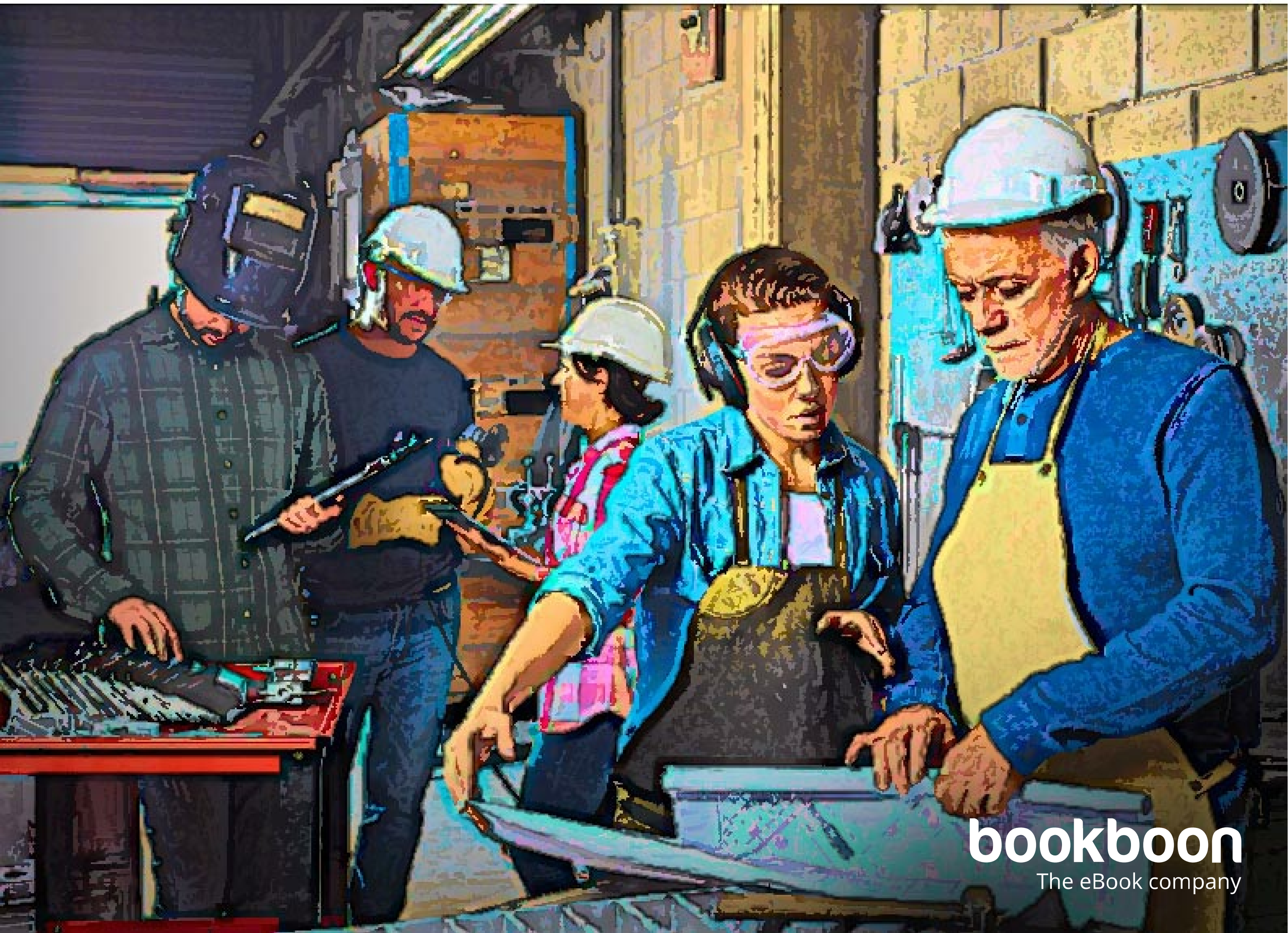
Dieter Hartrampf

Work Planning in Production



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DIETER HARTRAMPF

WORK PLANNING IN PRODUCTION

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ABOUT THE AUTHOR

Dipl.-Ing. (FH) Dieter Hartrampf, born in 1958, has been an academic staff member of the Technical University Wildau (Brandenburg, Germany), in the Industrial Engineering department, since 2010.

He teaches in the full-time and extra-occupational studies in the subject areas production preparation, facility design as well as production planning and control in the study courses of Industrial Engineering, Mechanical Engineering, Aeronautical Engineering / Aviation Logistics and Traffic System Technologies.

After receiving his “Abitur”-certificate, accomplishing an apprenticeship as a lathe operator and practical work in the “Berliner Metallhütten und Halbzeugwerk” steel plant in Berlin, he began to study the Technology of Manufacturing Industry at the Engineering School for Mechanical Engineering in Wildau.

Since 1986 Dieter Hartrampf is a member of the Engineering School (later Technical University) Wildau, as an engineer for teaching and research, in the study programs Mechanical Engineering and Industrial Engineering.

His later activity as an academic staff member is characterized by lectures, seminars, laboratory exercises, but also through responsible participation in industrial assignments, the organization of courses for students in the lecture-free time at the Technical University Wildau (REFA, MTM) and publications in the form of teaching letters especially for extra-occupational studies.

PREFACE

This book is intended for students of the natural and engineering sciences, especially from the departments of Mechanical and Industrial Engineering, as well as students of Business Administration and Logistics.

Therefore, the book is designed as a goal-oriented guide to systematically further the understanding of the individual steps of the work planning process. The main focus lies on the contents of the short-term and medium-term work planning (bill of materials administration, work plan creation, CNC programming and calculation) within the operations scheduling.

The main content of the long-term work planning, the investment and facility planning, is described in the e-book "Modern Facilities (Factory) Planning".

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The selection of topics and contents was strongly oriented towards company practice. The book was written within the framework of lectures, seminars and laboratory exercises, which the author has been holding for years at the Technical University Wildau in the subject area "Production Preparation", but also from the experience gained from industrial assignments and the supervision of diploma and bachelor theses.

This book was originally written in German and has been translated into English. Since the word formation and sentence structure of both languages are fairly dissimilar, the content matter could not be translated verbatim. Because of that, especially the technical terms have been subject to rephrasing.

Translation by:

Tobias Wittek, B.Eng.

INTRODUCTION

According to the AWF (Ausschuss für wirtschaftliche Fertigung e.V. [German]; transl.: Committee of Economic Manufacturing), work preparation comprises planning and control tasks (work planning and work control) with all their inevitable monitoring functions.

Work planning is an essential link between the product design and the production department.

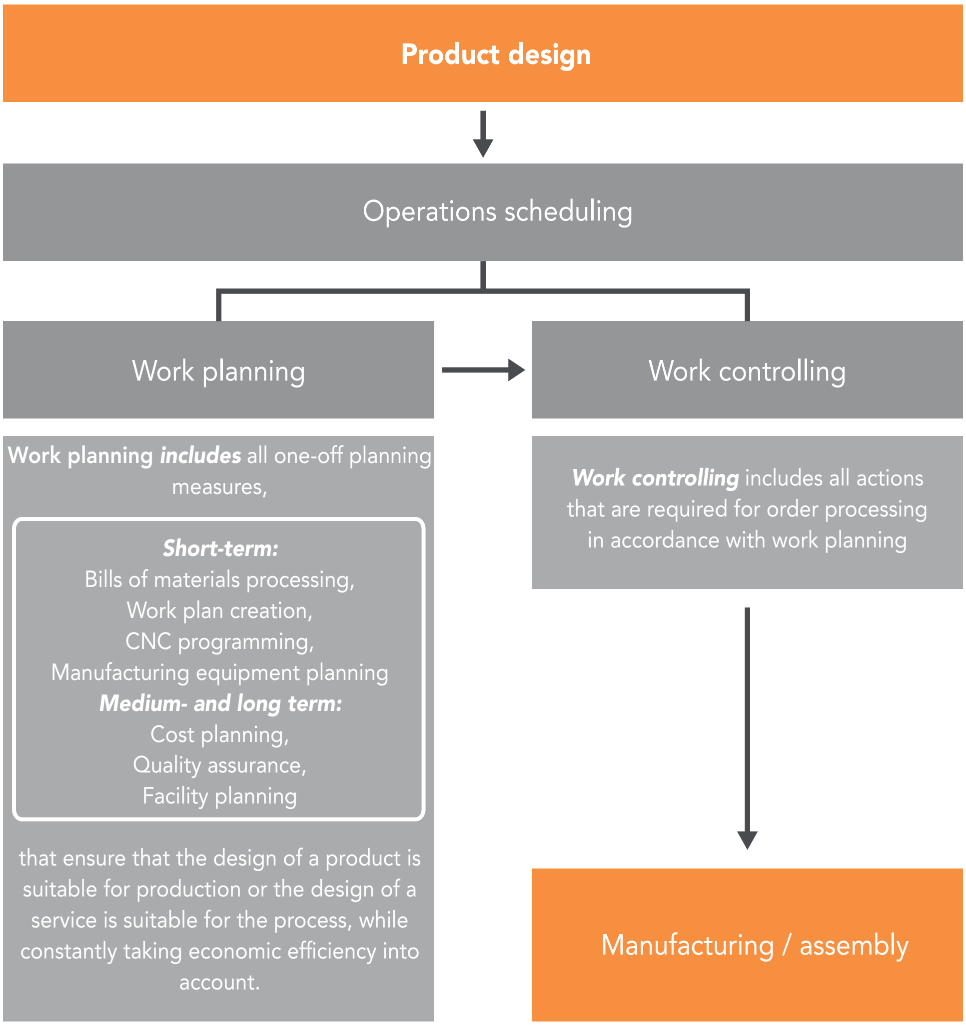


Figure 1 Contents of operations scheduling

While the design department determines the products in terms of their design and function, the main task of work planning is to determine the manufacturing of these products. In addition to the necessary machining and assembly steps, it also determines the necessary operating equipment, such as plants, jigs and tools. This book conveys classic contents of work planning in a condensed form.

The main content of the short-term work planning, the preparation of a work plan, is explained in Chapter 2, whereby the necessary steps for the preparation of the work plan, the blank calculations, the selection of operating equipment, the determination of technological data and the calculation of target times are discusses here.

Basic terms on product structure, drawing contents and bill of materials formats are briefly described in Chapter 1.

Chapter 3 focuses on the programming of machine tools according to DIN and PAL. Finally, there is a compilation of important information on accounting (Chapter 4), with the emphasis here on costing.

1 SET OF DRAWINGS

In this introductory chapter you will get to know:

- the documentation of product information (technical documentation) as a basis for creating work plans
- the subdivision of a product into a product breakdown and its graphic representation
- types and contents of drawings, bills of materials and parts where-used lists, as well as their use in production planning

DIN 6789 (Deutsches Institut für Normung [German]; transl.: German Institute for standardization) describes the basic terminology for document systematics. According to this DIN, a technical product documentation is the totality of technical documents produced during the lifetime of a product. Typically, products consist of a large number of assemblies and components.

Under DIN, the set of drawings is a set of documents consisting exclusively of drawings. In practice, however, the set of drawings created in the design department (see Chapter 1.2) is supplemented with the set of bills of materials (see Chapter 1.3) and referred to as the set of drawings for a product.

1.1 PRODUCT CLASSIFICATION

Products are manufactured by assembling in-house production parts or assemblies and purchased parts or assemblies. Therefore, according to DIN 199 (this DIN was withdrawn, replaced and extended by DIN 6789 and DIN EN ISO 10209:2012-11), a product is referred to as a "usable or saleable item resulting from production" (own translation). As a rule, products consist of a large number of assemblies and components. Depending on the point of view, products are also called final products. According to DIN 6789, sometimes a product consists of only one single component, or a certain group is available both as an independent product and for fitting into other products. Below, the product breakdown via several disposition levels is explained.

The product structure is the totality of the relationships between the assemblies, individual components (in-house production, purchased parts) and blanks (as per DIN 6789) defined according to a certain aspect. Figure 2 shows an example of a product structure according to the aspects of assembly (see also Figure 7 in Chapter 1.3.1) in form of a schematic diagram. This representation is mainly used in the assembly process.

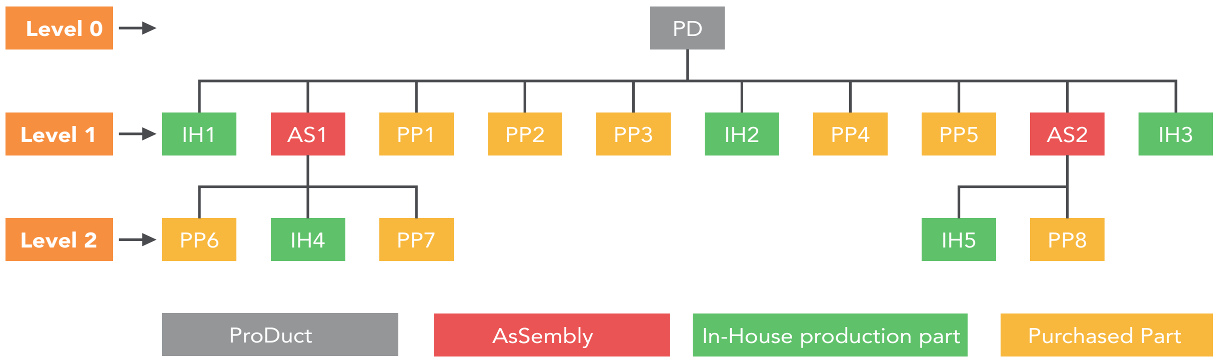


Figure 2 Product structure according to the aspects of assembly

In-house production parts are finished parts (objects in functional or ready-to-install condition), own (possibly also external) development and own production. In the case of purchased parts, also known as third-party parts, the responsibility for development and production lies with the external company. The object of own development, but external production is called outsourced production.

To determine the required quantities or requirements (e.g. for quantity planning and costing within production planning and control), products are displayed according to the aspects of materials planning and control. The low-level code for a part is the structural level within an assembly-oriented product structure at which this part occurs for the first time, when viewed from the lowest structural level.

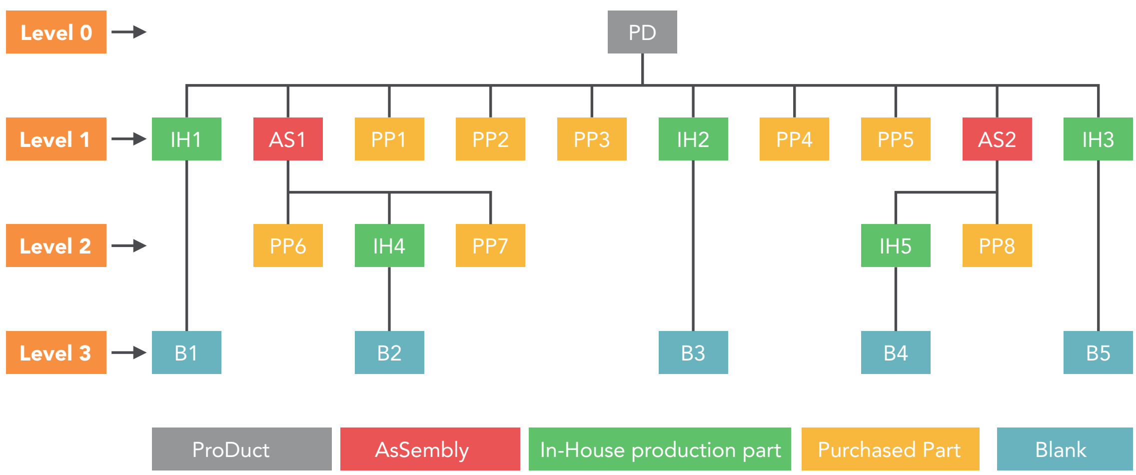


Figure 3 Product structure according to materials planning aspects

Figure 3 shows the product structure (including the blanks for the in-house production parts) from the point of view of materials planning and control. Blanks are usually non-cutting parts (e.g. forgings or castings, see Chapter 2.2.2 "Blank calculations") which are further processed.

1.2 DRAWINGS

Technical drawings as part of the product documentation contain the necessary information for the production and description of individual parts, as well as all information for the assembly of assemblies and products, in both graphical and written form. Generally, they do not contain any customer-related or order-related data.

Apart from the scaled graphic representation of the geometry consisting of lines, supplemented by measurements and tolerances (geometric information), a drawing contains technological information (e.g. surface finish) and organizational information. The organizational information (e.g. scale and drawing number) is largely contained in the title block. The standard DIN EN ISO7200 regulates the design of title blocks.

In addition to the individual part drawings and assembly drawings described below, there are other types of drawings, such as manufacturing drawings (with all the information required to manufacture the item depicted in the drawing), third-party drawings (containing information for ordering, installing and testing the third-party part) and test drawings (with information for testing the item depicted in the drawing).

A technical drawing which, in contrast to an assembly drawing, represents an individual part without any spatial assignment to other parts, is called an **individual part drawing**.

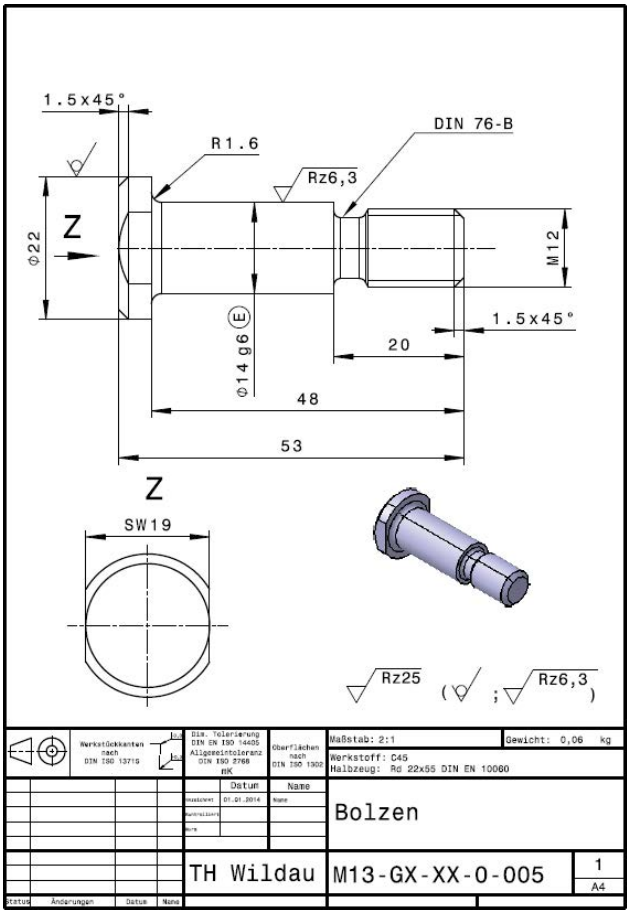


Figure 4 Individual part drawing "Bolzen"

The individual part drawing shown in Figure 4 shows the item "Bolzen" which can be found under item number 5 in the assembly drawing of the product "Spannvorrichtung" (see Figure 5).

An **assembly drawing** serves to explain the spatial position and number of parts especially for the assembly process.

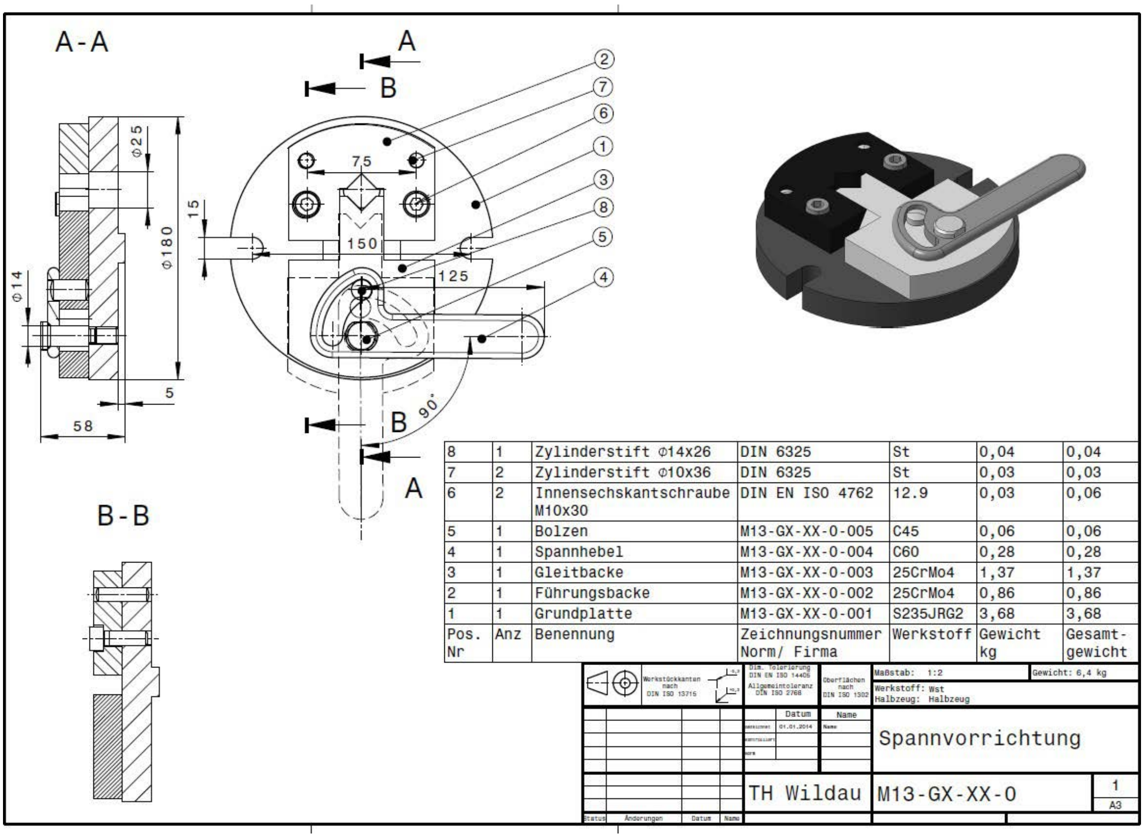


Figure 5 Assembly drawing of the product "Spannvorrichtung"

In a blow-up drawing, also known as an **exploded drawing**, a complex product is disassembled into its individual parts and assemblies and displayed spatially separated from each other.

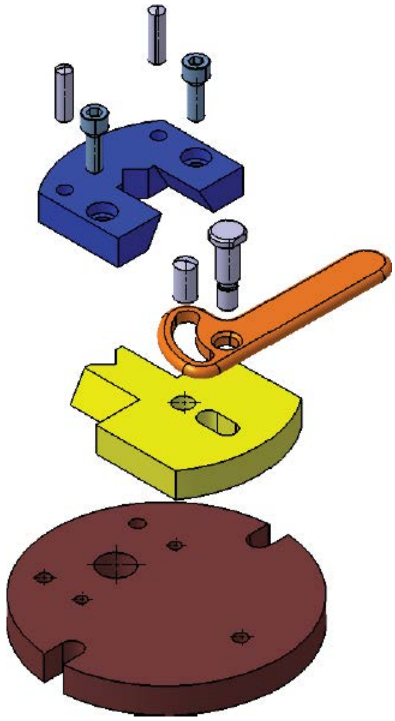


Figure 6 Exploded drawing of the product "Spannvorrichtung"

Figure 6 shows the uniqueness of this type of drawing. An exploded view shows the interrelation between the product and its parts as well as their position, so that the function and assembly of the assemblies and individual parts are clearly visible in this type of representation.

According to DIN 6789, a set of drawings is a set of documents consisting exclusively of drawings, which is handled either independently or as part of comprehensive documentation. In order to describe a product in detail, this set is supplemented by the set of bills of materials, which is described in more detail in the following chapter.

1.3 BILLS OF MATERIALS

A parts list is a list of assemblies, subassemblies and individual parts (with their associated unmachined parts), stating their name, identification number (if applicable also item number in the assembly drawing, material and weight, see Figure 5) and quantity contained in a product.

The order- and production-neutral design bill of materials always refers to the quantity 1 of the product. It is used to derive other types of bills of materials, such as production and assembly bill of materials, variant bill of materials, and costing bill of materials.

The following describes the structure of the different types of bills of materials, the determination of demand using the bills of materials explosion method, and the contents of a parts where-used list.

1.3.1 TYPES OF BILLS OF MATERIALS

Bills of materials are divided into types according to their arrangement (structure and display of levels).

Using the example of the product "roller base" (assembly drawing and product breakdown, see Figure 7), the types quantity bill of materials, structured bill of materials and single-level bill of materials are explained below.

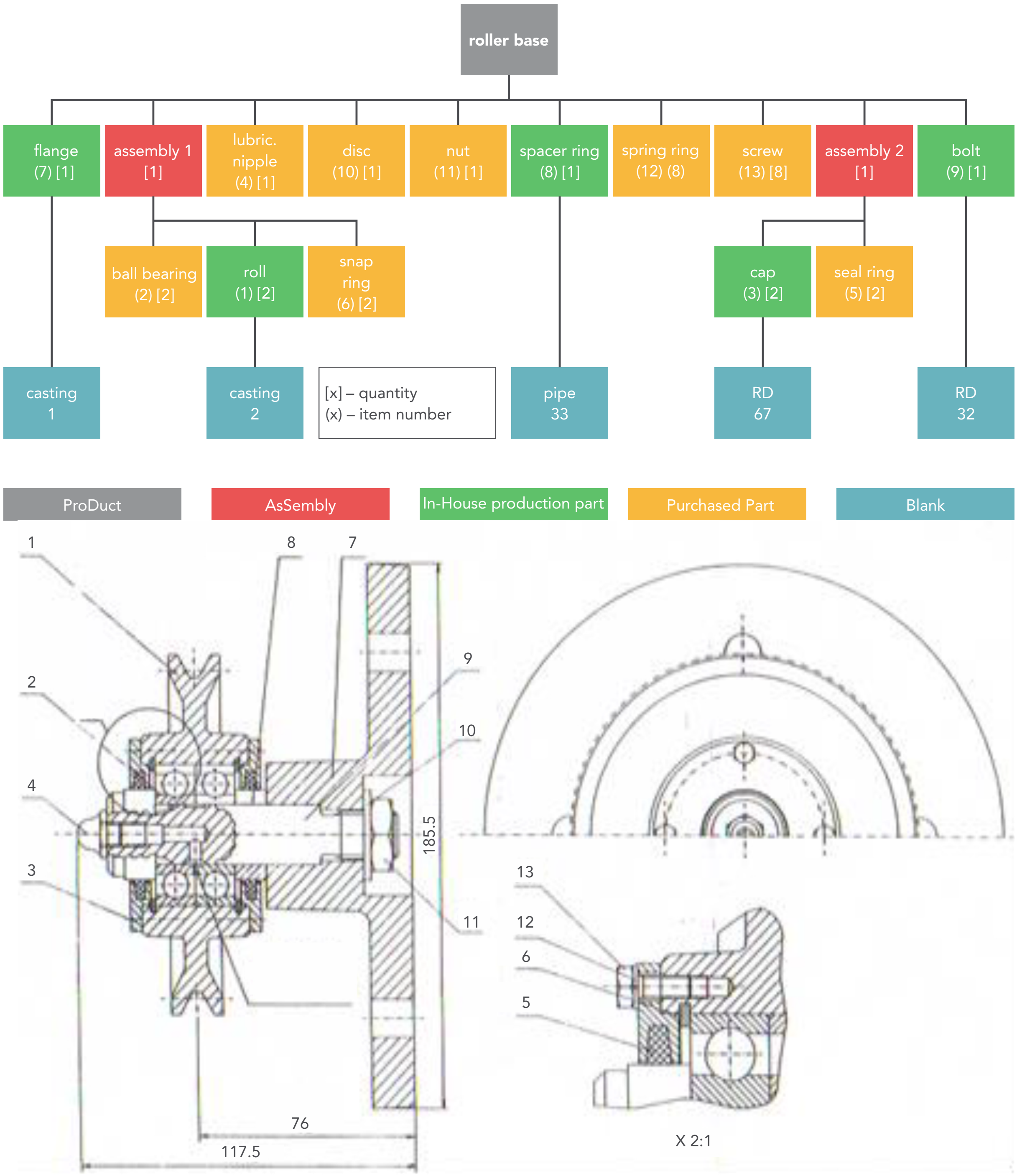


Figure 7 Product "roller base"

The **quantity bill of materials**, also known as the quantity overview bill of materials, does not show the element structure of the product. Each component appears only once in the list along with its total quantity.

Therefore, this type of bill of materials is suitable for procurement and can be used partially for costing. The quantity bill of materials for the product "roller base" (see Figure 7) shown in Table 1 contains assemblies and individual parts, whereby the corresponding blanks are assigned to the in-house production parts.

Product "roller base" – quantity bill of materialsmaterials			
Position	**Assembly / part**	**Quantity**	**Blank**
	assembly 1	1	
	assembly 2	1	
1	roll	2	casting 2
2	ball bearing	2	
3	cap	2	RD 67
4	lubricating nipple	1	
5	seal ring	2	
6	snap ring	2	
7	flange	1	casting 1
8	spacer ring	1	pipe 33
9	bolt	1	RD 32
10	disc	1	
11	nut	1	
12	spring ring	8	
13	screw	8	

Table 1 Quantity bill of materials

A **structured bill of materials** (multi-level) shows the product structure with its manufacturing stages, that is, the classification of the components. The product (or assemblies and sub-assemblies) is broken down into all its sub-assemblies and individual parts. Components of the same type can appear several times (but at different positions) in the list. The list therefore becomes confusing for complex products. The structured bill of materials is common in product design and production planning, but also in manufacturing, costing, and quality control. Table 2 shows the structured bill of materials of the product "roller base" (see Figure 7); the allocation of assemblies and individual parts to the corresponding levels becomes apparent here.

Product "roller base" – structured bill of materials							
Level			Assembly / part	Position	Quantity	Blank
1	2	3				
X			assembly 1		1	
	X		ball bearing	2	2	
	X		roll	1	2	casting 2
	X		snap ring	6	2	
X			assembly 2		1	
	X		cap	5	2	RD 67
	X		seal ring	5	2	
X			flange	7	1	casting 1
X			lubricating nipple	4	1	
X			disc	10	1	
X			nut	11	1	
X			spacer ring	8	1	pipe 33
X			spring ring	12	8	
X			screw	13	8	
X			bolt	9	1	RD 32

Table 2 Structured bill of materials

Single-level bills of materials divide the parts into their assemblies. They only contain assemblies, subassemblies, and individual parts of the next lower structural level. There must be a single-level bill of materials for each assembly. The bills of materials are therefore arranged in a hierarchy and contain only one level. They are used in the assembly process and in production planning. It is possible to derive the other two types of bills of materials from the single-level bill of materials. The 3 single-level bills of materials required for the representation of the product "roller base" (see Figure 7) can be found in Table 3.

Product "roller base" – single-level bill of materials		
Position	**Assembly / part**	**Quantity**
	assembly 1	1
	assembly 2	1
4	lubricating nipple	1
7	flange	1
8	spacer ring	1
9	bolt	1
10	disc	1
11	nut	1
12	spring ring	8
13	screw	8
Assembly 1 – single-level bill of materials		
Position	**Assembly / part**	**Quantity**
1	roll	2
2	ball bearing	2
6	snap ring	2
Assembly 2 – single-level bill of materials		
Position	**Assembly / part**	**Quantity**
3	cap	2
5	seal ring	2

Table 3 Single-level bills of materials

Within production planning, the product is introduced in the form of a single-level bill of materials. Internally, the structured bill of materials and the quantity bill of materials are then generated automatically. The input through single-level bills of materials also has the advantage that certain assemblies contained in several products only have to be entered once. The input of the raw materials is an absolute necessity for the calculation, but also for the procurement of the blanks on the start dates determined in the lead time scheduling. This will be explained in detail in the following chapter.

1.3.2 DETERMINATION OF DEMAND USING BILLS OF MATERIALS EXPLOSION

Bills of materials explosion, as a step in determining demand, is an evaluation of bills of materials in which the required quantities of objects (assemblies, individual parts, and blanks) for the production of a product are determined.

Based on the quantity of the product to be produced (**primary demand**, for such as a sales order), the bills of materials explosion determines the quantity of all required assemblies, individual parts (in-house production parts and purchased parts), and raw materials. This determination of the **secondary demand** is also called demand planning. The necessary auxiliary and operating materials are referred to as **tertiary demand** (see Figure 8). According to the existing stock, a breakdown into gross and net demand is made.

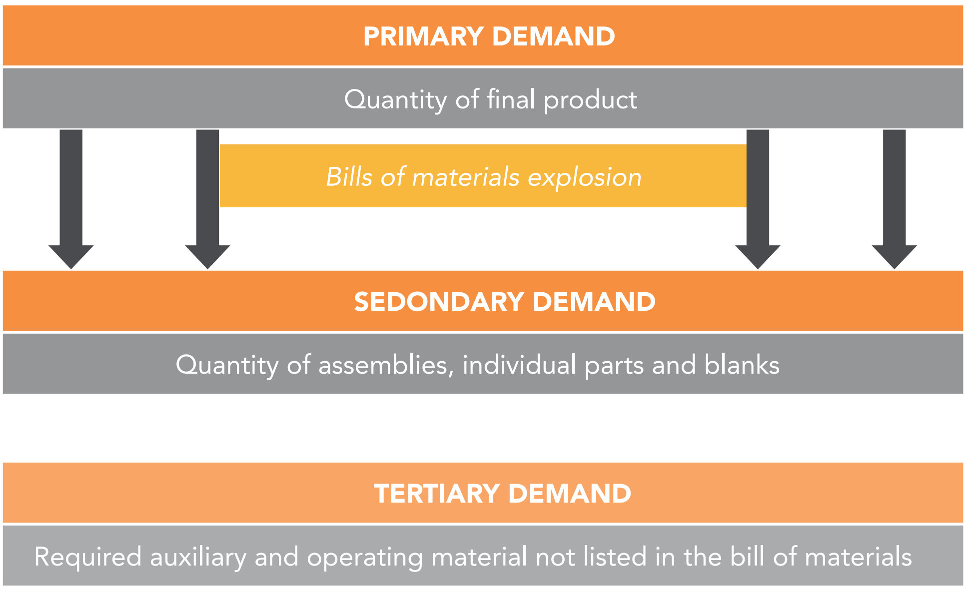


Figure 8 Types of demand

Within production planning, entering the in-house production parts creates the basis for the following planning of the lead time of the order (lead time planning), which starts after the demand planning has been carried out.
The input of purchased parts is necessary to ensure that the times determined in the lead time planning for the procurement of the purchased parts for assembly are met. In order to carry out the costing and to plan the purchase order of the blanks according to the start dates for the production of the individual parts as determined in the lead time scheduling, it is essential to input the raw materials.

Product "roller base"	Quantity	Flange	Quantity
assembly 11	1	casting 1	1
assembly 2	1		
lubricating nipple	1	**Roll**	**Quantity**
flange	1	casting 1	1
spacer ring	1		
bolt	1	**Spacer ring**	**Quantity**
disc	1	pipe 33	Ø67X10
nut	1		
spring ring	8	**Cap**	**Quantity**
screw	8	RD67	Ø67X10
Assembly 1	**Quantity**		
roll	2	**Bolt**	**Quantity**
ball bearing	2	RD32	Ø32X105
snap ring	2		
Assembly 2	**Quantity**	in-house production part	raw material
cap	2		
seal ring	2		

Table 4 Single-level bill of materials (incl. raw materials)

The determination of demand within a production planning and control system is carried out by entering single-level bills of materials for a product, from which the quantity bill of materials, the structural bill of materials and the parts where-used list (see Chapter 1.4) are generated computer-internally. In order to carry out the costing and to plan the purchase order of the initial parts at the start dates determined in the following lead time scheduling, it is essential to input the raw materials. Table 4 contains the necessary 8 single-level bills of materials of the product "roller base" including the pipe parts in order to plan and control the product.

1.4 PARTS WHERE-USED LIST

According to DIN 199, the where-used list for a part number is a directory that lists *all* items grouped according to certain criteria in each of which this part number is or may be contained. Accordingly, there are, for example, material where-used lists and parts where-used lists.

In contrast to the analytical structure (consisting of a dependency) in a bill of materials, a **parts where-used list** specifies synthetically in which products the individual components are contained (focuses on dependency → in which products a particular part or assembly is contained?).

Similar to the types of bills of materials, a distinction is made between quantity parts where-used lists, structure parts where-used lists and single-level parts where-used lists.

Within production planning and control systems, the parts where-used lists are automatically generated after the input of the single-level bill of materials. The procurement department carries out a where-used list, if in case of defects or delivery delays it has to be determined which orders along with which quantities are affected and which priorities have to be set for the elimination of delivery bottlenecks.

This applies, for example, to product recalls in the automotive industry and in the food sector. This is also of interest for the design department; the parts where-used list can be used, for example, to determine the effects of a design change.

Exercise for Chapter 1:

Create according to the product breakdowns in the following figure:

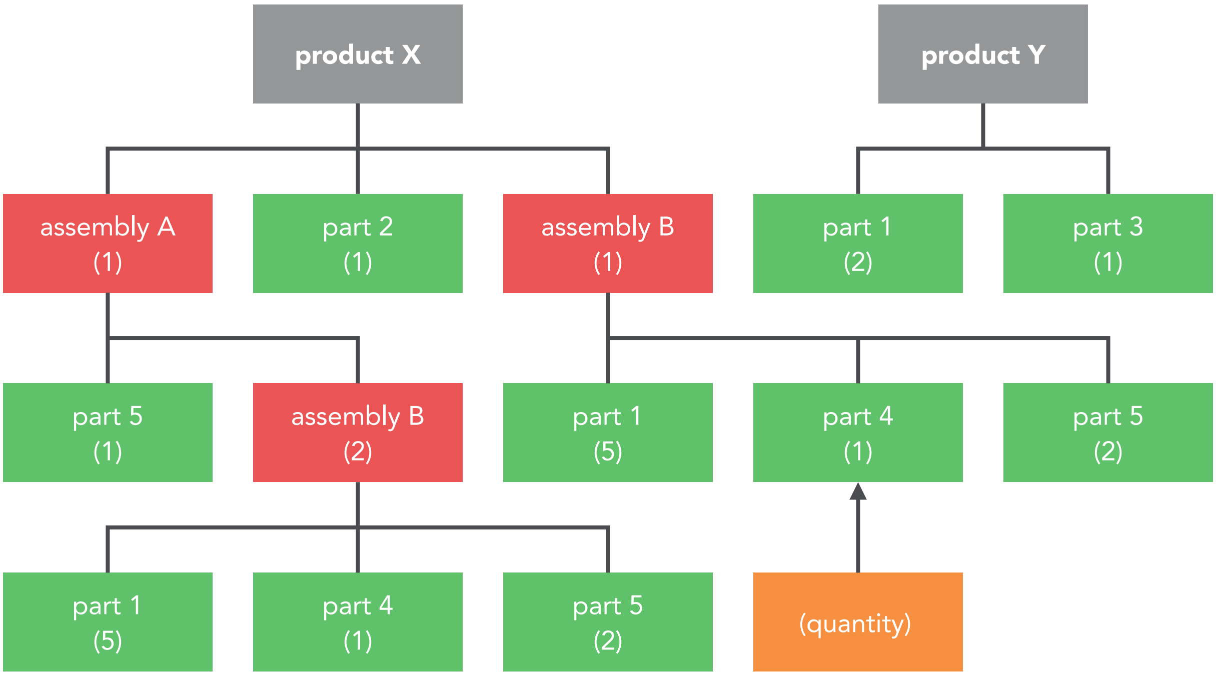


Figure 9 Product breakdown for exercise in Chapter 1

a. the structured bill of materials for product X.
b. the quantity bill of materials (without assemblies) for product X.
c. the single-level bill of materials for product X.
d. the quantity parts where-used list for the part 1 in products X and Y.

2 WORK PLAN CREATION

In this chapter you will get to know:

- content and areas of application of the work plan
- methods and steps for creating a work plan
- determination of technological data
- creation of manufacturing specifications and calculation of target times

The product-related information contained in the set of drawings (see Chapter 1) forms the basis for creating the work plan. This information, as well as data on machines, tools, jigs and output materials, serves as the foundation for creating an order-independent work plan (basic or master work plan).

2.1 BASICS FOR THE WORK PLAN

In practice, a standardized template of a work plan does not exist; it is usually divided into the areas header zone, material zone, and work sequence zone (see Figure 10).

Data in the header zone (general information about the work plan):

Company, division, work plan number, creator, creation date, modification date, description, part number, drawing number, part family, economic and time-minimal batch size (see Chapter 4.2).

Data in the material zone (definition of the initial state of the part):

Material, dimensions and weight of the blank. The weight of the finished part can be found in the drawing of the individual part but is sometimes also included in the work plan.

Data in the work sequence zone for each work process:

Work process number, workstation, workstation group (cost center), process description, tools (jigs, utilities), target times (t_s and t_u with time unit, usually in minutes – see Chapter 2.2.5), hourly machine rate and wage cost rate (see Chapter 4.1), if applicable also wage group, multiple station work (factor for multiple machine operation).

Header zone

Designation: Part No.: Drawing No.:	Kupplungsscheibe 1:06:2019 1:04:2019.01	Filed: Work plan No.: Economic batch size:	12.06.2019 Mustermann 0023-2019 123 parts/batch

Material zone

round steel D = 180mm,
blank lenght = 125mm

Material: C45	Blank: Rd 180X125	Blank mass: 25 kg

Work sequence zone

work process · set-up time · time per unit · hourly machine rate wage cost rate · factor for multiple machine operation

WP No.	Workstation	Cost center	WP description	t_s [min/batch]	t_u [min/unit]	M_h [€/h]	W_h [€/h]	f_{MMO}
10	060302	1901	Sawing l=125mm	10	6.1	14.25	12.90	0,57
20	010201	1105	turning	55	13.5	30.20	17.10	1
30	020301	1106	drilling	45	7.5	16.86	17.10	1
40	070610	1310	grinding	55	6.2	69.20	18.20	0,57
45	151100	3000	inspection	10	2.3	20.30	20.20	1

Figure 10 Contents of a work plan

The information contained in the work plans is used in the company both in manufacturing and in assembly, but also in sales, in quality management, in materials management, in business administration (costing - see Chapter 4.3, wage calculation, calculation for the comparison of variants) and in the organization of production (production planning and control), as well as in factory planning (see e-book “Modern Facilities (Factory) Planning”).

The manufacturing type is decisive for the accuracy of the creation of the routing. Large quantities (high volume production and mass production) allow to realize highly automated solutions for the manufacturing of parts due to the distribution of fixed costs among many product units. In these cases, high planning accuracy is required.

When creating the work plan, the cooperation between the work planner and the designer is very important. Only this cooperation can solve problems (e.g. due to non production-oriented design) and ensure minimum production costs.

2.2 STEPS FOR CREATING A WORK PLAN

The methodology (new planning, similarity planning, variant planning) for creating a work plan differs as follows:

When carrying out ***new planning***, it is not possible to refer back to existing work plans. The technological sequence and all data necessary for the respective work process (e.g. suitable workstations and target times) must be determined.

In ***similarity planning***, the work plan of a similar part is used as the base plan. The new plan is created by changing, deleting or adding current data.

Variant planning (by using standard work plans) is the most effective method. The prerequisite here is the classification of the assortment of individual parts according to part families (similar shape of final parts and same production process) or manufacturing families (parts with similar shaped elements and therefore the same machining in individual work processes). Only the data valid for a specific individual part (variable data) must be determined and entered.

You will find the six steps for creating a work plan together with their main contents in Table 5.

Step	Main content
Analysis of the finished part	inspection of the assembly drawing (functional analysis) verification of the individual part drawing (drawing review) creation of the technological review (design review)
Description of the blank	determination of the blank type evaluation of blank variants calculation of material consumption (blank costs)
Determination of the technological sequence (work processes)	determination of the work sequence according to • the existing shape elements (workpiece) and • the possible manufacturing processes
Allocation of manufacturing equipment	for the individual work processes, the assignment takes place in regard to • the workstations (qualitatively) • necessary jigs • special tools and testing equipment
Determination of technological data, manufacturing specification	for the individual work processes the following may take place • the determination of cutting data e.g. feed • a cutting arrangement and manufacturing specification • a preliminary calculation of working times
Calculation of target times	for the individual operations a calculation takes place for • the set-up time with use of the basic set-up time • the time per unit with use of the action time by taking into account recovery times, distribution times and waiting times (according to REFA)

Table 5 Steps for creating a work plan

In the following, the contents of these steps are described in detail.

2.2.1 ANALYSIS OF THE FINISHED PART

In order to specify the manufacturing task more precisely, the work planner must check the design requirements and work out a technological review, which may lead to changes in the geometry, tolerances and properties of the surfaces.

Inspection of the assembly drawing (functional analysis)

To identify the intended application and functions of the part to be manufactured within an assembly, the assembly drawing must be checked. This stage involves recognizing the function of the workpiece (individual part) in the overall system, usually within an assembly. The object of this functional analysis is, for example, the position and interaction with other individual parts. This results in the technical requirements.

Verification of the individual part drawing (drawing review)

The individual part drawing contains technological, geometrical and organizational information (see Chapter 1.2). Important technological information includes amongst others material data, surface quality, type of heat treatment, but also quality-related acceptance conditions (e.g. special requirements by the customer). These specifications and geometric information (e.g. specification of tolerances and position deviations) largely determine the content of the work plan. Organizational information, such as part and drawing numbers, are transferred directly to the work plan (header zone).

The main content for the verification of the individual part drawing is the critical analysis of dimensions (main geometry), the type and position of the form elements, the tolerances of dimensions, form and position, the required surface qualities, the material and the functional surfaces on the workpiece, which are of particular importance for the technological process. Furthermore, technological requirements, e.g. increased demands for surface quality, which necessitate fine machining (e.g. finishing in turning processes) and thus require a high level of economic effort, must be examined. By evaluating the functional analysis and the drawing review, the work planner develops the technological review (design review).

Creation of the technological review (design review)

As a result of the evaluation of the functional analysis and the drawing review, the technological review has to be created. Measures according to this design review are, if necessary, consultations with the design department and a modification of the set of drawings (see Chapter 1) with regard to a design that is suitable for production or NC.

2.2.2 DESCRIPTION OF THE BLANK

In the finished part drawing, the material and the blank (semi-finished product) are contained in the marking field (see Figure 5). The designer defines both, primarily to ensure the functional properties of the workpiece.

The task of the work planner is to critically evaluate this selection, especially from the point of view of the following machining, but also to define the necessary technological additions with regard to the manufacturing of the blank (e.g. draft angles and curves during drop forging) and the machining of the finished part (machining allowances, losses due to cutting, heat treatment). In preparation for the later costing and the determination of the economic batch size (see Chapter 4), but also for the calculation to conduct a variant comparison or a cost-utility analysis, the costs of the blanks must be determined on the basis of the material consumption. The determination of the blank has a decisive influence on the quality and profitability of the manufacturing process.

Determination of the blank type

The selection of blanks is determined by technological criteria as well as economic and organizational aspects.

Technological criteria are the material (structure, composition ...), shape and surface (roughness depth) of the finished part. From an economic point of view, the procurement costs for blanks and the subsequent machining costs must be examined. From an organizational point of view, the work planner must also take into account the timely and quality-compliant delivery of material and semi-finished products by the supplier as well as the customer's requirements for proof of quality when selecting blanks.

Types of blanks (selection):

- semi-finished products (rods, pipes, sheets, profiles)
- forged blanks (open die forging, drop forging)
- flame-cut blanks
- casting blanks (investment casting, shell casting, centrifugal casting, sand casting)
- sinter blanks
- welding groups

When selecting blanks, it should also be noted that, for example, the selection of cast blanks can be necessary, as it is perhaps not possible to manufacture the mold using other processes or that special properties of the casting materials are required.

Evaluation of blank variants

The blank costs and manufacturing costs are to be considered when comparing variants of blanks. Preformed blank types with low machining allowances (e.g. castings and drop forgings) often have high blank costs and jig costs (see Chapter 2.2.4), but lower manufacturing costs (due to shorter machining time).

In contrast, the production cost increases for non-preformed blanks with high machining allowances (e.g. round steel from rods). To further detail the blank costs, a distinction must be made between one-off costs (e.g. die costs for forging or model costs for casting) and running costs for the blank production. This results in differences in costs depending on the number of units produced. In the case of blanks made from castings, the costs for building models or molds are comparatively high, but are relativized by the number of castings.

In the end, the production cost of the individual variants is compared in €/piece:

= material costs + manufacturing costs + special manufacturing costs, e.g. jigs

The material costs (blank costs) contained in the production cost is calculated by determining the material consumption for the selected blank variant, as described below.

Calculation of material consumption (blank costs)

The blank costs are to be calculated by determining the material consumption for the selected blank variant. The calculation of material consumption is described below using round steel as an example. In this case, the blank mass is calculated from the mass of the finished part supplemented by the machining allowance MA_D for the diameter and MA_L for the length. In order to calculate the total material requirement (e.g. for costing), further losses (cutting allowance MA_{CT}, remaining rod portion MA_{RP} and clamping loss MA_{CL}) must be taken into account. Table 6 shows the calculation bases and excerpts from reference tables. The calculation of the remaining rod portion and the clamping loss (each in mm/piece) is carried out by determining the clamping length at the saw or the remaining piece of the rod (each in mm/rod) and dividing by the number of parts per blank rod.

Calculation of material consumption – round steel

Blank diameter D_B [mm]

Diameter of finished part [mm]		Length of finished part [mm]		
		up to 160	250	400
above	up to	M_{AD} in mm		
1	16	1.5	2	2
17	40	3	3	3
41	80	4	4	5
81	125	5	5	6
125	200	6	7	7

D_B = maximal diameter of finished part + MA_D
The calculated diameter must be adapted to standardized rod diameters by rounding up if necessary!
MA_D machining allowance on the cross section [mm]
Depending on the maximum diameter and the length of the finished part, the machining allowance MA_D is determined according to the table on the left (extract from machining and cutting allowances by Degner).
E.g. MA_D = 5 mm for a diameter of the finished part of 110 mm and a final length of 200 mm.

Blank length l_B [mm]

Diameter of finished part [mm]		Length of finished part [mm]			
		Up to 400		400 up to 1000	
		one-sided	two-sided	one-sided	two-sided
above	up to	MA_L in mm			
–	16	1	1,5	–	–
16	40	1,5	2,5	2	3
40	100	2,5	4	3	5
100	250	7	7	5	8

l_B = length of finished part + MA_L
MA_L machining allowance on the plane surfaces [mm]
If a centering is removed after machining, an additional centering allowance is required. Depending on the diamter and length of the finished part, as well as the required one-sided or two-sided machining, the machining allowance MA_L is determined according to the table on the left.
E.g. MA_L = 7 mm (diameter = 110 mm / length = 200 mm) for the machining of both planes (two-sided)

Blank mass m_B [Kg/piece]
ρ (density steel e.g. 7.85 g/cm²)

$$m_B = \frac{\pi}{4} * D_B^{\,2} * l_B * \rho \qquad \text{[Kg/piece]}$$

Material consumption length l_{MC}

Diameter of finished part [mm]		Separation process	
		hacksaw	circular saw
above	up to	MA_{CT} in mm	
–	16	2	2
16	40	3	5
40	100	3	6
100	250	4	8

$l_{MC} = l_B + MA_{CT} + MA_{RP} + MA_{CL}$ [mm/piece]
MA_{CT} cutting allowance [mm]
E.g. MA_{CT} = 8 mm (blank diameter = 115 mm for cutting with circular saw)
MA_{RP} remaining rod portion [mm/piece]
MA_{CL} clamping loss [mm/piece]

Material consumption mass m_{MC}
ρ (density steel e.g. 7.85 g/cm²)

$$m_{MC} = \frac{\pi}{4} * D_B^{\,2} * l_{MC} * \rho \qquad \text{[Kg/piece]}$$

Blank costs C_B [€/piece]

$c_B = m_{Mc} * C_M$ C_M material costs in €/Kg

Table 6 Calculation of material consumption – rod material

For forged blanks, the material utilization is primarily determined by the additional material required for the forge-compatible design of the blanks (e.g. draft angles), the loss of material due to the formation of burrs when using non-closed dies, and the loss due to burn-off. Since round or square steel is usually used as the initial shape in forging, in addition to the losses mentioned, e.g. cutting allowances, clamping losses and remaining rod portions must also be calculated (see Table 6).

Calculation of material consumption – forgings	
Forging sketch	preparation of a forged part sketch with consideration of • machining allowances and • manufacturing related allowances
Input mass m_I [Kg/piece]	calculation of input mass (from forging sketch)
Output mass m_O [Kg/piece]	calculation of output mass, considering forging losses
Blank dimensions D_B, l_B [mm]	selection of a suitable starting material (e.g. rod diameter and blank length) under consideration of the compression ratio
Material consumption l_{MC}, m_{MC}	calculation of the material consumption length and the material consumption mass (similar to round steel see Table 6)
Blank costs C_B [€/piece]	$C_B = m_{MC} * C_M$ C_M material costs in €/Kg The determined costs are to be supplemented, if necessary, by proportional costs for the manufacturing of a die and the removal of the burr.

Table 7 Calculation of material consumption – forgings

Table 7 shows the necessary steps from the preparation of the forging sketch based on the finished part drawing to the calculation of the blank costs for forging processes.

2.2.3 DETERMINATION OF THE TECHNOLOGIAL SEQUENCE

The technological sequence determines how a blank is converted into a finished state (finished part) by gradually changing its shape and/or material properties.

There are two main questions:

- Which form elements of the finished part (e.g. holes and threads in the finished part drawing) are to be machined most effectively in which sequence?
- Which manufacturing processes are to be selected for the machining of the form elements?

This takes place in work processes at a workstation. A **work process** is a workflow that is designed to fulfill a specific work task (a work step at a single workstation). Usually, a work process comprises only one manufacturing process (sawing, turning, milling, drilling, grinding, etc.) with one-time setup. Work processes are sub-sections of an overall process that can be delimited in terms of time and organization.

The **sequence of work** processes defines the order in which an object in the unfinished state (blank) is transferred to a finished state (finished part) by gradually changing the shape and/or material properties. **Determining the sequence of work processes** therefore consists of defining a series of work processes for creating the finished part from the selected blank (see Table 8).

Blank	→	Work processes	→	Finished part
• semi-finished product • forgings • cast blanks with their blank dimensions	→	10 sawing 20 turning 30 drilling 40 grinding	→	with their properties: • shapes • dimensions • tolerances and surface qualities

Table 8 Determination of the technological sequence (sequence of work processes)

The sequence of work processes is generated by first determining the sequence in which the form elements are processed (preliminary structuring of the workflow). Afterwards, suitable manufacturing processes are selected to match the process steps identified.

The allocation of suitable processes takes place by using technological criteria. Here, attainable tolerances and surface qualities are compared with the machining requirements.

The following shows rough values of surface quality for average roughness depths (Rz in μm) that can be achieved with the corresponding manufacturing processes:

- sand casting (25), investment casting (10), die casting (6.3)
- drop forging (100), extrusion (10), rolling (1.6)
- turning (3.2), drilling (12), milling (3.2), grinding (0.4)

Frequently, average surface finishes (Ra in μm) are given in drawings. According to DIN 4768-1, the following approximate relationships Ra → Rz are recognizable: Ra=0.4 → Rz=2.6 / 0.8 → 4.6 / 3.2 → 15.6 / 12.5 → 63 / 23 → 100.

Taking into account the specific situation (existing machinery, manufacturing type and batch size), general rules must be observed when determining the sequence of work processes:

- checking whether the raw part must be pre-machined (e.g. by sandblasting of cast parts, burr removal and descaling of forged parts)
- machining of form elements with large tolerances in shape, dimension and position always ahead of those with high demands on tolerances and surface quality
- compliance with the sequence → rough machining (roughing RZ>25μm - rough approximate value) then fine machining (finishing RZ<25μm)
- multiple set-ups should be avoided through as few work processes as possible
- machining of finished surfaces through final work processes, avoiding clamping on machined surfaces as far as possible

Heat treatment processes are of particular importance for determining the sequence of operations. Structural changes caused by heating (e.g. during abrasive cutting) are reversed by normalization, forgings often require normalization. In order to relieve stresses that have arisen, stress-relief annealing is used for welded parts, for example. The heat treatment (hardening) required by the design must always be carried out after the production of the extension forms (e.g. by turning), but always before fine machining (e.g. grinding).

It should also be noted that after some processes (e.g. gear machining) a work process washing is necessary to free the workpieces from adhering oil.

2.2.4 ALLOCATION OF MANUFACTURING EQUIPMENT

The content of this step for the work planning is,

- the selection of a suitable machine tool (workstation)
- the selection of the clamping device
- the definition of special tools
- the selection of required jigs
- the choice of special test equipment

In order to conduct the **selection of a suitable workstation** for the work processes, a list of available machine tools in the company is required. This list is contained in a machine file along with all important information. This information (machine data), but also workpiece data and economic criteria form the basis for machine selection (see Table 9).

Workpiece data	Machine data	Economic criteria
maximal: • machining diameter • machining lengths clamping length required: • tolerances • surface qualities blank mass blank dimensions	• motor capacity • work area • speed range • feed range • tool storage • tool mounting • clamping devices • number of axes	rapid traverse speed tool change time availability wage costs according to wage group hourly machine costs: • energy consumption • coolant consumption • tooling costs • interests, depreciations • occupancy costs

Table 9 Factors influencing the selection of the workstation

The basic condition for the selection is that the machining process can be carried out on the machines and that the quality requirements are met. Workpiece data according to the individual part drawing, the technical features of the machine and the technological limits, but also manufacturing organizational and economic criteria must be considered.

The **choice of a suitable clamping device** (form and type of chuck jaws) must be checked according to the available clamping force. Furthermore, it must be determined whether hard or soft chuck jaws (clamping on previously machined surfaces) must be used.

Usually, only **special tools** are specified in the work plan; standard tools (e.g. turning tool holders and indexable inserts) can be found in the manufacturing specification (see Chapter 2.2.5).

Jigs are special clamping devices for workpieces which cannot be clamped directly in the chuck or vice due to their special geometry (e.g. preformed blanks such as castings) or special guides for tools (e.g. drilling templates). The demands for the fixture identified in the work plan creation must be addressed within the design of the equipment. Accordingly, it must guarantee compliance with the technical conditions, such as dimensional and positional tolerances.

In the work plan, only **special testing equipment** is listed for a work process; in the work instruction (see Chapter 2.2.5), the test equipment required for a stage of the work process is named. Test equipment for testing work processes is specified in the test plan.

2.2.5 DETERMINATION OF TECHNOLOGICAL DATA AND MANUFACTURING SPECIFICATION

The depth of planning determines the scope and level of detail in the preparation of manufacturing documents. Is it sufficient to plan the rough phases (work processes in the work plan) within the work planning or is it necessary to plan their sub-processes (work process steps)?

The main factors influencing the planning depth are the quantity, the quality and the complexity of the parts. With increasing complexity, quality, quantity of parts (manufacturing type: series and mass production) and higher manufacturing form (serial and flow production) the planning depth becomes larger and a detailed elaboration and optimization of the operating equipment, the work processes, the technological data and the determination of target times becomes necessary. The detailed elaboration of the work process in individual work process stages is documented in the manufacturing specification. A prerequisite for the preparation of the manufacturing specification for machining processes is the cutting arrangement, which often requires the calculation of the maximum cutting depth, which again depends on technological data.

In the following, the determination of the technological data, the creation of a cutting division and the content of the manufacturing specification are roughly described using the example of the turning manufacturing process.

Determination of technological data – cutting data (turning)

On conventional machines, the speed and feed are adjusted, whereas the cutting depth is determined by the positioning. On NC machines (see Chapter 3) it is possible to machine at a constant cutting speed, whereby the speed is determined by the diameter.

The selection and optimization of these parameters result in, including:

- increasing the tool life,
- improved chip formation,
- compliance with the required surface quality and
- the generation of as large a chip volume as possible during rough machining (roughing).

Tool life (usually the tool travel during drilling) means the use of a tool until regrinding (for soldered tools) or replacement (for indexable inserts in clamping holders).

The **chip shape** describes the shape of the chip after completion of the cutting process. It is essentially influenced by the material of the workpiece, the tool geometry (chip grooves) and the cutting conditions. The ratio between cutting depth and feed should be in the range of 4:1 to 10:1 in order to achieve a favorable chip formation.

Unfavorable chip shapes (ribbon chips and tangled chips) can compromise the machining process, especially during automatic processes on NC machines. Favorable chip shapes (screw broken chips and spiral broken chips) pose little danger to the operator and the chips are easy to transport.

The **choice of the feed** for **roughing** is influenced by the drive power, but also by the stability of the machine and the ratio of feed to cutting depth. If the available drive power is too low, the cutting speed must be reduced. The corner radius of the indexable insert is a key factor in roughing stability (f ≈ 0.5 X corner radius in roughing).

The **selection of the feed** for **finishing** is decisively determined by the requirements for surface quality and tolerance accuracy, whereby the cutting edge geometry (radius of the chisel tip) must also be taken into account. The achievable surface quality (average roughness depth Rz in µm) is calculated using the following formula.

$$Rz = \frac{f^2}{8 * R}$$

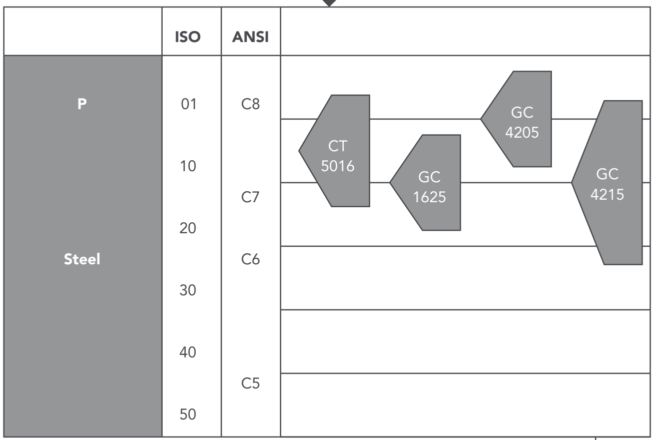
R … radius of the chisel tip of the tool [mm]   f … feed [mm/rev]

Cutting data is taken from the catalogues of the tool manufacturers. The following Figure 11 contains an extract of the tables for determining the **cutting speed V$_c$** for general turning from the catalogue of the tool manufacturer Sandvik-Coromant.

Material classes

ISO	MC	CMC	Country Europe / Standard / DIN EN
P			**Non-alloyed steel**
	P1.1.Z.AN	01.1	S235JR G2
	P1.1.Z.AN	01.1	S235J2 G3
	P1.1.Z.AN	01.1	C15
	P1.1.Z.AN	01.1	C22
	P1.1.Z.AN	01.1	C15E
	P1.1.Z.AN	01.1	C25E
	P1.1.Z.AN	01.1	S380N
	P1.1.Z.AN	01.1	17MnV7
	P1.1.Z.AN	02.1	55Si7
	P1.1.Z.AN	02.2	-
	P1.2.Z.AN	01.2	C35
	P1.2.Z.AN	01.2	C45
	P1.2.Z.AN	01.2	40Mn4
	P1.2.Z.AN	01.2	36MN5

Selection of cutting materials



Cutting speeds V_c [m/min] for different types of cutting material and feeds f [mm/rev] (based on a tool life of 15 minutes)

ISO P MC-No.	CMC-No.	Steel Workpiece material	Specific cutting force k_c 0.4 N/mm2	GC4205 0.1-0.4-0.8	GC4215 0.1-0.4-0.8
P1.1.Z.AN P1.2.Z.AN P1.3.Z.AN	01.1 01.2 01.3	**Non-alloyed steel** C = 0,1 – 0,25% C = 0,25 – 0,55% C = 0,55 – 0,80%	2000 2100 2200	620-450-330 560-405-295 530-385-275	570-405-300 510-356-265 460-330-240
P2.1.Z.AN P2.1.Z.AN P2.5.Z.HT P2.5.Z.HT	02.1 02.12 02.2 02.2	**Low-alloy steel** (alloying constituents < 5%) Unhardened Ball bearing steel Hardened and tempered Hardened and tempered	2150 2300 2550 2850	610-410-285 530-350-250 330-230-175 265-185-140	560-370-260 460-305-215 300-210-155 240-170-125
P3.1.Z.AN P3.1.Z.HT	03.11 03.21	**High-alloy steel** (alloying constituents < 5%) Annealed Hardened tool steel	2500 3900	445-295-215 220-140-105	405-270-200 200-130-95
P1.5.C.UT P2.6.C.UT P3.0.C.UT	06.1 06.2 06.3	**Cast steel** Non-alloyed Low-alloyed (alloying constituents ≤ 5%) High-alloyed (alloying constituents > 5%)	2000 2100 2650	335-235-185 290-205-155 225-150-115	300-215-170 260-185-140 205-135-105

Cutting material

Feed

Material classes **Cutting speeds**

Figure 11 Determination of cutting speed
(extract from tool catalogue of the company Sandvik Coromant)

To determine the cutting data, materials with similar properties are grouped together in material groups, at Sandvik e.g. CMC numbers (C45 → CMC 01.2 see Figure 11). After determining the CMC number of the material and selecting the cutting material (e.g. GC4205 as Sandvik's multi-range grade), the cutting speed for the combination of material and cutting material and the selected feed is read from the cutting data recommendations (see Figure 11). The specific cutting force can also be read here.

The cutting speeds given in the tables refer to a tool life of 15 minutes. A compensation factor allows a longer service life (e.g. 0.8 → 45 minutes) by reducing the cutting speed.

Tool life [min]	10	15	20	25	30	45	60
Compensation factor	1.1	1	0.95	0.9	0.87	0.8	0.75

The **speed** n [1/min] is calculated using the following formula:

$$n = \frac{V_c * 1{,}000}{\pi * D}$$

V_C …. cutting speed [m/min]
D …. diameter [mm]

This calculated max. speed must be adapted to the speed range and the speed series of the lathe if necessary.

The calculation of the maximum cutting depth a_p [mm] is carried out using the equation for determining the motor capacity P_C [KW] according to Sandvik:

$$P_C = \frac{V_C * a_p * f * Kc_{0.4}}{60{,}000} * \left[\frac{0.4}{f * \sin \varkappa_r}\right]^{0.29}$$

$Kc_{0.4}$ … specific cutting force for chip thickness 0.4 mm
f … feed [mm/rev], χ_r … entering angle [deg]

In practice, the calculation of cutting force and power is also carried out using the basic equation according to Kienzle.

The selection of suitable tools (cutting material, tool holder and indexable inserts) and cutting data, often also the calculation of the main activity times (see Chapter 2.2.6) can also be carried out digitally via “electronic tool catalogues” of the tool manufacturers (see Figure 12). These “cutting data calculators” are suitable tools for fast optimization purposes.

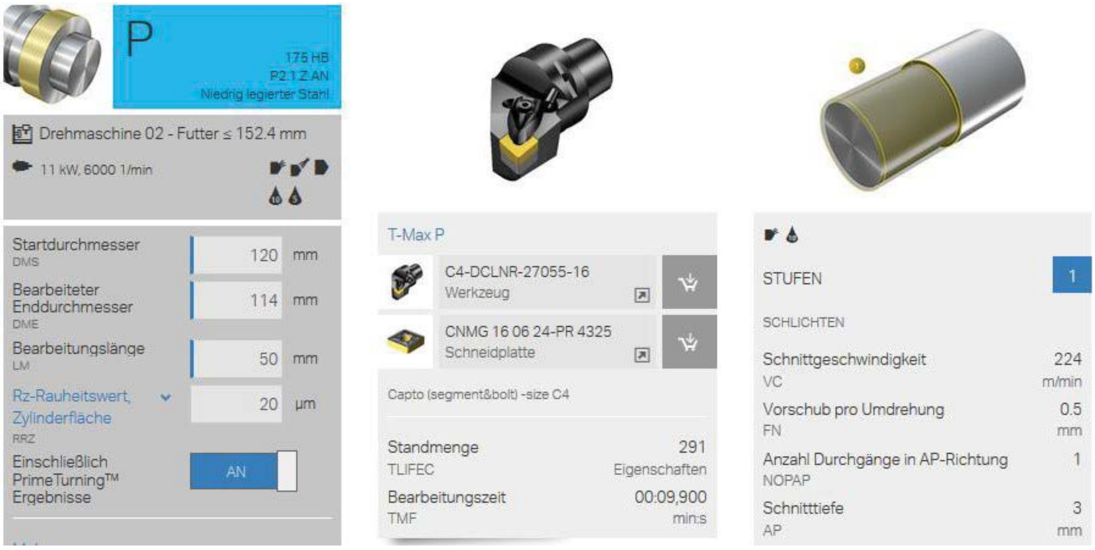
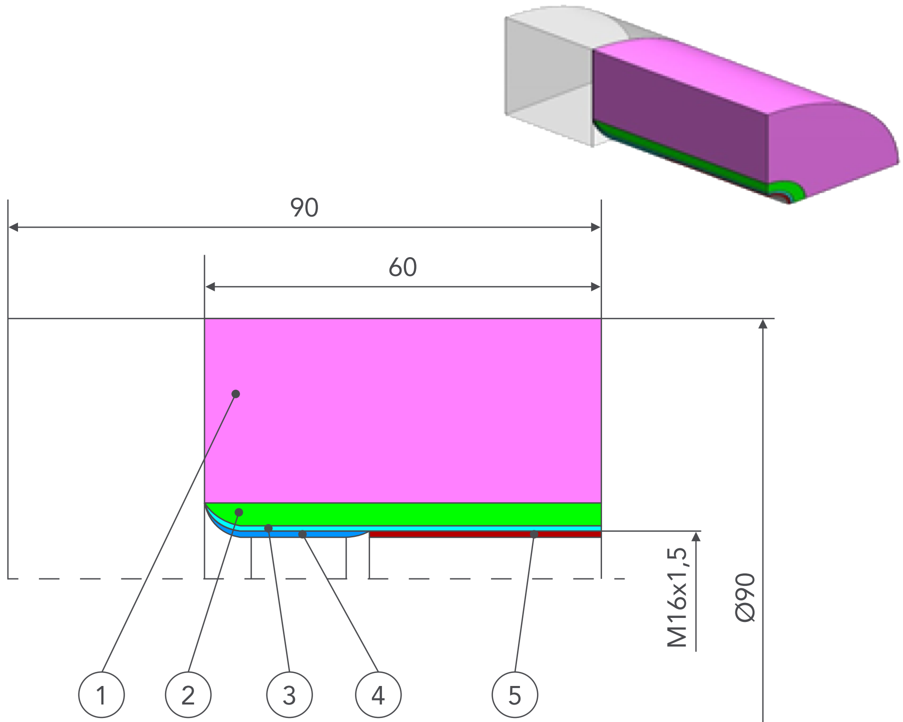


Figure 12 Computer-aided determination of cutting data (Sandvik)

The **cutting arrangement** (see Figure 13) consists of two components:

- the graphic representation of the cuts from the blank (round steel with a diameter of 90 mm and a length of 90 mm) to the finished part with main dimensions and
- the table with the technological data (cutting depth, speed, feed, cutting speed and number of cuts) for the individual turning cuts.



Cut number	D [mm]	d [mm]	a_p [mm]	f [mm/u]	n [min^{-1}]	V_c [m/min]	Number of cuts
1	90	26	4	0,4	560	160	8
2	26	18	4	0,4	1900	160	1
3	18	16	1	0,1	3180	180	1
4	16	14	1	0,1	3580	180	1
5	M16x1.5	–	–	1,5	1000	50	8

Figure 13 Cutting arrangement – turned part

The manufacturing specification is intended for the object-dependent descriptions and necessary information for machining, assembly and test sequences that are not contained in the work plan and therefore provides an exact description of an operation. Depending on the requirements, the work is carried out in plain text form, as text with machining sketch or only as visual representation.

Technische Hochschule Wildau Technical University of Applied Sciences WILDAU	**Manufacturing specification** belongs to work plan of the same drawing number	Designation: Musterteil Drawing number: 1:00:300:4711

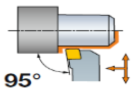
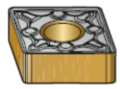
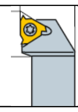
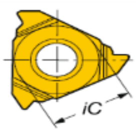
WP-No.:		40
Editor:		Mustermann
Material / semi-finished product:		C45 / RD 60 x 80 mm
Blank mass:		0.45 Kg
Multi-piece clamping:		–
Multiple machine operation:		–
Workstation No.:		010201
Cost center:		1200
No.	**Work process step**	**Tools, jigs**
10	clamping	three-jaw chuck
20	turning long Ø90 to Ø26 l=60mm	holder: DCLNR/L 1616H12 
	a=4mm, i=8, f=0.4 mm/rev, n=560 1/min	insert: CNMG 120408 PM GC4215 
30	turning long	
.		
.		
50	turning thread M16X1.5 l=40mm	holder: 266R/L FG1616-16 
	i= 8, n=1000 1/min	insert: 266R/LG 16MM01A150 GC1125 
.		
90	unclamp	

Table 10 Manufacturing specification (extract) for the work process turning

Table 10 shows that the manufacturing specification contains the working steps (e.g. WP step 20, long turning cut with 8 cuts at a cutting depth of 4 mm) with the required tools (specification of tool holder and indexable inserts with order numbers) and the cutting data to be used. It is the basis for calculating the specified times in the next chapter.

2.2.6 CALCULATION OF TARGET TIMES

The REFA (Reichsausschuss für Arbeitszeitermittlung [German]; transl.: National committee for determining working times) association, founded in 1924, is Germany's oldest organization for work design, business organization and company development. REFA develops methods for determining operational data and for management, coordinates these with the unions and management and has become the standard for time determination. REFA target times are specified times for work processes carried out by people (basic times, recovery times and distribution times) and operating equipment (basic times and distribution times). Figure 14 shows the REFA time classification scheme for people.

Normally, the setup time [min/batch] and the time per unit [min/piece] for an operation are part of the work process.

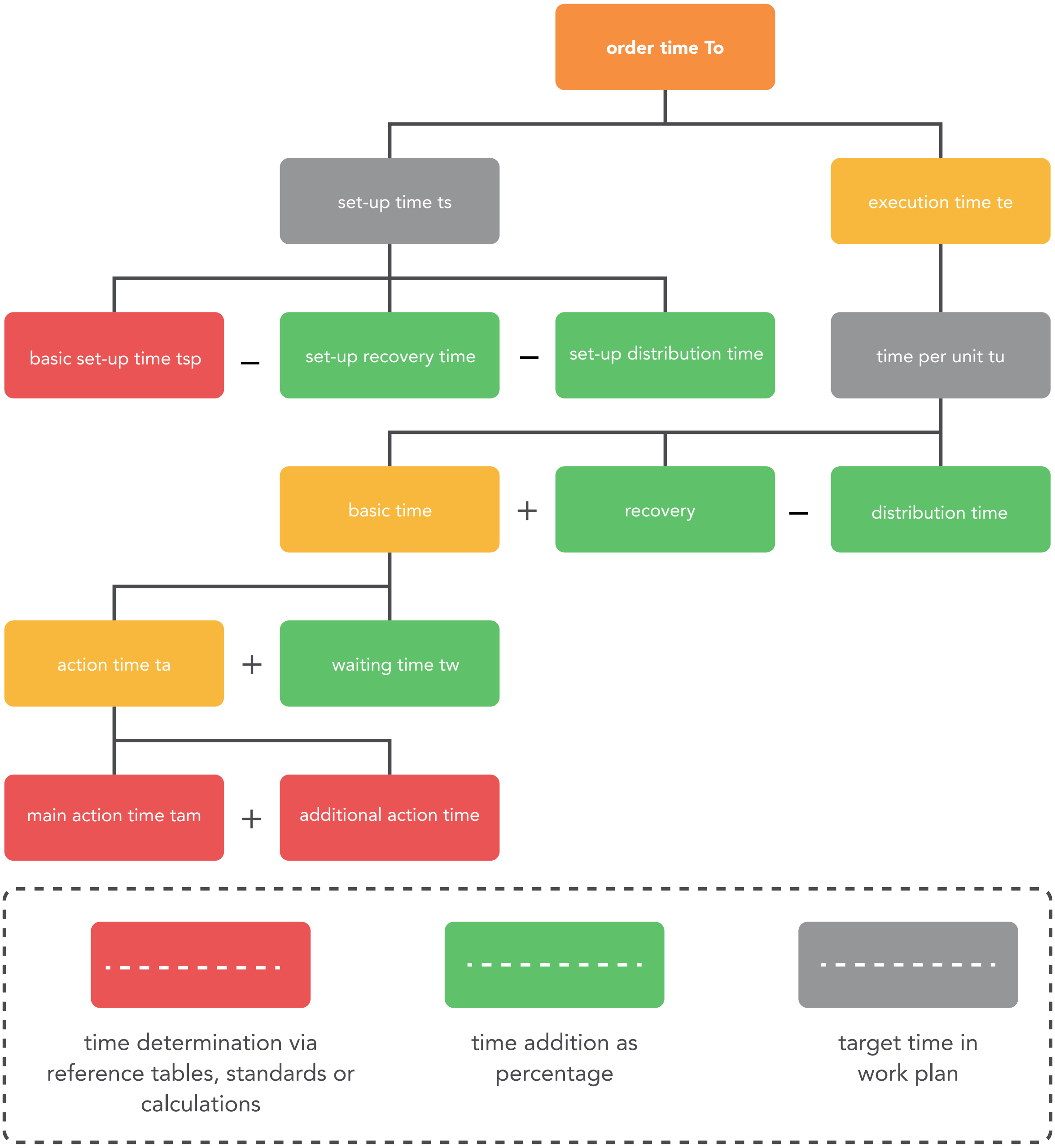


Figure 14 Time classification according to REFA

To calculate the target times, recovery times, distribution times and waiting times are required. Recovery and distribution times are often shown as a percentage of the basic time.

The recovery or distribution time percentages are determined as an admission or study according to REFA to determine the average distribution or recovery times in a company.

Recovery times consist of target times for the recovery of humans necessary as a result of the activity. Their share in the target times depends on the amount and duration of the strain placed on people by work.

The **distribution times** consist of target times that occur in addition to the planned execution. A distinction is made between *personal distribution times* (e.g. regulating heating, going to the toilet or other personal tasks ...) and *objective distribution times* (e.g. cleaning workstations, scheduled lubrication, conducting business calls, occasionally changing tools due to breakage ...).

The **waiting time** consists of the sum of the target times of all steps with the sequence type sequence-related interruption, (e.g. waiting for the cooling of a mold before picking up a new workpiece, waiting for the next workpiece in the case of flow work...) which occur during the scheduled execution of a sequence. While waiting, it is not the human being, but the equipment or the work object that determines the time.

The **set-up time ts** (also called preparation time and completion time in min per batch) is part of the order time in the sense of the REFA association and includes the target times that occur once during the preparation of an order. Machinery is prepared for the order and returned to its previous condition after the order has been processed.

The setup time is composed of the basic setup time (**tsb** - e.g. receiving and reading the order and the drawing, providing tools, setting the machine...) and the percentage of recovery time **tsre** and distribution time **tsd** for setup.

$$\mathbf{ts = tsb + tsre + tsd \qquad [min/batch]}$$

The basic setup time **tsb [min/batch]** is calculated from reference tables and standards as the sum of individual tasks performed by the operator in preparation of the machine (setting up the operating equipment) for the production of the batch.

The **time per unit** (also unit time) **tu** is the target time for the execution of a process by a human being; it generally refers to the quantities 1, 100 or 1,000 (REFA). The main component of the time per unit is the action time, which is supplemented by recovery times **ture**, distribution times **tud** and waiting times **tw**.

$$\mathbf{tu = tb + ture + tud \qquad [min/piece]}$$

The **base time tb** is the time for a human to execute a unit quantity of 1.
It consists of two types of time, action time and waiting time.

$$\mathbf{tb = ta + tw \qquad [min/piece]}$$

The **action time ta** consists of the main action time and the additional action time.

ta = tam + taa [min/piece]

The **main action time tam [min/piece]** is the time with immediate progress in terms of changing the geometry or other characteristics of the part (tool operation). It is calculated, for example, using reference values and machining data. The following formula, for example, applies to the long turning process in min/cut:

$$\text{tam} = \frac{\text{L}}{\text{vf}} = \frac{\text{l} + \text{ls} + \text{lo}}{\text{f} * \text{n}}$$

L......turning distance (feed distance)
l.......turning length (tool in operation) [mm]; ls …start-up [mm]; lo …overrun [mm]
vf.....feed rate [mm/min]
f.......feed [mm/rev]; n … speed [1/min]

Additional action times taa [min/piece] are regular times which only indirectly contribute to the progress of work, e.g. clamping of the workpiece, testing of the workpiece and positioning of the tool. The determination takes place via machine-specific reference tables (standard).

The setup time and time per unit for the work plan are determined on the basis of the manufacturing specification (Table 10) and the cutting arrangement (Figure 13) in working time calculations.

The **order time To** in min per batch or order is the target time for the completion of an order by a person. The order time To is divided into setup time ts and execution time te.

To = ts + te = ts + (m * tu) [min/batch]

The **execution time te** depends on the order size m and the time/unit tu. It is order variable.

te = m * tu [min/batch]

The calculation of the time per unit for the work processes on CNC machines (see Chapter 3) is simplified by evaluating the CNC program with corresponding modules in the programming system. After entering parameters such as the rapid traverse speed, tool change time and the time for clamping operations, the main and additional activity time is issued.

Exercises for Chapter 2:

E 2.1: Name the information (data) contained in the work plan.

E 2.2: Briefly describe the steps for creating a work plan.

E 2.3: Calculate the blank length (no centering), the material consumption length, and the material consumption mass according to the data given in the following table:

length finished part: 122 mm	clamping loss: 0 mm	remaining rod p.: 12 mm
blank diameter: 80 mm	separation process: circular saw	density: 7.85 g/cm^3

E 2.4: Calculate the surface quality (Rz) and the main action time tam for a long turning cut.

feed: 0.25 mm/rev	speed: 1,000 1/min
radius chisel tip: 1 mm	feed distance: 120 mm

E 2.5: Calculate the maximum cutting depth for a rough cut

motor capacity: 12 KW	feed: 0.4 mm/rev
specific cutting force for chip thickness 0.4 mm: 2,300 N/mm^2	
cutting speed: 240 m/min	entering angle: 90°

E 2.6: What are the proportions of time that make up the time per unit and the order time according to REFA?

E 2.7: The following values were determined by calculations and time recordings:
basic set-up time: 56.5 min/batch, set-up resting time: 5 %, set-up distribution time 4 %, main action time: 7.8 min/piece, additional action time: 11.5 min/piece, recovery time: 8 %, distribution time: 6 %, waiting time: 4 %
Calculate the order time for the operation with a batch size of 100 pieces/batch.

3 PROGRAMMING OF MACHINE TOOLS

The contents of this chapter are:

- the definition of the basics and steps of CNC programming
- the description of the basic commands according to DIN and PAL and
- the explanation of the programming on the basis of examples specifically for the process turning.

The graphics contained in the following text are taken from the External Programming System (EXLS) and the NC Trainer (dialog-guided learning software) of the company LS Learning Solution Automation and Software UG. It is a competent partner for training systems in the CNC area and mechatronics.

3.1 BASICS OF CNC PROGRAMMING

3.1.1 BASIC TERMS, APPLICATION AND ADVANTAGES OF CNC PROGRAMMING

Machine tools today are usually equipped with a numerical control. Numerical controls interpret control commands and convert them into signals to the machine drives. In addition to machine tools, robots and measuring machines are now also equipped with controls (see Table 11).

	Manufacturing CNC-controlled machine tools (turning, milling ...) as turning centers and machining centers	**Handling** robot programming for workpiece handling functions and assembly tasks	**Quality control** CNC-controlled measuring machines e.g. CNC coordinate measuring machines
programming in the workshop area ↓ manual programming	manual programming according to DIN 66025/PAL or workshop-oriented programming (WOP)	teach-in-programming or playback-programming	teach-in-programming
programming in the area of operations scheduling ↓ machine programming (control neutral)	NC-programming system or CAD-CAM	by programming language or graphical interactive programming	by programming language or via CAD

Table 11 CNC application in the area of production

Robot programming includes workpiece handling functions as well as complex, sensor-guided tool movements or assembly tasks. A distinction is made between **online methods** [teach-in (approach and store) or playback (travel along a path)] and **offline methods** (programming directly using a problem-oriented language).

CNC-controlled **measuring machines** perform comprehensive tasks in the field of quality control. This ranges from the distinction between “good” and “reject” to the delivery of correction data for the manufacturing process.

The abbreviation NC stands for "numerical control". The essential task of a numerically controlled machine is to perform machining tasks fully automatically with high precision. The work and movement sequences are programmed with the aid of sequential control commands. The control commands are interpreted by the controller and transformed into corresponding signals for the machine drives. The control commands consist of measurements that indicate the relative position between tool and workpiece. Switch functions defined by the machine facilitate frequently recurring tasks such as tool or workpiece changes.

Essential **reasons for the application** of numerical control of operating equipment are, among others:

- reduction of additional action times within the time per unit (e.g. by faster positioning of tools in rapid traverse)
- reduced recovery time and distribution time within the time per unit (see calculation of target times according to REFA)
- drilling (eccentric) and milling (e.g. of grooves) is possible, e.g. in turning centers, through the use of driven tools, so that additional work processes are avoided by this complete machining process
- improvement of workpiece quality and reduction of rejects
- maintaining consistent workpiece quality for any batch sizes and replacement deliveries
- possibility of economical production of complicated workpieces with simple tools
- adaptability to changing production tasks
- humanization of work by limiting the strain
- savings in labor costs due to multi-job and team work
- NC machining techniques as a component of integrated manufacturing forms constitute new innovative developments in automation and information technology

Disadvantages are among others:

- additional costs for programming
- higher investment costs and tooling costs, thus increasing the hourly machine rate of the workstation
- the time required to set up the CNC machine (e.g. by the additional reading of the program and the test via a test piece) is greater than with a conventional machine.

3.1.2 PROGRAMMING LOCATION AND PROGRAMMING MODES

With regard to the **location** where the programming takes place, a distinction is made between programming in the workshop area (near the machine) and programming in the area of operations scheduling (far from the machine), also known as AV-programming (see Table 11).

In **workshop programming**, the programming takes place on the shop floor directly at the machine or at a programming station. Workshop programming is used in small and medium-sized enterprises with only a few machines and controls by highly qualified skilled workers or set-up personnel.

In large companies with an extended machine park and complicated geometries, **AV-programming** is used, whereby the programming takes place in the area of operations scheduling on programming systems (machine programming), often with connection to CAD-CAM.

The NC program can be sent directly to the individual machines (controls) via data carriers, such as USB flash drives, but also via a wireless LAN connection. DNC (Direct Numerical Control) is an operating mode in which several NC or CNC machines and other manufacturing equipment (tool presetters, measuring machines, robots...) can be connected to a computer via cable connections.

This network guarantees a secure, prompt data transmission from and to the CNC machines from the machine programming. In addition, the NC programs are managed by DNC systems.

Regarding the type of programming, a distinction is made between manual programming and machine programming (see Table 11).

Manual programming according to DIN 66025 or PAL

In this procedure (also called textual programming or alphanumeric programming), the programmer describes the machining task in an NC code. Programming is usually carried out directly in the control of the machine tool, whereby the program blocks are formulated on the basis of the shop drawing.

However, with this standardization, only the structure of a program code and some basic commands have been unified. The providers of CNC control systems are largely free to integrate their own NC commands into their controls. The generation of the work step sequence as well as the creation of tool and clamping plans and the set-up sheet are not sufficiently supported.

A more modern form of program creation in the workshop using menu techniques including function keys and graphic symbols is **workshop-oriented programming (WOP)**. Here, the programmer is supported graphically and can program and simulate the distances a tool has to cover before production. Workshop-oriented programming has the disadvantage that no complex workpieces can be programmed. In addition, programming takes a certain amount of time despite the support from the software.

Machine programming

Here, NC programming systems (also called computer-aided programming or control-neutral programming) are used in the planning area, which are graphically oriented and enable extensive simulations. This includes the blank description and the production sequence as well as the information on wiring. So-called form features are often already used in the workpiece description using a CAD system. With this method, process optimization and the prevention of damage through 3D simulations are possible.

The result of the machine programming process is a **machine-independent NC program** in CL data (cutter location data) format. The machine-independent NC program is adapted to the machine-specific conditions with the aid of an adaptation program, the **postprocessor**. A special postprocessor is required for each combination of controller and machine tool.

In recent years, the development has gone towards computer-aided manufacturing with a **CAD-CAM system**. A CAM software is, similar to the programming system, decoupled from the CNC machine (control) and combines design and programming so that (theoretically) no CNC programmer is required. The designer draws the workpieces to be produced on the computer and the CAM system uses the CAD data to create the necessary CNC program. This can then be transferred to the machine. This shortens programming times considerably. This procedure is especially suitable for the programming of complicated workpieces.

3.1.3 CONTROL TYPES AND REFERENCE POINTS

The application and capability of a CNC machine depends essentially on the performance of its control system. There are three different basic types of controls (**control types**):

- point-to-point control
- line motion control and
- contouring control

Point-to-point or positioning control system. In this case, only the end point of a movement can be defined. In particular, there is no graduated speed control during the movement, but the drives usually run as fast as possible. Therefore, the tool can only engage at the end points of the movement and drill or stamp a hole. The point-to-point control is used with simple stamping machines, spot welding machines, drilling machines or gripping robots if they do not have to travel a defined distance.

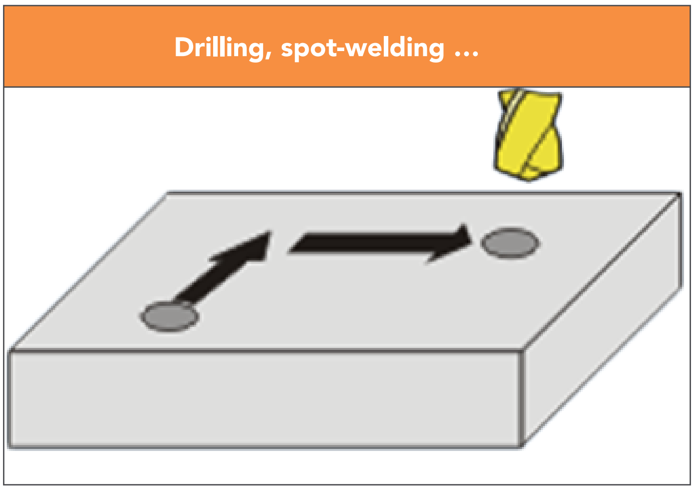


Figure 15 Point-to-point control

The **line motion control** system is essentially a point-to-point control system in which the speed of movement can also be precisely controlled. Only one axis drive is moved at a time and its travel length and speed are controlled. Thus, it is possible to travel an axis-parallel movement with working feed and therefore, for example, mill a straight groove. The line motion control is used with simple lathes (only cylindrical workpieces) and simple milling machines (only rectangular workpieces).

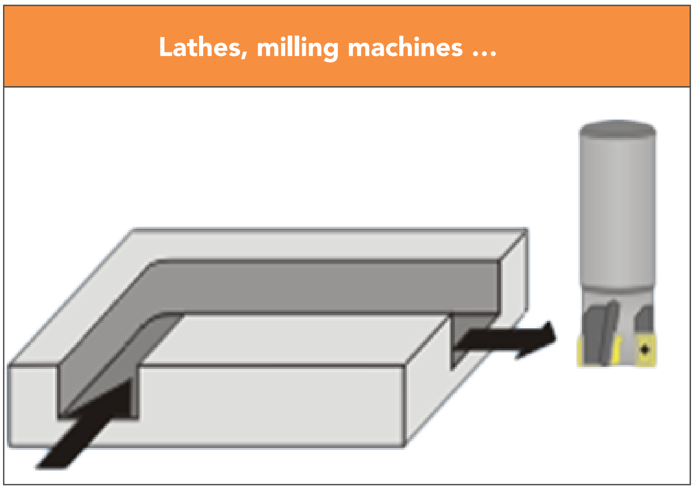


Figure 16 Line motion control

Contouring control system. Using the contouring control system, any contours can be created. The intermediate values of the contours are calculated by linear interpolation (straight contours) or circular interpolation (radii, circular arcs). In addition to the tasks of a line motion control, it enables feed movements to be carried out to any points on the workpiece. Within the contouring controls there are levels with regard to the ability to control two or more axes simultaneously to create tool paths. The 2 D contouring control moves any contours with two fixed axes (often sufficient for lathes). If one can choose between the interpolated, controlled axes, one speaks of a 2½ D-path control (standard for lathes with driven tools). If three controlled axes can be interpolated with each other, they are called 3 D-path control (standard for milling machines).

Contouring control is mainly used for milling machines, turning centers, machining centers and eroding machines.

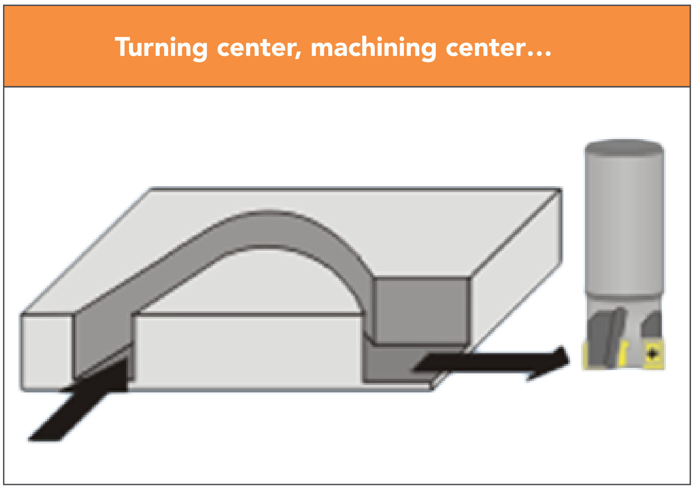


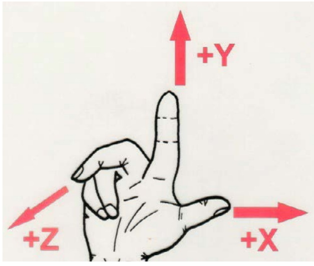
Figure 17 Contouring control

The definition of **coordinate systems** and reference points in the working space of the machine tool is a necessary prerequisite for the description of machining movements.

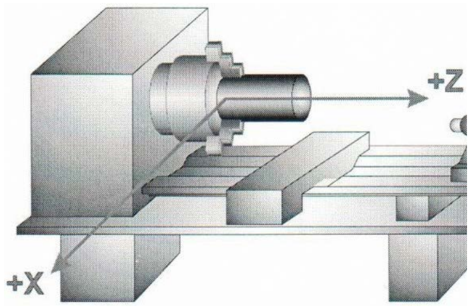
Movement axes (coordinates) of a machine tool are physically movable axes with one degree of freedom. They describe the movement possibilities of the workpiece or tool. The number and type of axes are machine-dependent.

The following general definitions determine a coordinate system:

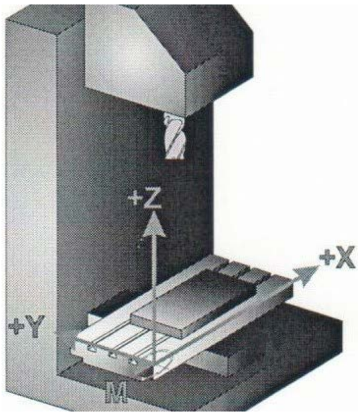
- Cartesian coordinate system with the X-, Y- and Z-axes aligning with the main guideways of the machine and referring to the workpiece clamped in the machine. The positive direction of rotation is determined by the right-hand screw rule.



- The Z-axis is parallel to or identical to the axis of the work spindle. The positive direction of the Z-axis is from the workpiece to the tool or, in the case of lathes, from the spindle to the workpiece.

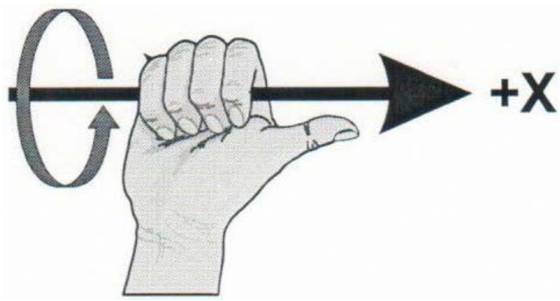


Turning

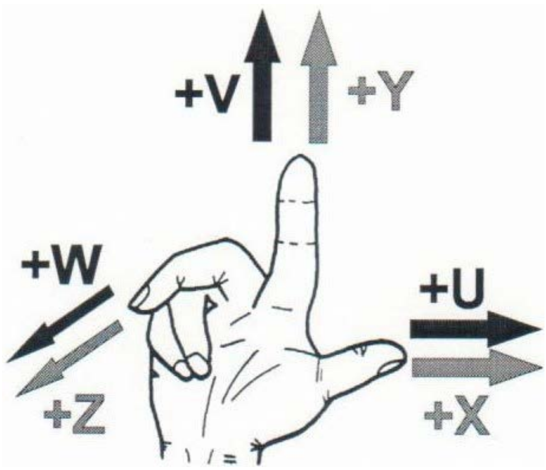


Milling

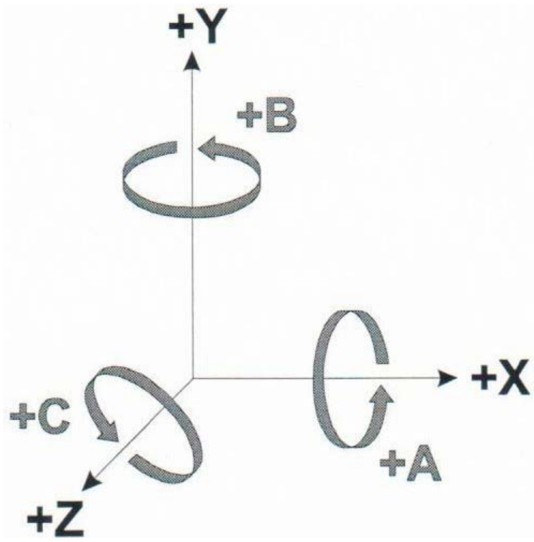
- The X-axis is the main axis in the positioning plane. It is generally parallel to the workpiece clamping surface and runs as horizontally as possible.



- If coordinate axes exist parallel to the X-, Y- or Z-axis, these are designated U, V and W.



- The letters A, B and C identify rotary axes, such as rotary tables, which are assigned to the X-, Y- and Z- coordinates.



X, Y, Z	translational movement of the tool
X‘, Y‘, Z‘	translational movement of the workpiece
A, B, C	rotational movement of the tool
A‘, B‘, C‘	rotational movement of the workpiece
U, V, W	additional possible movements of the tool
U‘, V‘, W‘	additional possible movements of the workpiece

A number of zero points and reference points are arranged in the working area of the machine.

The five **reference points** of an NC machine are machine zero point (M), workpiece zero point (W), reference point (R), tool reference point (T) and tool change point.

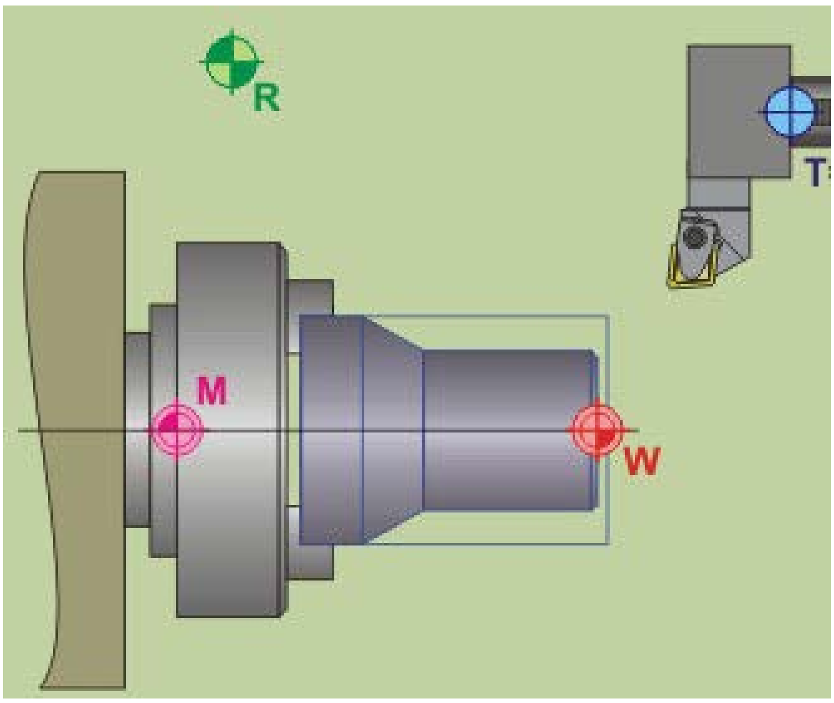


Figure 18 Reference points on a lathe

Table 12 below explains these points in detail.

Machine zero point
Origin of the machine coordinate system and fixed point on the machine. The position of the machine zero point (turning: in the center of the main spindle axis at the height of the contact surface of the clamping device, milling: e.g. on vertical milling machines above the left corner edge of the tool slide) is defined by the machine manufacturer and cannot be changed. It is important for the alignment of the path measuring system, since the control works internally with machine coordinates.
Workpiece zero point
Freely definable point as the origin of the workpiece coordinate system (for prismatic parts usually at the lower left corner of the upper side of the workpiece), which is defined by the programmer by specifying his distance from the machine zero point. The workpiece zero point is an instrument for simplifying programming.
Reference point
Fixed defined position of the machine slide. Since machine controls record the position of the slide incrementally, it is necessary to move to this fixed point each time the machine or the control is switched on, which is triggered by the operator via the corresponding function on the machine. This ensures synchronization between the path measuring system and the control.
Tool reference point
Also known as the tool holder point, it is a defined point on the tool holder of the turret (tool carrier reference point). The machine control determines the position of the tool reference point via the machine's own measuring system. However, since the position of the tool tip is crucial for machining the workpiece contour, but tools have different dimensions, these must be entered in the machine control. When the tool is selected, the corresponding dimensions are activated (tool setting point).
Tool change point
Defined position outside the work area for automatic tool change, since the automatic gripping of the tool requires a fixed position known to the control.

Table 12 Contents of the reference points

In the workpiece coordinate system, it refers to the workpiece zero point for easy programming. The position of this point must be selected with a zero offset so that the drawing details are transferred directly to the coordinates (e.g. face side of the finished part during turning).

The **zero offset** (coordinate transformation) is a shift of the machine zero point to the current workpiece zero point. It allows the workpiece dimensions from the CAD model to be used directly to describe the machining process within the NC program.

In the CNC program, up to four different zero offsets can be recalled with the commands G54, G55, G56 and G57. Before starting the CNC program, the offsets (turning in X and Z) must be entered in the zero point register of the control on the machine. Command G55, for example, calls the zero offset in the second register.

3.2 STEPS OF PROGRAMMING

Before starting programming, the **required information** (output data) must be compiled.

The most important initial data can be taken from the individual part drawing with the geometry and the required quality, e.g. surface quality (see Chapter 1) and the work plan (see Chapter 2), which often already exists at the time of programming and contains the technological sequence (work processes) with the selected machines and required fixtures.

The target times (setup time and time per unit) for the CNC work process are determined after programming. Here, the setup sheet (for calculating the setup time) and the values determined in the simulation by the programming system for the main action time (tool engaged) and additional action time (e.g. time for tool change and positioning in rapid traverse) are important aids for calculating the time per unit.

Further carriers of information are:

- machine catalogue (information on performance, speed and feed range, max. workpiece size, mounting of clamping devices...)
- tool catalogue
  - information on cutting materials and cutting values: cutting speeds, feeds…
  - information on tools: tool mounts, tool holders, indexable inserts…
- clamping devices and fixture catalogue
- if necessary, also order data (quantity, date)

Before "programming", a suitable **clamping device** must be selected in accordance with the blank specified in the work plan.

On the basis of the blank geometry and the finished part geometry, the **work process steps** (machining steps within the work process) for generating the shape of the workpiece are to be determined.

Then, the required **tools** for the individual steps must be selected (from the tool catalog or tool database). The possible assignment in the existing turret of the machine tool must be taken into account.

In the next step, the cutting materials and the **technological data** (cutting speed, speed, feed, cutting depth) are determined from tool catalogs or databases (see Chapter 2).

Before the CNC program is generated, the **workpiece zero point** is defined. The **CNC program** can be **entered** directly at the machine via the control panel or via a programming system with a subsequent **simulation**.

After checking the program, it is transferred to the machine directly or via DNC operation.

The **result** of programming is a **set-up sheet** (set-up plan), the **tool list** for presetting and the **programming sheet** with the CNC program.

The most important document for setting up a CNC machine is the **set-up sheet**. It contains information about the machine used, the clamping device, the work steps (with cutting values) and the tools to be used (designation, cutting material, tool length, radii). The CNC machine is set-up on the basis of the set-up sheet and the tool list.

Important additional activities when configuring (setting up) a CNC machine compared to a conventional machine:

- preparing tools, including presetting
- entering or updating tool geometry data in the control system
- preparing and installing clamping devices, jigs and measuring equipment
- defining the workpiece zero point and entering it in the registers
- entering or importing a CNC program (after machine programming)
- testing of the CNC program (sample)

Technische Hochschule Wildau *Technical University of Applied Sciences* WILDAU	**Set-up sheet** belongs to work plan of the same drawing number	**Designation:** baseplate **Drawing No.:** ET-0815:02

WP-No.:	30
Editor:	Mustermann
Material / semi-finished product:	16MnCr5 / 100 x 70 x 10
Workstation No.:	01091
Cost center:	1203

Program	%471101	Date	17.12.2017
Programmer	Digitalus	Clamping device	vice
Machine	FP5	Clamping depth	4 mm

Number	**Work step (WS)**
10	milling outer contour
20	milling groove
30	milling rectangular pocket
40	spudding 8 x Ø12
50	drilling 8 x Ø8

Tool compartment	**Tool type Cutting material**	**Tool length [mm]**	**Tool-Ø [mm]**	**Cutting data**	**in WS**
T1	endmill HSS	140	10	f=80 mm/min n=680 1/min	10
T2	groove cutter HSS	100	8	f=120 mm/min n=1,800 1/min	20 30
T3	pilot drill HSS	100	12	f=90 mm/min n=8,000 1/min	40
T4	spiral drill HSS	140	8	f=120 mm/min n=1,200 1/min	50

Table 13 Content of a set-up sheet

Tool management is particularly important when setting up a CNC machine. It is common practice to preset tools using an external tool presetter in order to reduce set-up times. In order to avoid errors, the test piece must be measured, and a compensation must be made directly at the machine using a compensation switch.

3.3 CNC PROGRAMMING ACCORDING TO DIN 66025 OR PAL

In DIN 66025 (program structure for numerically controlled machines) and ISO 6983, programming has been standardized. Since this DIN only describes the basics and was not adapted to the technical state of the art, the control manufacturers developed new codes and cycles based on the basic commands according to DIN 66025, which simplify and shorten programming.

PAL stands for **P**rüfungs**a**ufgaben- und **L**ehrmittelentwicklungsstelle ([German]; transl.: examination task and teaching material development office) of the IHK Stuttgart and has existed since 1948. PAL supplies the written, practical and integrated intermediate and final examinations for the industrial-technical professions. These are developed in technical committees and working groups. The PAL programming system for turning and milling developed in 2007 (extended in 2012) is used for training and further education and enables examination performance to be compared independently of the controls used in the respective companies. In addition, it has developed into an industry standard, here specifically related to cycles as an extension to DIN 66025.

3.3.1 BASIC COMMANDS, ADDRESS LETTERS AND ADDITIONAL FUNCTIONS

A program consists of a **program start**, a sequence of **program blocks**, and the **program end** (command M30).

A program block consists of program words. Each program word begins with an **address** (e.g. N, G, M, T ...) by which a function of the command is defined.

Path conditions are identified by the address letter G and a number (e.g. G01) and always have a reference to the movement within the coordinate system (e.g. G00 X80 Z5).

Each program word is followed by an address, a **parameter** or a parameter list, depending on the command (address letter and sequence of digits).

Additional functions are defined by the address letter M and a number, usually commands to switch special functions on and off (e.g. M8 coolant on → M9 coolant off).

N10 M03 M08 T3 G96 S125

N20 G92 S3000

.

N70 G0 X75 Z2

N80 G1 Z-35 F0.4

.

.

N200 M30

Address letters within CNC programs

The address letters (see Table 14) in combination with a number and a prefix form program words. The programming instructions for the special controller define the meaning and sequence. Depending on the address letter, the number has the meaning of a code (e.g. M08) or a value (e.g. X80).

Addresses	Explanation
A	rotation around the X-axis
B	rotation around the Y-axis
C	rotation around the Z-axis
D	rotation around additional axis or freely available
E	rotation around additional axis or freely available
F	feed
G	path condition
H	tool length compensation
I	circular interpolation parameters or thread pitch parallel to X-axis
J	circular interpolation parameters or thread pitch parallel to Y-axis
K	circular interpolation parameters or thread pitch parallel to Z-axis
L	freely available, mostly used to call subroutines
M	additional function (machine commands, switching functions)
N	block number
O	tool offset parallel to axis or offset (do not use if possible)
P	third rapid traverse limit
Q	second rapid traverse limit
R	first rapid traverse limit or reference plane
S	main spindle speed
T	tool number, possibly with compensation value
U	second axis parallel to X-axis
V	second axis parallel to Y-axis
W	second axis parallel to Z-axis
X	first main axis
Y	second main axis
Z	third main axis

Table 14 Address letters as extra page

The path conditions G (see Table 18) and additional functions M (see Table 16) are described in detail later.

Address letters (coordinates) to which the tool is moving:

X, Y, Z, - first main axis

U, V, W - second axis

I, J, K - circular interpolation

A, B, C, D, E - rotations (angle)

The **block number** e.g. N30 is the first word of a block. In the NC editor for entering the NC program, the automatic assignment of the block number or the subsequent generation of the block number often takes place.

The **feed f** describes the speed at which the tool moves (see Figure 19). The feed rate v_f is usually described in mm/min, but during turning it is often referred to the spindle revolution in mm/revolution (see geometry commands G94 and G95).

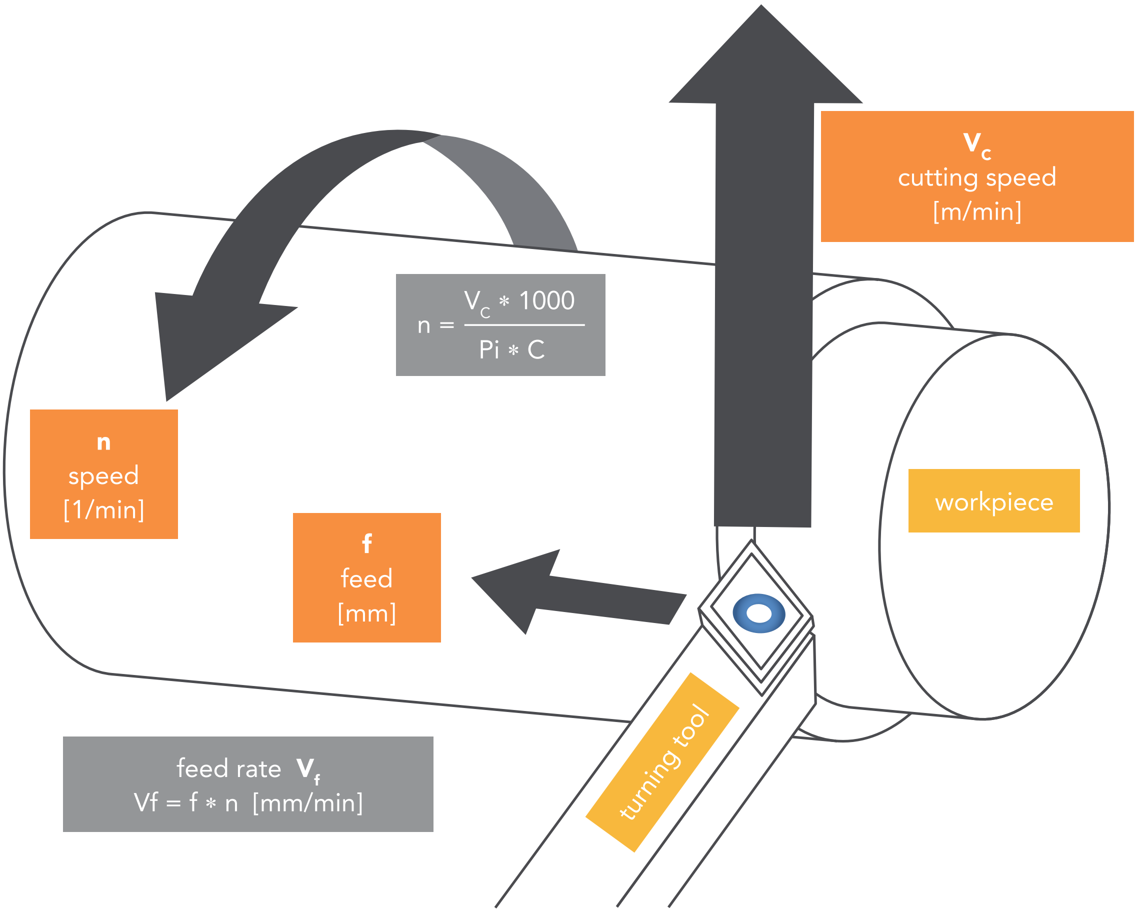


Figure 19 Speed, feed, cutting speed and feed rate

The **spindle speed S** can be programmed directly in revolutions per minute (constant speed standard setting → see also geometry commands G97 and G92), e.g. S1000 corresponds to a speed of 1,000 1/min. In combination with command G96, S describes a constant cutting speed (see geometry command G96).

The **tool position T** with the following code number, e.g. T5, is used to call the tool from the tool magazine and to store the tool dimensions in the tool compensation memory.

Special characters within CNC programs

Special characters (see Table 15) are used, among other things, to represent comments, but also as arithmetic operators in calculations.

Special character	Explanation
%	natural number → start (name) of main program
(	start of comment
)	end of comment
;	start of comment for single-line comment
+	prefix for decimal numbers / arithmetic operator
–	prefix for decimal numbers / arithmetic operator
*	arithmetic operator
/	arithmetic operator
=	arithmetic of values

Table 15 Special characters

Additional functions (M functions) within CNC programs

Additional functions (also called M functions or auxiliary functions, see Table 16) are defined by the address letter M and a two-digit code number. They contain technological information that is not covered by address letters, such as F, S and T.

Commands acc. to PAL	Commands acc. to DIN	Explanation
M00	M00	programmed stop, spindle, coolant and feed off, restart the program with the START key
M03	M03	spindle right rotation on (clockwise)
M04	M04	spindle left rotation on (counterclockwise)
M05	M05	spindle stop
---	M06	perform tool change
---	M07	coolant supply 2 on
M08	M08	coolant supply 1 on
M09	M09	coolant off
M17	---	end of subprogram
---	M19	spindle stop in certain angular position
M30	M30	end of program (main program) with reset to start of program
---	M31	release locking mechanism, e.g. safety door
---	M34	clamping pressure normal
---	M35	clamping pressure reduced
---	M40	neutral: gear stage 1 DIN: automatic gear shifting
---	M41 - M45	shifting gear stages 1 to 5
---	M48	overlay effective
---	M49	overlay ineffective
---	M60	workpiece change
M60	---	constant feed (tool cutting edge)
M61	---	constant feed with influence on inner and outer corners

Table 16 Additional functions (M functions)

The command **M00** is called a programmed stop. It includes spindle, coolant and feed off. By pressing the START key, the program continues to be executed at the point where it was interrupted. M00 is used, among other things, for reclamping, but also for measuring the workpiece.

Commands **M03**, **M04** (see Table 17) and **M05** (spindle stop) refer to the movement of the spindle.

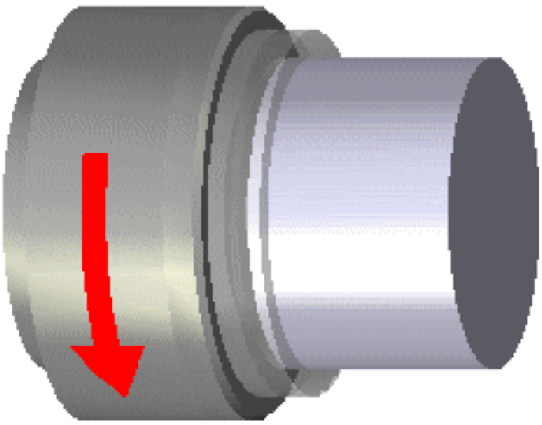
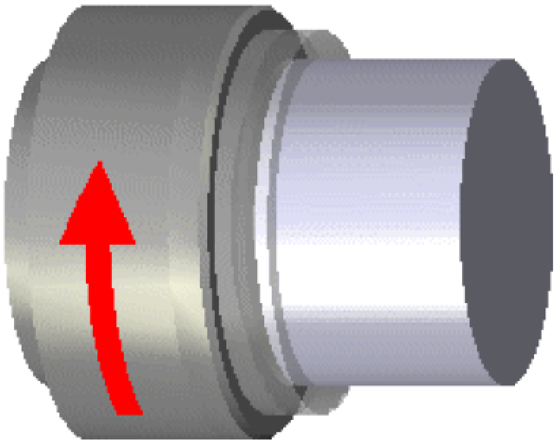
M3 – Spindle rotation right	M4 – Spindle rotation left
	
switching on the spindle in right rotation (clockwise)	switching on the spindle in left rotation (counterclockwise)

Table 17 Machine commands M3 and M4

Command **M08** activates the coolant or lubricant. M09 stops the flow of lubricant.

A called subprogram (see geometry command G22) is terminated by **M17** as the last program block. This command causes a return to the main program, which is the program block following the subprogram being called.

In a main program, command **M30** is always the last program block. It causes the drive spindle to be switched off, the coolant to be switched off and the end of the NC program being executed. The program will be reset to the beginning.

3.3.2 G COMMANDS (PATH CONDITIONS) - TURNING

G commands, also called geometry commands, define the geometric parts of the program together with the words for the coordinates. Their function is always related to motion. G commands usually define how the tool should travel the programmed path; on which path (e.g. via G0 X20 Z40 at rapid traverse to the specified coordinates) or with which property (e.g. via G97 S1200 at a speed of 1,200 rpm). A list of the most important commands can be found in Table 18.

Path conditions, similar to the additional functions, have a self-retaining character, i.e. after a function has been called once, it remains active until it is deactivated or replaced by another command.

Commands acc. to PAL	Commands acc. to DIN	Explanation
G00	G00	straight line interpolation in rapid traverse
G01	G01	straight line interpolation with feed
G02	G02	clockwise circular interpolation
G03	G03	counterclockwise circular interpolation
G04	G04	dwell time, time predetermined
---	G05	temporarily free available
---	G06	parabolic interpolation
---	G07	temporarily free available
---	G08	speed increase up to a programmed value
G09	G09	speed decrease from a programmed value when approaching a programmed point
---	G10 – G16	temporarily free available
G14	---	approaching of tool change point
---	G17	plane selection XY
---	G18	plane selection ZX
G18	---	rotary plane selection X-Z
---	G19	plane selection YZ
G22	---	call of subroutine
G23	---	program section repeat
G29	---	program jumps
G30	---	reclamping
	G33	thread cutting, constant pitch
---	G34	thread cutting, constantly increasing pitch
---	G35	thread cutting, constant decreasing pitch
---	G36 - G39	always freely available
G40	G40	cancel tool compensation
G41	G41	tool path compensation, left or tool radius compensation, left
G42	G42	tool path compensation, right or tool radius compensation, right
---	G43	always freely available
---	G44	cancel tool compensation

Commands acc. to PAL	Commands acc. to DIN	Explanation
---	G45 - G52	temporarily free available
G53	G53	canceling the zero offset
G54 - G57	G54 - G59	adjustable zero offset
G59	---	programmable (incremental) zero offset
---	G60 - G62	temporarily free available
---	G63	thread drilling
---	G64 - G69	temporarily free available
G70	G70	dimensions in inch
G71	G71	dimensions in mm
---	G72 - G73	temporarily free available
---	G74	move to reference point
---	G75 - G79	temporarily free available
---	G80	cancel work cycle
---	G81	working cycle 1, drilling, centering
---	G82	working cycle 2, drilling, face countersinking
---	G83	working cycle 3, deep-hole, chip breaking
---	G84	working cycle 4, thread drilling
---	G85 - G89	working cycle 5 - 9
G90	G90	absolute dimensions
G91	G91	incremental or relative measurements
G92	G92	set memory (e.g. for speed limitation)
---	G93	time-reciprocal encryption of feed
G94	G94	indication of the feed rate in mm/min (for DIN with G70 in inch/min)
G95	G95	indication of the feed in millimeters per revolution (for DIN with G70 inch per revolution)
G96	G96	constant cutting speed S in m/min (DIN with G70 ft/min)
G97	G97	indication of spindle speed in 1/min
---	G98 - G99	temporarily free available

Table 18 Geometry commands

Absolute (G90) and incremental (G91) programming

The absolute dimension is the power-on state; it remains active until it is switched off with command G91. The differences between absolute and incremental programming are shown in Figure 20.

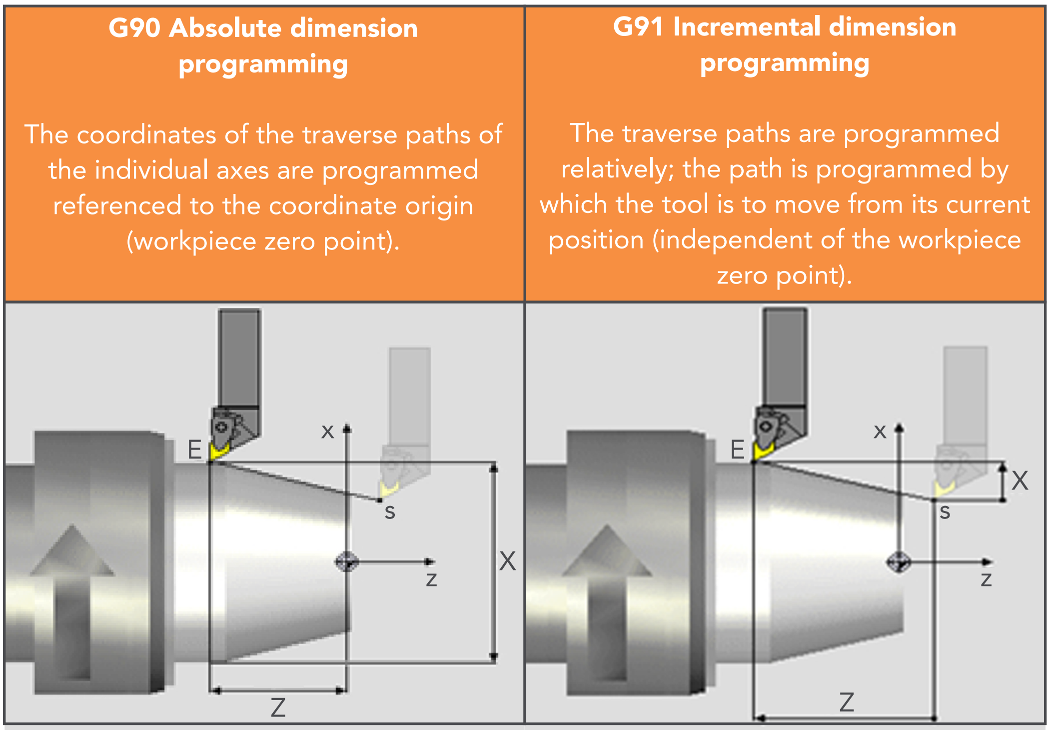


Figure 20 Absolute (G90) and incremental (G91) dimensions

Command G00 - linear interpolation at rapid traverse

The tool moves linearly from the starting point S to the programmed end point E (exact stop) at the maximum possible rapid traverse speed (depending on the machine), see Figure 21.

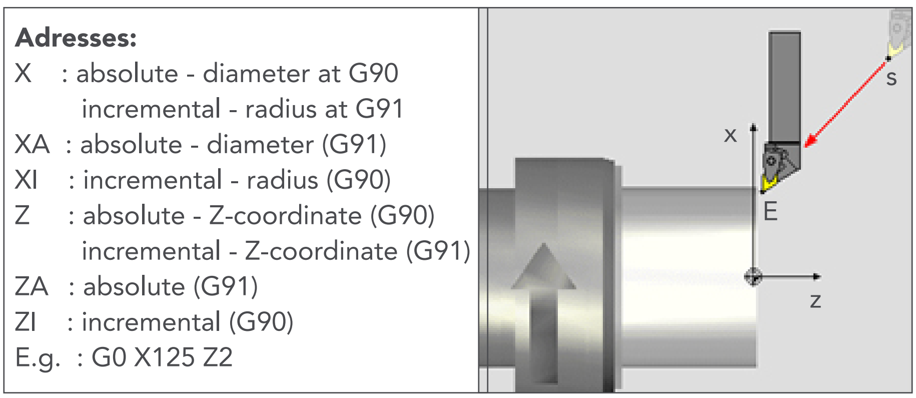


Figure 21 Moving in rapid traverse (G00)

Command G01 - linear interpolation in operation (feed)

The tool moves linearly from the starting point S to the programmed end point at the programmed feed rate.

By specifying AS (angle of climb), a target coordinate can be replaced by an angle, see Figure 22.

Adresses:

X : absolute - diameter at G90
incremental - radius at G91
XA : absolute - diameter (G91)
XI : incremental - radius (G90)
Z : absolute - Z-coordinate (G90)
incremental –Z-coordinate (G 91)
ZA : absolute (G91)
ZI : incremental (G90)
E.g.: G1 X125 Z-45 F0.4

D : length of travel distance
AS : angle of climb for straight line
RN : transition element to next
contour element
RN+ radius of curvature
RN - chamfer width
E.g.: G1 Z-45 RN-2

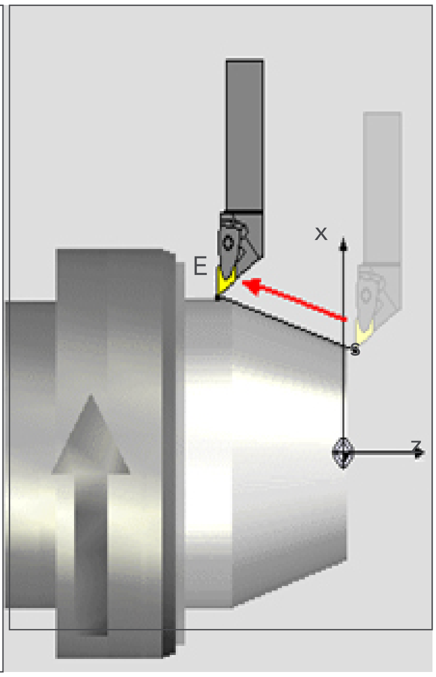


Figure 22 Linear movement with feed (G01)

…G1 X50 Z-30

G1 X61 AS150 …

Transition elements are programmed by RN+ (radius of curvature to the next contour element) or RN- (chamfer width to the next contour element).

Commands G97, G96 and G92

Command G97 (constant speed) is the power-on state. It remains active until it is switched off by command G96. The command is supplemented by the address S (here speed).

E.g.: G97 S1200 → constant speed of 1,200 rpm

At constant cutting speed (G96), the current speed is calculated by the control via the respective X-value. The command is supplemented by the address S (here: cutting speed).

E.g.: G96 S200 → constant cutting speed of 200 m/min

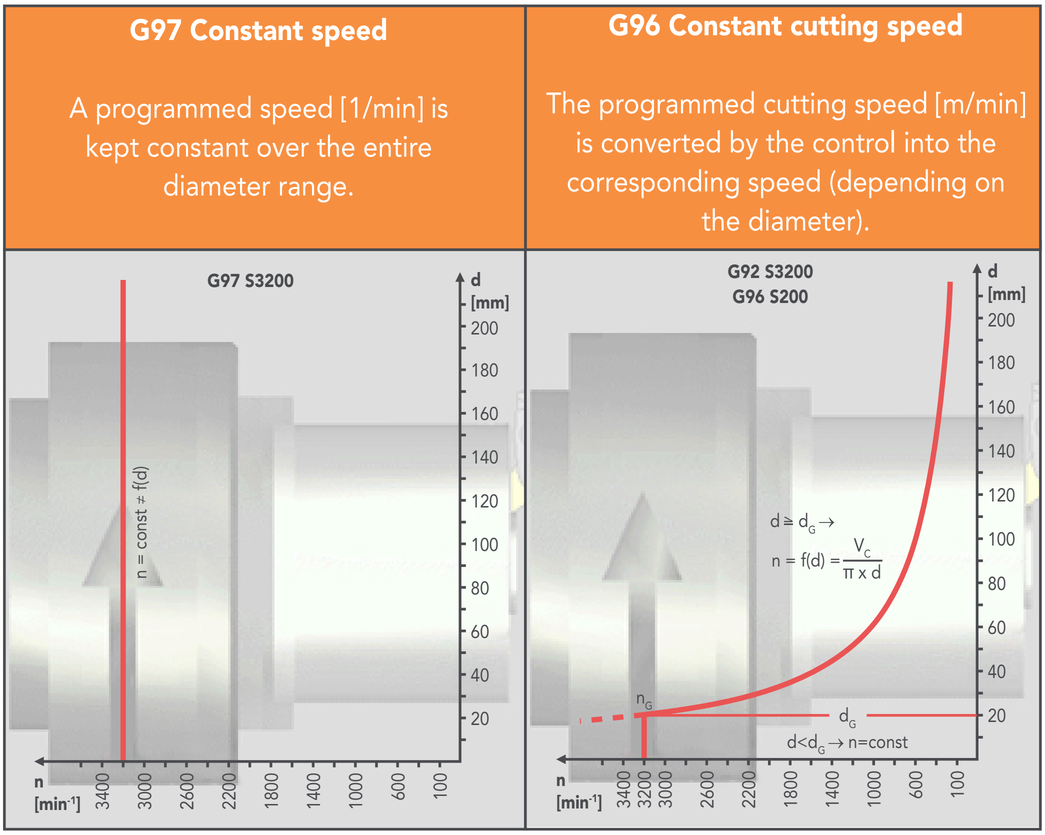


Figure 23 Constant speed (G97) and constant cutting speed (G96)

Command G92 (speed limit) must be used in conjunction with command G96. This speed limit is necessary because, at a constant cutting speed, the speed increases with decreasing diameter (when facing and parting towards infinity). The command is completed by the address S (in this case speed).

E.g.: G92 S2500 → maximum spindle speed of 2,500 rpm

Commands G94 and G95

Commands G94 and G95 (see Figure 24) are used to program the feed rate in different ways using the address F.

E.g.: G95 F0.4 → feed = 0.4 mm/revolution

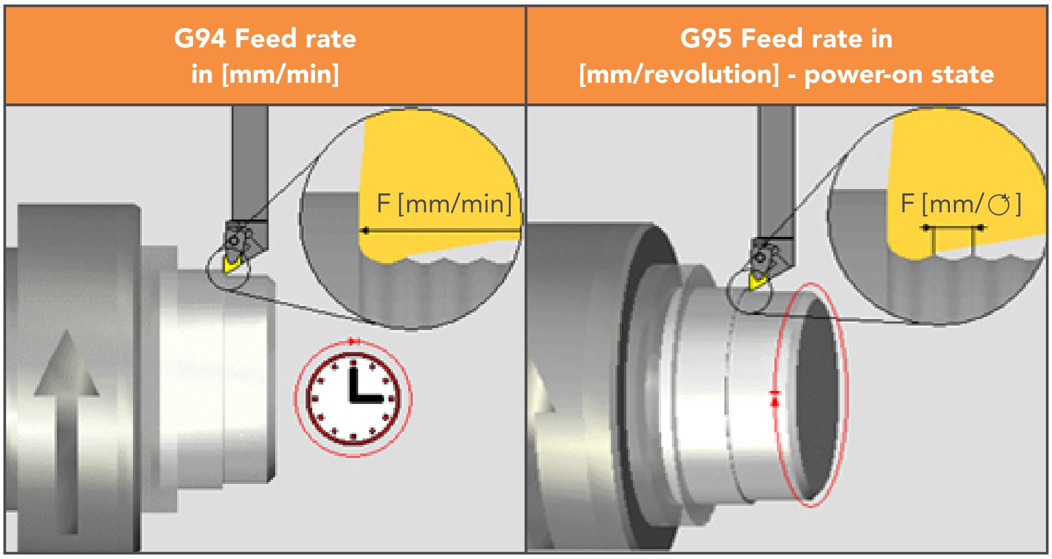


Figure 24 Feed rate (G94 / G95)

Commands G40, G41 and G42

In order to achieve the necessary tool life, all turning tools have a rounded cutting tip with a radius (0.2 … 2mm), so that the theoretical chisel tip and the center of the radius do not coincide. If the turning tool moves axis-parallel or plane-parallel, no contour errors occur, but this is not the case with circular paths and conical surfaces. The contour errors that then occur are corrected by calling the tool radius compensation left (G41) or right (G42). With these commands, the control moves the tool so that the center of the cutting radius is guided parallel to the workpiece contour (equidistant) at a distance of the cutting radius (see Figure 25). This avoids the contour errors that occur.

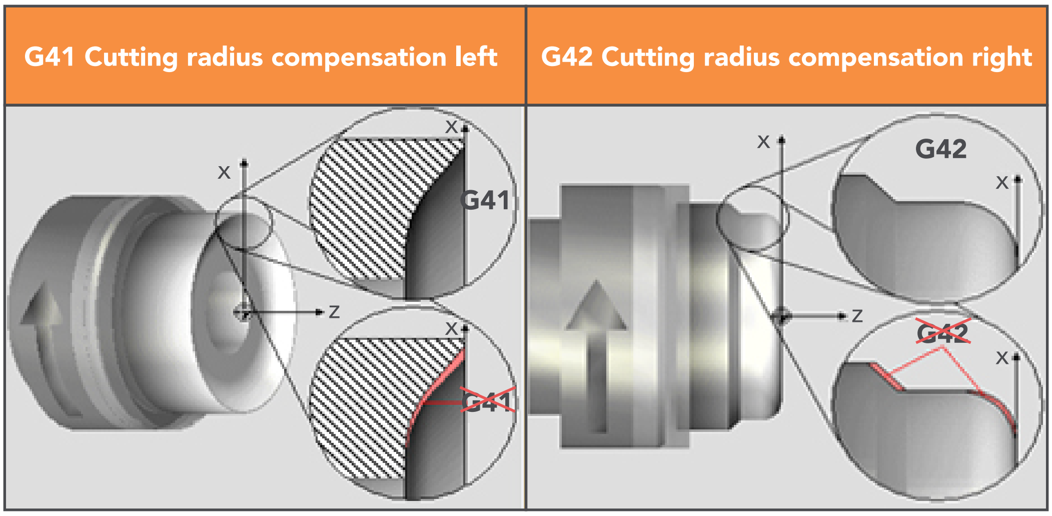


Figure 25 Cutting radius compensation

Command G40 (power-on state) cancels a programmed radius compensation.

Commands for circular movement G2 / G3

The commands G2 (clockwise) and G3 (counterclockwise) cause a circular movement from a current position in the program (starting point) to an end point of the arc (see Figure 26). The position of the end point is described with the coordinates X and Z (usually absolute). The radius is programmed by the interpolation parameters I and K (distance from the starting point to the center), or directly under the address R.

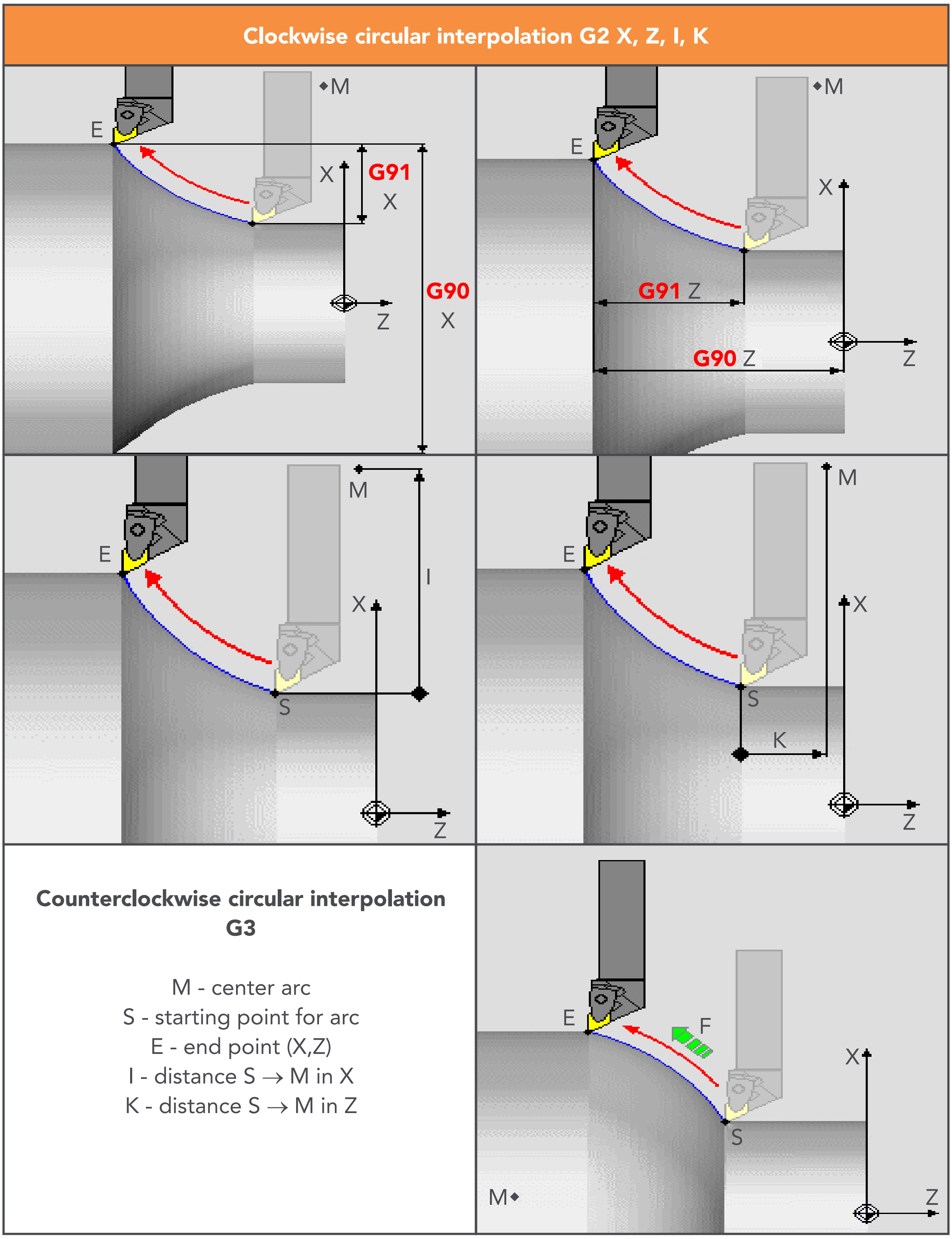


Figure 26 Circular interpolation G2 and G3

E.g.: Radius 5 mm each

…G1 X20 Z-5

G3 X30 Z-10 I0 K-5

G2 X40 Z-15 R5 ……

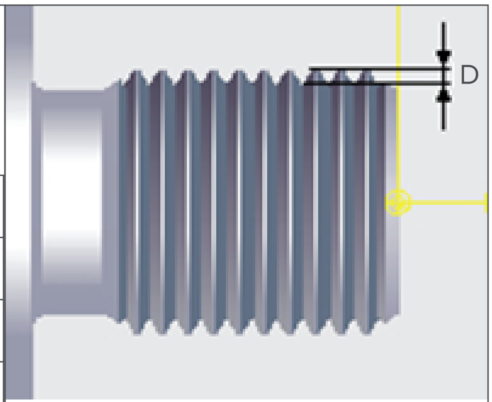
3.3.3 PROGRAMMING CYCLES - TURNING

Modern controls of CNC machines work with an extended coding of commands, which is not part of DIN 66025. The use of such cycles considerably reduces the programming effort for certain standard tasks. In the following, the turning cycles that exist after the PAL coding are described.

Threading cycle G31

This cycle supports the programming of cylindrical and tapered threads.

G31 THREAD CYCLE MANDATORY PARAMETERS: COORDINATES (X,Z), END POINT PITCH F, THREAD DEPTH D
THREAD END POINT IN Z (Z, ZI, ZA)
THREAD END POINT IN X (X, XI, XA)
PITCH
THREAD DEPTH
THREAD STARTING POINT ABS. IN Z
THREAD STARTING POINT ABS. IN X
THREAD STARTING DISTANCE
THREAD OVERRUN DISTANCE
NUMBER OF CUTS
NUMBER OF EMPTY RUNS
IMMERSION ANGLE TO X-AXIS
TYPE OF POSITIONING
SPEED / CUTTING SPEED
1. M FUNCTION
2. M FUNCTION



POSITIONINGS (REFERENCE):

PITCH	1	2	3	4
NUMBER	5	8	12	14

Figure 27 Threading cycle G31

Threading is done by a number of passes (positionings) of the indexable insert along the part of the workpiece to be threaded. Thereby, the full cutting depth of the thread is divided into small cuts. The number of positionings required depends on the pitch of the thread, the cutting material and the material itself (medium strength). Rough reference values for medium-strength steel can be found in Figure 27. A blank cut is an additional cut without positioning.

Thread chasing G33

In contrast to thread turning, a tool for thread chasing has several cutting edges in series, the distance between the cutting edges corresponds to the pitch. Only one pass is required.

Cycle G33 supports the machining of cylindrical or tapered threads with a multi-tooth indexable insert; mandatory parameters are the end point of the thread in Z and the pitch F.

Tapping cycle G32

Production of internal threads with taps.

G32 TAPPING CYCLE MANDATORY PARAMETERS: COORDINATE (Z) ENDPOINT, PITCH F	
THREAD END POINT IN Z	**Z**
PITCH	F
SPEED / CUTTING SPEED	S
1. M FUNCTION	M
2. M FUNCTION	M

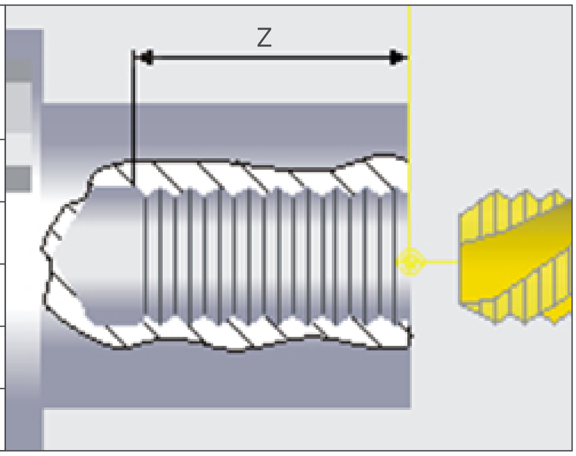


Figure 28 Tapping cycle G32

Drilling cycle G84

Cycle both for spudding and centering short holes and (thanks to its optional parameters - see Figure 29) for deep-hole drilling in several positionings with chip breaking and chip emptying.

DRILLING DEPTH	**ZA**
POSITIONING DEPTH	D
SAFETY DISTANCE	V
SAFETY DIS. BEFORE DRILL BOTTOM	VB
REDUCED VALUE POSIT. DEPTH	DR
MINIMUM POSITIONING	DM
RETRACTION DISTANCE	R
SPUDDING DEPTH	DA
DWELL TIME DRILL BOTTOM	U
SELECTION DWELL TIME UNIT	O
INPUT REDUCTION IN %	FR
SPUDDING FEED	E
FEED	F
SPEED / CUTTING SPEED	S
1. M FUNCTION	M
2. M FUNCTION	M

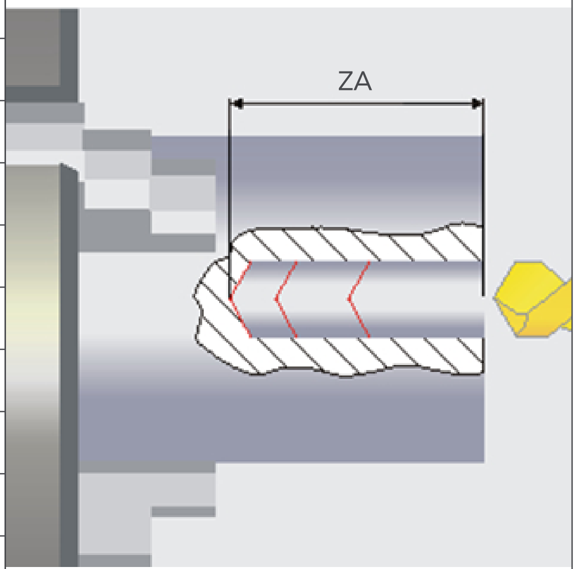


Figure 29 Drilling cycle G84

The mandatory parameter in this cycle is the drilling depth.

Undercut cycle G85

In order to produce standardized thread undercuts (DIN 76) and undercuts according to DIN 509 (Form E and F), this cycle is used with the undercut position in X and Z as a mandatory parameter.

UNDERCUT POSITION (Z, ZI, ZA)	**Z**
UNDERCUT POSITION (X, XI, XA)	**X**
UNDERCUT DEPTH	I
UNDERCUT WIDTH	K
GRINDING OFFSET	SX
CORNER RADIUS IF DEVIAT. FR. DIN	RN
UNDERCUT FORM	H
IMMERSION FEED	E
FEED	F
SPEED / CUTTING SPEED	S
1. M FUNCTION	M
2. M FUNCTION	M

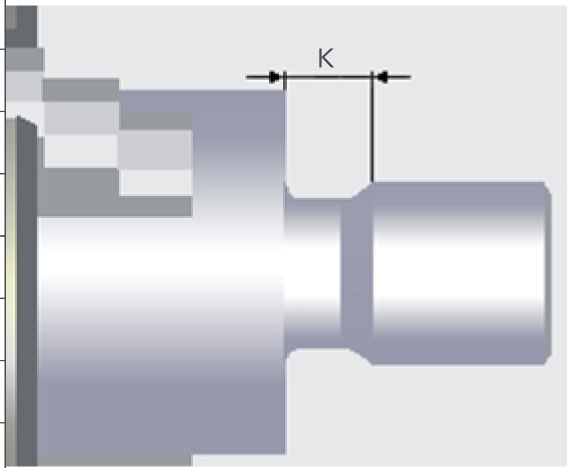
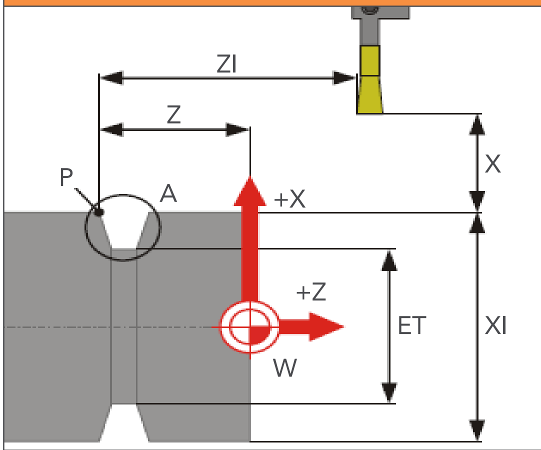
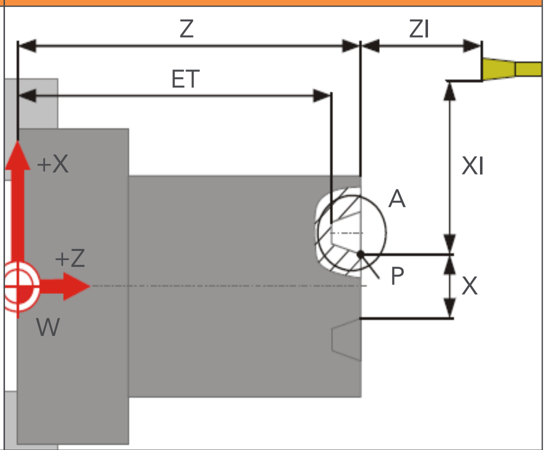


Figure 30 Undercut cycle G85

G86 / G88

The production of radial form recesses (G86) and axial form recesses (G88) is supported by the cycles described in Figure 31.





G86 RADIAL RECESS CYCLE		G88 AXIAL RECESS CYCLE	
SET POINT DEFINITION	EP	RECESS PLANE (Z, ZI, ZA)	**Z**
RECESS SET POSITION (Z, ZI, ZA)	**Z**	RECESS POSITION (X, XI, XA)	**X**
RECESS SET POSITION (X, XI, XA)	**X**	RECESS BOTTOM IN Z ABSOLUT	ET
DIAMETER ABSOLUT	ET	WIDTH AND POSITION OF RECESS	EB
WIDTH AND POSITION OF RECESS	EB	SET POINT DEFINITION	EP
POSITIONING DEPTH IN X	D	POSITIONING DEPTH IN Z	D
EDGE ANGLE START POINT	AS	EDGE ANGLE START POINT	AS
EDGE ANGLE END POINT	AE	EDGE ANGLE END POINT	AE
ROUND./CHAMFER UPPER CORNERS	RO	ROUND./CHAMFER UPPER CORNERS	RO
ROUND./CHAMFER LOWER CORNERS	RU	ROUND./CHAMFER LOWER CORNERS	RU
CONTOUR PARALLEL OFFSET	AK	CONTOUR PARALLEL OFFSET	AK
OFFSET IN X	AX	OFFSET IN X	AZ
MACHINING TYPE	H	MACHINING TYPE	H
POSITIONING WIDTH IN %	DB	POSITIONING WIDTH IN %	DB
SAFETY DISTANCE OVER OPENING	V	SAFETY DISTANCE OVER OPENING	V
SOLID MATERIAL FEED	E	SOLID MATERIAL FEED	E
RECESS TRUNING FEED	F	RECESS TRUNING FEED	F
SPEED / CUTTING SPEED	S	SPEED / CUTTING SPEED	S
1. M FUNCTION	M	1. M FUNCTION	M
2. M FUNCTION	M	2. M FUNCTION	M

Figure 31 Recess cycles G86 and G88

Mandatory parameters are the recess position (in X and Z) and the diameter of the recess bottom (ET).

Contour cycles

Cycles serve to simplify programming tasks and reduce the program length by calling recurring sequences only once and adding parameter values. The following contour cycles in particular offer great support for the programmer.

In the following cycles, their call is executed with command **G80** in an extra program line. The first contour point must be approached absolutely with G0 or G1. The contour description can take place either directly after calling the cycle in the main program (see example in Figure 32), after the main program or in an external subprogram. In principle, contour cycles work with a cutting radius compensation.

Longitudinal contour roughing cycle G81 / planar contour roughing cycle G82

In these cycles, turning in the longitudinal direction (long turning G81) or in the face direction (facing G82) is carried out by an automatic cutting arrangement on a programmed contour (see Figure 32). The positioning (cutting depth) is a mandatory parameter in each case.

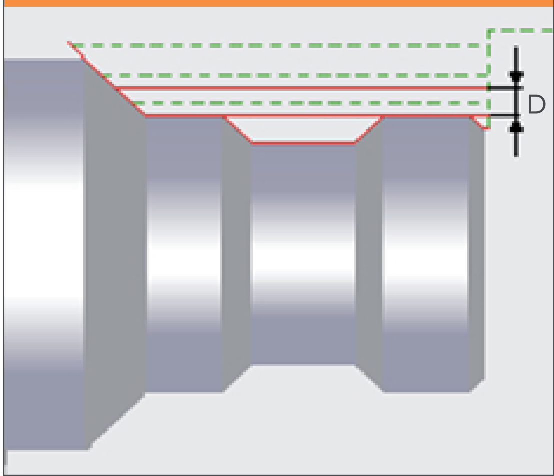
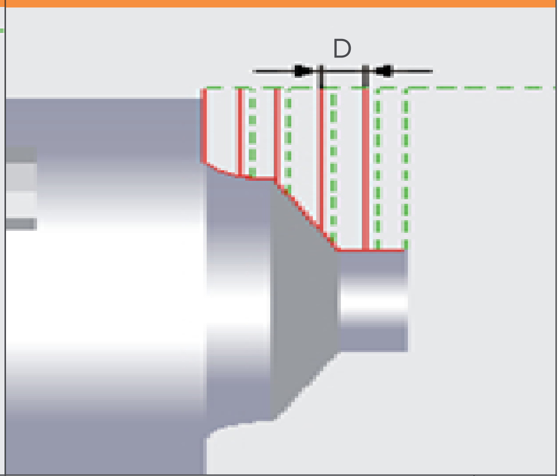
G81 LONGITUDINAL ROUGHING CYCLE		G82 PLANAR ROUGHING CYCLE	
			
FEED	D	FEED	D
MACHINING TYPE	H	MACHINING TYPE	H
CONTOUR PARALLEL OFFSET	AK	CONTOUR PARALLEL OFFSET	AK
OFFSET IN Z	AZ	OFFSET IN Z	AZ
OFFSET IN X	AX	OFFSET IN X	AX
IMMERSION ANGLE	AE	IMMERSION ANGLE	AE
EMERSION ANGLE	AS	EMERSION ANGLE	AS
SAFETY ANGLE	AV	SAFETY ANGLE	AV
MACHINING STARTING POINT	O	MACHINING STARTING POINT	O
EMPTY CUT OPTIMIZATION	Q	EMPTY CUT OPTIMIZATION	Q
SAFETY DISTANCE IN Z AT Q2	V	SAFETY DISTANCE IN Z AT Q2	V
IMMERSION FEED	E	IMMERSION FEED	E
FEED	F	FEED	F
CUTTING SPEED	S	CUTTING SPEED	S
1. M FUNCTION	M	1. M FUNCTION	M
2. M FUNCTION	M	2. M FUNCTION	M

Figure 32 Contour cycles G81 and G82

Contour parallel roughing cycle G83

In this cycle, the cuts are automatically divided in the contour parallel direction to a programmed contour (Figure 33).

POSITIONING	D
MACHINING TYPE	H
CONTOUR PARALLEL OFFSET	AK
OFFSET IN Z	AZ
OFFSET IN X	AX
IMMERSION ANGLE	AE
EMERSION ANGLE	AS
SAFETY ANGLE	AV
MACHINING STARTING POINT	O
EMPTY CUT OPTIMIZATION	Q
IMMERSION FEED	E
FEED	F
CUTTING SPEED	S
1. M FUNCTION	M
2. M FUNCTION	M

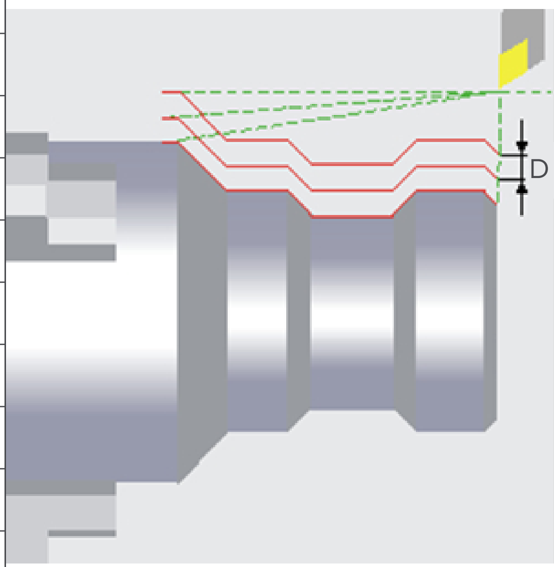
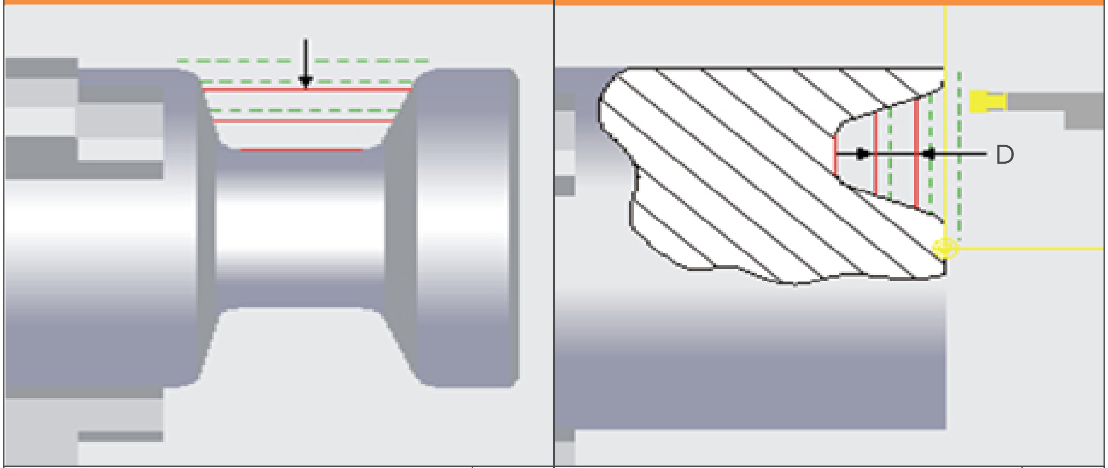


Figure 33 Contour parallel roughing cycle G83

The cycle is particularly suitable for machining of preformed blanks (e.g. castings) using machining mode H4 (contour finishing).

Radial contour plunge cycle G87 / axial contour plunge cycle G8

These two universal cycles support the programmer axially and radially as contour plunge cycles along a programmed contour.



G87 RADIAL CONTOUR PLUNGE CYCLE		G89 AXIAL CONTOUR PLUNGE CYCLE	
POSITIONING DEPTH IN X	D	POSITIONING DEPTH IN Z	D
CONTOUR PARALLEL OFFSET	AK	CONTOUR PARALLEL OFFSET	AK
OFFSET IN X	AX	OFFSET IN Z	AX
MACHINING TYPE	H	MACHINING TYPE	H
POS. WIDTH IN % OF CHISEL WIDTH	DB	POS. WIDTH IN % OF CHISEL WIDTH	DB
MACHINING SELECTION	O	MACHINING SELECTION	O
EMPTY CUT OPTIMIZATION	Q	EMPTY CUT OPTIMIZATION	Q
SAFETY DISTANCE	V	SAFETY DISTANCE	V
SOLID MATERIAL FEED	E	SOLID MATERIAL FEED	E
RECESS TRUNING FEED	F	RECESS TRUNING FEED	F
SPEED / CUTTING SPEED	S	SPEED / CUTTING SPEED	S
1. M FUNCTION	M	1. M FUNCTION	M
2. M FUNCTION	M	2. M FUNCTION	M

Figure 34 Radial and axial contour plunge cycle

The positioning depth in X (G87) or in Z (G89) is a mandatory parameter here.

3.3.4 PROGRAM REPETITIONS, PROGRAM JUMPS AND SUBPROGRAMS

The following commands are used in order to simplify programming and make it more effective.

Program section repetition G23

To execute parts of a program several times, the command G23 is supplemented with the number of the start block and the end block of the program section to be repeated (mandatory parameter), as well as optionally the number of repetitions (default setting H1).

E.g.: G23 N110 N210 H2

Program jumps G29

After calling this command, program parts are skipped or an unconditional or conditional jump to a program block occurs.

E.g.: G29 N120 Unconditional jump to block 120

As a condition, the logical comparison of the value from two parameters with a comparison relation (O1 → is equal, O2 → is unequal, O3 → greater than, O4 → smaller than) can be performed.

E.g.: N100 G29 P1 O1 P2 N400

N110 ....

The program continues in line 400 if the value of parameter P1 is equal to the value of P2. If the condition is not met, it continues with the next block (line 110).

Subprograms G22

With subprograms, programming can be greatly simplified. Geometries that are repeatedly used (e.g. undercuts) are saved as subprograms. They can then be called from a main program.

A subprogram is defined with command G22 followed by parameter L with the number of the program to be called (mandatory parameter) and the number of repetitions H (default setting H1). In addition, levels can be hidden (skipping blocks in the subprogram).

E.g.: G22 L122 H2

Subprograms should be written with relative (incremental) coordinates in order to use them universally (command G91 at the beginning of the subprogram). Each subprogram can again call another subprogram.

At the end of the subprogram is command M17; the called subprogram is terminated and there is a return to the called program in the block that follows the call of the subprogram.

In connection with a contour cycle, the description of the contour can also be in a subprogram.

E.g.: cycle G81 (contour description in subprogram)

G81 D4 H24 AK1 V2 O2

G22 L110 H1

G80

Subprogram L110

G1 X20 Z0 start of the description of the final contour

Z-20

X40

Z-50

X70

Z-80

X100 end of the description of the final contour

M17 end of subprogram – return to main program

Exercises for Chapter 3:

E 3.1: Name the advantages of CNC programming.

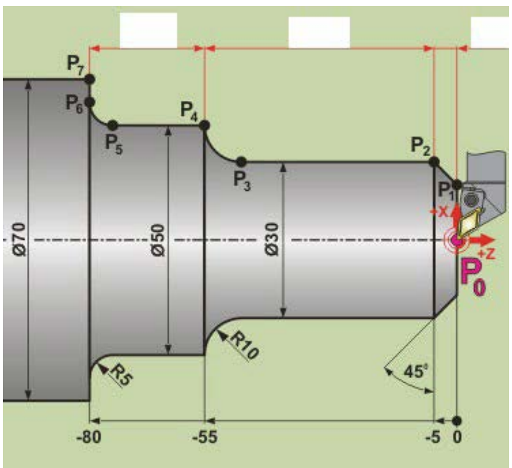
E 3.2: Briefly explain the types of programming.

E 3.3: Name the control types, on which types of machines they are used?

E 3.4: Briefly explain the reference points of a CNC machine.

E 3.5: Name the steps for creating the program and the results (documents).

E 3.6: Add incremental programming to the program according to the final contour specified (P0 … P7).



```
N40   G0   X0   Z2  {Werkzeug anstellen}
N50   G         Z      {Punkt P0}
N60   G    {Umschalten inkremental}
N70        X    {Punkt P1}
N80        X    Z      {Punkt P2}
N90             Z      {Punkt P3}
N100  G    X    Z    R    {Punkt P4}
N110  G         Z      {Punkt P5}
N120  G    X    Z    I    K    {Punkt P6}
N130  G    X    {Punkt P7}
N140  G    {Umschalten absolut}
```

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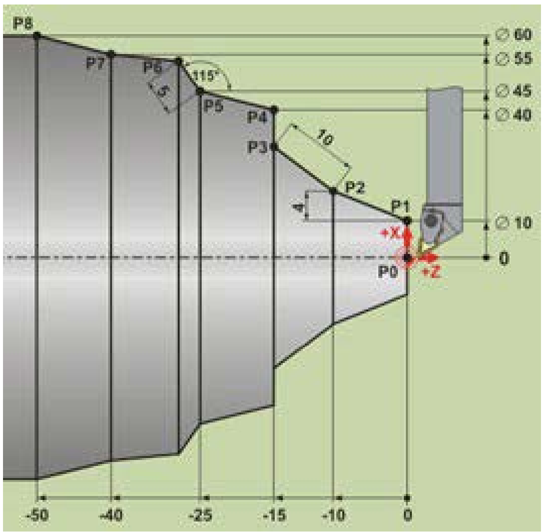
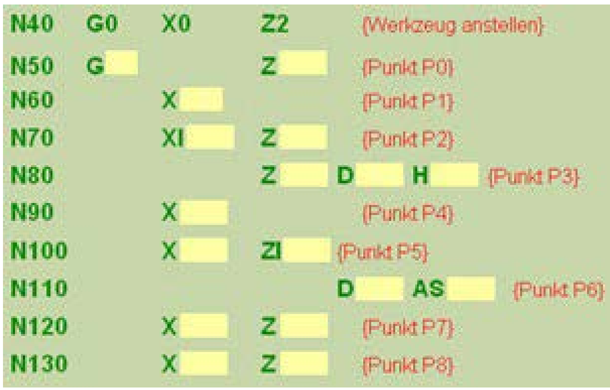
E 3.7: Write down the programming commands with their parameters:

- call zero offset in the first register
- spindle on in counterclockwise direction, coolant on, programmed stop
- call tool in holder compartment 5, end of main program
- approach tool change point
- constant speed of 1,200 1/min
- constant cutting speed 150 m/min
- speed limitation to 2,000 1/min
- feed 0.1 mm/revolution, cutting radius compensation left

E 3.8: Complete the program with absolute programming according to the final contour specified (P0 ... P8).





N40	G0	X0	Z2	{Werkzeug anstellen}				
N50	G		Z	{Punkt P0}				
N60		X		{Punkt P1}				
N70		XI	Z	{Punkt P2}				
N80			Z	D	H	{Punkt P3}		
N90		X		{Punkt P4}				
N100		X	ZI	{Punkt P5}				
N110				D	AS	{Punkt P6}		
N120		X	Z	{Punkt P7}				
N130		X	Z	{Punkt P8}				

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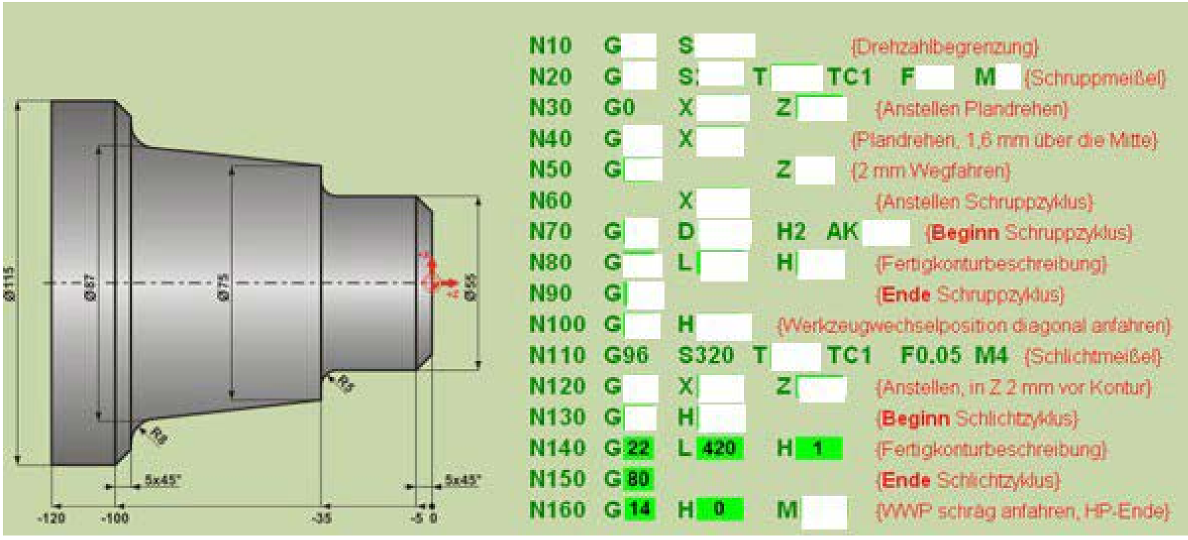
E 3.9: Complete the main program (longitudinal roughing cycle with subsequent finishing) with the following parameters:

- max. spindle speed - 4,000 1/min
- constant cutting speed - 240 m/min
- roughing turning tool in holder compartment 1
- positioning for facing and roughing cycle to diameter = 117 mm

- roughing cycle with a cutting depth of 2.5 mm and a contour-parallel offset of 0.5 mm
- call the contour in subprogram L420
- finishing of the contour (H4) with turning tool in holder compartment 3



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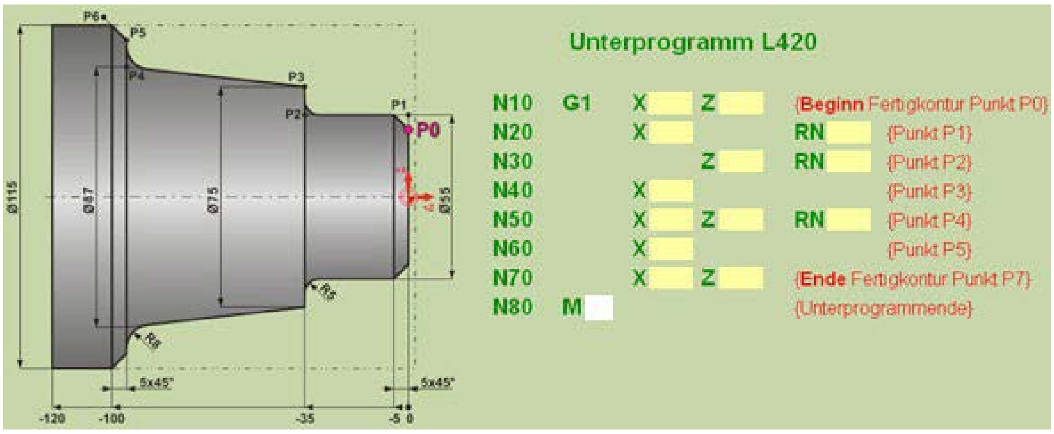
Add the subprogram L420 (specifying the final contour) using the transition elements (RN+ → chamfer width; RN- → radius).



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4 ACCOUNTING

In this chapter you will get to know:

- how cost rates are determined
- the methods for determining order and batch sizes
- the basis for the costing of orders

The aim of this chapter is to make you familiar with the basics and tasks of operational accounting. The necessary determination of hourly machine rates and wage cost rates in the company forms the basis for the calculation of the economic batch size and the costing (main component of internal accounting).

4.1 DETERMINATION OF COST RATES

The total costs of a product result from the direct costs (can be allocated directly to the product, such as material costs and manufacturing costs) and the overhead costs.

Overhead costs are calculated by distributing the costs that cannot be directly allocated to the product in the cost distribution sheet (CDS). It is an aid in the form of tables to distribute certain types of costs (auxiliary wages, operating materials, rent, electricity, administration costs, advertising costs ...) across the cost areas to the individual cost centers (points of consumption).

To calculate the manufacturing costs (see Chapter 4.3 - Costing), cost factors are necessary, which are described in more detail below.

Hourly machine rate

The hourly machine rate includes the costs incurred by using the operating equipment (machine tool) for one hour (in €/hour).

The aim of the hourly machine rate calculation is therefore to determine the costs incurred per hour of operating time on a machine. It is calculated by dividing the overhead costs attributable to the machine (imputed depreciations, imputed interests, occupancy costs, consumption costs and maintenance costs) by the operating time of the machine (in hours).

To calculate the hourly machine rate, the effective operating time must be determined. The structure of the machine times (load time, idle time, auxiliary time, maintenance time, resting time) can be found in the VDI standard 3258. According to this standard, operating time is the time in which the machine or manufacturing plant is used for a cost unit (individual part, assembly, product) and is connected to the power grid.

The operating time in h/year results from the number of working days per year, the working time per shift and the shift regime:

E.g.: calculation TO (1 shift): $\boxed{= 250 \frac{\text{days}}{\text{year}} * 8 \frac{\text{hours}}{\text{shift}} * 1 \frac{\text{shift}}{\text{day}}}$ $[^{h}/_{year}]$

The effective operating time TOe is calculated by multiplication with a utilization coefficient which takes into account personnel and machine related downtimes (age and wear of the machine, but also organizational standstill times).

Imputed depreciations (ID) are determined taking into account the applicable replacement value (simplified also acquisition value) including installation and ramp-up costs, the estimated service life and the effective operating time.

$$\boxed{ID = \left(\frac{AV}{SL}\right) * \frac{1}{TOe}} \quad [^{€}/_{h}]$$

AV	[€]	acquisition value (base price, equipment, accessories, transport, assembly and installation...)
SL	[year]	service life
TOe	[h/year]	effective operating time

Imputed interests (II) are usually applied in the form of the usual interest rates (%) for long-term debt capital. In order to simplify the calculation and to make it easier to compare different periods, interests are calculated from the half of the replacement value (acquisition value).

$$\boxed{II = \left(\frac{AV}{2}\right) * \frac{r_i}{100} * \frac{1}{TOe}} \quad [^{€}/_{h}]$$

r_i interest rate (e.g. 10 at 10%)

Occupancy costs (imputed rent) are related to the floor space occupied by the machine including all adjacent areas.

They include depreciations and interests on buildings and factory facilities, maintenance costs for buildings, costs for lighting, heating, insurance and cleaning. These costs are usually calculated using the room cost rate (€/m² per year) from the cost accounting (cost rate for room or land and buildings).

Consumption costs (CC) for the operation of the machine include costs for electricity, gas, water etc. and are determined by recording the respective demand over a longer period of time.

$\mathbf{CC}\text{energy} = \text{machine power (in kW)} * \text{electricity costs} \left(\frac{€}{\text{kWh}}\right)$	$[€/_{h}]$
$\mathbf{CC}\text{air} = \text{air consumption} \left(\text{in } \frac{\text{m}^3}{\text{h}}\right) * \text{air costs} \left(\frac{€}{\text{m}^3}\right)$	$[€/_{h}]$
$\mathbf{CC}\text{water} = \text{water consumption} \left(\text{in } \frac{\text{m}^3}{\text{h}}\right) * \text{water costs} \left(\frac{€}{\text{m}^3}\right)$	$[€/_{h}]$
$\mathbf{CC}\text{gas} = \text{gas consumption} \left(\text{in } \frac{\text{m}^3}{\text{h}}\right) * \text{gas costs} \left(\frac{€}{\text{m}^3}\right)$	$[€/_{h}]$
$\mathbf{CC}\text{oil} = \text{oil consumption} \left(\text{in } \frac{\text{l}}{\text{h}}\right) * \text{oil costs} \left(\frac{€}{\text{l}}\right)$	$[€/_{h}]$

Maintenance costs (ongoing maintenance, repairs) can be calculated as annual average values over longer periods and can be taken into account using suitable key figures (e.g. ratio of maintenance costs to replacement value or depreciations as maintenance cost rate in %/year).

The recording and calculation of **tooling costs** causes greater difficulties, since in operational practice tool consumption is not recorded down to the individual work station and no distinction is made between normal tools belonging to the machine (relevant for the hourly rate) and order-related tools (not relevant).

Service costs (also cleaning costs) are included in the hourly machine rate if maintenance work (on mechanics or controls) is outsourced to the supplier of the operating equipment or to maintenance companies.

Manufacturing overheads

Manufacturing overheads include auxiliary wages, salaries, social costs, auxiliary and operating materials, heating costs and other apportionment costs (mostly cost center related from the cost distribution sheet). They can be included directly in the hourly machine rate via an overhead cost factor using the wage but are usually only taken into account in costing (by multiplying the factor with the wage costs) (see Chapter 4.3).

Wage costs

Wage costs are the sum of wage-related expenses paid by the employer to the employee. They are calculated per hour and include the hourly wage and the non-wage labor costs that the employer must pay in accordance with the employment contracts, company agreements, statutory regulations and collective agreements. These include the employer's social insurance contributions (employer's contribution of 50 percent from the employee's income to its social insurance). Here, the share in the long-term care insurance (1.65% insured without children or 1.52% insured with children), pension insurance (9.3%), unemployment insurance (1.25%) and in the health insurance (7.3% + additional contribution) → as of 2019.

Furthermore, additional non-wage labor costs may arise, e.g. through surcharges for shift work, premiums and Christmas bonuses.

4.2 CALCULATION OF THE ECONOMICAL BATCH SIZE

The main content of work controlling (see Figure 1) is production planning and control. The main functions and basic functions are shown in Figure 35. An important basic function is the creation of manufacturing orders.

Planning complex	Main function	Basic function
Production planning	PROGRAM PLANNING	• program planning • program allocation
	QUANTITY PLANNING	• demand planning
	SCHEDULING AND WORKLOAD PLANNING (time management)	• flow planning • scheduling • *creation of manufacturing orders* • *load planning*
Production control	ORDER INITIATION	• order approval • workshop scheduling (machine allocation)
	ORDER MONITORING	• order tracking • factory data collection

Figure 35 Contents of production planning and control

A **manufacturing order** is an internal order for the production of a defined quantity of parts, assemblies, or finished products. It is triggered by a sales order or an internal customer.

The aim of the **creation of a manufacturing order** is to define manufacturing batches that are within the range of cost-effective manufacturing. This can be achieved by **blocking** (combining uneconomical partial quantities into larger total quantities within a preview period that has to be defined) or **splitting** (splitting large quantities into economic partial quantities).

The main factors influencing the creation of manufacturing orders are the size of the sales order and the economic batch size. Other factors include:

- time minimal batch size
- manufacturing type, production program
- tool life of the tools
- transportability of the batch
  - capacity of conveying aids (pallet)
  - capacity of conveyor (pallets per transport)

A **batch** is the quantity of identical work objects (products, assemblies, individual parts) that passes together through the production process and is manufactured at the work stations in a contiguous manner with a one-time setup time.

Simplified, the **time-minimal batch size** is used to determine the optimal batch size. With the time-minimal batch size, it is assumed that the set-up percentage for each batch must not be too large, since each workpiece has to take a high proportion of the set-up costs for small batches. This is limited by a set-up coefficient that is not scientifically justified. The ratio of set-up time and time per unit covers only a small part of the economic effects of batch size formation; the time-minimal batch size determines only the beginning of the economic range and is accordingly also called the minimum batch size (m_{lmin}).

$$\boxed{m_{l_{min}} = \frac{\sum t_s}{a * \sum t_u}}$$ time-minimal batch size [pieces/batch]

a set-up coefficient (0.05 → large and complicated parts, 0.08 → simple and easy parts, 0.1 → standard and automated parts)
t_s – set-up time [min/batch] t_u – time / unit [min/piece]

Various theories exist for calculating the **economic batch size**, also known as the optimum batch size. The classic here is the calculation according to Andler.

$$\mathbf{m_{l_e}} = \sqrt{\frac{\mathbf{AC * m_y * 200}}{\mathbf{p * C_{u1}}}}$$ economic batch size [pieces/batch]

my – yearly quantity [pieces/year], AC – availability costs for all work processes [€/batch], p – factor for manufacturing type (small series 30%, medium series 25%, large series 20%), C_{u1} – costs per unit [€/pieces]

The **manufacturing type** is characterized by the frequency of activity repetitions in the production process. A differentiation is made on the basis of the number of copies of manufacturing orders and the repetition frequency of identical or similar manufacturing objects. The division of the manufacturing types is primarily based on the quantity of the order. In small series production, small quantities are produced with a low repetition rate; in serial production, large quantities are produced with a low to high repetition rate.

Availability costs for all work processes

$$\mathbf{AC} = \sum \left[\frac{\mathbf{t_s}}{\mathbf{60}} * (\mathbf{C_{Ws}} + \mathbf{C_{Mh}}) \right]$$

C_{Ws} – wage costs set-up [€/h]
C_{Mh} – machine costs [€/h]

Costs per unit (material and manufacturing)

$$\mathbf{C_{u1}} = \mathbf{C_M} + \mathbf{C_{Mf}}$$

C_{Mf} – manufacturing costs [€/piece]
C_M – material costs [€/piece]

$$\mathbf{M_C} = \text{blank costs } (\mathbf{C_B}) * \text{material overhead surcharge } (\mathbf{MO})$$

Manufacturing costs (wage + machine costs) for all work processes [€/piece]

$$\mathbf{C_{Mf}} = \sum \left[\frac{\mathbf{t_u}}{\mathbf{60}} * (\mathbf{C_{Wm}} * \mathbf{f_{MMO}} + \mathbf{C_{Mh}}) \right]$$

C_{Wm} – wage costs manufacturing [€/h]
f_{MMO} – factor for multiple machine operation

This formula for calculating the economic batch size is based on the assumption that a batch runs through the manufacturing stages as a closed item. The storage costs increase with its size (costs for binding cash assets, stocks of materials and unfinished products), while the set-up costs decrease because fewer batches have to be created and therefore fewer set-up operations have to be carried out to produce the same quantity. Therefore, the sum of the two types of costs depends on the batch size. You can represent it as a function of the batch size and thus find its minimum.

4.3 COSTING

In the sales module of the **p**roduction **p**lanning and **c**ontrol system, **pricing of an offer** is based on quantity planning (see Figure 35 and Chapter 1.3.2). It is a foresighted costing and enables the customer to compare the costs of the product with those of other suppliers.

For the company, calculation means, on the one hand, not to impose excessive price demands, which would mean awarding the contract to the competition, but, on the other hand, not to impose too low a price demand, which would lead to losses.

A distinction is made between pre-costing in the planning phase and post-costing. The pre-costing is used during the implementation phase of new products to calculate the production cost and the sales price. Once a product has been introduced, you can often restrict yourself to post-costing. Pre-costing is very important in order-related production and in contract manufacturing. It serves as an individual basis for a quotation. Post-costing, on the other hand, is used to check orders that have already been completed and the general basis of costing for further calculations.

Pre-costing and post-costing are usually created according to the same costing scheme. However, in pre-costing you are dependent on certain assumptions and empirical figures, whereas in post-costing you are dependent on the real values, that is, the recorded values, that can be used e.g. via the factory data collection within order monitoring (see Figure 35). The necessary data for the calculation are hourly machine rates, wage cost rates and overhead cost factors (see Chapter 4.1), the necessary work processes, including the target times from the work plans (see Chapter 2.2.3-2.2.6), the calculated blank costs (see Chapter 2.2.2), costs for jigs, programming and packaging, as well as bill of materials information (see Chapter 1.3) and assembly times for multi-level products.

The **cost-plus costing** is used for make-to-order and series production, i.e. for each individual product (order) or series a separate costing must be carried out. This requires separation into direct costs and overheads.

In **differentiated cost-plus costing**, you break down the direct costs (costs for labor, costs for the machine, and special direct costs, for example, for jigs, packaging, customs) and overhead costs (material overhead, manufacturing overhead, administrative overhead, and sales overhead) into different types of costs. The material overheads refer to the manufacturing material, the manufacturing overheads to the manufacturing wages, and the administrative and sales overheads to the production cost.

Manufacturing costs (CMf) in €/piece

$$\boxed{C_{Mf} = C_{Mh} + C_W + C_{MfO}} \quad [^{€}/_{piece}]$$

C_{Mh}	[€/piece]	machine costs
C_W	[€/piece]	wage costs
C_{MfO}	[€/piece]	manufacturing overheads

Machine costs

$$\boxed{C_{Mh} = (t_u * M_h) + \left(\frac{t_s}{ml} * M_h\right)} \quad [^{€}/_{piece}]$$

Wage costs

$$\boxed{C_W = (t_u * C_{Wm} * f_{MMO}) * \left(\frac{t_s}{ml} * C_{Ws}\right)} \quad [^{€}/_{piece}]$$

M_h	[€/h]	hourly machine rate (see Chapter 4.1)
C_{Wm}	[€/h]	wage costs manufacturing (see Chapter 4.1)
C_{Ws}	[€/h]	wage costs set-up (see Chapter 4.1)
ts	[min/batch]	set-up time (see Chapter 2.2.6)
tu	[min/piece]	time per unit (see Chapter 2.2.6)
ml	[pieces/batch]	batch size (see Chapter 4.2)
f_{MMO}	[---]	factor for multiple machine operation

Manufacturing overheads

$$\boxed{C_{MfO} = C_W * f_{Mo}} \quad [^{€}/_{piece}]$$

fMo [---] factor for manufacturing overheads (from cost distribution sheet)

Material costs (C_M) in €/piece

C_M = blank costs (C_B) * material overhead surcharge (**MO**)

see Chapter 2.2.2 percentage surcharge for expenses for material purchasing

Production cost (C_{PR}) in €/piece

C_{PR} = material costs (C_M) in €/piece + manufacturing costs (C_{Mf}) in €/piece + special direct costs for manufacturing (**SD**$_M$) in €/piece

costs for jigs, special tools, special test equipment (see Chapter 2.2.4),

design (see Chapter 1), programming costs (see Chapter 3) …

Cost price (C_p) in €/piece

C_P = production cost (C_{PR}) in €/piece

+ administration overheads (percentage surcharge according to CDS from C_{PR})
+ sales overheads (percentage surcharge according to CDS from C_{PR})
+ special direct costs sales (costs for packaging, freight, customs duties …)

Net offer price (NP) in €/piece

NP = cost price (C_p)

+ mark-up (e.g. 25%)

= cash sale price

This price may has to be cleared with customer account or customer discount. Adding value-added tax results in the **gross sales price**.

Exercises for Chapter 4:

E 4.1: Name the cost components of the hourly machine rate.

E 4.2: Calculate for an individual part the manufacturing costs, production costs, and the cost price under the following conditions:

WP	t_s min/ batch	t_u min/ piece	f_{MMO}	C_{Mh} €/h	C_{Ws} €/h	C_{Wm} €/h	f_{MMO}
10	25	3.6	1	15.25	10.49	10.49	1
20	55	12.5	0.65	26.50	13.39	11.16	0.7
blank costs: 4.35 €/piece				batch size: 100 pieces/batch			
jig costs: 100.00 €				programming costs: 50.00 €			
manufacturing overhead surcharge: 80 %				packaging costs: 200 €			
(not included in hourly machine rate)				administration overheads: 8 %			
material overhead surcharge: 6 %				sales overheads: 6 %			

SOLUTIONS TO THE CONTROL QUESTIONS

Chapter 1

The following tables show the results of the Chapter 1 exercise:

a) Structured bill of materials - product x				
Level			Assembly / part	Quantity
1	2	3		
x			assembly B	1
	x		individual part 1	5
	x		individual part 4	1
	x		individual part 5	2
x			assembly A	1
	x		individual part 5	1
	x		assembly B	2
		x	individual part 1	5
		x	individual part 4	1
		x	individual part 5	2
x			individual part 2	1

b) Quantity bill of materials - product x (without assemblies)	
Part	**Quantity**
individual part 1	15
individual part 2	1
individual part 4	3
individual part 5	7

c) Single-level bill of materials - product x	
Product x	
Assembly / part	**Quantity**
assembly A	1
assembly B	1
individual part 2	3
Assembly A	
Assembly / part	**Quantity**
assembly B	2
individual part 5	3
Assembly B	
Assembly / part	**Quantity**
individual part 1	5
individual part 4	1
individual part 5	2

d) Quantity overview - parts where-used list for individual part 1	
Is present in	**Quantity**
assembly B	5
assembly A	10
individual part x	15
individual part y	3

Chapter 2

E 2.1: Header zone: designation and part number, drawing number, economical and time-minimal batch size ….

Material zone: material, dimensions and weight of the blank

Work sequence zone: number, workstation, cost center, process description, if applicable tools, set-up time, time per unit, wage group, factor for multiple machine operation

E 2.2: (1) Examination of documents: functional analysis and drawing review
(2) Blank selection and calculation of material consumption with their allowances, if necessary blank comparison
(3) Determination of the technological sequence → work sequence if applicable variant comparison or breakdown into work steps with cutting arrangement
(4) Assignment of the needed machine tools, tools, jigs and testing equipment for the individual work processes
(5) Calculation of target times → calculation of set-up time and time per unit

E 2.3: Data from Table 6: z2 (two-sided) = 4mm; z3 (no centering) = 0 mm;
z4 (hacksaw) = 6 mm
blank length lB = 122 mm + 4 mm + 0 mm = 126 mm
z5 (remaining rod portion = 12 mm);
z6 (clamping loss) = 0 mm
l_{MC} = 122 mm + 4 mm + 0 mm + 6 mm + 12 mm + 0 mm = 144 mm = 288 mm
m_{MC} = 5,680 g

E 2.4: $Rz = \frac{f^2}{8*R}$ → Rz 7.5

$tam = \frac{L}{vf} = \frac{l+ls+lo}{f*n}$ → tam = 0.48 min per cut

E 2.5: $P_C = \frac{V_C*a_p*f*Kc_{0.4}}{60,000} * \left[\frac{0.4}{f*\sin\varkappa_r}\right]^{0.29}$ $\left[\frac{0.4}{f*\sin\varkappa_r}\right]^{0.29} = 1$

convert to ap $\frac{P_C*60,000}{V_c*f*Kc_{0.4}} = 3.26$ mm

E 2.6: see Figure 14

E 2.7: t_s = 61.6 → 62 min/batch
t_a = 19.3 min/piece, t_b = 20.07 min/piece, t_u = 22.88 min/piece,
T_o = 2.350 min/batch

Chapter 3

E 3.1: see Chapter 3.1.1

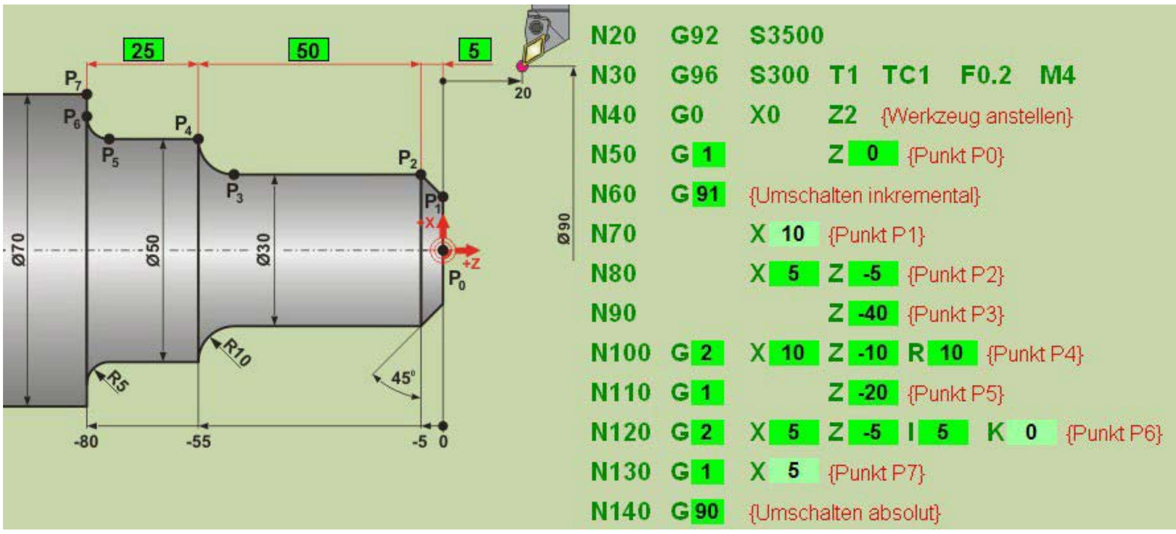
E 3.2: see Chapter 3.1.2

E 3.3: see Chapter 3.1.3

E 3.4: see Table 12

E 3.5: see Chapter 3.2

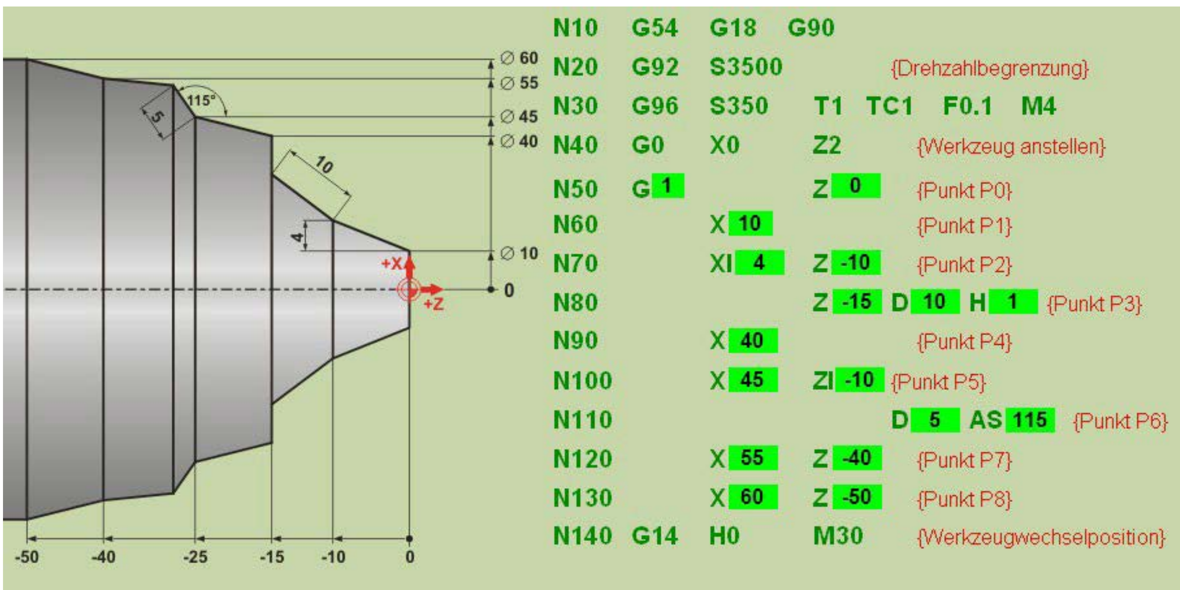
E 3.6:



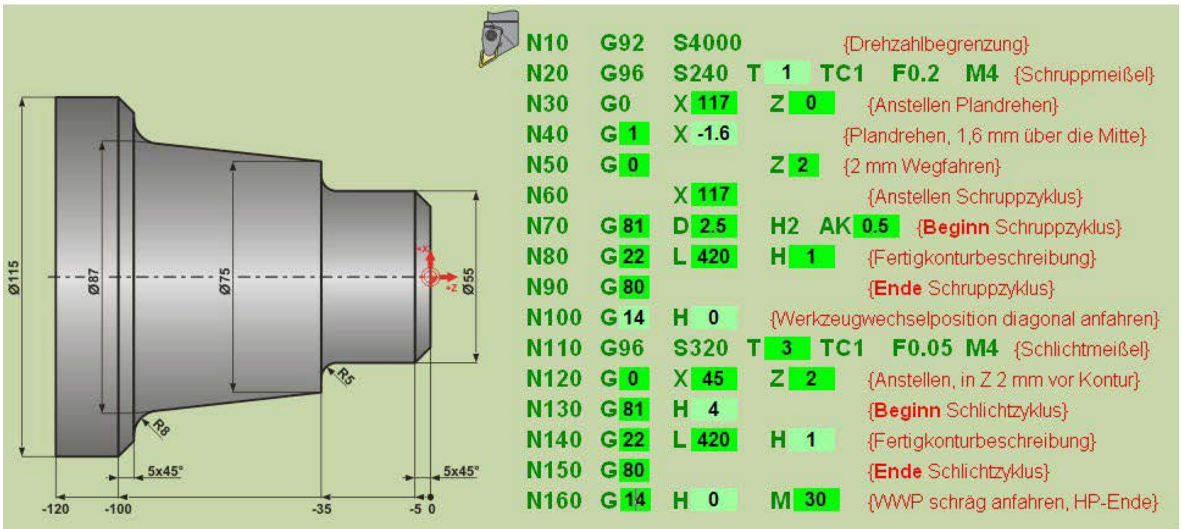
E 3.7:

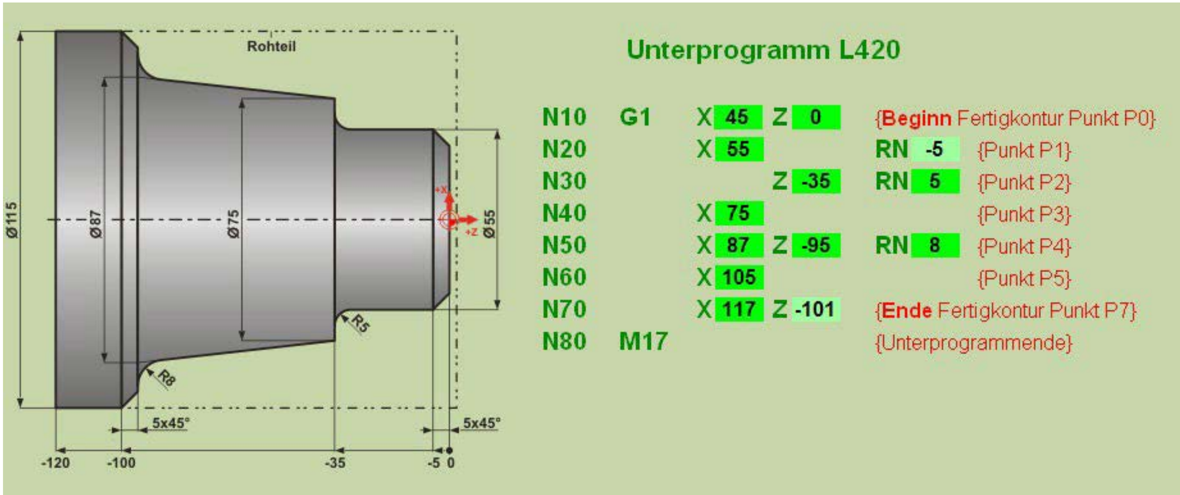
- G54
- M04, M08, M00
- T5, M30
- G14
- G97 S1200
- G96 S150
- G92 S2000
- F0.1, G41

E 3.8:



E 3.9:





Chapter 4

E 4.1: Imputed depreciations, imputed interests, occupancy costs, consumption costs, maintenance costs, tooling costs, service costs

E 4.2: $C_{Mh\ WP10}$ = 0.98 €/piece, $C_{Mh\ WP20}$ =5.76 €/piece, C_{Mh} =6.74 €/piece

$C_{W\ WP10}$ = 0.76 €/piece, $C_{W\ WP20}$ =1.80 €/piece, C_W = 2.47 €/piece

C_{MfO} = 1.98 €/piece

C_{Mf} = 11.19 €/piece

C_M = 4.61 €/piece

SD_M = 1.5 €/piece

C_{PR} = 17.30 €/piece

Packaging costs = 2 €/piece

C_P = 21.72 €/piece

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LIST OF FIGURES

LIST OF TABLES