KAUNAS UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING AND DESIGN
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DEVELOPMENT OF CALCULATOR OF PROCESSING PARAMETERS FOR CNC MILLING MACHINE OPERATOR

Final project for Master degree

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Development of calculator of processing parameters for CNC milling machine operator

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29 May 2015
Kaunas

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Astafjeva, E. Development of calculator of processing parameters for CNC milling machine operator. *Master degree* final project / supervisor Assoc. Prof. Dr. Saulius Baskutis; Kaunas University of Technology, mechanical engineering and design faculty, production engineering department.

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SUMMARY

This paper describes development of calculator of processing parameters for CNC milling machine operator. The aim of the master project: to create a product that allows quick selection of the optimum cutting tool and cutting parameters corresponding to it, for the selected operation. To implement the objectives, next tasks were set: research of working principal of similar existing programs; evaluate importance of optimal tool selection; research factors, that influence the metal cutting tool selection process for CNC machining; suggest long term solution that will allow to choose optimal cutting tool, based on manufacturers recommendations, identifying the external factors of influence.

Developed products importance is evaluated based on the F.Taylor's Equation for Tool Life Expectancy, and Sandvik Coromant publicly available information about the effective work zone.

Developed product: reduced time which is required for calculation of the cutting parameters; gives a opportunity to choose not only the right tool, but a optimal tool for performance of selected operation; selects cutting tool, which enables to reduce the cost required for the purchase of the cutting tool.

Astafjeva, E. Apdirbimo parametrų skaičiuoklės SPV frezavimo staklių operatoriui sukūrimas. Magistratūros studijų baigiamasis projektas / vadovas doc.dr. Saulius Baskutis; Kauno Technologijos Universitetas, mechanikos inžinerijos ir dizaino fakultetas, gamybos inžinerijos departamentas.

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SANTRAUKA

Šiame darbe aprašomas skaičiuoklės programinio valdymo staklių operatoriui kūrimas. Magistrinio projekto tikslas, sukurti produktą, leidžianti greitai parinkti tinkamiausią įrankį pjovimui ir jam atitinkančius pjovimo parametrus, pasirinktai operacijai. Tikslo įgyvendinimui buvo suformuoti sekantis uždaviniai: išstudijuoti panašių esamų programų veikimo principą; įvertinti optimalaus įrankio parinkimo svarbą; išstudijuoti faktorius, kurie įtakoja įrankio pasirinkimą; pasiūlyti ilgalaikį tikslo įgyvendinimo sprendimą, kuris leistu pasirinkti optimalų pjovimo įrankį, remiantis įrankio gamintojo informaciją, bei įvertinant išorinius įtakojančius faktorius.

Kuriamo produkto svarba yra įvertinta remiantis F.Teiloro lygtimi „Įrankio tarnavimo laiko priklausomybė nuo pjovimo greičio“, bei Sandvik Coromant viešai skelbiama informacija apie efektyvią darbo zoną.

Baigiamojo projekto eigoje sukurtas produktas: sumažino laiko sąnaudas, reikalingas pjovimo parametrų skaičiavimui; davė galimybę pasirinkti ne tik reikalingą įrankį, bet tinkamiausią įrankį operacijos įvykdymui; parinko pjovimo įrankį, kurio naudojimas leidžia sumažinti išlaidas, reikalingas pjovimo įrankio įsigyjimui.

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Studijų programa PRAMONĖS INŽINERIJA IR VADYBA

Magistrantūros studijų, kurias baigus įgyjamas magistro kvalifikacinis laipsnis, baigiamasis darbas yra mokslinio tiriamojo ar taikomojo pobūdžio darbas (projektas), kuriam atlikti ir apginti skiriama 30 kreditų. Šiuo darbu studentas turi parodyti, kad yra pagilinęs ir papildęs pagrindinėse studijose įgytas žinias, yra įgijęs pakankamai gebėjimų formuluoti ir spręsti aktualią problemą, turėdamas ribotą ir (arba) prieštaringą informaciją, savarankiškai atlikti mokslinius ar taikomuosius tyrimus ir tinkamai interpretuoti duomenis. Baigiamuoju darbu bei jo gynimu studentas turi parodyti savo kūrybingumą, gebėjimą taikyti fundamentines mokslo žinias, socialinės bei komercinės aplinkos, teisės aktų ir finansinių galimybių išmanymą, informacijos šaltinių paieškos ir kvalifikuotos jų analizės įgūdžius, skaičiuojamųjų metodų ir specializuotos programinės įrangos bei bendrosios paskirties informacinių technologijų naudojimo įgūdžius, taisyklingos kalbos vartosenos įgūdžius, gebėjimą tinkamai formuluoti išvadas.

1. Darbo tema: Apdirbimo parametrų skaičiuoklės SPV frezavimo staklių operatoriui sukūrimas.
Patvirtinta 2015 m. gegužės mėn. 11d. dekano įsakymu Nr. ST17-F-11-
Development of calculator of processing parameters for CNC milling machine operator
Approved on May 11, 2015. May. Dean's Order No. ST17-F-11-2
2. Darbo tikslas: sukūrti skaičiuoklę, leidžiančia greitai surinkti informaciją apie pjovimo parametrus (frezavimo operacijoms) ir kita informacija, reikalinga techninems skaičiavimama.
Create calculator for CNC operator, that would allow quickly obtain information of cutting modes (for milling processing) and other necessary parameters for technical calculations
3. Darbo struktūra: Apžvalginė dalis: esamų skaičiuoklių apžvalga, parametrų svarbumo įvertinimas. Metodinė dalis: informacijos, reikalingos skaičiuotuvo sukūrimui analizė. Rezultatų pristatymo dalis: Apdirbimo parametrų skaičiuoklės SPV frezavimo staklių operatoriui pristatymas bei rezultatų apibendrinimas.
4. Reikalavimai ir sąlygos: Apdirbimo parametrų skaičiuoklės SPV frezavimo staklių operatoriui sukūrimas, remiantis įrankio gamintojo informaciją, bei įvertinant išorinius įtakojančius faktorius.
5. Darbo pateikimo terminas 2015m. gegužės mėn. 29 d.
6. Ši užduotis yra neatskiriama baigiamojo projekto dalis
Išduota studentui Elinai Astafjevai

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Introduction

This work is continuous of topic I started researching while presenting my bachelor thesis: “Influence of set-up times, on the net cost of the manufactured part”. Topic was chosen because nowadays a lot of manufacturers that are focusing on the metal processing are facing problem of correct calculation of production price.

Problem occurs, because of incorrect time calculation for production as well as selection of inexact parameters for processing. This starts serious errors and as a consequence the loss of time and decrease of expected profit.

From time to time there are developments made that minimize this problem, but they are usually quite expensive and not available to most businesses.

Master project topic is focusing on precise calculations of processing parameters for metal processing on CNC machines, with expectations to make production planning and time calculation process easier, less time consuming and more accurate.

While researching machining times, it accrued to me, that looking for right feeds, which have to be used in CNC processing, takes a lot of time (even for a skilled worker time consumption to find information for one operation is around 3 min), taking in mind that in production of part that is medium complexity, average number of operations is 20, therefore 20 different sets of parameters have to be looked up in directories, it come to my understanding that in average an hour of time is being consumed bay employee not for a production, but for a preparation.

In my master project I am planning to present calculator, which helps to find needed information fast and is easy to use. Factor that helps to make most precise calculations is that data is collected from actual working enterprise, taking in mind real factors of influence, like: qualification of worker, tool wear, machine depreciation, material of work-piece indicators and recommendations of equipment manufacturer.

Practical part of my research work, was carried out in two parts:

1. Goal of first part was to research production planning process in metal processing manufactory, from the technologist point of view. Emphasis was made on time calculation for production; price calculation when working with CNC machine; production planning. The study found that company uses a system of cost calculation, which is based on benchmark production – benchmark process is considered to be a process, processing parameters of which were calculated beforehand bay the physical observations. Depending on how much

manufactured item differs from the reference, correction coefficient is introduced. Disadvantages of this type of system, consists in the fact that with time, calculation accuracy decreases, due to the fact that technology for production evolves; time calculation and price calculation in this type of system, considered as two separate processes, linked to each other with only few indexes.

- *First part of practical research was covered during Erasmus internship*

2. Second part of practical research was covered by observing operator of CNC milling machine in working progress; influence of inaccurate cutting parameters on process planning was researched; metal cutting process - choice of optimal cutting tools and calculation of cutting parameters were investigated.

   The study found that worker, in small and medium batch production, calculates cutting conditions independently, often without reference to the data that is introduced. As a result, inadequate data of cutting conditions is reflecting on process of production planning, which splits into two parts: theoretical and actual.

   - *Second part of practical research was covered during internship in home country at "Example Company".*

Second part of practical research was carried out by observing CNC milling machine operator, therefore limitation was accepted to investigate metal processing by milling; selection of optimal mill for CNC machining; calculation of optimal processing parameters of milling for CNC machining.

Objective: create calculator for CNC operator, that would allow quickly obtain information of cutting modes (for milling processing) and other necessary technological parameters for technical calculations.

Tasks:

1. Explore systems, which are currently used for calculation of cutting modes, investigate its drawbacks.
2. Determine the importance of accurate calculations of cutting modes.
3. Investigate factors, which are affecting processing of the metal, when processing on CNC machines; investigate their importance to the overall process of production planning.
4. Suggest a solution that would have a positive influence on the productivity of the manufacturing.

1. Variables which affect the efficiency of production - CNC machining

Industrial company can increase its profits by raising revenue and reducing losses. Engineering and technological design are initial stages of the product life cycle – any changes or decisions that are made at this point, can significantly affect prime cost of the manufactured product and thus make difference for profit of the enterprise.

1.1.Variables to be consider to secure performance

According to Christer Richt, technical editor for Sandvik Coromant [1], there are few main variables that has to be considered most, to secure performance and obtain the desired results in manufacturing: profitability and sustainability [2]:

- ***Metal cutting efficiency.*** Productivity for any operation is directly related to its metal cutting efficiency – how fast material is removed, and what is the cost of it.
- ***Machine utilization.*** When considering the productivity of a machine - machine utilization is equally important. This is because 100% speed that occurs only 50% of the time still leaves a lot of room for improvement.
- ***Total manufacturing time (TMT).*** Percentage of actual metal cutting time in TMT is generally low, and therefore the total flow of supply needs to be understood better. Since each step in the supply chain is a critical important, ensuring fewer steps in combination with a shorter TMT would help to achieve higher level of delivery accuracy.

1.2. SECO Tools research on production optimization and reduction of manufacturing costs

One of the leading manufacturers of cutting tool in metal processing – Seco Tools [3], carried out the research [4]:

Purpose of research: find ways for production optimization and reduction of manufacturing costs.

Investigation: evaluate economic effect of increased productivity; evaluate economic effect of cutting tool price reduction.

Sources of information: researched data was collected from production companies who are clients of Seco Tools [3].

According to investigator, approximate structure of production costs of the enterprise, can be divided in 5 main components: labors cost, machinery expenses, premises maintenance costs, price of materials and cutting tool costs (Fig. 1.1):

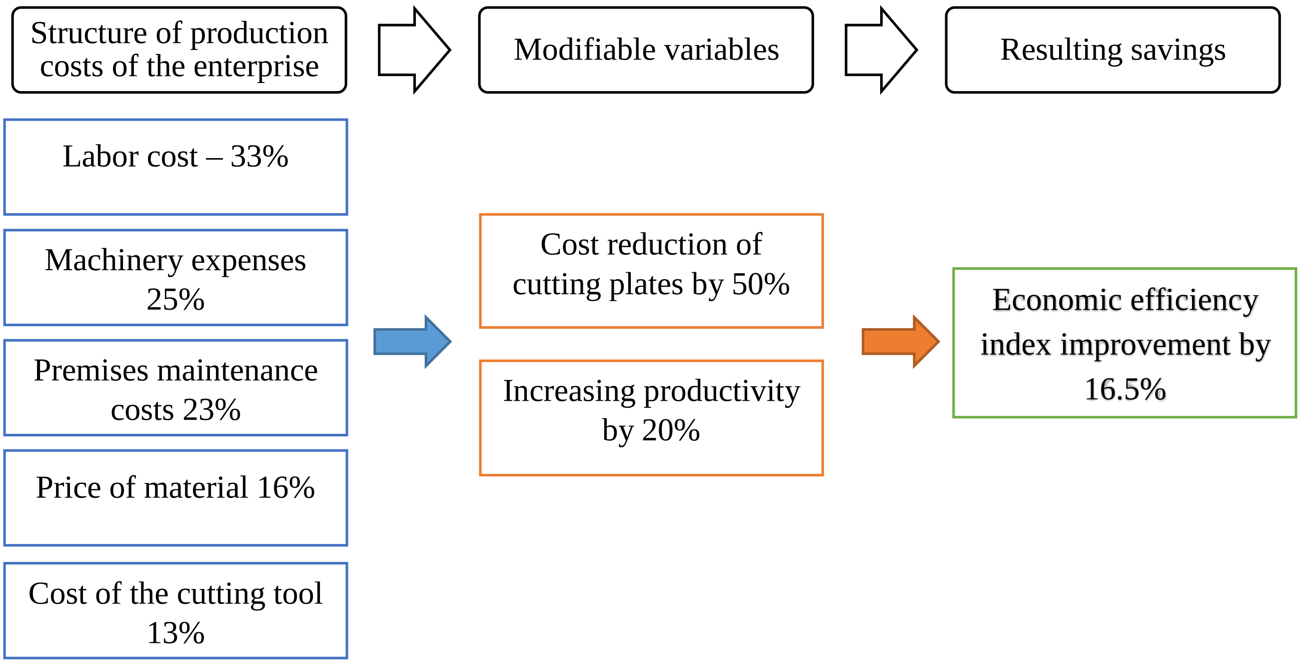


Fig. 1.1 Structure of production costs of the enterprise

Research result: reducing the cost of cutting plates by 50%, leads to savings of 1.5%; increasing productivity by 20% can improve the economic efficiency index of production by 15%.

Total amount of operating costs of the enterprise is not a constant value. As researched of SECO Tools [3] showed, changing value of component, makes perceptible effect on prime cost. Some expenses are fixed, and influencing them would lead to a minimal savings or no savings at all; other components still leave place for optimization process (Fig. 1.2).

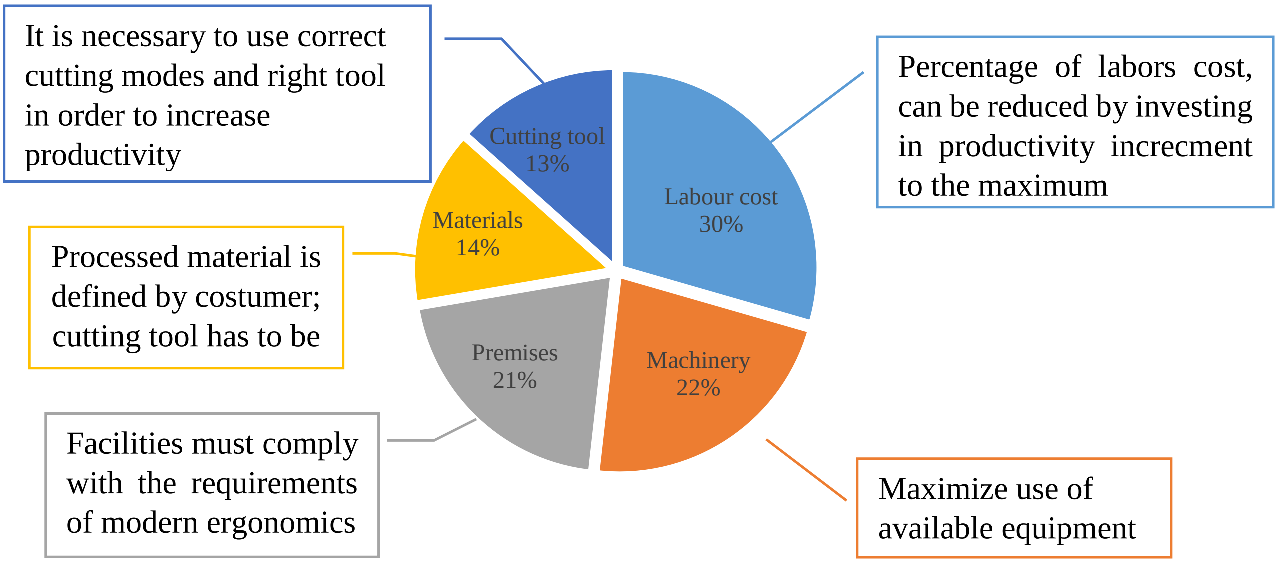


Fig. 1.2 Actions that can be taken, to reduce losses and raise bigger profit

Operating efficiency of CNC machines is largely determined by correct technological utilization. Ergonomically designed manufacturing process, choice of optimal cutting modes in particularly, provides increased reliability and optimized manufacturing process.

1.3. Current applied methodologies for selection of cutting tools/cutting parameters

Selection of a cutting tool is carried out by various branches of an enterprise. Common cases: a search of a cutting tool by a technologist, in the stage of development of a machining process; search of a cutting tool, carried out by a mechanic, in selection of a cutting tool analog.

The emergence of a large range of cutting tools, raises the problem of optimal choice. The task of optimal tool selection, for both organizational and technical conditions, is time-consuming process. The provision of information and necessary data sources for technologists and engineers-economists, or any other implemented parties, becomes an important factor in the organizational aspect [5].

Summarizing the main sources of the required data, most essentials should be allocated:

- Directories of cutting tool manufacturers;
- Online databases for each cutting tool;
- Online resources;
- Technical handbooks

Online databases for cutting tools

Most convenient source are the online databases. However, they commonly lack the additional technical information. Online data bases of leading cutting tool manufacturers, usually are equipped with automated search engine. This significantly speeds up and simplifies the process of selection. Specifying commonly used once, next databases could be listed [6]:

Sandvik	www.sandvik.coromant.com
ISCAR	www.iscar.com
Mitsubishi	www.mitsubishicarbide.com
SECO	www.secotools.com
Walter	www.walter.com
Korloy	www.korloy.com
Guhring	www.guhring.com

During the time of the research, to investigate the working principle of the online database, two leading manufacturers were highlighted:

Sandvik CoroGuide system [7], provides a search of a tool, from all range of products. The system allows a user to narrow the search according to processing type (turning, milling and drilling). After selecting a type of processed material, marking cutting tool and its alloy, also its technical information – systems calculates: the recommended cutting speeds, speed of the spindle, required power of machine, surface roughness and ect.

Seco Cut system [8] allows user to receive information on the cutting data recommendations (like feed, speed, power, etc) for milling, turning and drilling. The first step, is to choose type of processing (milling, turning ore drilling), it also allows user to choose a hard alloy of cutting tool, material of work piece, machining diameter and depth of cut. Seco Cut system allows to calculate theoretical surface roughness, which would be achieved, in condition that calculated modes of cutting will be used for processing.

1.3.1. Disadvantages of online databases for cutting tools

In general, these kinds of systems, helps a client in the selection of the cutting tool, but they also have a number of disadvantages:

- The range of cutting tools that are presented, is limited to one manufacturer;
- No option is given to update data base manually: add information about new cutting tool, or delete and replace the old one;
- The system does not allow you to compare tools of the same type, from different manufacturers;
- In general, listed systems are just electronic versions of the directories from the manufacturers of cutting tools;
- Depreciation of equipment, cutting tool and other exterior factors are not considered
- Systems lack integration with modern CAM and CAD systems (no possibility to transfer technical drawings from CAD system, to system which allows you to select the cutting tool and cutting modes, or a reverse information transfer)

1.3.2. CAD/CAM systems

Another option in selection of cutting conditions, offers CAD / CAM-system [9]. Using these systems in professional activity, technologist has the ability to carry out computer simulation processing with simulation of tool paths and determination of the cutting conditions. Furthermore, modern CAD / CAM-systems can generate the control program for CNC machines (Fig. 1.3 [10]).

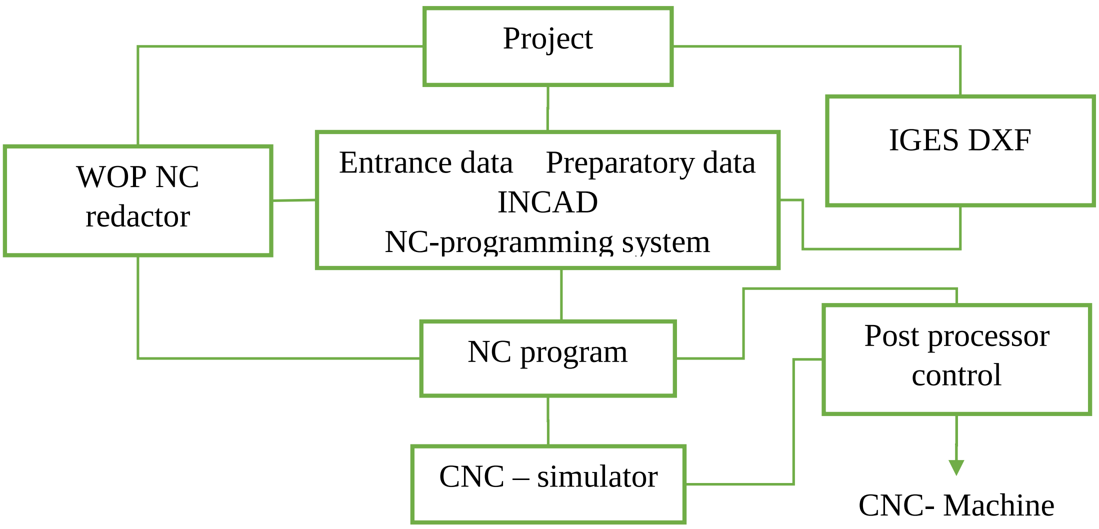


Fig. 1.3 MTS company - Integrated NC and CNC system flowchart

In most modern CAM module definition of cutting conditions is hidden from the user; cutting tool data base is limited to certain manufacturers.

These circumstances cause:

1. Selection of cutting modes, that aren't optimal for chosen type of processing;
2. Production might use services of different supplier for cutting tools; which differs from suggested ones in type of geometry of cutting tool and material of cutting tool.
3. CAM module data base can be supplemented with information about a new cutting tool, but this information contains only data about the tool geometry, and not about physic-mechanical characteristics of the material, from which cutting tool is made.

1.4.Determination of cutting modes based on personal experience

In reality, determining the parameters with high efficiency for CNC processing requires a lot of calculations and time. Therefore, most engineers-technologist simply refuse to calculate this parameters due to time constraints. Calculations of cutting modes for 1 part, that is medium complexity would take approximately 1 hours. Considering amount of parts, technological process of which has to be developed by technologist, it can be concluded, that in small and medium production, technologist, physically wouldn't be able to select optimal cutting modes for each part processing.

Considering disadvantages of systems, which are used for determination of cutting modes, and limitations of time that is putted on technologist, it can be concluded, that: technical information, that is provided to CNC machine operator as supplement of workpiece is inaccurate. In conclusion to this, CNC operators use suboptimal approaches in selection of cutting tools and cutting modes, relying on trial and error instead of applying suggested information. Which contributes to selection of inaccurate data for processing, even worse, as knowledgeable people retire, the risk increases of having all that knowledge walk out the door [11].

Selection of cutting modes based on own experience of the operator, can be justified bay following: metal removal operation can be performed, using range of different cutting modes, however, selection of optimal cutting modes, based on personal experience of machine operator, is close to impossible.

1.5. Importance of selecting correct cutting parameters

1.5.1. Efficient work zone

Determination of effective work zone, graphically shown in the catalog of the manufacturer Sandvik Coromant [1]. Suggested by the company chart (Fig. 1.4) reflects the dependence of the operating costs from the cutting speed.

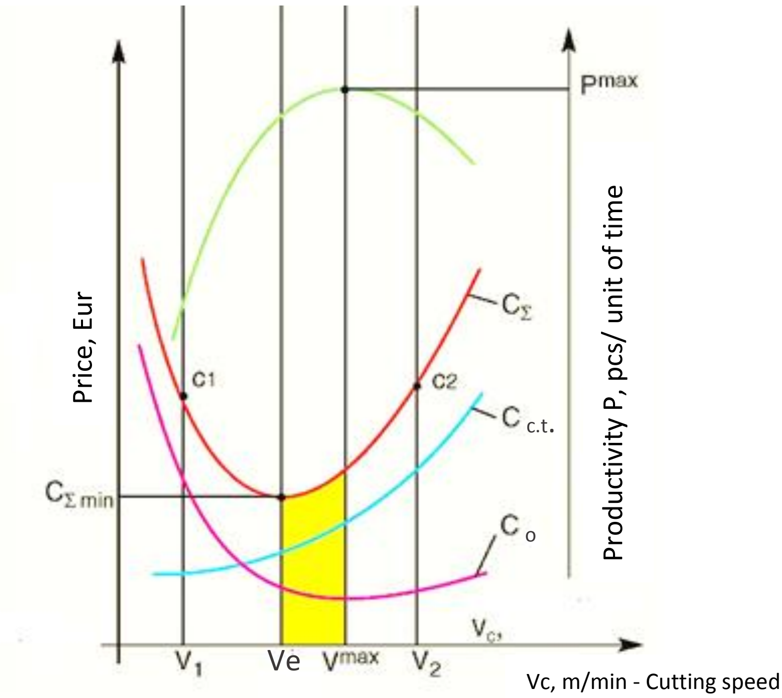


Fig. 1.4 Determination of effective work zone

Data for the chart:

1. Production productivity P, *parts per unit of time*
2. $C_{c.t.}$ – cutting tool expenses, *Euro*
3. C_o - operating costs of cutting equipment, *Euro*
4. $C_{\sum}$ - total cost of machining (Sum of $C_{c.t.}$ and C_o), *Euro*
5. V_c – cutting speed, *m/min*

Basic indicators that were used by Sandvik Coromat [1], for determination of effective work zone:

- For calculation of machining time and total time for production, company used coefficient α - machine utilization rates, relation between machining time and total production time; for CNC machine equals 0.3-0.4. [12]
- According to publicly available information from Sandvik Coromat, life time of cutting tool in CNC machining is equal to 7-15min [13].

Suggested chart shows:

- While increasing cutting speed, cutting tool expenses $C_{c.t.}$ are rising as well, but the tool life, expressed in number of manufactured parts, decreases.
- With increase of cutting speed V_c, laboriousness of manufacturing which is expressed in machine-minutes drops, and thus operating costs of cutting equipment decreases as well.
- Identifying in graph curve, that shows manufacturing productivity dependence on cutting speed, gives understanding that at first productivity will increase almost proportionally to the cutting speed; then productivity growth will slow down and even decrease. That is because decrease in resistance increases the effect of downtime required to replace the tool.
- Graph shows, that reduction of cutting modes with purpose to increase sustainability of cutting tool, economically impractical. It leads to raise of operating costs since it leads to an increase in the total cost of treatment to the point C_1, which is equivalent to a decrease of profitability and lengthening payback period of cutting equipment.
- There is the cutting speed V_e, in which total cost of machining is minimal. V_e – economically justified cutting speed.

Establishment of effective work zone. Effective work zone (in Fig.2.4 highlighted in yellow) is established by selecting the point of maximum productivity P_{max} and its corresponding cutting speed V_{max}. Then the area of cutting speeds between V_e and V_{max} is determent as zone of effective work. Processing with speeds that are close to V_e, allows to minimize $C_{c.t.}$ and reduce C_o. Approaching speed V_{max} allows to raise productivity and get the maximum production volume.

Operating outside the effective work zone. Though this explanation justifies the choice of cutting conditions referring to the experience of the operator, since optimal speed corresponds to the interval of cutting speeds, and select correct speed is theoretically possible. But selecting speed that does not correspond to the effective work zone interval resorts in economically inappropriate decision:

- Accepting the cutting speed greater than V_{max} does not provide productivity gains, but demands the expenses (point C_2)
- Accepting the cutting speed under Ve with the aim to raise the tool life, leads to an increase in the total cost of treatment to a point C_1, which is equivalent to a decrease of profitability and payback period lengthening of cutting equipment.

While not optimal modes will accomplish the machining task, work will be performed not in the best way and therefore will make a negative impact on the economic factor of productivity.

In conditions of actual production, number of limiting factors is considerably high. With each limitation factor, task of optimization, becomes more complex, and therefore, ideal optimization is almost impossible to implement. In most cases, when determining the cutting conditions, optimization is performed partially, taking into account the most significant limiting factors.

The simplest task is to define the processing modes, taking in to account extreme factors of optimization and don't consider limiting factors [14].

1.5.2. Taylor's Equation for Tool Life Expectancy

Cutting speed is one of the main indicators in the calculation of processing parameters. The dependence of the tool lifetime on the cutting speed can be described using an empirical formula of Taylor [15]:

$$\boldsymbol{V_c \times T^n = C} \quad (1.1)$$

Where V_c – cutting speed, m/min; T – tool life, min; n – constants (material); C – constants (work)

Table 1.1. n coefficient value for different cutting tool materials

HSS	*Hard alloys*	*Ceramics*
0.1-0.2	0.2-0.5	0.5-0.7

Equation (1.1) shows: tool life, is inversely proportional to the cutting speed, and varies exponentially:

$$\frac{V_{c_2}}{V_{c_1}} = \left(\frac{T_1}{T_2}\right)^n \qquad (1.2)$$

Assuming, that for machining was chosen hard alloy tool with coefficient *n*=0.4, and increased cutting speed by 10%, tool lifetime will decrease by:

$$110\% = \left(\frac{T_1}{T_2}\right)^{0.4}, \rightarrow T_2 = \frac{T_1}{1.1^{\frac{1}{n}}} = 27\% \qquad (1.3)$$

Using the same method of calculation, intermediate values are calculated. The results of calculations, displayed graphically (Fig. 1.5).

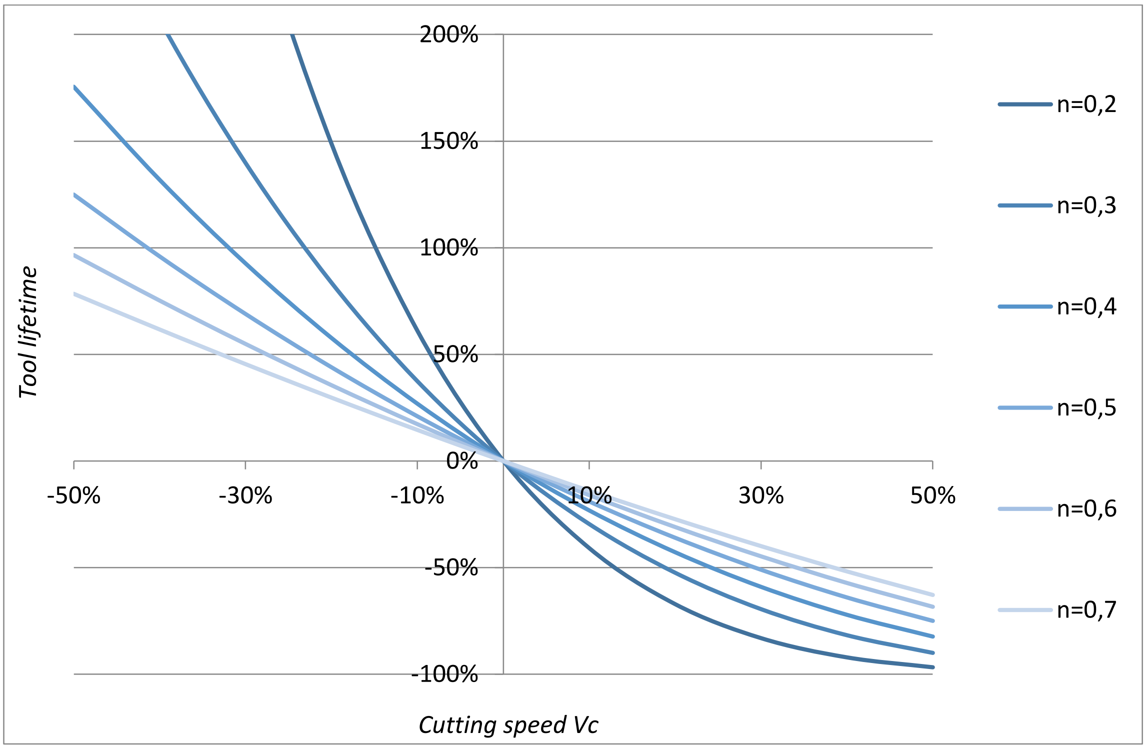


Fig. 1.5. Dependency of tool life on cutting speed

Obtained graph shows how much the cutting speed affects the tool life.

1.6 Target of the Master Project

Task of master project is to present calculator, which will allow to select optimal cutting tool and best cutting modes for it, while processing metal on CNC machine.

Target:

1. Provide an opportunity to calculate cutting conditions in fast and simple way
2. Provide an opportunity to select the optimal tool, not just a suitable tool
3. Present calculator, based on information provided from manufacturers of equipment, to get the most accurate recommended modes
4. Present system, which allows to enter correction factors and characteristics of the selected machine
5. Present a long-term solution to the problem; offer a product with database which can be supplemented and corrected if necessary
6. Gives the possibility of rapid reorientation of the calculator for use of different branches of enterprise (technologist, technologist-programmer, machine operator, estimator)

Thru the period of research work, results of which are presented in this project, research was conducted at the CNC milling machine - DMU50 [16].

Due to the fact, that metal processing on CNC machine can be performed with big assortment of cutting tools, as well as selection can be done from big range of tool manufacturers, limitation was done to analyze selection process of solid end mills which are produced by SECO tools [3]. Other tools can be selected in accordance with the proposed principle.

Accurate analysis of influence factors of metalworking, has to be performed in order to create wanted system, as well as understanding of influence for each factor.

2. Process of production planning

2.1. Development of manufacturing process for machining the workpiece

Development of manufacturing process for machining the workpiece, is basis for all process planning of organization. Accuracy and completeness of machining process development, affects organization of production, and further technical and economic calculations. Tasks which are solved in the development process [17]:

- Analysis of technical drawing
- Selection of method for manufacturing a workpiece.
- Selecting a processing plan
- Selection and calculation of machining allowances.
- Selection of equipment
- Selection of cutting tool
- Selection of adaptations
- Machine-tool
- Selection of tool fixtures.
- Selection of measuring instruments and dimensional inspection.
- Selection of cutting modes
- Technical normalization of time for operation
- Equipment selections for transportation of workpieces.
- NC programming.
- Feasibility studies of developed process

All stages of machining process development have significant effect on end result, which is why, each stage can be analyzed as part of total process, as well as individual problem.

2.2. Metal machining process

Regardless of what type of processing has to be carried out (turning, drilling, milling) main processing parameters will be determined by three main indicators: material of work piece, cutting tool and CNC machine that will be chosen for processing. Each indicator has own characteristics and risk factors, which should be taken in to account.

For more specific information, which would be: cutting modes, efficiency, machining time, following steps in technical-process, differ depending on the type of processing.

After researching different proposition, for process of selection of cutting mill, Sandvik Coromat [1] was chosen as most convenient, based on personal opinion. Therefore this scheme (Fig. 2.1) was taken as a basis for further guidance [18]:

Selection process stage	*Matters that require attention*		
Analysis of the part • Type of operation and processing type • Workpiece material and size of production	Detail: - Flat surfaces - Deep Pockets - Thin walls / bottoms - Grooves	Workpiece material - Workability - chip formation - Hardness - The content of alloying elements	Required accuracy/ quality - Dimensional accuracy - roughness - Form error - Integrity of the surface
Analysis of equipment • Parameters of machinery	Machine - The power of the machine - Age / condition- stiffness - Horizontal / vertical fulfillment	- The type and size of the spindle - Number of axles / Configuration	Auxiliary equipment - Departure - Reliable fastening - Axial / radial run out
Cutting tool selection • Cutting tool selection	- Types of tools - Technological parameters of the material of the cutting part	- The angles of sharpening of the cutting edges - Other technical parameters	
Method of application • Cutting moods, toolpath etc.	It is very important to choose the number of cutting edges, this selection affects both the performance and the stability of the processing	Stiffness: Using the spindle the maximum size	Chip control: always use climb milling. using a cutter with a diameter of 20-50% biger than the width of milling

Fig. 2.1 Selection of cutting mill – Sandvik Coromat

2.3. Material of workpiece

The set of the various properties of the processed material, that characterize the ability of a material to be subjected by machining process, is called machinability of material [19].

Cutting machinability of metals varies and depends on material properties: hardness, strength, toughness, etc. Processed materials are classified, in accordance with ISO, into six basic groups. The materials of each group are characterized by unique properties concerning machinability [20]:

Table 2.1 Workpiece material groups

	**ISO P** – Steel is the largest material group in the metal cutting area, ranging from unalloyed to high-alloyed material, including steel castings and ferritic and martensitic stainless steels. The machinability is normally good, but differs a lot depending on material hardness, carbon content, etc.
	**ISO M** – Stainless steels are materials alloyed with a minimum of 12% chromium; other alloys may include nickel and molybdenum. Different conditions, such as ferritic, martensitic, austenitic and austenitic-ferritic (duplex), create a large family. A commonality among all these types is that the cutting edges are exposed to a great deal of heat, notch wear and built-up edge.
	**ISO K** – Cast iron is, contrary to steel, a short-chipping type of material. Grey cast irons (GCI) and malleable cast irons (MCI) are quite easy to machine, while nodular cast irons (NCI), compact cast irons (CGI) and austempered cast irons (ADI) are more difficult. All cast irons contain SiC, which is very abrasive to the cutting edge.
	**ISO N** – Non-ferrous metals are softer metals, such as aluminium, copper, brass etc. Auminium with a Si-content of 13% is very abrasive. Generally high cutting speeds and long tool life can be expected for inserts with sharp edges.
	**ISO S** – Heat-Resistant Super Alloys include a great number of high-alloyed iron, nickel, cobalt and titanium based materials. They are sticky, create built-up edge, harden during working (work hardening), and generate heat. They are very similar to the ISO M area but are much more difficult to cut, and reduce the tool life of the insert edges.
	**ISO H** – This group includes steels with a hardness between 45-65 HRC, and also chilled cast iron around 400-600 HB. The hardness makes them all difficult to machine. The materials generate heat during cutting and are very abrasive for the cutting edge.

Workpiece material determine the future choice of cutting tool material with accordance to it. To determine the optimal tool selection, at the first steps of analysis, it is important to understand the classification of processed materials, which is suggested by cutting tool manufacturers.

Generally, in the first stages of separation of materials into groups, manufacturers of metalworking tools, adhere to the ISO classification, that is classification of processed materials into 6 main groups. However, following steps in material sorting methods, differ with almost every manufacturer in one's own way. Example of subgroup differences:

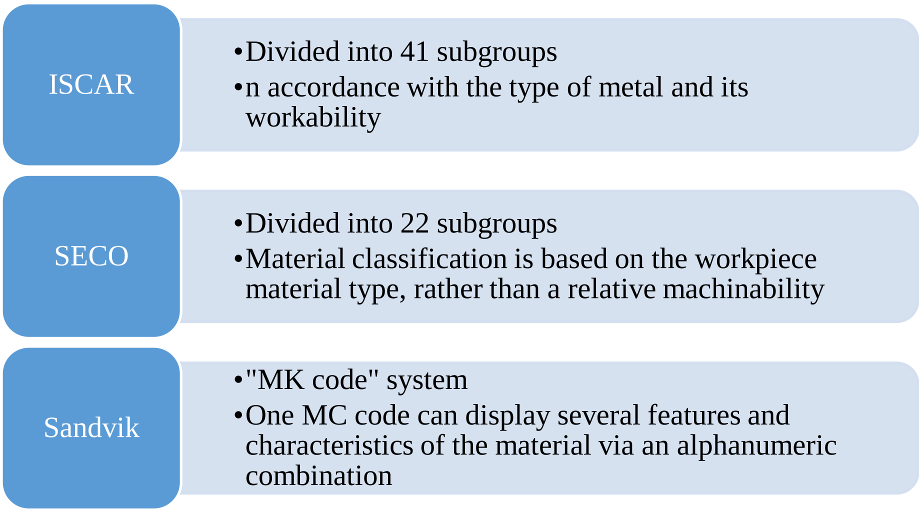


Fig. 2.2 Material sorting methods of different manufacturers of cutting tool

Depending on classifications that are used by manufacturers of cutting tools, different parameters which determined machinability are offered.

The number of manufacturers of cutting tools is quite large; to understand the classification of processed materials of each supplier is time-consuming process. This paper will cover research of classification and tools from manufacturer SECO tools [3].

2.4.Group of workpiece materials – SECO tools

As well as all manufacturers, SECO tools divides all metals in 6 main groups according to classifications of ISO (P,M,S,H.K.N). 6 main groups manufacturer have combined in to 4 groups [21]:

- Merging group P with group H – category of steels

- Merging group S with group N; definition of group is “other materials”

Obtained 4 groups, are divided in to 22 subgroups, using “SMG v2” system [22]. As mentioned above, basis for “SMG v2” system is classification of materials is based on their workpiece material types, instead of relative machinability.

4 main groups are rather extensive. For each SMG group, there is defined standard material in a specific state which is considered as a benchmark for an adjustment of the cutting conditions for any actual material, comparable to reference of SECO material. An example of classification and adjustment Vc according to SMG v2 can be found in appendix no 1.

Directories provide information on the indicators of machinability of material, according to subgroup of the material (information on indicators can be found in appendix 2):

- Ultimate tensile strength R_m N/mm^2 (minimal and maximal value);
- Specific cutting force k_c N/mm^2;
- Exponent used for calculating power demand – m_c

Technical information about the material of the workpiece, is an important factor of indication for product in development – calculator. To easier operate given information, data that is given in different directories was combined. Materials properties, according Werkstoff numbering system [23] that is used in Example Company, were combined with materials coding of SECO tools.

As mentioned above, SECO tools has divided all materials in 4 main groups and 22 subgroups. First task was to correlate Werkstoff numbering system with coding system that company SECO tools is using (Table 2.2). Some of materials have already been correlated, and this information was available in directories of SECO tools. Others were correlated in reference to type of material, indicated cutting forces, and m_c.

Taking in mind 55 different materials, that went thru stock of Example Company, and were registered in productions material list, next table was formed:

Table 2.2 Material list

Materials, that went thru stock of Example Company				Info from SECO		
№	**W-stoff**	**Brief description of the materials**	**Specific weight g/cm3**	**SECO no**	Specific cutting force,kc1 (N/mm²)	**mc**
1	**1,0035**	General construction steel, Rm <500 MPa	7,85	**1**	1350	0,21
2	**1,0037**	General construction steel, Rm <500 MPa	7,85	**1**	1350	0,21
3	**1,0330**	General construction steel, Rm <500 MPa	7,85	**1**	1350	0,21
4	**1,0402**	Structural steels not intended for heat treatment, Rm <500 MPa	7,85	**1**	1350	0,21
5	**1,0503**	Structural steels not intended for heat treatment, Rm <500 MPa	7,85	**3**	1500	0,25
6	**1,0570**	Structural steels not intended for heat treatment, Rm <500 MPa	7,85	**3**	1500	0,25
7	**1,0715**	Structural carbon steel containing C <0,12%, or Rm <400 MPa	7,85	**2**	1500	0,22
8	**1,0718**	Structural carbon steel containing C <0,12%, or Rm <400 MPa	7,85	**2**	1500	0,22
9	**1,1191**	Structural carbon steel containing C> = 0,25%.. <0,55%, or Rm> = 500 <700 MPa	7,85	**4**	1700	0,24
10	**1,1231**	Structural carbon steel containing C> = 0,55%, or Rm> = 700 MPa	7,85	**4**	1700	0,24
11	**1,2210**	Steels with special physical properties	7,85	**5**	1900	0,24
12	**1,2436**	Steel for various applications	7,85	**6**	2000	0,24
13	**1,2842**	Instrumental steel Cr-V, Cr-V-Si, Cr-V-Mn, Cr-V-Mn-Si	7,85	**5**	1900	0,24
14	**1,4057**	Stainless steel c <2,5% Ni no Mo, Nb and Ti	8,5	**5**	1900	0,24
15	**1,4104**	Stainless steel c <2,5% Ni and Mo, no Nb и Ti	8,5	**4**	1700	0,24
16	**1,4301**	Stainless steel c => 2,5% Ni and Mo, no Mo, Nb и Ti	8,5	**8**	1750	0,22
18	**1,4310**	Stainless steel c => 2,5% Ni and Mo, no Mo, Nb и Ti	8,5	**8**	1750	0,22
19	**1,4401**	Stainless steel c <= 2,5% Ni and Mo, no Nb и Ti	8,5	**10**	2050	0,20
20	**1,4404**	Stainless steel c <= 2,5% Ni and Mo, no Nb и Ti	8,5	**9**	1900	0,20
21	**1,4460**	Stainless steel c <= 2,5% Ni and Mo, no Nb и Ti	8,5	**11**	2150	0,20
22	**1,4462**	Stainless steel c <= 2,5% Ni and Mo, no Nb и Ti	8,5	**11**	2150	0,20
23	**1,4571**	Stainless steel with special additions	8,5	**9**	1900	0,20
24	**1,4835**	Heat-resistant steelc> = 2,5% Ni	8,5	**10**	2050	0,20
25	**1,6582**	Special steel containing Cr-Ni-Mo, c <0,4% Mo + <2% Cr	8,5	**5**	1900	0,24
26	**1,7035**	Special steel containing Cr, Cr-B	8,5	**4**	1700	0,24
27	**1,7131**	Special steel containing Cr-Mo-V	8,5	**4**	1700	0,24
28	**1,7139**	Special steel containing Cr-Mo-V	8,5	**4**	1700	0,24
29	**1,7225**	Special steel containing Cr-Mo, c <0,35% Mo, Cr-Mo-B	8,5	**4**	1700	0,24
30	**2,0060**	Copper and copper alloys	8,2	**18**	700	0,27
31	**2,0321**	Copper and copper alloys	8,2	**18**	700	0,27
...						

Affirmative advantage of formed table, is that it can be supplemented, if new material will be registered in material stock list of Example Company.

2.5.CNC machine - the machine on which the processing is carried out

CNC - computer numerical control — is one in which the functions and motions of a machine tool are controlled by means of a prepared program containing coded alphanumeric data. CNC can control the motions of the workpiece or tool, the input parameters such as feed, depth of cut, speed, and the functions such as turning spindle on/off, turning coolant on/off [24].

Features of the machine include the following parameters: the spindle speed, magnitude of table feeds, amount of coordinates, and capacity of machine. Great importance does the condition of rigidity of the machine, condition of bearings, and rectilinear motion of supports, tilt and beating of spindle. Important factor for rigidly is condition and accuracy of clamping devices.

Proper selection and maintenance of clamping devices, directly related to performance and capacity of processing.

Features of the machine, which should be analyzed:

- The spindle speed, magnitude of table feeds, amount of coordinates, and capacity of machine
- Condition of bearings, and rectilinear motion of supports
- The accuracy of the movement along the axes

A machine which is chosen for performing operations, greatly influences the choice of the tool (however, one can choose a tool that compensates for the shortcomings of the machine).

Thereby, selection of information about parameters of working equipment, which is available in production of Example Company, was made. Obtained data were tabulated (Table 2.3), which is then supplemented and will continue to be supplemented, as necessary. First part of the table contains passport data of machinery (complete table can be found in annex no 3):

Table 2.3 Passport data of equipment

1	2	3	4	5	6	7	8	9	10
Type of machine	Dimension -X	Dimension -У	Dimension -Z	Max spindle speed	Max Working feed	Max blank feed	Number of slots in the drum	Spindle power (Kw)	Emulsion feed
DMU 50	500	450	400	10000	8000	10000	16	9	0
DMU 35	350	240	340	6300	5000	30000	1	10	0
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

Machinery equipment manufacturers recommend not to use CNC machines at maximum capacity, so second part of the table reflects recommended parameters for processing (Table 2.4), additionally some secondary data about machinery is added. Recommended data shall be used to calculate parameters of processing (complete table can be found in annex no 3):

Table 2.4 Recommended data for machinery

11	12	13	14	15	16	17	18	19
Type of machine:	Recommended spindle speed	Recommended Max Working feed	Recommended Max blank feed	Recommended max load on the spindle (Kw)	**Emulsion feed through the spindle**	**Number of slots in the drum**	maximum accuracy in the processing of the holes (mm for ø)	maximum accuracy in the processing thru the coordinates X,Y,Z(mm)
DMU 50	7500	6000	10000	4.05	0	16	0.01	0.02
DMU 35	4725	3750	30000	7.5	0	1	0.01	0.02
….	….	….	….	….	….	….	….	….

2.6.Selection of cutting tool in metal processing

Cutting tool should be considered as one of the most important reserves for increase of productivity, reduction of processing cost, improvement of product quality.

Selecting the tool for different processing groups (turning, milling, drilling), has similarities in essence (due to the overall essence of the cutting process), however there are differences, due to the specifics of the processing method. In this regard, tool selection of different groups is carried out by different specificities.

When selecting the cutting tool first step is to identify type of instruments, required for machining in chosen processing group. Then determination is done according to the technological parameters of each type of instrument: material of cutting part, angles of sharpening and ect. Final stage is selection of technical parameter of cutting tool: cutter diameter D, the length of the cutting part l, free height of cutter L, number of teeth z, radius of end mills sharpener r, selection of the front and rear angles, depending on various factors, and performed in accordance with regulatory guidelines from manufacturer of cutting tool (explanation of technological parameters of the mill can be found in appendix no 3) .

Choice of material for cutting edge, is determined depending on the material that is being processed, that is why material of cutting part, is an important indicator of the cutting tool.

All investigated in this paper mills have carbide coating on the cutting edge of the tool.

2.7. Tool material - hard alloys

Hard alloys [25] - alloys based on highly rigid and refractory carbides of tungsten titanium, tantalum, interconnected metal binder, usually cobalt. Currently, they are the main cutting edge material, providing high-performance processing of material. Among the total number of cutting edge materials, used in machining production, the proportion of carbide is 30…35%. Thus carbide tool to remove 65% shavings, as the allowable cutting speed, used in the processing with these tools 2…5 times higher, than cutting speeds of high-speed tools [26].

Depending on the material and the form of chips produced, in accordance with ISO, solid alloys are subdivided into six cutting groups– P, M, K, N, S and H, each of which is indicated by a specific color. Cutting groups are subdivided into groups of application, are indicated by the letter (cutting group) and a numerical index (application group). The larger index of application, the lower the hardness and wear resistance of hard alloy and the allowable cutting speed, but higher strength (toughness), allowable feed and depth of cut [24].

Table 2.5 Fields of application of hard alloys

Group of cutting	Main field of application
P (blue)	Processing of chipping materials, (mainly steel)
M (yellow)	Processing of materials, which give both: drain shavings and chipping (corrosion-resistant steels and alloys)
K (red)	Cast iron - Chipless cleaving
N (green)	Processing of aluminum and copper alloys
S (brown)	Processing hard materials (heat-resistant steels and alloys, titanium and its alloys)
H (gray)	Processing of hardened and cast irons

Small group index corresponds to the application of the finishing operation, when hard alloys are required to have high strength and low wear. Large index corresponds to the roughing operation, which is when hard alloys should have high strength properties. In this regard each model has its preferred area of application, in which alloy provides maximum efficiency and performance of the processing. Application groups are defined approximately and rather ambiguous. Therefore, a number of model of hard alloys can well preform in two-three application groups or even in different cutting groups [24].

2.8. Reference data about mills

2.8.1. Reference data about used mills

There is a huge amount of mills that can be used in different production areas. Limitation have been already done, to analyze only mills that are produced by SECO tools. Example Company has defined number of solid-end mills, which gave another limitation for number of analyzed mills. After consulting CNC operator, suggestion was made to analyze next articles: JS512; JS513; JS514; JS520; JS532; JS534; JS553; JS554; JHP950; JHP992; JH414; JH970 (*JS532; JS534; JH970 – mills used for milling volume surfaces).*

In order to systemize information, about these tools, all necessary data that is needed for technical calculations, was collected from directories of SECO tools [27], about each elected mill. To make it easier to operate, information was tabled (Table 2.6):

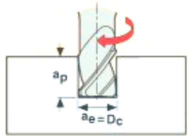
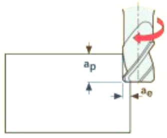
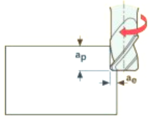
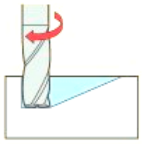
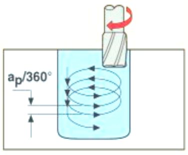
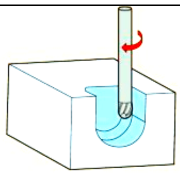
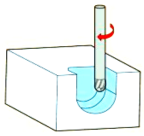
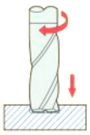
Table 2.6 Nomenclature of end mills of the company SECO

JS512					**JS514**					**JS532**					**...**
c×45^0					**c×45^0**					**0,5d**					**...**
d	**Z**	**a_p**	**R**	**EUR**	**d**	**Z**	**l_1**	**R**	**EUR**	**d**	**Z**	**a_p**	**R**	**EUR**	**...**
1	2	2	0,01	18,3	1	4	2	0,01	17,4	1	2	2	0,5	29,5	...
1,5	2	3	0,02	18,3	1,5	4	3	0,02	17,4	1,5	2	3	0,8	28,7	...
2	2	4	0,02	19,6	2	4	5	0,02	18,7	2	2	4	1	27,4	...
										2,5	2	5	1,3	27,4	...
3	2	6	0,03	19,5	3	4	7	0,03	17,6	3	2	6	1,5	27,4	...
										3,5	2	7	1,8	31,7	...
4	2	8	0,04	19,6	4	4	10	0,04	19,5	4	2	8	2	33,1	...
										4,5	2	9	2,3	34,3	...
5	2	10	0,05	20,1	5	4	12	0,05	20,8	5	2	10	2,5	37,5	...
6	2	12	0,06	19,0	6	4	13	0,06	21,3	6	2	12	3	41,4	...
8	2	16	0,08	24,0	8	4	18	0,08	26,9	8	2	16	4	56,3	...
10	2	20	0,10	34,7	10	4	22	0,10	40,5	10	2	20	5	68,7	...
12	2	24	0,12	49,6	12	4	26	0,12	54,3	12	2	24	6	94,4	...
16	2	30	0,16	79,2	16	4	32	0,16	85,9	16	2	32	8	148,8	...
20	2	35	0,20	126,7	20	4	40	0,20	144,5	20	2	40	10	236,3	...
25	2	40	0,25	174,3	25	4	50	0,25	183,6						...

2.8.2. Reference data about mills according to different processing techniques

There are 8 different types of processing that can be done with analyzed mills, which are:

Table 2.7 Types of processing that can be done with analyzed mills

Slot milling	Side milling (rough)	Side milling (finish.)	Ramping
			
Helical interpolation ramping	Volumetric milling (rough)	Volumetric milling (finishing)	Drilling
			

Different mills, can perform different processing, not all of them are suited for one or another process.

Depending on the processing method, cutting conditions also vary. For example, when choosing side milling roughing, for article JS513, parameters V_c and V_f is given in the directories of cutting tool manufacturer [26]. When preforming finishing, with same mill, recalculation required for V_c, V_f, a_p, a_e – in the accordance to the conversion table which offered by manufacturer [28].

All this information, can be found in directories, but since it is hard to operate directories every time while changing the mill or processing type, more skilled workers preform operation choosing mills from general understanding or using own skills. However, if correctly systemize (Table 2.8), information, can be found quite easy. This was next step of systemizing, information was tabled and categorized:

Table 2.8.a Fragment of the table “V_c and V_f for mills, depending of processing type”

Side milling (rough)			JS512		JS513		JS514		JS520		JS532		JS534		JS553		JS554	
		Z =	2		3		4		5_8		2		4		3		4	
			Vc	Vf	Vc	Vf	Vc	Vf	Vc	Vf	Vc	Vf	Vc	Vf	Vc	Vf	Vc	Vf
1	2	1_2	165	830	163	935	163	1860	180	2290	160	405	160	1020	190	1720	190	2295
3	4	3_4	150	755	150	860	150	1720	150	1910	150	380	150	955	175	1585	175	2120
5	6	5_6	125	475	125	595	125	1115	130	1655	140	265	140	715	150	1130	150	1510
7	7.9	7	63	475	63	720	63	955	150	795	—	—	—	—	65	280	65	370
8	9	8_9	100	510	100	475	100	510	125	1590	110	280	110	700	100	605	100	805
10	11	10_11	63	320	63	300	63	320	100	1275	90	170	90	460	65	295	65	395
12	13	12_13	188	955	188	900	188	1195	150	1910	190	485	190	1210	200	1510	200	2015
14	15	14_15	165	830	163	780	163	1035	130	1655	170	435	160	610	175	1320	175	1760
16	16	16	500	3500	500	2385	500	5730	500	6365	600	2290	600	5345	750	6075	750	8105
17	17	17	500	3500	500	2385	500	5730	400	5095	600	2290	600	5345	750	6795	750	9060
18	18	18	313	1795	313	2690	375	4295	400	5095	400	1530	400	3565	750	6075	375	4050
19	19	19	—	—	—	—	—	—	60	475	60	115	60	230	780	4805	50	425
20	20	20	—	—	—	—	—	—	60	475	60	115	60	230	50	320	50	425
21	21	21	—	—	—	—	—	—	40	320	30	40	30	75	30	220	30	295
22	22	22	75	335	75	360	75	860	80	1020	80	255	80	510	90	545	90	725
23	23	Graphite	500	4140	500	6205	625	10345	500	6365	600	3820	600	7640	625	8440	625	11255
24	24	Soft plastic	500	4140	500	6205	625	6365	400	6365	600	3820	600	7640	625	8440	315	5670
25	25	Hard plastic	500	3500	500	6205	625	7160	400	5095	500	3185	500	6365	625	5910	315	3970

Table 2.8.b Fragment of the table “a_p and a_e for mills, depending on processing type”

Mat.gr.		JS512		JS513		JS514		JS520		JS532		JS534		JS553	
		$a_p \times D$	$a_e \times D$	$a_p \times D$	$a_e \times D$	$a_p \times D$	$a_e \times D$	$a_p \times D$	$a_e \times D$	$a_p \times D$	$a_e \times D$	$a_p \times D$	$a_e \times D$	$a_p \times D$	$a_e \times D$
1	2	1,2	0,4	1	0,4	1	0,3	2	0,1	1,5	0,15	1,5	0,1	1	0,4
3	4	1,2	0,4	1	0,4	1	0,3	2	0,1	1,5	0,15	1,5	0,1	1	0,4
5	6	1,2	0,4	1	0,4	1	0,3	2	0,1	1,5	0,15	1,5	0,1	1	0,4
7	7,1	0,6	0,03	0,6	0,03	0,6	0,3	2	0,02	1,5	0,15	—	—	0,8	0,2
.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Mill of one geometry might differ in size (usually 3 different sizes are possible for one mill). In accordance with the size of the mill, processing modes are changing as well. The procedure for required parameters value recalculation, can be found in the manufacturer's directories [21]. This data is required for the processing parameters, which is why this information also has to be tabled:

	All values are a percentage of the basic – which are 100%, cutting conditions		Slot processing				Side milling roughing				Side milling finishing			
			vc	fz	ap	ae	vc	fz	ap	ae	vc	fz	ap	ae(% from Dc)
JS512	1	Standard	100	100	100	100	100	100	100	100	110	63	125	3
	1	L	100	100	30	100	100	50	167	25	110	63	208	3
	1	XL	–	–	–	–	–	–	–	–	66	63	292	3
JS513	2	Standard	100	100	100	100	100	100	100	100	110	83	150	3
	2	L	100	100	29	100	100	50	200	19	110	83	250	3
	2	XL	–	–	–	–	–	–	–	–	66	83	350	3
JS514	3	Standard	100	100	100	100	100	100	100	100	110	56	150	3
	3	L	–	–	–	–	100	50	200	25	110	56	250	3
	3	XL	–	–	–	–	–	–	–	–	66	56	350	3
JS520	4	Standard	–	–	–	–	100	101	102	100	133	63	100	2
	4	L	–	–	–	–	–	–	–	–	133	63	175	2
	4	XL	–	–	–	–	–	–	–	–	–	–	–	–
JS532	5	Standard	–	–	–	–	100	100	100	100	120	125	100	3
	5	L	–	–	–	–	–	–	–	–	120	75	53	3
	5	XL	–	–	–	–	–	–	–	–	–	–	–	–

Fig. 2.3 Recommended conversion rates according to standard sizes of cutting edge and selecting processing type

Cutting parameters also vary depending on the free height of the mill. Formula to recalculate a_p, is given in directories of manufacturers (formula for recalculation can be found in appendix no 4).

2.9. Processing modes calculations

After receiving the workpiece and familiarize himself with the technical drawing of the future part, machine operator has next parameters:

- Parameters his the machine
- Material of workpiece
- Type of the cutting tool, taking into account the limitations of existing mills in the manufactory
- Constructive parameters of the cutting tool (diameter of the mill; length of cutting part; free height of the mill; number of cutting edges of mill; sharpening radius of mill)

At this stage of the process, the operator must make a choice out of four options:

1. Perform processing using the modes that were proposed by technology.
   - In the production of individual parts and small/medium batches, taking in mind the volume of orders, the technology most often simply do not have the time for calculation of all relevant parameters.
2. Perform the processing, based on the accumulated experience of his own.
   - The cost of the tool for operator with extensive experience and for operator with basic knowledge, is the same. Therefore, operator with low qualification can cause tangible damage to the company.
3. Perform processing after independently calculating optimal cutting data, using directories of cutting tool provided by manufacturer.
   - Analysis of the information to select the optimal cutter, physically is not possible, since even skilled worker will spend approximately 3min to select parameters for one operation.
4. To use the calculator of manufacturer of cutting tools.
   - Time that will be spend for calculations will shorten, but difference is minor. Need to have printed directory from manufacturer is not eliminated. After receiving the data to standard tools/operations further recalculation is still required.

Frequent cases: the calculation of cutting conditions, using printed directory from manufacturer.

2.10. Exercise

In order to have a realistic idea of the complexity of selection of modes and cutting parameters, I have repeatedly carried out calculations of cutting parameters. As a result of the gained experience, the time spent on calculations decreased almost double, but also in this case, it is not less than 5 minutes.

Calculate cutting modes for metal processing of:

Werkstoff number:	1.0037
Method of processing:	Finishing-milling of later
Diameter of the mill:	10mm
Free height of the mill:	45mm
Manufacturer of cutting tools:	SECO
Manufacturers code of mill:	JS553

Process of selection of the mill and calculation of cutting parameters:

1. Selection of SECO tools material group number that corresponds with Werkstoff number.
   - Material 1.0037 is included in 1st group of SECO tools material groups [21].
2. In the table of contents find the page on which it is necessary to seek information on the geometry of the selected tool
   - Working with the directory for solid end mills of SECO tools (year 2012) [27], information can be found on p. 34.
3. Selection of needed parameters, with correspondence to selected mill and material of workpiece. Parameters are given for rough milling.

Table 2.9 Selection of needed parameters from manufac. directories

n, RPM	f_z, mm	v_f, mm/min	v_c, m/min	a_p, mm	a_e, mm
6050	0.095	1720	190	10	4

4. Recalculation of cutting modes in correspondence with selected processing method. Information for recalculation is given on p.77 [28]. Selected mill can perform 8 types of processing, each processing type requires its own recalculation of parameters.

Table 2.10 Given information of cutting modes in correspondence with selected processing method

v_c, m/min	a_e, mm	f_z, mm	a_p, mm
210.9	0.3	0.05	15

$$n = \frac{\mathrm{V_c} \text{ x } 1000}{\pi \text{ x } D_c} = 6716.5RPM \quad (2.1)$$

$$V_f = n \text{ x } z_n \text{ x } f_z = 1007.5\ mm/min \quad (2.2)$$

5. Free height of the mill 45mm>4D, therefore recalculation should be done in correspondence with free height of the mill. Provided formula for recalculation of a_p, can be found in directories of SECO tools (appendix no 4):

$$a_p(new) = a_p(from\ catalog) \text{ x } \left(\frac{4 \text{ x } D_c}{Novij\ vilet\ frezi}\right)^2 = 11.9mm \quad (2.3)$$

3. Research results

3.1.Calculator of cutting modes for CNC operator

All the information and the necessary indicators, which were summarized in the tables, makes it easy to operate available data. And most importantly, it gives CNC operator possibility to quickly calculate main necessary modes and processing parameters.

To make it easier for use, and shorten the time period, which is required for information input in the calculator, each mill, which is bought by enterprise, is given separate code; as well, code is entered for the size of the cutting edge. For example, every solid end mill from SECO manufacturer, has code from 1 to 5; the size of the cutting edge has code from 1 to 3.

Codes that correspond to the parameters of the tool, are shown in the initial window of the calculator. Moreover, as a supplement, inserted photos which depict the shape of the cutting part and the number of cutting edges of selected mill. Operator, doesn't have to remember anything – explanation can easily be found in the calculator.

Calculator function, which is available in Excel, makes it possible to calculate the cutting modes in the program. Calculation is based on the formulas, which are provided by manufacturer of cutting tool. EXCEL gives possibility to operate large amounts of data at the same time, i.e. same calculation, using different tool options is carried out simultaneously. In the end result, information is provided for 5 different mills. The program was made with an option to eliminate unsuitable mills for chosen method of processing (mills are eliminated when choosing a method of processing, selecting the diameter of the mills, and the size of the mill).

In order to enable the calculator, the operator must enter the following information (fields are marked in green):

1. Werkstoff number of workpiece
2. The code of the selected geometry of the mill
3. Size of the mill (2D;3D;5D)
4. Diameter of the mill
5. Free height of the mill

Code	SECO mill code
1	JS513
2	JS514
3	JS520
4	JS553
5	JHP 992

W-stoff no of material		1,0037	
Code	Size of the working part of the mill		
1	Standard	up to	2D
2	L	up to	3D
3	XL	up to	5D

Window for needed information input				
№	Code – mill type	Code – size of work. part of the mill	D	Free height of the mill, mm
1				

Fig. 3.1 Window of the calculator – initial information input

After enabling the calculator, the operator receives modes and cutting parameters for all methods of processing that are possible with the selected mill.

Table of calculated milling modes													
D	Mill	Milling of the slot				Lateral roughing				Lateral finish milling			
		S RPM	F mm/min	ap, mm	ae, mm	S RPM	F mm/min	ap, mm	ae, mm	S RPM	F mm/min	ap, mm	ae, mm
12	JS513	3450	495	8,4	12,0	4326	935	12,0	4,8	4758	776	18,0	0,4

Fig. 0.2 Table of calculated milling modes

Calculator has a possibility to accept information about several mills at the same time. This gives a possibility to enter data about mills once at the beginning of the shift, and afterwards not return to the issue of revising the cutting conditions, if necessary, changing only Werkstoff number of workpiece (Fig. 0.3).

Window for needed information input					Table of calculated milling modes													
№	Code – mill type	Code – size of work. part of	*D*	Free height of the mill, mm	*D*	Mill	Milling of the slot				Lateral roughing				Lateral finish milling			
							S RPM	F mm/min	ap, mm	ae, mm	S RPM	F mm/min	ap, mm	ae, mm	S RPM	F mm/min	ap, mm	ae, mm
1	**1**	**1**	**12**	**40**	**12**	**JS513**	**3450**	**495**	**8,4**	**12,0**	**4326**	**935**	**12,0**	**4,8**	**4758**	**776**	**18,0**	**0,4**
2	**3**	**1**	**8**	**45**	**8**	**JS520**					**3623**	**1158**	**16,0**	**0,8**	**5033**	**1006**	**16,0**	**0,2**
3	**5**	**1**	**10**	**30**	**10**	**JHP992**	**4777**	**860**	**15,0**	**10,0**	**5732**	**1375**	**15,0**	**4,0**				

Fig. 0.3 Fragment of the table "Table of calculated milling modes for several mills"

3.2.Criteria for evaluation the effectiveness of the cutting conditions

The final stage of the development technological process, is the evaluation of effectiveness of the developed process. This indicator helps technologist to determine the correctness of the developed technological process. The essential problem is that the efficiency index can be calculated only after the entire process is developed, if the efficiency seem not suitable, the data of cutting modes will have to be change, and therefore additional time will have to be spent.

Another important decision, that technologist has to make, is to decide how to evaluate effectiveness of technological process.

Directories of cutting tool manufacturers, suggests formula for calculation of the material removal rate - Q cm3/min (appendix 4).

However, this indicator should be considered as an auxiliary parameter for the calculation of the efficiency, instead of determining the effectiveness, because removal rate can be increased due to increase of cutting speed, but this increases the cost of the tool wear as well[1].

[1] Information on Effective work zone, can be found in chapter 1

Criteria for evaluation of cutting conditions, becomes a factor of optimization, i.e. factors which will be pushed to the limit value. Conventionally, the evaluation criteria, can be divided into three main groups: economical, power consumption based and energy based criteria.

Economic group of criteria includes the following valuation parameters: the minimum cost of processing, the minimum cost of processing operations, and the minimum cost of removing the volume unit.

Optimal option is the cutting conditions under which the calculated or selected values:

- Practically can be implemented on the available cutting machines;
- Satisfy the requirements of all the constraints included in the technical specification;
- Enable to reach the maximum or minimum value of optimization factors

3.3. The criterion of minimum cost of processing.

Ensuring minimum cost of production is one of the main factors for release of the competitive products. In this regard, it is proposed to enter a coefficient that determines the cost of the removed metal in accordance with the cutting tool wear.

Knowing the metal removal rate - Q cm3/min; price of the selected mill; and taking in mind, that tool life is equal to 15min [13], it is possible to determine the tool wear in EUR, for the removal of $1cm^3$ of the material, using selected cutting modes.

Accepted criterion determines not only the effectiveness of the processing, but also simplifies the calculation of the prime cost, as the data on tool wear, is calculated immediately in the calculator.

3.4. Calculator for technologist

Data that have been tabulated, and makes the database for the calculator, enable to calculate not only the cutting modes, but also to estimate the effectiveness of selected cutting tool and machine.

In addition to the parameters required by the machine operator, a great interest when selecting the technology for processing are:

1. The radius at the end of mills (to determent the possibility for processing of volumetric surfaces).
2. The cost of mills
3. Metal removal rate - Q cm^3/min
4. Efficiency of the tool, cm^3/EUR (knowing the price of the tool and metal removal rate, based on tool life = 15min [13]) – how much cm^3 of material can be removed by mill, by 1 euro investment in cost of the mill.
5. "Cost" of 1 cm^3 of removed material (considering that tool life = 15min [13])
6. Required power, for cutting tool work (it must comply with the capabilities of the selected for processing machine)

All this information is visible at the same time for all mills that are registered in the stock of the enterprise (Fig. 0.4). Therefore selection of optimal tool and its effectiveness can be done easy and fast. It significantly affects the cost the manufactured part.

Selection of optimal SECO manufacturer mill, for processing

	Mil parameters	JS512	JS513	JS514	JS520	JS532	JS534	JS553	JS554	JHP 950	JHP 992	JH141	JH970
Lateral roughing	The radius of the chamfer	0,1	0,1	0,1	0	5	5	1	1	0,5	0,2		5
	Price of the mill, EUR	34,68	33,49	40,55	60,52	68,68	73,7	48	53,465	67	61,36	88	88
	Cutting speed - V_c m/min	**165**	**163**	**163**				**190**	**190**		**180**		
	Feed rate - V_f m/min	**415**	**468**	**930**				**1806**	**2410**		**1031**		
	Rotation frequency - **n** RMP	**5255**	**5191**	**5191**				**6051**	**6051**		**5732**		
	Feed per tooth - f_z mm	**0,039**	**0,030**	**0,045**				**0,099**	**0,100**		**0,045**		
	Cutting depth - a_p, mm	**20,04**	**20**	**20**				**20**	**20**		**15**		
	Cutting width - a_e, mm	**1,00**	**0,76**	**0,75**				**1,52**	**1,52**		**2,00**		
	Metal removal rate - **Q** cm^3/min	**8,3**	**7,1**	**14,0**				**54,9**	**73,3**		**30,9**		
	Metal removal rate - Q g/min	**65,3**	**55,8**	**109,5**				**431,0**	**575,1**		**242,9**		
	Effectiveness of the tool cm^3/EUR	**3,6**	**3,2**	**5,2**				**17,2**	**20,6**		**7,6**		
	"Cost" of 1 cm^3 of removed material, EUR	**0,28**	**0,31**	**0,19**				**0,06**	**0,05**		**0,13**		
	Required power, kW	**0,6**	**0,5**	**1,0**				**3,1**	**4,1**		**2,0**		

Fig. 0.4. Calculator for technologist - selection of optimal mill for processing

As already mentioned above, the working modes are limited by the possibility of the machine. Information on the available equipment, which was collected during the research, is used in the calculator as an indicator of the power, which is needed for the processing of selected operation. Since the use of maximal possibilities of the machine is not recommended by the manufacturer, before determination of limitation, calculator calculates the spindle power of the machine that used, taking into account 30% of the reserve:

Type of the machine	1	2	3	4	5	…	14	15	16	Selection
	FV 56	DMU 50	DMU 35	DMC 63	DMC 635		XV 560	V 20	V 30	
		1								
Recommended momentum of the spindle, RPM	7500	7500	4725	6000	7500		7500	6000	7500	**7500**
Recommended Max Cutting feedrate mm/min	7500	6000	3750	6000	6000		7500	3000	3000	**6000**
Recommended Max холостая подача mm/min	36000	10000	30000	30000	20000		10000	10000	10000	**10000**
Spindle power (Kw)	11	9	10	11	8		11	7	7	**9**
Spindle power used by the machine, taking into account 30% of the reserve, kW:										**6.3**

Fig. 0.5 Spindle power of the selected machine with 30% reserve

Taking into account the determined value, calculator indicates the cutting modes, taking into account the possibility of the equipment. If the selected modes go over the capabilities of the machine, calculator makes correction.

Selection of optimal SECO manufacturer mill, for processing												
Mill parameters	**JS512**	**JS513**	JS514	JS520	JS532	JS534	**JS553**	**JS554**	JHP 950	**JHP 992**	JH141	JH970
Cutting modes, calculated with consideration of machine possibilities												
Recommended momentum of the spindle, RPM	**2588**	**2588**					**2986**	**2986**		**2986**		
Feed rate -V_f m/min	**415**	**495**					**402**	**458**		**688**		
Cutting depth -a_p, mm	**5**	**3**					**6**	**6**		**11**		

Fig. 0.6 Selection of optimal mill, with respect to possibilities of the CNC machine

Use of suggested calculator shortens the time for calculation of needed cutting modes dozens of times. The flexibility of the system with respect to changing conditions (purchase of new machine or cutting tool) unlimited and cost free. Control and maintenance of the calculator, can be carried out by anyone who has basic knowledge of metal processing and information technology.

4. Prospects for the calculator

4.1. Tool wear control

The entered parameter of processing efficiency – "cost" of 1 cm^3 of removed material, may serve as an indicator of tool wear.

Considering that tool life is equal to 15min [13]; knowing the price of the mill; determining cost of removed material - obtaining information can then be combined with information about the amount of metal removed per operation (this information typically can be obtained from modeling program).

Mill - JS553							
"Cost" of 1 cm3 of removed material, EUR	0,17 €	0,21 €	0,18 €	0,18 €	0,40 €	0,04 €	0,70 €
The amount of metal removed per operation, cm3	0,2	1,2	0,5	0,68	0,15	1,3	0,89
Tool wear per operation, EUR	0,03 €	0,25 €	0,09 €	0,12 €	0,06 €	0,05 €	0,62 €
Cutting tool price, EUR	110,40 €		Reserve of the cutting tool			**109,17 €**	

Fig. 4.1. Cutting tool wear control with help of introduced coefficient

4.2. Application of the entered coefficient for determination of production efficiency

Influence on the tool wear, which is made by selection of incorrect/not optimal cutting modes, was investigated in chapter 2. Taking in mind, that calculator helps to select optimal cutting modes, as well as optimal tool, from the ones that are available in the enterprise, economical effect of calculator can be estimated.

For this purpose, the following situation was researched:

Table 4.1. Information about the processing task

Lot size	100 pcs
Operation that has to be performed	Side milling (finishing)
Workpiece materials wekshtoff number	1.0037
Volume of the removed material per pcs	1.5 cm^3
Cutting modes are selected by	Technologist/Operator of CNC machine
Diameter of the mill	12 mm

- Option 1: Operator selects cutting tool and cutting modes, based on personal experience
    - Cutting modes were defined after consultation with CNC operator
- Option 2: Technologist selects cutting tool and cutting modes, based on the choice of calculator
    - Cutting modes were defined using developed calculator

Option 1

For operation – side milling-finishing, operator chosen mill JS513, substantiating the choice on the fact that selected mill is:

- main working tool on the selected CNC machine
- cheapest solid end mill, that is available at the manufactory, therefore lowest economical loss will be done, if selected modes are not optimal

Cutting modes that were chosen by operator:

- n = 5500 RPM
- V_f = 750 mm/min
- a_p = 18 mm
- a_n = 0.5 mm

Based on selected cutting modes:

$$v_c = \frac{5500\ x\ 3.14\ x\ 12}{1000} = 207.4\ m/min \tag{4.1}$$

$$Q = \frac{18\ x\ 0.5\ x\ 750}{1000} = 6.75\ cm^3/min \tag{4.2}$$

Option 2

After entering all needed data, in to the calculator, technologist receives information only on those mills, which can be used on selected machine and type of processing.

Received information:

Side milling – finishing: Mil parameters	JS513	JS514	JS553	JHP 992
The radius of the chamfer	0,12	0,12	1	0,2
Price of the mill, EUR	47,09	54,32	66,32	87,2
Cutting speed - V_c m/min	163	163	190	180
Feed rate -V_f m/min	468	930	1806	1031
Rotation frequency - n RMP	4326	4326	5042	4777
Feed per tooth - f_z mm	0,036	0,054	0,119	0,054
Cutting depth -a_p, mm	24	24	24	18
Cutting width -a_e, mm	0,91	0,90	1,82	2,40
Metal removal rate -Q cm^3/min	10,2	20,1	79,1	44,6
Metal removal rate -Q g/min	80,3	157,7	620,6	349,7
Effectiveness of the tool cm^3/EUR	3,3	5,5	17,9	7,7
"Cost" of 1 cm^3 of removed material, EUR	0,31	0,18	0,06	0,13
Required power, kW	0,8	1,4	4,2	2,7

Fig. 4.2 Selection of optimal SECO manufacturer mill, for processing

For operation – side milling-finishing, technologist would chose mill JS553, substantiating the choice on the fact that tool "cost" for 1 cm^3 of removed material is 0.06Eur (comparing to 0.31Eur for mill JS513), but for purpose of research, calculations will be made based on mill JS513 (this will give a possibility to compare tool ware, metal removal rate, ect.).

Based on information, that is shown in the calculator, selected cutting modes are:

- n = 4326 RPM
- V_f = 468 mm/min
- a_p = 24 mm
- a_e = 0.91 mm
- V_c = 163 m/min
- Q = 10.2 cm^3/min

To estimate effect, that calculator can offer, if using it at working enterprise, data of both options should be compared.

1. Operator of CNC machine, have chosen cutting modes that made influence on cutting speed. Since calculator gives optimal parameters, V_{c2} is considered to be optimal cutting speed, therefore, V_{c1} differs from optimal cutting speed:

$$\begin{Bmatrix} \text{Option 1}: v_{c1} = 207.4\frac{m}{min} \\ \text{Option 2}: v_{c2} = 163\frac{m}{min} \end{Bmatrix}, \rightarrow\ v_{c_1} was\ increased\ by\ 27.2\%$$

In accordance with Taylor's Equation for Tool Life Expectancy[2]:

$$127.2\% = \left(\frac{T_1}{T_2}\right)^{0.4}, \rightarrow T_2 = \frac{T_1}{1.272^{\frac{1}{0.4}}} = 8.22\ min \quad (4.3)$$

Based on the fact, that calculator provides information on optimal cutting modes, time of 15min for tool life in "option 2" is accepted [13].

Taking in mind, that lot size is equal to 100pcs, and 1.5cm^3 has to be removed from each part, total volume of the removed material is:

$$100pcs\ x\ 1.5cm^3 = 150cm^3 \quad (4.4)$$

Number of needed mills and cutting tool expenses for implementation of the task (considering that technologist would choose optimal tool for production, which is mill JS553):

$$\begin{Bmatrix} \text{Option 1}: \dfrac{150\ cm^3}{8.22 \min x\ 6.75\frac{cm^3}{\min}} = 2.7 \\ \text{JS553}: \dfrac{150\ cm^3}{79.1\frac{cm^3}{\min}} = 0.98 \end{Bmatrix}, \quad (4.5)$$

$$\rightarrow \begin{Bmatrix} 2.7\ x\ 47.09\ (price\ of\ the\ mill, EUR) = 127.14\ Eur \\ 0,98\ x\ 66.32\ (price\ of\ the\ mill, EUR) = 64.99\ Eur \end{Bmatrix} \quad (4.6)$$

Time expenditures for implementation of task:

[2] Information on Taylor's Equation for Tool Life Expectancy is presented in chapter 1

$$\begin{Bmatrix} \text{Option 1: } \dfrac{150\ cm^3}{6.75\ cm^3/\min} = 22.2min \\ \text{JS553 mill: } \dfrac{150\ cm^3}{79.1cm^3/\min} = 1.9min \end{Bmatrix} \tag{4.7}$$

Selection of the optimal tool and optimal cutting modes, would perceptibly influence production costs of the enterprise[3] in a positive way:

- Machinery expenses 22%; *metal processing of the workpiece can be completed 11.5 times faster. Therefore CNC machine utilization can be increased and productivity of the machine would raise as well.*
- Labor cost 30%; *metal processing of the workpiece can be completed 11.5 times faster. Therefore same amount of labor hours, can produce bigger volumes of parts.*
- Cost of the cutting tool 13%; *selection of optimal mill and cutting modes, would reduce the cost of the cutting tool for operation by 50%.*
- Taking in to account that for medium complexity part, time consumption for calculation of cutting parameters manually is equal to 1 hour, when calculation of parameters with calculator is equal to 10min (considering that input of information in to the calculator will take 30 seconds for one operation), time consumption for calculation of cutting parameters will decrease six times.

[3] Data is taken from SECO Tools research on production optimization and reduction of manufacturing costs – chapter 1

Conclusions

1. Research of systems that are currently used for selection of cutting tool and calculation of cutting modes was done. Based on the research, the followings for optimization were determined: efficiency of metal processing; time consumption for development of technological process for machining on CNC machine; selection of optimal tool; selection of optimal cutting parameters.

2. Importance and influence on total production process of selected factors for optimization was determined. Importance determination was based on the results of studies that were carried out by reliable sources:

- effective work zone determination, which was presented by Sandvik Coromat cutting tool manufacturer, was used for determination of optimal cutting modes selection;
- Taylor's Equation for Tool Life Expectancy, was used for investigation of tool wear; afterword this information was used to evaluate economical factor of unforeseen tool wear.

3. Main factors that influence metal processing on CNC machine were researched:

- reference data about CNC machines that is available at Example Company was collected. This information was used in the developed calculator.
- an information about workpiece material classification that is used by SECO tools was correlated with Werkshtoff numbering system used in Example Company. Correlation result, was used for determination of machinability of processed material by calculator.
- reference data about cutting tools (mills) was collected and systemized in the way, that helped to find needed parameters for metal processing in much faster way;

4. Research that was carried out, gave possibility to introduce not just calculator for CNC operator, but production planning tool for technologist as well. Calculator provides an opportunity to select not just suitable tool, but most optimal tool and cutting modes for it. Development gives possibility to choose optimal tool based on: cutting speed, feed rate, metal removal rate, tool efficiency, and cost of tool that is spent to remove 1 cm^3 of material. Developed calculator has possibility to supplement its data base in an easy way, this option will keep calculator relevant for a long period of time.

5. Calculations were carried out, to evaluate effectiveness of calculator and enable:

- using cutting parameters that are provided by calculator, to ensure possibility to reduce cutting tool expenses up tp 50%
- using technological parameters, which are suggested by calculator, to ensure productivity of CNC machine, since same operation can be performed 11.5 times faster.
- to reduce time that is spent for selection of cutting tool and processing modes, to 10 minutes, instead of 1 hours that would be consumed if calculating cutting parameters manually.

6. Productivity effectiveness parameter was introduced. Accepted criterion determines not only the effectiveness of the processing, but also simplified the calculation of the prime cost, as the data on tool wear, is calculated immediately in the calculator.

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Appendices

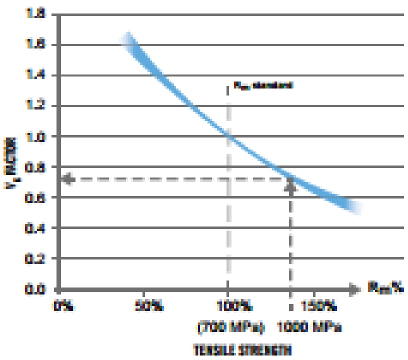
Appendix no 1. Classification of workpiece materials SECO tools system – SMG V2.

DETERMINING PRECISE CUTTING PARAMETERS USING THE CUTTING DATA FACTOR – SAMPLE WORK MATERIAL 42 CRMO 4

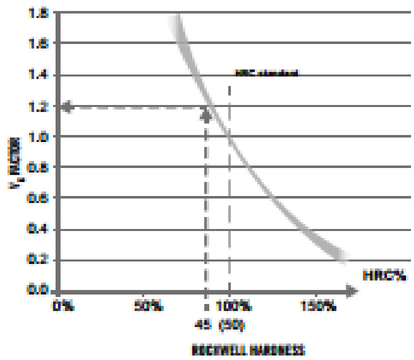
The reference work material 42 CrMo 4 can be assigned to both SMG P5 and SMG H5, depending on the condition (either annealed or hardened). If the tensile strength is below $R_m = 1200$ N/mm², the work material is assigned to material group SMG P5. A hardness of 38 HRC upwards (which equates to a tensile strength of $R_m = 1200$ N/mm²) means 42 CrMo 4 is classified as material group SMG H5.

Depending on the tensile strength or hardness of the work material, the cutting data factor is adjusted for a reference work material that has been tempered (R_m curve – left-hand diagram for ISO P) and for one that has been hardened (HRC curve – right-hand diagram for ISO H).

ISO P – ADAPTING THE CUTTING SPEED



ISO H – ADAPTING THE CUTTING SPEED



THE SIMPLE WAY TO DETERMINE CUTTING DATA – USING EXAMPLE OF 42 CRMO 4 ISO P, TENSILE STRENGTH BELOW 1200 N/MM²

The tensile strength R_m of the work material to be machined plays a crucial role in being able to calculate the cutting speed (corresponding to the bead structure) more accurately.
In the SMG P5 material group, the nominal cutting speed at a tensile strength of $R_m = 700$ N/mm² is $v_c = 280$ m/min. A sample tensile strength of $R_m = 1000$ N/mm² therefore produces a v_c factor of 0.75, resulting in a recommended cutting speed of $v_c = 210$ m/min (280 m/min x 0.75).

ISO H – FROM A HARDNESS OF 38 HRC UPWARDS (= 1200 N/MM²)

The same calculation is used to adjust the nominal cutting speed of the hardened work material 42 CrMo 4.
In the SMG H5 material group, the nominal cutting speed at a hardness of 50 HRC is v_c = 50 m/min. A sample hardness of 45 HRC therefore produces a v_c factor of 1.2, resulting in a recommended cutting speed of $v_c = 60$ m/min (50 m/min x 1.2).

Appendix no 2. Indicators of machinability of material

Ultimate tensile strength (UTS), often shortened to tensile strength (TS) or ultimate strength,[1][2] is the maximum stress that a material can withstand while being stretched or pulled before failing or breaking. Tensile strength is not the same as compressive strength and the values can be quite different.

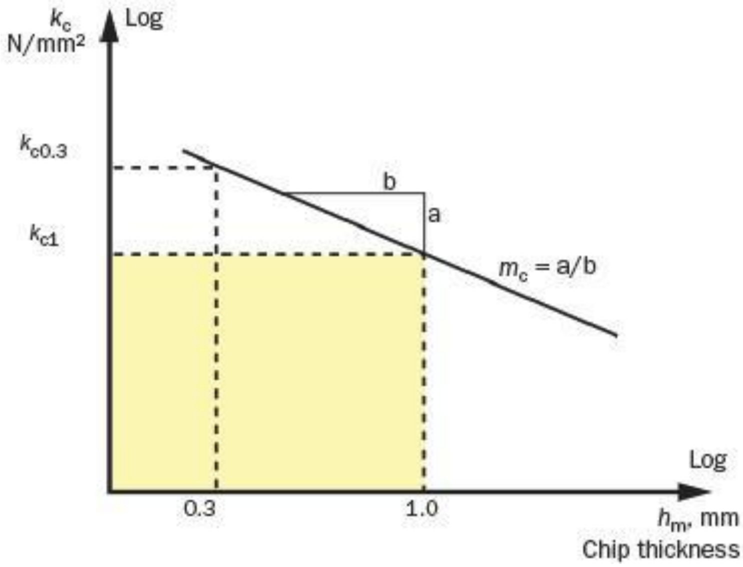
Specific cutting force kc N/mm2

For power, torque and cutting force calculations, the specific cutting force, or kc1, is used. It can be explained as the force, Fc, in the cutting direction (see picture), needed to cut a chip area of 1 mm² that has a thickness of 1 mm. The kc1 value is different for the six material groups, and also varies within
each group.

The kc1 value is valid for a neutral insert with a rake angle, $\gamma 0$, = 0°; other values must be considered to compensate for this. For example, if the rake angle is more positive than 0 degrees, the actual kc value will decrease, which is calculated with this formula:

Specific cutting force (kc)
(N/mm²)

$$k_c = k_{c1} \times h_m^{-m_c} \times \left(1 - \frac{\gamma_0}{100}\right)$$



If the actual chip thickness, hm, is, for example, 0.3 mm, the kc value will be higher, see diagram.

Exponent used for calculating power demand – m_c

Appendix no 3. Technical information about mill

Measurement drawing should be read as follows:

dm_m = Shank diameter

D_c = Milling cutter diameter

m = Minimum clamping length

l_2 = Total length

l_3 = Maximum milling cutter depth

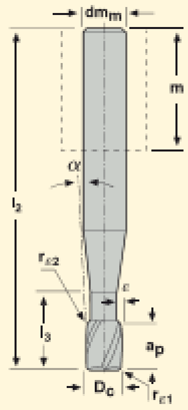
a_p = Effective cutting length

$r_{\varepsilon 2}$ = Radius behind the cutting edge

$r_{\varepsilon 1}$ = Corner radius

ε = OD Reduction per side

α = Maximum angle of attack (engagement angle)



Calculating the power demand

$$P_c = \frac{a_e \cdot a_p \cdot v_f}{60\,000\,000 \cdot \eta} \quad \kappa_c$$

p_c = Power (kW)

a_p = Depth of cut (mm)

a_e = Width of cut (mm)

v_f = Feed speed (mm/min)

η = Efficiency

κ_c = Effective cutting length

Appendix no 4. Formulas for calculation of cutting mode

Nomenclature and formulae:

RPM

$$n = \frac{v_c \cdot 1000}{\pi \cdot D_c} \quad \text{(rev/min)}$$

Cutting speed

$$v_c = \frac{n \cdot \pi \cdot D_c}{1000} \quad \text{(m/min)}$$

Feed speed

$$v_f = n \cdot z_n \cdot f_z \quad \text{(mm/min)}$$

Feed per revolution

$$f = z_n \cdot f_z \quad \text{(mm/rev)}$$

Metal removal rate

$$Q = \frac{a_e \cdot a_p \cdot v_f}{1000} \quad \text{(cm}^3\text{/min)}$$

Cutting speed and RPM for copying

$$v_c = \frac{n \cdot \pi \cdot D_w}{1000} \quad \text{(m/min)}$$

$$n = \frac{v_c \cdot 1000}{\pi \cdot D_w} \quad \text{(rev/min)}$$

$$D_w = 2 \cdot \sqrt{a_p (D_c - a_p)} \quad \text{(mm)}$$

Calculation of a_p vs. overhang length

If the overhang length is longer than 4 x D_c and Cylindrical shanks are used it is important to adopt another depth of cut (a_p) value than indicated in the table.
Use the following formula to calculate the new a_p value

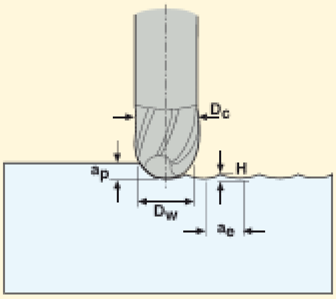
$$a_p \text{ (new)} = a_p \text{ (catalogue)} \times \left(\frac{4 \times D_c}{\text{New overhang length}} \right)^2$$

a_e	=	Width of cut, radial depth of cut	(mm)
a_p	=	Depth of cut, axial depth of cut	(mm)
D_c	=	Cutter diameter	(mm)
f	=	Feed per revolution	(mm/rev)
f_z	=	Feed per tooth	(mm/tooth)
z_n	=	Number of teeth	
n	=	RPM	(rev/min)
Q	=	Metal removal rate	(cm^3/min)
v_c	=	Cutting speed	(m/min)
v_f	=	Feed speed	(mm/min)
D_w	=	Working diameter	(mm)
la_m	=	Max. cutting depth rel. to	

Profile height

$$H = \frac{D_c}{2} - \frac{\sqrt{D_c^2 - a_e^2}}{2}$$

$$D_w = 2 \cdot \sqrt{a_p (D_c - a_p)} \quad \text{(mm)}$$



Profile height H (μm)
Pitch a_e (mm)

D_c	0,06	0,08	0,11	0,15	0,2	0,3	0,45
1	0,90	1,6	3,0	5,7	10	23	53
2	0,45	0,80	1,5	2,8	5,0	11	26
4	0,23	0,40	0,76	1,4	2,5	5,6	13
6	0,15	0,27	0,50	0,94	1,7	3,8	8,4
8	0,11	0,20	0,38	0,70	1,3	2,8	6,3
10	0,09	0,16	0,30	0,56	1,0	2,3	5,1
12	0,08	0,13	0,25	0,47	0,83	1,9	4,2