the work piece as an elastic mass system we obtain the new equation for the compliance from the equation

We obtain, $$c_w = \frac{L^3}{3EI} \tag{4.15}$$

where

$E = \text{Young's Modulus},\ I = \text{Moment of Inertia}, L =$

$\text{Length of workpiece(by coordinates)}$

of a **cantilever beam**:

We obtain,

$$c_{Y1} = c_s + c_w = \frac{k_{By} + k_{Ay}}{k_{By}k_{Ay}} + \frac{L^3}{3EI} = \frac{3EI\left(k_{By} + k_{Ay}\right) + k_{By}k_{Ay}L^3}{3EIk_{By}k_{Ay}} \tag{4.16}$$

By combining the two equations for the compliance of the single-mass system

Accordingly, we obtain the equation for the stiffness of the entire

Thus,

$$k_{Y1} = \frac{1}{c_{Y1}} = \frac{3EIk_{By}k_{Ay}}{3EI\left(k_{By} + k_{Ay}\right) + k_{By}k_{Ay}L^3} \tag{4.17}$$

system by applying the principle in equation 4.13:

This is the equation for the stiffness compliance relationship in the single mass system expressed in Figure 4.3.

4.3.2.2 Clamping with the chuck and dead center

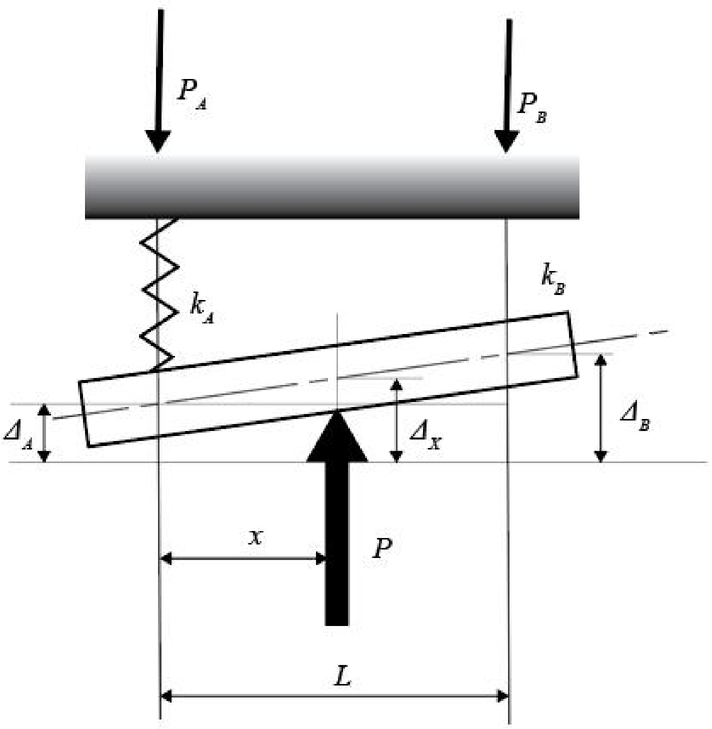

Figure 4.5 Force system for clamping with a chuck and dead center

For this clamping set up, we used the same procedure as in the previous example. However, since we have used the stiffness-compliance relationship to resolve the first single-mass system while ignoring the maximum deflection, we will do the opposite in this case.

First of all, we continue once again by evaluating the forces affecting the single-mass system show in Figure 4.5. By expressing the force at both

We obtain,

$$P_A = \frac{P(L-x)}{L}, P_B = \frac{Px}{L} \quad (4.18)$$

{A – spindle, B - fastening}

ends as a factor of the reaction force:

By doing simple algebraic substitution:

We obtain the maximum deflection,

$$\Delta_A = \frac{P_A}{k_A}, \Delta_B = \frac{P_B}{k_B} \tag{4.19}$$

In order to obtain the deflection of the system at a given coordinate

We obtain,

$$\Delta_x = \frac{\Delta_B + (\Delta_B - \Delta_A)x}{L} \tag{4.20}$$

(specifically on X-coordinate),

After substitution and other basic algebraic transformations, we

$$\Delta_x = \frac{P_A}{k_A}\left(1 - \frac{x}{L}\right) + \frac{P_B x}{k_B L} = \frac{P(L-x)^2}{k_A L^2} + \frac{P x^2}{k_B L^2} \leq 0.05 \tag{4.21}$$

obtained a formula for the deflection of the single mass system.

If the deflection of the system is over 0.05, then the rigidity of the system needs to be increased.

From equation (4.21), we the calculated the stiffness of the single-mass

$$k_x = \frac{P}{\Delta_x} = \frac{k_A k_B L^2}{k_A x^2 + k_B (L-x)^2} \tag{4.22}$$

system using Hook's law:

Eventually, we considered **compliance of the rest (k_r)** by using the same approach for the system 1:

We obtain,

$$c_{s2} = \frac{1}{k_r} + \frac{1}{k_x} = \frac{k_r k_A x^2 + k_r k_B (L - x)^2 + k_A k_B L^2}{k_r k_A k_B L^2} \qquad (4.23)$$

Also, by considering the compliance of the work piece as an elastic mass system we obtain the new equation for the compliance from the equation

We obtain,

$$c_{w2} = \frac{x^2 (L - x)^2}{3EI * L} \qquad (4.24)$$

where

$E = \text{Young's Modulus},\ I = \text{Moment of Inertia}, L =$

$\text{Length of workpiece(by coordinates)}$

of a **supported beam**:

By combining the two equations for the compliance of the single-mass system

We obtain,

$$c_{Y2} = \frac{3EI\left[k_{ry} k_{By} k_{Ay} L x^2 (L - x)^2 + k_{Ay} k_{By} L^2 + k_{ry} k_{By} (L - x)^2 + k_{ry} k_{Ay} x^2\right]}{3EI k_{By} k_{Ay} k_{ry} L^2} \qquad (4.25)$$

and immediately specifying the coordinate Y

Since we know that the compliance of the system is the inverse of the stiffness and through the use of simple arithmetic transformations and substitutions, we simplify the equation.

Hence from 4.23,

$$k_{Y2} = \frac{3EIk_{ry}k_{By}k_{Ay}L^3}{b_1 + b_2 + b_3 + b_4} \tag{4.26}$$

Where $b_1 = k_{ry}k_{By}(L-x)^2, b_2 = k_{ry}k_{Ay}x^2, b_3 = k_{Ay}k_{By}L^2,$

$b_4 = k_{ry}k_{By}k_{Ay}Lx^2(L-x)^2$

To obtain the stiffness of both of the conditions of clamping along the Z-

$$k_{z1} = \frac{3EIk_{Bz}k_{Az}}{3EI\,(k_{Bz} + k_{Az}) + k_{Bz}k_{Az}L^3} \tag{4.27}$$

$$k_{z2} = \frac{3EIk_{rz}k_{Bz}k_{Az}L^3}{b_1 + b_2 + b_3 + b_4} \tag{4.28}$$

Where $b_1 = k_{rz}k_{Bz}(L-x)^2, b_2 = k_{rz}k_{Az}x^2, b_3 = k_{Az}k_{Bz}L^2,$

$b_4 = k_{rz}k_{Bz}k_{Az}Lx^2(L-x)^2$

coordinate, the indexes were changed.

4.3.3 Cutting tool constraints

During the machining process, the tool changes its original form as a result of material loss. This change is called tool wear. Due to this deformation, the cutting efficiency of the tool decreases, thereby reducing the quality of the finished surface of the work piece. Tool wear comes in different forms including diffusion wear, adhesive wear, chemical wear, hard particle wear, and fracture wear. Since tool fracture is the most destructive of all the forms of tool wear, this form of tool wear is evaluated.

To avoid the fracture of the cutting tool, a lot of factors need to be taken into consideration:

- Surface roughness – the cutting tool should be chosen according to the material of the work piece and the nature of the surface. The higher the surface roughness (Ra), the more susceptible to fracture the tool. This is as a result of high friction.
- The cutting force – this is the force the cutting tool exerts on the work piece during the cutting process. If the cutting force exceeds the permissible value, the chances of the cutting tool to fracture increases exponentially. This is the reason why there is a necessity for a constraint on the cutting force.

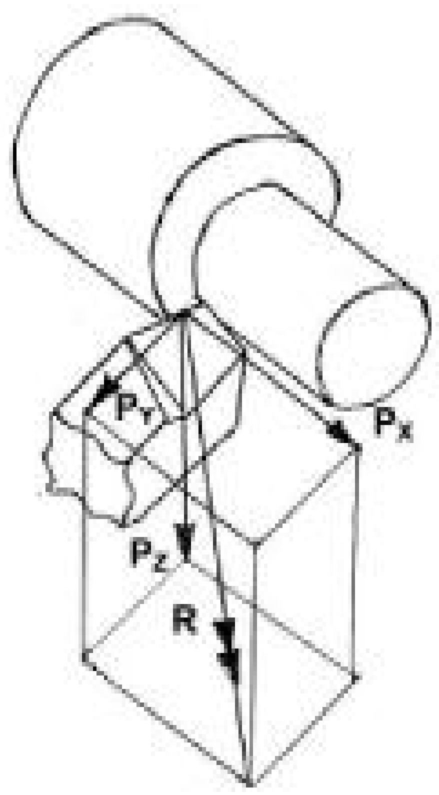

Figure 4.6 Cutting force components

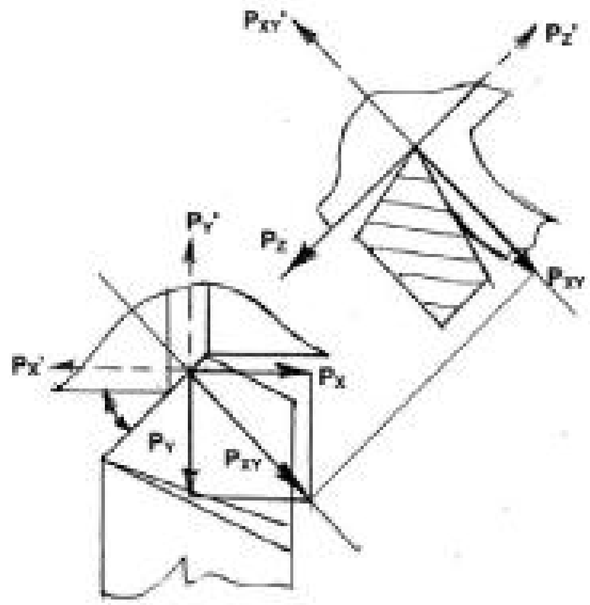

Figure 4.7 Expression of the cutting force into individual components

P_x = Axial force along X: This force is insignificant in turning operations.

P_y = Radial force along Y: This force causes vibration and inaccuracy.

P_z = Tangential force along Z: This is the main cutting force which determines the cutting power.

Resultant force,

$$R = \overline{P_z} + \overline{P_{xy}} \qquad (4.29)$$

Tool holder toughness constraint

To determine the constraints of the toughness of the tool-holder, we

Permissible stress, (4.30)

$$\frac{P_Z L_O}{Z_{zz} 10^{-7}} + \frac{P_X L_O}{Z_{xx} 10^{-7}} \leq F_a$$

Where L_O = Tool overhang, Z = Section Modulus

Section modulus for P_Z and P_X

$$Z_{zz} = \frac{BH^2}{6};\ Z_{XX} = \frac{B^2 H}{6} \tag{4.31}$$

Where B = Width of cutting tool; H = Height of cutting tool

examine the tool as beam with loads at the ends. We obtain:

Bending Moment,

$$M \leq \frac{Z_s \sigma_u}{SoF} \tag{4.30}$$

Where σ_u = bending stress, Z_s = Section Modulus, SoF = Safety factor

Substituting from

(4.6) and (4.7) $\quad P_z = C_p H^{x_p} f^{y_p} k_p \pi D n$ (4.31)

Also, (4.32)

$$M = P_z L_O \, ; \; Z_s = \frac{BH^2}{6};$$

By establishing the nf- relationship for this constraint in the turning operation

$$nf^{y_p} \leq \frac{Z_s \sigma_u * 10^3}{C_p H^{x_p} k_p \pi D L_O} \tag{4.33}$$

Where B = Width of cutting tool; H = Height of cutting tool

Tool insert toughness constraint

To determine the constraints of the toughness of the tool insert, we

Constraint on insert,

$$P_z \leq 34c^{1.35} H^{0.77} \left(\frac{\sin 60^\circ}{\sin\varphi}\right)^{0.8} \tag{4.34}$$

Where c = Thickness of insert; φ = Rake angle

examine the cutting force:

By establishing the f- relationship for this constraint in the turning operation

We obtain the f- relationship for constraint on insert,

$$f^{y_p} \leq \frac{34c^{1.35}\left(\frac{\sin 60^\circ}{\sin\varphi}\right)^{0.8}}{C_p H^{(x_p-0.77)} k_p} \tag{4.35}$$

Where c = Thickness of insert; φ = Rake angle

and substituting for P_Z:

Tool Stiffness constraint

To determine the constraints of the stiffness of the tool under the influence of the cutting force, we examine the cutting force in relation to the sag (S):

Cutting for via Sag,

$$P_Z \leq \frac{3SEI}{L^3} \tag{4.36}$$

where E = Young's Modulus, I = Moment of Inertia;

I (for circular section) = $0.05D^2$; I (for rectangular section) = $\frac{BH^3}{12}$

S = 0.1 mm (rough turning) and S = 0.05 mm (finishing); L = Length of cutting tool

Since the permissible values for the Sag is given, we get an equation by simple arithmetic substitution:

Constraint on insert,

$$S \leq \frac{P_Z L^3}{3EI} \approx 0.1mm \tag{4.37}$$

Where c = Thickness of insert; φ = Rake angle

4.4 Validation of Results

The experiment was conducted on a HAAS ST-10 lathe suing a 3-jaw chuck. The cutting tool CP-25BR-2020-11 was fitted with a CP-B1108-M5 4325 insert. The material of the work piece was AISI 1045.

With the constraints perfectly established, the experiment was conducted meticulously to obtain the results in Table 4.1.

$$H * f = \boldsymbol{MRR}\ (mm2/min) \tag{4.38}$$

Table 4.1 Experimental Results

№	**H, (mm)**	**n_{opt}, (rpm)**	**f_{rev}, (mm/rev)**	**N_{cut}, (kWatts)**	**P_z, (N)**	**f_{opt}, (mm/min)**	**H*f = MRR (mm^2/min)**
1	1.0	560	0.480	2.60	1107.2	268.80	**268.80**
2	2.0	490	0.480	3.96	1927.8	235.20	**470.40**
3	3.0	392	0.484	4.41	2683.1	189.73	**569.18**
4	4.0	322	0.484	4.56	3377.4	155.85	**623.39**
5	5.0	280	0.480	4.71	4012.4	134.40	**672.00**
6	6.0	238	0.476	4.60	4613.5	113.29	**679.73**
7	**7.0**	**210**	**0.472**	**4.56**	**5186.0**	**99.12**	**693.84**
8	8.0	210	0.412	4.58	5211.3	86.52	**692.16**
9	9.0	210	0.364	4.59	5218.2	76.44	**687.96**
10	10.0	210	0.324	4.58	5202.5	68.04	**680.40**
11	11.0	210	0.292	4.57	5193.4	61.32	**674.52**
12	12.0	210	0.268	4.59	5220.9	56.28	**675.36**

Graphs and other results

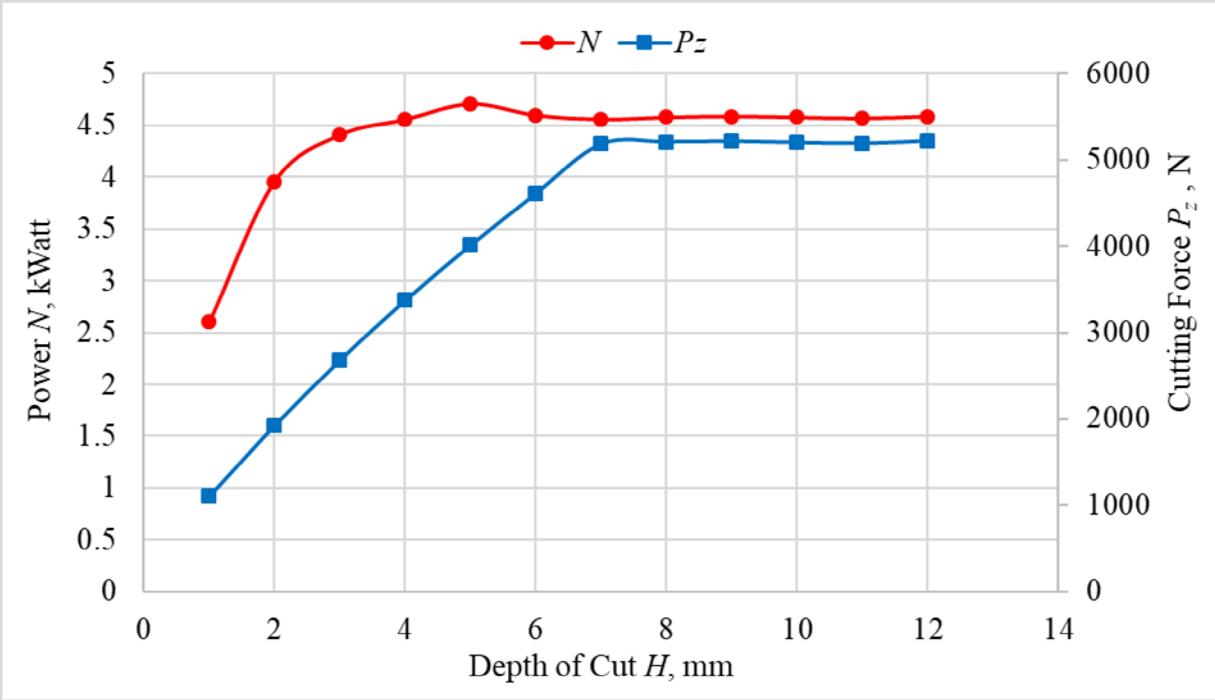

Figure 4.8 Relationship of depth of cut to cutting power and cutting force

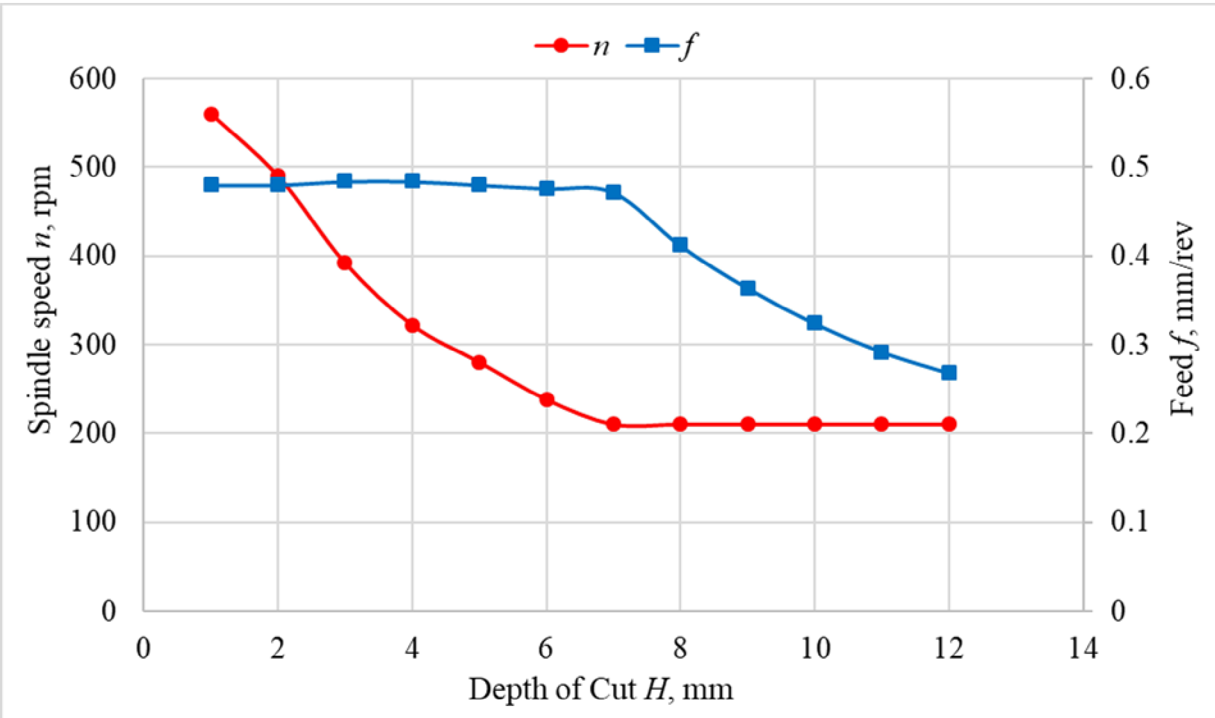

Figure 4.9 Relationship of depth of cut to Spindle speed and feed

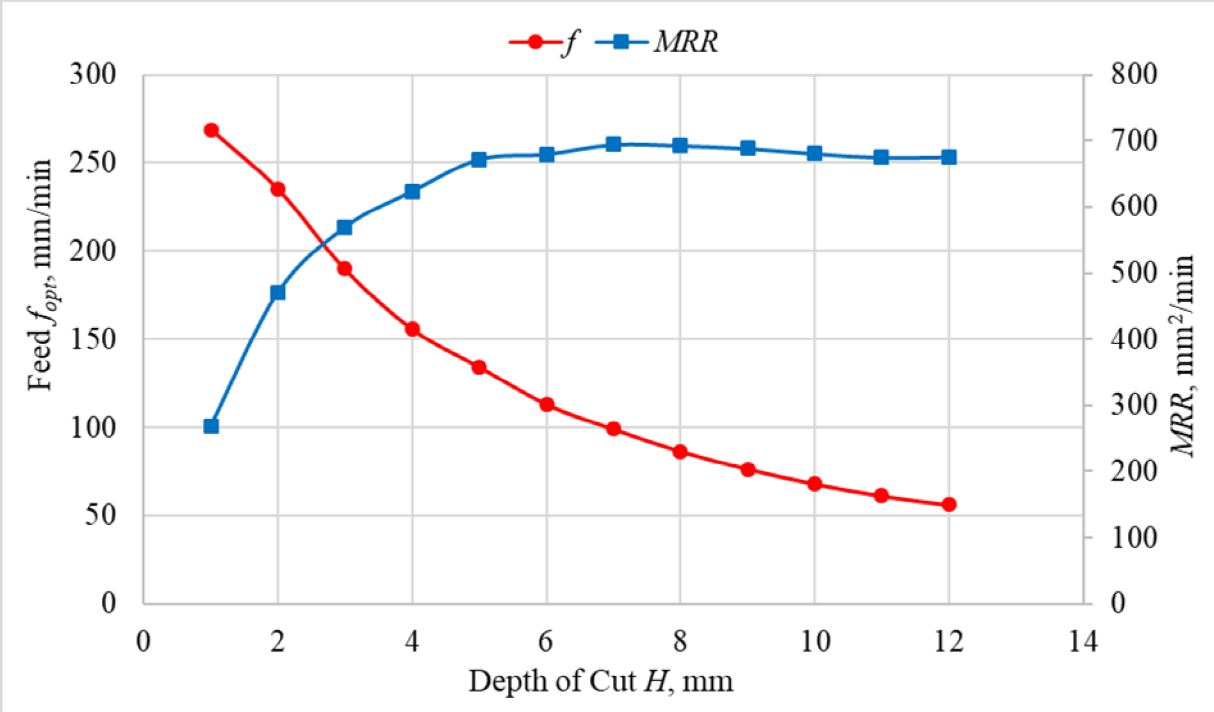

Figure 4.10 Relationship of depth of cut to feed and MRR

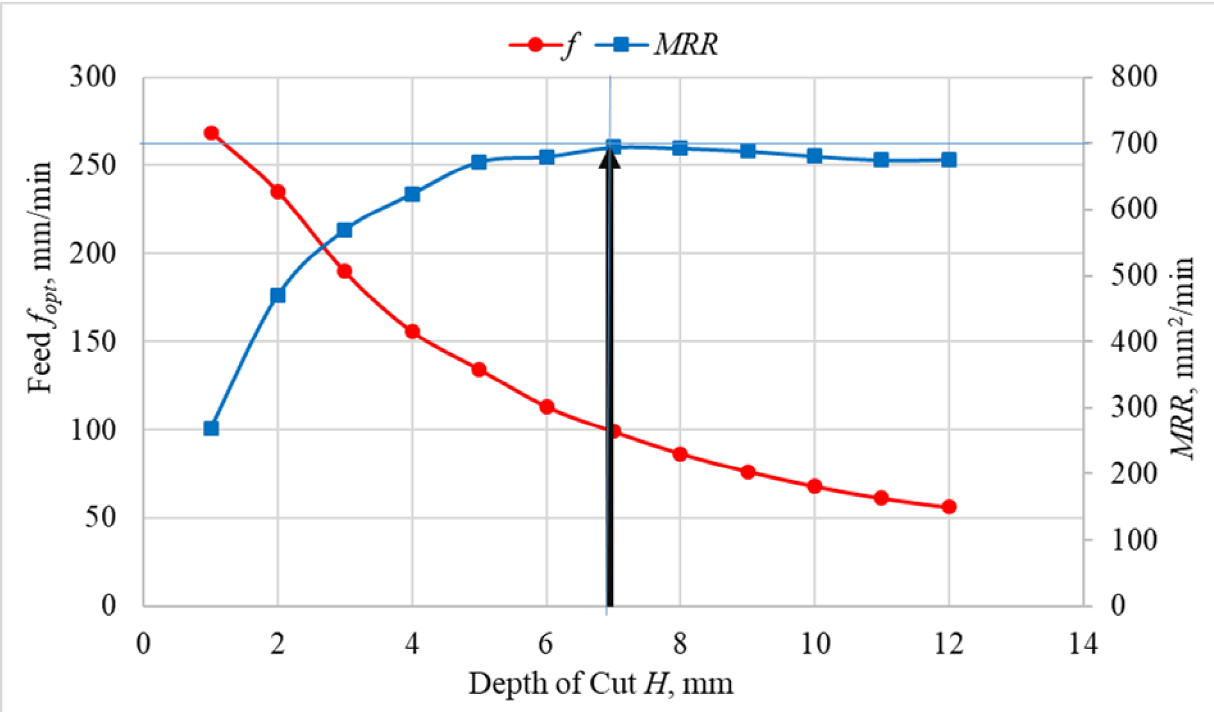

Figure 4.11 Relationship of depth of cut to MRR

Table 4.2 Summary of graph results

Depth of cut = 7mm	**MRR = Maximum**

Conclusions

From the result obtained, the graphs were plotted. Then in order to determine the optimum cutting conditions, we analyze the graphs meticulously.

In Figure 4.8, a graph showing the relationship between the depth of cut *H* and the cutting power *N* and cutting force *Pz* is posted. As the depth of cut increases there is a sharp increase in both the power and force. After both values peak, the values for both parameters gradually stop changing.

In Figure 4.9, a graph showing the relationship between the depth of cut *H* and the spindle feed *f* and speed *n* is posted. As the depth of cut increases there is a sharp downward spike in the spindle speed. After a point, the values for this parameter gradually stabilizes. For the spindle feed, the values are stable up to the point of optimum at which a massive dip occurs.

In Figure 4.10 and 4.11, a graph showing the relationship between the depth of cut *H* and feed *f* and material removal rate *MRR* is shown. As the depth of cut increases the feed values decrease sharply. After the values peak, the parameters gradually stop changing. The opposite can be said for the feed.

However, since all the values meet at an inflexion point which is at a depth of cut of approximately 7 mm, this is the point of optimum productivity for this operation.

CHAPTER 5

DEVELOPMENT OF A PROGRAM FOR OPTIMIZATION OF TURNING OPERATIONS

5.1 Introduction

A startup is an unregistered company that is still in the developmental stages. Most startups are based on the creation of innovative ideas mostly focused on recent technology.

A major reason for developing a startup is the promotion and investment of large corporations in modern technical innovations. This is a way for the big companies to cope with the fast-pace developments in marketplace. By using startups, these companies can stay in pace with the modern developments while saving money on introducing new ones. Because of these reasons mentioned above, the viability of startups continues to increase in the modern day.

The first step to making a viable startup is by coming up with an innovative idea. Once you come up with a unique idea, you just have to create a plan of execution. This plan is referred to as the **startup plan**. When you plan is in place, the startup can now be appraised for a commercial value. The commercial value depends on the uniqueness of the idea. Another factor that plays a role is the market demand for the product you are proposing. Sometimes, a new idea might not necessarily be the most benefitting.

In the situation of Ukraine in this present day, a lot of companies are investing in youth. These companies provide different training services and motivation to young entrepreneurs all over the country. This practice is of massive benefit to both the youth as well as the companies involved. Also, the companies field the massive financial implications of developing an idea when they deem it viable in the market place. Judging from the poor credit situation in the country as well as the pressures from other economic giants, young entrepreneurs can benefit a lot from the support of these corporations

5.2 Program for optimization of turning

Subsequently, the necessity of an automated program that will perform the task of optimization becomes quite obvious. The reason for this necessity is the fact that modern manufacturing processes make use of automated machines which help in maximizing productivity while reducing the cost of production as well as the time spent on a given operation.

To this effect, a computer program was created to work in unison with the lathe operator in maximizing the productivity of the process.

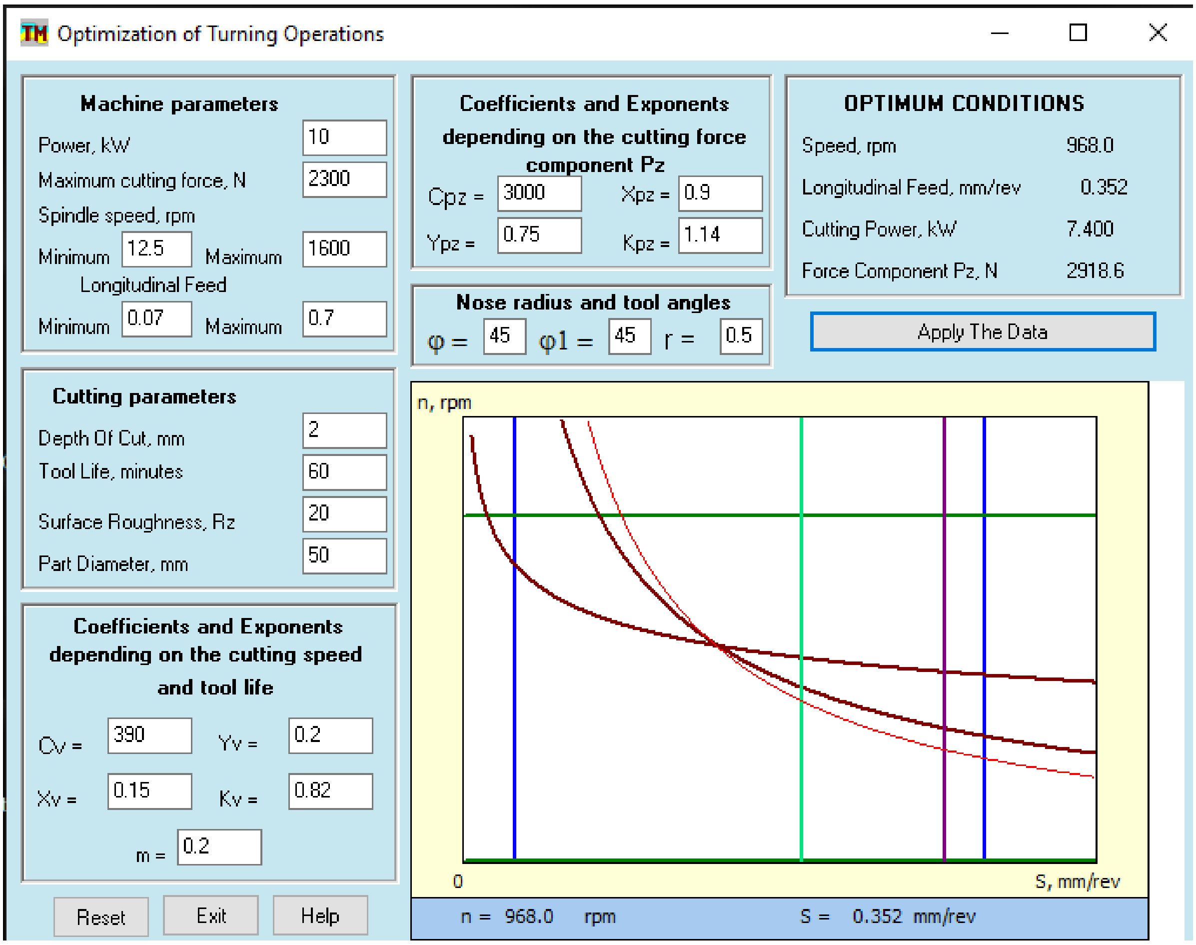

Figure 5.1 Computer program for optimizing turning operations

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5.2.1 How the program works

The program was written using **Embarcadero Rad Studio 10 Seattle.** This builder is based on a program which is a versatile and efficient, and reliable programming language. This program will run on any machine that operates on a 32-bit windows operating system or lower.

The fundamental approach to developing this program is by creating functions and variables and naming them after the cutting parameters. These variables are then used to create functions which are representations of the different cutting conditions. Also, the constraints are created as different variables and included into the functions for greater accuracy.

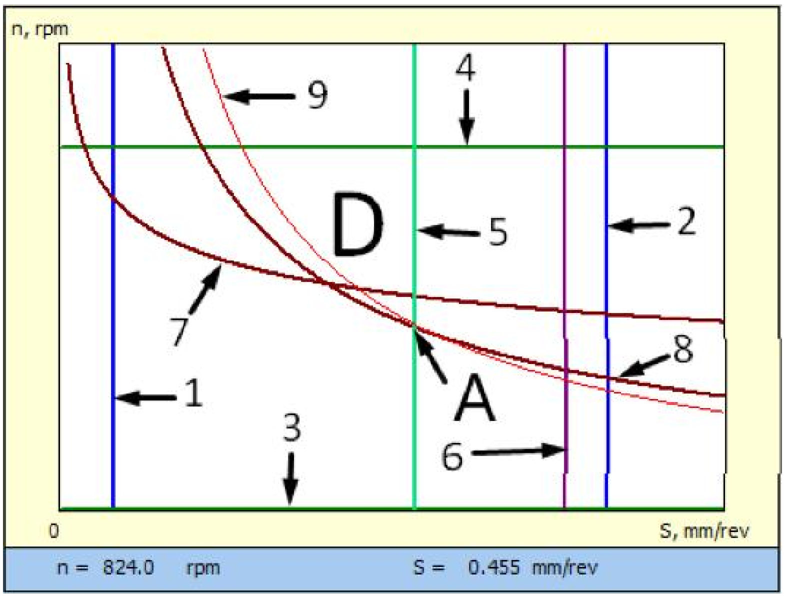

Figure 5.42 Interface of the program

1,2-Feed (max, min), 3,4- Spindle feed (max, min), 5- Surface Roughness constraint, 6- Cutting force constraint, 7- Tool life constraint, 8- Power constraint, 9- optimization line, D- Region of permissible values, A- Point of optimum.

By clicking on the “Apply The Data” button, the program automatically calculates the optimum conditions according to the new parameters and the constraints of the experiment.

5.3 The general idea behind the program

In the current economic and technological climate of modern metalworking equipment is increasing exponentially. So, in order to attain maximum productivity and optimum quality of work pieces, it is necessary to use the optimum cutting conditions without increasing the cost of production (manufacturing).

The main idea of a startup project is to develop a software that will predict the optimum working conditions of a turning operation on a lathe.

Table 5.1. General idea behind the program

General Idea	*Area of specialization*	*User Benefits*
Properly evaluating the sustainability of the turning process by taking into account the machine parameters and the optimal cutting modes	Improving the maximum productivity of a turning operation	Reduces guesswork involved in the choice of optimum cutting conditions
	Optimization of the cutting conditions in a turning operations	Extensively improves the productivity of the process

The software simulates the processes that takes place during the turning in an elastic mass system. With this program, one can determine the optimal cutting conditions at which the entire system will remain stable.

Also, this program simulates the entire cutting processes that takes place in a turning operation. In addition, the mathematical model which forms the fundamental of the application factors in parameters of the cutting too.

As at today, there are no established solutions of this sort within an affordable price range. The only available analogues are exclusively used by large corporations.

This program can be applied to a system is considered for production on a lathe, with the aim to achieving maximum productivity by optimizing the cutting parameters during a turning operation.

5.4 Determining the strong and weak points of the program

By analyzing the Weak (W), Strong (S) and Neutral (N) characteristics and properties of the project, we can determine its ability to compete in the market place. To this effect, we have implemented a table using the WSN analysis technique.

Table 5.2. Determining the strong, weak and neutral sides of the program

№	*Techno-economic characteristics*	*Potential product VS competitions (Comp)*				*W*	*N*	*S*
		Mine	*Comp1*	*Comp2*	*Comp3*			
1	Size of Investment							+
2	Trademark					+		
3	Popularity					+		
4	Concentration levels						+	
5	Delivery speed							+
6	Price flexibility							+
7	Buyer							+

5.5 Technological audit of the product

In order to understand how to technically implement the idea of the startup, a technological audit of the project using standard techniques is a necessity. The guiding principle is to develop a software that can effectively evaluate the sustainability of the entire system, and therefore, we will seek similar technologies that will provide a solution to this problem.

According to the analyzed data (Table 5.3), the following technological approaches were selected: Sales of finished products for the enterprise with the provision of user instructions for determining the raw data. This decision was made based on the availability and of necessary technology.

Table 5.3. Technological audit

№	*Project Idea*	*Technology of development*	*Availability of Tech*	*Access to Technology*
1	Development of a software product for assessing the sustainability of the system	Sales of finished products for the enterprise, providing user instructions for determining the raw data.	Yes	Yes
2	Development of a software product for assessing the sustainability of the system	The use of a software by our specialist to determine the output at the enterprise	Yes but needs completion	Yes

5.6 Analysis of the market capability of the product

Identification of market opportunities that can be used in the market implementation of the project and market threats that may impede the implementation of the project allows you to plan the directions of project development, taking into account the state of the market environment, needs of potential clients and proposals of competing projects.

We identify potential customer groups, their characteristics and form an indicative list of product requirements for each group (Table 5.4).

Table 5.4. Characteristics of potential clients

№	*Demand*	*Target audience (target market segments)*	*Differences in the behavior of different potential target customers*	*Consumer demands*
1	High quality of the processed surface	Entrepreneurs, manufacturers	Requirements for the quality of the treated surface	Maximization of productivity during turning
2	Payback of lathe	Entrepreneurs, manufacturers	High productivity of lathe	Providing optimal cutting conditions

After identifying potential customer groups, an analysis of the market environment is performed using analytical systems. Therefore, we compile tables of factors that contribute to market implementation of the project and factors that impede it (Table. 5.5-5.6).

Table 5.5. Risk factors

№	*Factor*	*Threat content*	*Possible reactions*
1	Production decline in the field of mechanical engineering	No demand on product	Product creation for other industries
2	Opening of economic borders	Appearance of new technology	Implementation of new technology
3	Inflation	The drop in solvency, including the companies with which we cooperate	Flexible pricing

Table 5.6. Opportunity factors

№	*Factor*	*Threat content*	*Possible reactions*
1	Protectionism policy	Protection of the domestic manufacturers to develop the startup consumer industry	Attraction of related industries in the consumers circle
2	Stimulating the development of innovative entrepreneurship	Reducing the tax pressure on startups	Scaling up a startup

Table 5.7. Step-by-step analysis of market competition

Features of the competitive environment	*Manifestation of these characteristics*	*Impact on the activity of the company (possible actions to become competitive)*
Type of competition	Monopolistic competition	Competition: a market situation in which a relatively large number of small producers offer similar but not identical products
Level of competition	National level	National competition and competitiveness of individual firms, enterprises and organizations occurs and appears nationally
By industry	Inter-industry	Application of the software is possible only in the manufacturing of machines, aviation, instrument making
By type of product	Commodity competition	Tracking market trends with the possibility of substituting products on the market
By the nature of competitive advantage	Pricing	Flexible pricing based on demand dynamics. Improvement of technology aimed at enhancing basic benefits
By intensity - branded / non-branded	Non – branded	Providing scalability of the startup in the near future to create a sustainable perception of the startup as a separate business unit

After the analysis of competition, we conduct a more detailed analysis of the conditions of competition in the industry by model 5 forces of M. Porter (table. 5.8).

Table 5.8. Potter analysis of the competition

	Direct competition	*Potential competitions*	*Suppliers*	*Clients*	*Substitutes*
Components of analysis	Competition1; Competition2; Competition3	Consumer commitment to certain brands; Access to distribution channels	no need for suppliers	ability to influence prices	the substitute price is higher
Conclusions	Average intensity of competition	Market entry opportunities; Potential competitors	Suppliers do not dictate market conditions	Customers may require more advanced technology	Market restrictions due to better known substitute product firms

Therefore, there are possibilities for the product in the market.

On the basis of the competition analysis given in table. 5.8, as well as taking into account the characteristics of the project idea (Table 5.2), consumer requirements for the product (Table 5.4) and factors of the marketing environment (Table 5.5-5.6), determine and justify the list of factors of competitiveness. The analysis is formalized in table. 5.9.

Table 5.9. Justification of the competitiveness factors

№	*Competitiveness factor*	*Rationale (based on the factors that make the comparison of competing projects meaningful)*
1	The rate of increase of the industry	Opportunity to increase sales
2	Increase in the number of consumers	Increase in profit
3	Dynamics of market expansion	Attracting new customers
4	The degree of product updates	Meeting the current needs of consumers
5	The degree of technology upgrade	New opportunities for improvement
6	The level of demand saturation	Price increase
7	Public perception of the product	Sales stability
8	State regulation of expansion	Investment in development
9	Increasing number of competitors	Exchange of experience
10	The degree of obsolescence of products	Identify product weaknesses

The strengths and weaknesses of the startup project are analyzed by the identified factors of competitiveness (Table 5.9) (Table 5.10).

The final stage of market analysis of project implementation opportunities is the compilation of SWOT analysis (Strength and Weakness matrix, Troubles and Opportunities) (Table 5.11) based on the selected market threats and opportunities, and strengths and weaknesses (Table 5.10).

Table 5.10. Comparative analysis of the strengths and weaknesses of the project

№	*Competitiveness factor*	*Points*	*Competitor rating compared to Competitor 1*						
			–3	*–2*	*–1*	*0*	*+1*	*+2*	*+3*
1	The rate of increase of the industry	-1			+				
2	Increase in the number of consumers	0					+		
3	Dynamics of market expansion	-1			+				
4	The degree of product updates	1						+	
5	The degree of technology upgrade	3						+	
6	The level of demand saturation	4					+		
7	Public perception of the product	7							+
8	State regulation of expansion	8					+		
9	Increasing number of competitors	8				+			
10	The degree of obsolescence of products	7			+				

Table 5.11. SWOT-analysis for the startup

Strengths:	*Weaknesses:*
• an experienced team of engineers; • investment attractiveness of the enterprise; • balanced pricing policy; • absence of competitors in the price category; • popularity of products; • taking into account the needs of consumers	• unknown brand; • low reputation of the company; • lack of experienced; managers and marketers
Possibilities:	*Threats:*
• increase in financial income of the population;	• appearance of competitors; • economic downturn;
• release of new products; • new technology; • Product rental services	• unstable economic situation of the country; • change of legislation

The list of market threats and market opportunities is compiled on the basis of an analysis of threat factors and factors affecting the marketing environment. Market threats and market opportunities are consequences (projected results) of the influence of factors and, unlike them, are not yet realized on the market and have a certain probability of realization.

For example: a decline in the income of potential consumers is a threat factor, on the basis of which one can make a prediction of an increase in the importance of the price factor when choosing a product and, accordingly, price competition (which is already a market threat).Based on the SWOT analysis, market behavior alternatives (list of measures) are developed to launch the startup project on the market and the approximate optimal timing of their market implementation in view of potential competitors' projects that may be launched on the market. The identified alternatives are analyzed in terms of terms and likelihood of obtaining resources (Table 5.12).

Table 5.12. Alternatives to market introduction of a startup project

№	*An alternative (indicative set of measures) to market behavior*	*Probability of receiving resources*	*Implementation period*
1	Strategy to neutralize market threats by the strengths of a startup	High	2 years
2	A strategy of strengthening strengths through market opportunities	High	1 year
3	A strategy to compensate for the weaknesses of existing market opportunities.	Medium	2 years
4	Market exit strategy	Low	None

5.7 Development of marketing strategy

Developing a market strategy as a first step involves defining a market outreach strategy: a description of the target groups of potential consumers (Table 5.13).

Table 5.13. Selection of target groups of potential consumers

№	*Description of the profile of your target audience*	*Readiness of consumers to accept the product*	*Target demand within the target group (segment)*	*Intensity of competition in the segment*	*Ease of entry into the segment*
1	Manufacturer (seller)	Ready	High	Average	Low
2	Manufacturer (buyer)	Ready	High	High	Low
3	Monitoring groups	Ready	Average	High	High

After analyzing potential consumer groups, the following three target groups were selected and a market outreach strategy identified. Because the company operates in one segment, we use a concentrated marketing strategy.

To work in the selected market segment, we formulate a basic development strategy, namely a specialization strategy (Table 5.14).

Table 5.14. Defining a basic development strategy

Basic development strategy	*Market outreach strategy*	*Key competitive positions according to the alternative chosen*
Specialization strategy	concentrated marketing	• Achieves high market share in the target segment, but always leads to small market share as a whole; • a large price gap relative to non-specialized products of competitors; • reducing differences in product requirements from the target segment and the market as a whole; • competitors' entry into even narrower sub-segments of the company's target market

The specialization strategy involves concentrating on the needs of one target segment without seeking to reach the entire market. The goal here is to meet the needs of your chosen target segment better than your competitors. Such a strategy can be based on both differentiation and cost leadership, or both, but only within the target segment. However, a low market share in case of failure of strategy implementation can significantly undermine the company's competitiveness.

The next step is to choose a competitive behavior strategy (Table 5.15). We choose a strategy to follow the leader.

Table 5.15. Defining a basic strategy for competitive behavior

Is the project a pioneer in the market?	*Will the company look for new customers or take on existing competitors?*	*Will the company copy the key features of a competitor's product, and which ones?*	*Competitive behavior strategy*
No	will take away existing competitors and look for new ones	No	Leader imitation strategy

Based on the requirements of consumers from selected segments to the supplier (start-up company) and to the product (see table 5.4), as well as depending on the selected basic development strategy (table 5.14) and strategy of competitive behavior (table 5.15) positioning (Table 5.16). which is to form a market position (complex of associations) by which consumers must identify the brand / project.

Table 5.16. Defining a positioning strategy

№	*Requirements for product's target*	*Basic development strategy*	*Key competitive positions of your own startup*	*Selection of associations to form an integrated position for their own*
1	Simple and clear interface	Specialization strategy	• Relatively low price for the required software product; • performance of work; • support and advice from the manufacturer	• available product in this segment; • use of information technology to model the processes that take place; • Improving the productivity of lathe equipment
2	Easy to use			
3	Easy to get input data for modeling			
4	Graphical representation of simulation results			
5	Adequacy of the results obtained			
6	Vibration damping in practice			

5.8 Development of a marketing program for a startup project

The first step is to develop a marketing concept product that the consumer receives. For this reason, in table. 5.17, the results of the preliminary analysis of the competitiveness of the goods should be summarized.

Table 5.17. Determining positioning strategy

Demand	*The benefits offered by the product*	*Key Competitive Advantages (existing or required)*
Technologies that will optimize turning processes and improve the performance of turning equipment	Increasing the material removal rate by choosing optimal cutting modes or optimal parameters of lathe	Assessment of the sustainability of the system based on traceability. Relatively inexpensive software cost.
	Improving the productivity of turning equipment	

The last component of the marketing program is the development of the concept of marketing communications, which relies on a pre-selected basis for positioning, defined specific behavior of customers (Table 5.18).

Table 5.18. Determining positioning strategy

№	*Specific behavior of target customers*	*Communication channels used by target customers*	*Key positions selected for positioning*	*The task of the advertising message*
1	Careful selection of potential adversaries, due to the peculiarity of the market for use Information technology	Internet broadcast	Technology	Draw attention to real-time analytics systems
2		Contextual advertising	Technology	
3		Special exhibitions, forums	Technology	

Conclusions

From a complete analysis of the startup and the holistic economic assessment of the product, we established the various aspects of the product which will be valuable in putting it up in the market. Also, we looked at ways to improve the product against other competitors. This improvement will help put this product at an advantage over other analogues. Ultimately, this product will be a good piece of investment by any interested party because it will help them make a lot of profit in terms of productivity and economy on technical advancements.

CHAPTER 6

CONCLUSIONS AND FUTURE WORK

6.1 Conclusions

The ever-increasing cost of manufacturing and equipment in the modern day has necessitated a research into ways of maximizing the productivity of every manufacturing process. As important as the task of maximizing productivity is, it however does not have to take precedence in the manufacturing process. It is also important to reduce the cost of the production to the barest minimum through the use of the most appropriate tool and material for the process. So, the value for maximum productivity should be the material removal rate during the turning operation.

This thesis explored the development of a technique for optimizing cutting operations on a lathe. Application of this new technique will benefit the cutting of steel materials bearing the same characteristics as ANSI 1045 steel. The lathe use and the tool were provided by HAAS and recommended by Sandvik tool catalogs respectively.

For the experiment, a number of constraints were established in order to control the order and the scope of the parameters under evaluation. The parameters provided be the manufacturers of the lathe and cutting tool still had to be chosen carefully according to the requirements of the cutting process.

Next, with the use of these constraints, there is need for a mathematical model based on these constraints. Since the mathematical model is not available as an empirical equation, an alternative to this equation was created. This alternative came about as a result of developing the function of maximum productivity as a factor of the spindle feed and speed. With the empirical formula of these parameters known, a mathematical model was then developed to represent the maximum productivity. With this model available, we now focused on conducting the experiment considering the constraints and other significant parameters.

Furthermore, the constraints on the cutting tool and tool holder were established. These constraints were established using the results if the analysis of the plastic deformation of the cutting tool under the influence of all the cutting force components. More so, the deformation of the tool holder using different clamping methods was also taken into account and incorporated into the model as one of the constraints.

After the completion of the useful mathematical model, a computer program was developed to predict the optimum conditions based on the given cutting parameters and the constraints. This program was developed using a very common programming language that is compatible with most Windows operating systems on which most machines work.

Also, despite the process explored being only rough turning, this technique can as well be applied to finishing operations. On the end of the experiment a number of conclusions have been made concerning the optimization of cutting conditions in turning operations.

- At a specific depth of field, the material removal rate of the turning operation is maximized for both virtual and real-life experiments.
- The constraints on the operation are also necessary to improve the economic implications of a turning operation.

This depth of cut coincides with the values obtained from the program as well as that from the experiment, this means that the point of optimum on both the real-life and virtual experiments coincide. Since this point of optimum us established, this signifies that this program is functioning properly and can be relied on to perform the task of optimization.

6.2 Suggestions for Future Research

Despite the holistic nature of the research carried out in this thesis, a lot still needs to be done in the optimization of cutting operations. This thesis covers only single criteria optimization. It is a recommendation that this technique of optimization be extended to multi-pass and turning and finishing just like that which was studied by Petty et al (1985).

The strong point of this work lies on the optimization of single-pass turning of simple. However, the restriction to this thesis remains that it only focuses on simple work pieces without considering other more complex surfaces of modern machine parts. Also, more work needs to be done on predicting cutting forces for specific tools with increased levels of accuracy. This high level of accuracy will help narrow down the range of the constraints and as such, increase the level of productivity.

With the use of these more accurate parameters, the prediction model developed with provide a far more efficient alternative for a program that predicts the cutting conditions for all forms of turning operations.

References

1. Abido, M. A., (2000) *Robust Design of Multi-Machine Power System Stabilizers Using Simulated Annealing*, IEEE Transactions on Energy Conversion, Vol. 15, No. 3, pp:297-304.
2. Abido, M., Abel-Magid, Y., Al-Baiyat, S., & Mantawy, A. (1999). Simultaneous Stabilization of Multimachine Power Systems via Genetic Algorithms. *IEEE Transactions On Power Systems, 14*(4), 1428-1439.
3. Agapiou, J. S., (1992) The optimization of machining operations based on a combined criterion, Part 1: The use of combined objectives in single-pass operations, Part 2: Multi-pass operations. *J. Eng. Ind., Trans. ASME* 114: 500–513.
4. Barker, T. B. (1990) *Engineering quality by design* (New York: Marcel Dekker)
5. Chanin, M. N., Kuei, C., Lin, C., (1990). Using Taguchi design, regression analysis and simulation to study maintenance float systems. *Int. J. Prod. Res.* 28: 1939–1953.
6. Chen, M, Chen, K. Y., (2003) Determination of optimum machining conditions using scatter search. *New optimization techniques in engineering*, pp 681–697.
7. CoroPlus ToolGuide: Find the right tool for your application. (2019). Retrieved 8 December 2019, from https://www.sandvik.coromant.com/en-gb/products/Pages/toolguide.aspx
8. Dash, S.K., (2012), “Multi Objective Optimization of Cutting Parameters in Turning Operation to Reduce Surface Roughness and Tool Vibration,” B.Tech. thesis, Department of Mechanical Engineering, National Institute of Technology, Rourkela.

9. Davim, P., & Conceicao, A. (2001). Optimization of cutting conditions in machining of aluminium matrix composites using numerical and experimental model. *Journal Of Materials Processing Technology*, *112*(1), 78-82.
10. Kackar R N, Shoemaker A C 1986 Robust design: A cost effective method for improving manufacturing processes. *AT & T Tech. J.* 65(Mar–Apr): 39–50.
11. Kolahan, F., & Abachizadeh, M., (2008). Optimizing Turning Parameters for Cylindrical Parts Using Simulated Annealing Method. *World Academy Of Science, Engineering And Technology*, *46*, 436-439.
12. Kuriakose, S., & Shunmugan, M. (2005). Multi-objective optimization of wire-electro discharge machining process by Non-Dominated Sorting Genetic Algorithm. *Journal Of Materials Processing Technology*, *170*(1-2), 133-141.
13. Manocha, L., George, P., Raghunath, B., & Warrier, M., (2004). EDM machining of carbon–carbon composite—a Taguchi approach. *Journal Of Materials Processing Technology*, *145*(1), 66-71.
14. Melkote, S., & Thiele, J., (1999). Effect of cutting edge geometry and work piece hardness on surface generation in the finish hard turning of AISI 52100 steel. *Journal Of Materials Processing Technology*, *94*, 216-226.
15. Melkote, S., Ng, C., Rahman, M., & Kumar, S. (2006). Experimental study of micro- and nano-scale cutting of aluminum 7075-T6. *Int J Mach Tools Manufacturing 46*, *9*, 929-936.
16. Oktem, H., Erzurumlu, T., & Mustafa, C. (2008). A study of the Taguchi optimization method for surface roughness in finish milling of mold surfaces. *A Study Of The Taguchi Optimization Method For*

Surface Roughness In Finish Milling Of Mold Surfaces, *28*(7-8), 694-700.

17. Orsila, H., Kangas, T., Salminen, E., & Hamalainen, T. (2006). *Parameterizing Simulated Annealing for Distributing Task Graphs on Multiprocessor SoCs*. IEEE publications.
18. Ozel, T., & Karpat, Y., (2006). Multi-objective optimization for turning processes using neural network modeling and dynamic-neighborhood particle swarm optimization. *The International Journal Of Advanced Manufacturing Technology*, *35*(3-4), 234-247.
19. Palanikumar, K., (2008). Application of Taguchi and response surface methodologies for surface roughness in machining glass fiber reinforced plastics by PCD tooling. *The International Journal Of Advanced Manufacturing Technology*, *36*(1-2), 19-27.
20. Petty, D. J., Tester, M., Barrow, G., Hinduja, S., (1985) Calculation of optimum cutting conditions for turning operations. *Proc. Inst. Mech. Eng*. 199(B2): 81–92.
21. Reddy N., Kumar S., and Rao P. V., (2008) *Selection of an optimal parametric combination for achieving a better surface finish in dry milling using genetic algorithms*. The International Journal of Advanced Manufacturing Technology, Vol.28, No.5-6, pp. 463-473.
22. Ribeiroa, M.V., Coppinib, N.L., (1999). “An Applied Database System for the Optimization of Cutting Conditions and Tool Selection”, *J. of Materials Processing Technology*, Vol. 92, 1999, pp. 371-374
23. Sardinas, R., Santana, M., & Brindis, E. (2006). Genetic algorithm-based multi-objective optimization of cutting parameters in turning processes. *Engineering Applications Of Artificial Intelligence*, *19*, 127-133.

24. Schneider, S., (1989), “High speed machining: solutions for productivity,” *Proceedings of SCTE '89 Conference*, San Diego, California
25. Taguchi G., (1989). *Quality engineering in production systems* (New York: McGraw-Hill)
26. Tosun, N., Cogun, C., & Tosun, G. (2004). A study on kerf and material removal rate in wire electrical discharge machining based on Taguchi method. *Journal Of Materials Processing Technology*, *152*(3), 316-322.
27. Tsai, P., (1986). *An optimization algorithm and economic analysis for a constrained machining model*. PhD thesis, West Virginia University
28. Tsui, K. L., (1999) Robust design optimization for multiple characteristics problems. *Int. J. Prod. Res.* 37: 433–445
29. Wang, X., Jawahir, I. S., (2004). Web based optimization of milling operations for the selection of cutting conditions using genetic algorithms. *Proc. Inst. Mech. Eng.* 218: 212–223
30. Zhou, J., Duan, Z., Li, Y., Deng, J., & Yu, D. (2006). , PSO-based neural network optimization and its utilization in a boring machine. *Journal Of Materials Processing Technology, 178*(1), 15-25.
31. Кроль, О.С., (2013). Методы и процедуры оптимизации режимов резания: монография. - Луганск: изд-во ВНУ им. В. Даля, 2013. – 260 с.: табл. 12. ил. 16. библиогр. 68 назв. Русск. язык.
32. Петраков, Ю.В., (2014) Автоматичне управління процесами обробки матеріалів різанням [Текст]/ 2014. – 81 с.