Feasibility study for strategic factory and technology planning in the field of power generation

Diploma Thesis

Graz University of Technology

Institute of Logistics Engineering

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by

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Graz, December 2010

-- *Finis coronat opus* --

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Abstract

Power Generation has to deliver the steady increasing demand of electricity in the future. Manufacturers, like Siemens Energy, are seeking innovative production technologies to meet the requirements of changing circumstances. Strong competitors within the energy sector are also driving their technologies to be present at the future market. Steam turbine rotor shafts (no nuclear versions) have basically two different production technologies within Siemens Energy.

The first technology is to machine the rotor shaft from a single piece of forged steel, which requires purchasing big forged blank rotor shafts that are expensive. Only a few suppliers are capable of delivering these goods, which keeps the price high.

The second technology is to divide the rotor design into smaller modules and join them by welding. These modules can be sourced more easily and may have different materials too. With special material combinations it is possible to meet the distinct requirements of every different temperature level within a steam turbine.

Welding of steam turbine rotor shafts has been introduced within Siemens Energy ten years ago. This first steam turbine rotor with two different materials has been joined with the use of a special Siemens narrow gap welding technology. Using a narrow gap welding technique instead of machining a rotor shaft from a single piece adds special requirements to the production process. The currently used process is a “horizontal-horizontal” process using tungsten inert gas narrow gap welding technology. This type of production method is used for one type of rotor within Siemens Energy. This thesis describes one possible way to develop the manufacturing process further in order to extend the production portfolio of welded steam turbine rotor shafts.

A new process setup has been defined and evaluated among the circumstances of the production facility of Siemens Energy in Mülheim an der Ruhr. All sub-processes have been linked together in an evaluation model. These processes have been investigated due to the circumstances in Mülheim plant and have been combined with the latest research and development knowledge from experts within Siemens Energy and Corporate Technology. An implementation study for Mülheim plant has been performed in order to show the potential of the new manufacturing process. The new process setup differs fundamentally from the current version. The whole welding procedure is now done in vertical orientation of the rotational axis. Results of the evaluation outline the high potential of the new process structure. Long welding times have been reduced by the implementation of an alternative welding technology. Different techniques of post weld heat treatment are demonstrated and a bottleneck of the whole structure has been identified. A realization of the new and innovative production process within Mülheim plant among the current production halls is possible. This new production concept enables Siemens Energy to be a technology leader in producing highly cost efficient steam turbine rotor shafts.

Acknowledgement

I want to say thank you to my parents Elisabeth and Otto M. Macher who made my education at the Technical University of Graz possible. Personally I have to say that it was and is a big pleasure for me to have the opportunity to get a university degree in mechanical engineering and economics. Elisabeth and Otto you have been a great role model for me and gave me the security and happiness of a solid family background.
Thanks also to my brother Michael Macher and all my other family members because of their interest and support in my thesis as well as in my university education at all.

Secondly I want to thank my supervisor and mentor Mr. Ing.(grad.) Anton Wimmer who made this thesis possible. Anton you have been a great mentor and discussion partner during my thesis and my TOPAZ traineeship time within Siemens.
I want to thank also Mr. Dipl.-Ing. Karl-Heinz Gunzelmann for his supervision, Mr. Dr. Frank Truckenmüller and Mr. Tim Schreiber for their support, my visits and time in Mülheim an der Ruhr.

Thanks also to Prof. Dr.-Ing. habil. Dirk Jodin and Mag. Daniel Tinello for their supervision of my thesis within the Institute of Logistics Engineering.

Thanks also to my friends and fellow students for the great time which we had together.
A study is not just a time together somewhere – it is a strong bridge for the future where you can rely on for years.

Table of contents

1 Introduction

Producing steam turbines is on the one hand a challenging and very complex engineering and on the other hand a tight and interesting production task.
To meet the demand of increasing consumption of electricity in the future and to be as responsible as possible to the environment, it is important to find ways of producing steam turbine rotors more efficiently. The following picture underlines the importance of efficient steam turbines and their production.

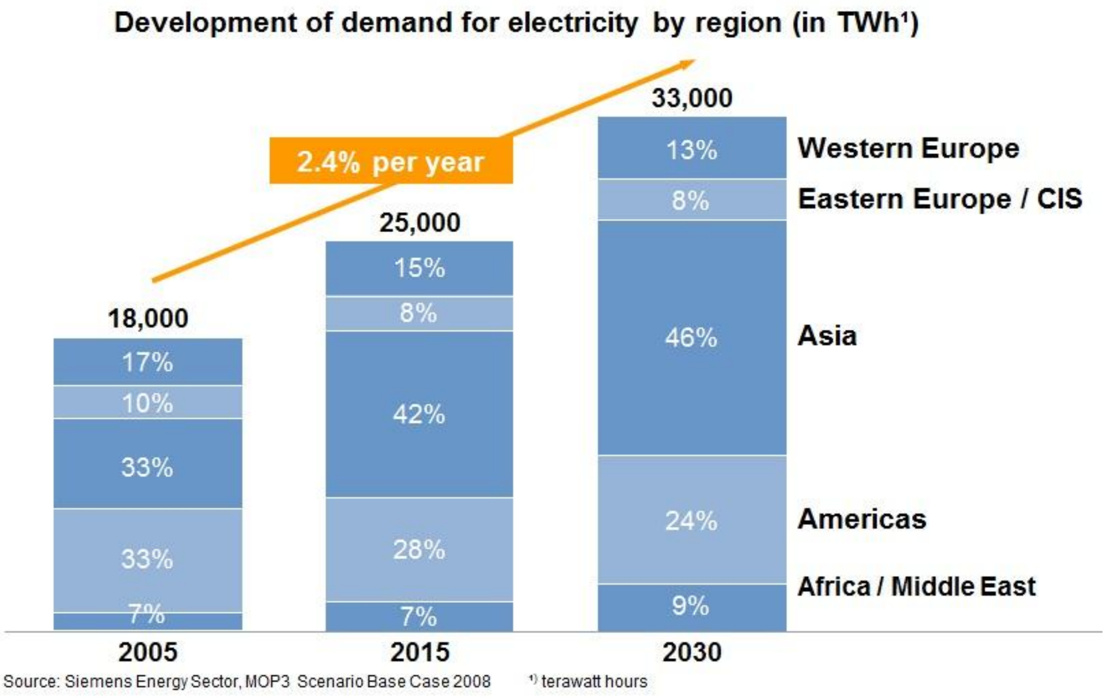


Fig. 1.1: Development of demand for electricity [Siemens Energy 2010]

1.1 Field of the diploma thesis

The background of this diploma thesis is an internal project of the department CT T DE HW1 of the Siemens AG with its office in Munich. The thesis covers several parts of the project itself. The main aim of this project, which is internally named "Business Case – Vertical Rotor Welding," is a technical and strategic study for Siemens Energy Fossil Power Generation plant in Mülheim an der Ruhr. This plant in Mülheim is an internal customer of CT T DE HW1. All necessary information sharing and decisions were carried out in cooperation with Energy Fossil to achieve a realistic and functional result.
To obtain and collect all the necessary information, several meetings and plant visits in Mülheim and visits with potential suppliers were carried out during the project time.

1.2 Topics of the diploma thesis

The following points describe the main aim of this thesis and what will be worked out in the following pages:

- To define the field of this thesis common factory planning methods for defining and developing a factory should be named and described in order to understand the procedure of planning tasks.

- The steam turbine production in the Siemens Energy Fossil plant is going to be investigated and described. Production alternatives are described and evaluated among the usability.

- As a result of a Siemens invention, a new production process should be described and evaluated according to the circumstances in Mülheim.

- An implementation planning should be worked out and evaluated among the circumstances within the plant in Mülheim.

1.3 Siemens AG

Siemens is a worldwide acting and highly innovative company with approximately 400.000 employees. The company has three sectors, cross sector business and equity investments. The figure below shows the company profile.

Industry Sector

Helps industry and infrastructure customers to increase their economic and environmental competitiveness >

Energy Sector

Offers products and solutions for the generation, transmission and distribution of electrical energy >

Healthcare Sector

Offers products and solutions from prevention and early detection to diagnosis to treatment and aftercare >

Siemens IT Solutions and Services

Delivers comprehensive IT-services from consulting to system integration, through to outsourcing >

Financial Services

Provides financial solutions on behalf of Siemens as well as business-to-business customers worldwide >

Equity Investments

Household appliances and communication networks are the core businesses >

Fig. 1.2: Sectors of the Siemens AG [Siemens 2010]

“With our outstanding innovative strength, our worldwide presence and our obligation to act sustainably, we provide answers to the toughest questions of our time.” [Siemens 2010] Siemens is a highly innovative company with steady increasing revenue. Actual numbers show that Siemens passed the financial crisis very well.

The numbers of the Siemens AG in the figure below reflect the sentence above very well.

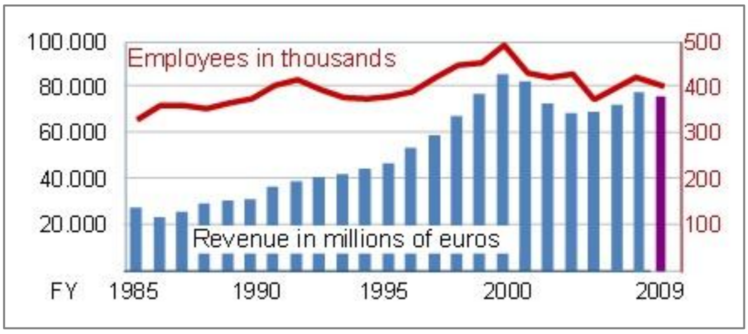


Fig. 1.3: Key numbers of the Siemens AG [Siemens 2010]

One strong innovation part of Siemens belongs to Corporate Technology (CT) which is a cross sector within the company. This means that CT is developing and inventing basic know how for the three sectors.

1.3.1 Siemens - Corporate Technology

"Corporate Technology (CT) and its worldwide network of experts is a powerful innovation partner for Siemens' business units. The organization provides expertise regarding strategically important areas to ensure the company's technological future, and to acquire patent rights that safeguard the company's business operations. Against the background of megatrends such as climate change, urbanization, globalization, and demographic change, CT focuses on innovations that have the potential to change the rules of the game over the long term in business areas that are of interest to Siemens.

A major role in Siemens' innovation activities is played by Corporate Research and Technologies (CT T). The 2,250 men and women who work within CT T's global research network focus primarily on key technologies and cross-sector technologies that have strategic significance for more than one business unit.

In order to ensure efficient and effective operations, a large proportion of the budget of Corporate Research and Technologies is covered through project agreements with the business units, which serve as its customers. CT T also receives corporate funding for the long-term development of new technologies and the establishment of new areas of expertise. All in all, CT T is responsible for approximately 7.5 percent of Siemens' total expenditure on research and development. This figure is made up of contract research for the Sectors (about 60 percent), corporate financing (31 percent), and external funding (9 percent)." [Siemens/innovation 2010]

1.3.2 Siemens Fossil Power Generation in Mülheim an der Ruhr

The Siemens Fossil Power Generation business unit is manufacturing steam turbines at the plant in Mülheim an der Ruhr for more than 80 years. The site Mülheim belongs to two divisions within the energy sector and has approximately 4.600 employees. The divisions of the energy sector are listed in the figure 1.4 below. The two divisions within Mülheim are: Fossil Power Generation and Energy Service.

Fig. 1.4: Divisions of the Energy sector [Siemens Energy 2010]

All the steam turbine engineering is taking place in Mülheim and also the main parts, as well as the final assembly, testing and shipping is done there. Therefore, the plant has a strategic place within the Siemens Fossil Power Generation business unit.

The energy sector is the second largest sector within the company. The total revenue of the individual sectors is shown in figure 1.5.

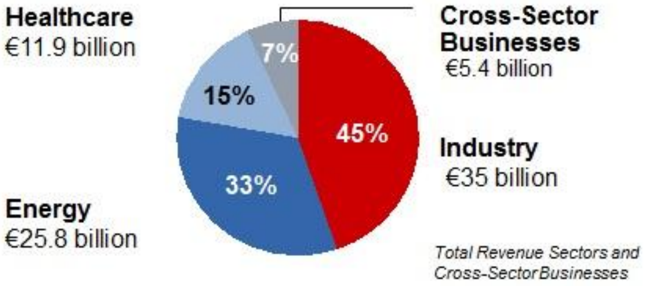


Fig. 1.5: Sector revenues [Siemens Energy 2010]

To be competitive in the future, Siemens Fossil Power Generation is seeking new products in order to fulfill their customer needs. Therefore, it is necessary to find new, even better and more innovative ways to produce steam turbines.
As an interesting engineering and production place in Germany, Mülheim has to play an important role in the future of the steam turbine production. Therefore, the business unit has to overcome all challenges rising up in the next few years - being as competitive as they are today. This diploma thesis shows one way for the facility, how these challenges can be managed and what is needed therefore.

2 Theory and background – steam turbine production in Mülheim a. d. Ruhr

The conventional manufacturing process within Siemens Energy is to machine steam turbine rotor shafts from a single piece of forged steel. This type of design is called monoblock and is the traditional way of manufacturing steam turbine rotors inside the company.

Due to technical requirements such as the combination of different material types for the different pressure levels and due to the supply markets of the monoblock rotors it was necessary to find ways to produce these rotors more cost efficiently.

Siemens produced in 1999 the first welded steam turbine with two different pressure levels at the plant in Mülheim an der Ruhr. [Schreiber 2008, p.9]

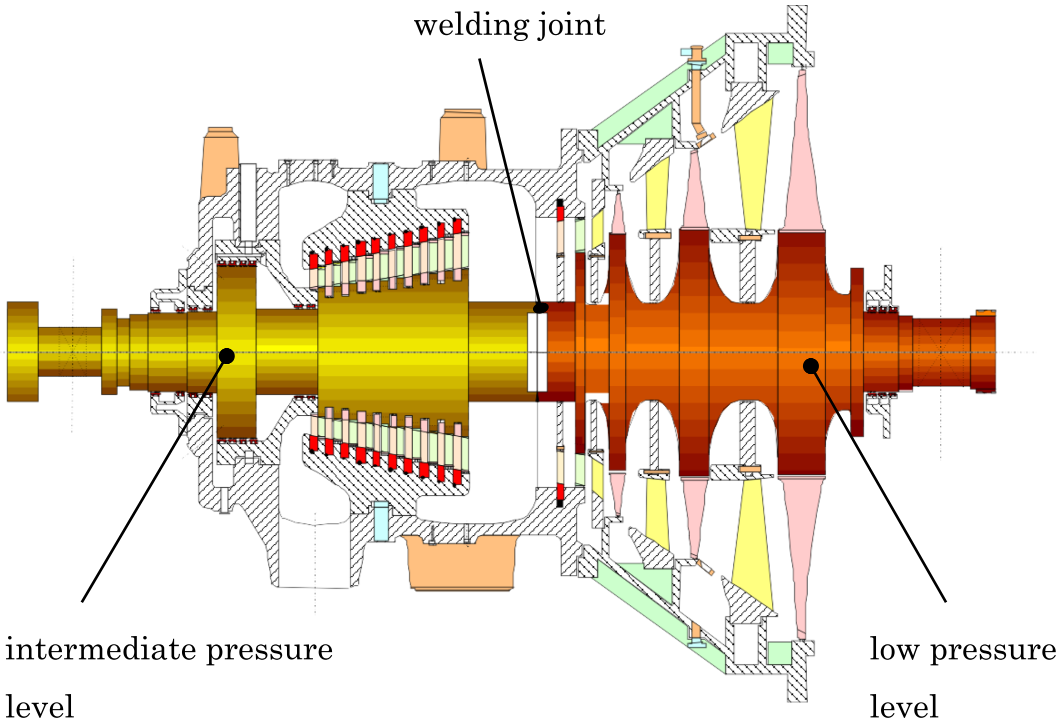


Fig. 2.1: Welded combined intermediate and low pressure steam turbine [Schreiber 2008, p.9]

The raising competition and the increasing steel prices force the company to find new, more cost effective production processes. Siemens has a huge portfolio of monoblock steam turbines which show big potential in decreasing the production and supply costs using the welding technology. Figure 2.1 shows a so called E-Type rotor with two different pressure levels. The rotor shaft consists of two modules which are different in material and are joined together by welding.

To apply this kind of welding joint, Siemens developed its own narrow gap welding process and equipment. This production process is described in chapter three.

The challenge is to apply this production process in the current production portfolio of Mülheim plant. This is going to be a strategic question and directly related to the factory and technology planning in the next few years in Mülheim. Therefore, the theoretical foundations of factory planning methods will be discussed within the next chapters. Three basic factory planning methods are named and described in order to show the complex intention of planning a new factory structure.

2.1 Principles of factory planning

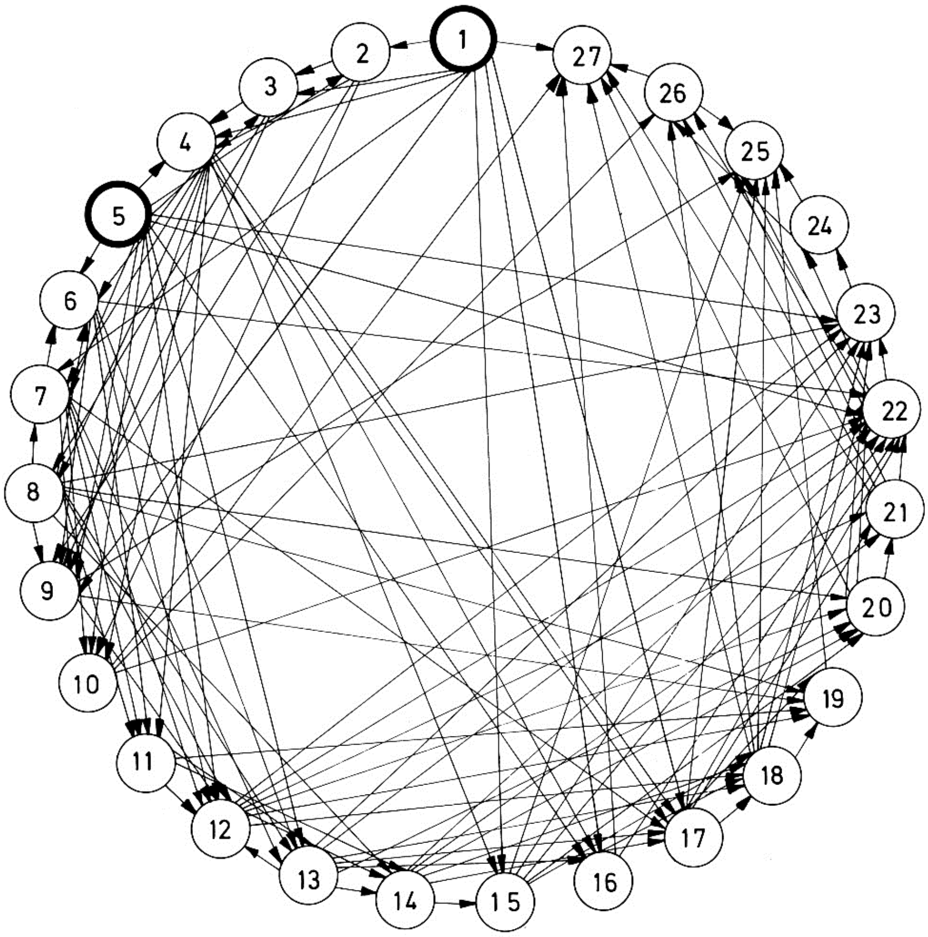
"Factory planning is the systematic, target orientated and structured step by step process with the use of methods and tools ranging from planning to realizing a factory." [Grundig 2009, p.10]

Factory planning is a complex and wide area of planning described by numerous successive and parallel working tasks. These tasks are summarized to one logical whole by the uniformly target definition and the approach. Products should be produced as rational as possible, the production has to consider the market need and the therefore needed systems should be planned optimally. [Aggteleky 1990, p.1]

To achieve these requirements, it is necessary to find an optimal technical-economical concept that ensures low investments, high productivity and efficiency, as well as the optimal use of production factors. The concept has to ensure an operational flexibility and modularity to be adaptive for further requirements that can occur in the future.

The fulfillment of these targets and requirements is seeking planning methods and a systematically approach of planning. It is not the solution of one sub-process or system, it is the whole system which has to be optimized. For bigger and more complex tasks it is useful to define a phase based structure. Phases that rise up are target planning, concept planning and implementation planning. *"Within complex systems a feasibility study becomes more and more important."* [Aggteleky 1990, p.1]

It does not matter if it is a new planning- or a re-planning project, factory planning has to solve a variety of linked sub-tasks. These tasks are interacting with internal and also with external influences. In figure 2.2 the connections and interactions between the tasks are shown. [Kettner et al. 1984, p.4]



1 Actual state, 2 forecast, 3 production program, 4 production technology, 5 choice of location, 6 general building plan, 8 material flow, 9 economic feasibility study, 10 scheduling, 11 ideal layout, 12 real layout, 13 logistics planning, 14 detail planning, 15 area determination, 16 personnel planning, 17 energy requirement, 18 building program, 19 cost of equipment, 20 machine layout, 21 installation planning, 22 structural design, 23 construction analysis, 24 announcement, 25 building costs, 26 building schedule, 27 implementation planning

Fig. 2.2: Linked sub-tasks of factory planning [Kettner et al. 1984, p.4]

The solution of all these sub-tasks cannot be done isolated. This has to be fulfilled in a whole principle of factory planning. Optimal solutions for sub-tasks do not guarantee an optimal solution for the whole system. Therefore it is necessary to set up an optimal overall plan in the early stages of the planning project, with detailed planning considered in later phases of the project. [Kettner et al. 1984, p.4]

Figure 2.3 illustrates a collection of common factory planning works. Three of them have been taken out and described within this thesis.

This thesis describes a feasible way of a new production structure in the field of producing steam turbine rotor shafts. Aggteleky B. defines a feasibility study as a fundamental basis for further planning tasks. Grundig defines the scope of interest in the field of factory planning. Schenk et al. describes a systematic- and situation driven planning model.

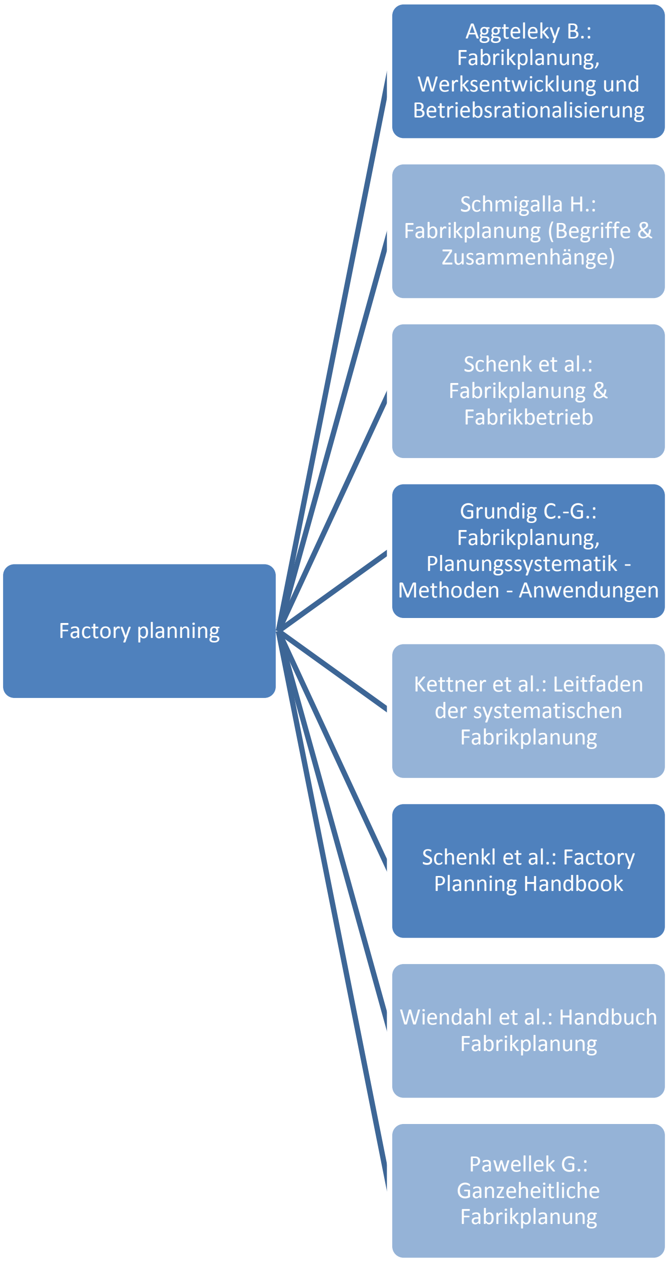


Fig. 2.3: Collection of factory planning works [Aggteleky 1990, Schmigalla 1995, Schenk et al.2004/2010, Grundig 2009, Kettner et al. 1984, Wiendahl et al. 2009]

2.2 Operation analysis and feasibility study according Aggteleky B.

The planning structure of the tasks and their logical approach are shown in the so called planning pyramid in figure 2.4. The pyramid shows that the optimal conception is preferably done within the project study (middle area of the pyramid).
A project or planning study is based on a given task, which was determined by the target study before (upper area of the pyramid). The study itself is initiated by an operation analysis. The operation analysis is used to determine all needed data and information according to the improvements and the cost reduction. [Aggteleky 1990, p.3]
According to Aggteleky, a feasibility or concept study is focusing the following concept and cost driven questions:

i) System and structure planning
ii) Global planning (rough planning)
iii) Area planning (fine planning)
iv) Invest and cost planning.

A concept study is closed with a detailed report and is the basis for further decisions of the whole planning subject.
All further details and planning tasks on the project are carried out in the implementation planning (lower part of the pyramid) after the decision on the planning project. [Aggteleky 1990, p.2]

The middle area of the planning pyramid is usually characterized by three main groups [Aggteleky 1990, p.3]:

i) Basics of concept planning:	Collecting of basic data
ii) Basics of project planning:	Questions of planning and optimizing

iii) Methods, techniques and tools of the different steps within a feasibility study.

The planning pyramid shown in figure 2.4 on the next page illustrates the mentioned concept above. To get a deeper understanding of the concept the next chapter provides information about the operation and cost analysis in front of a feasibility study.

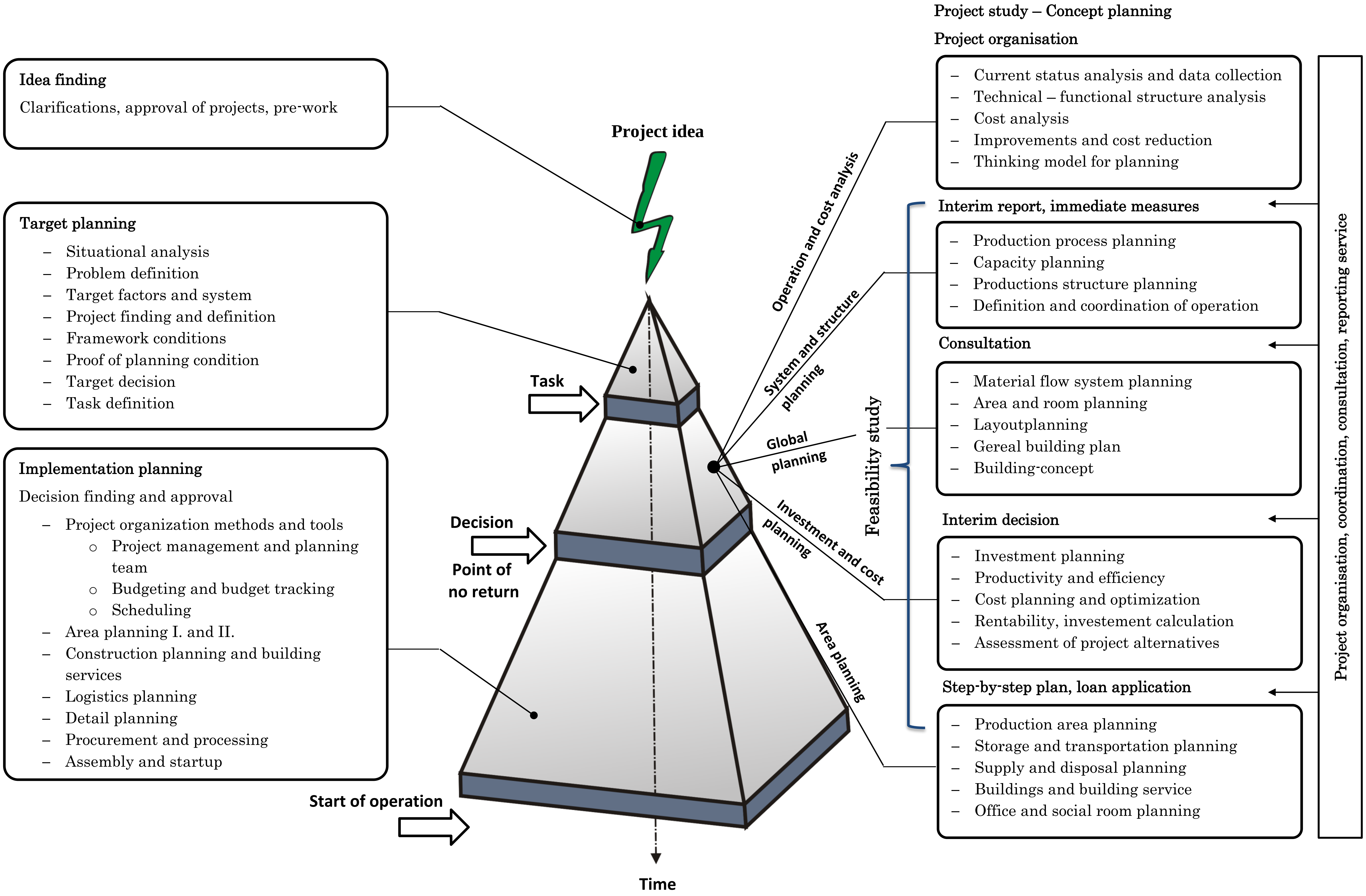


Fig. 2.4: Planning pyramid - structure of factory planning [adopted Aggteleky 1990, p.2]

2.2.1 Operation and cost analysis

The used planning procedure within a feasibility study is defined according to the target definition and the task of planning. The quality of the basic data and the given information affects the soundness and expressiveness of the planning results. A bright way to get qualitative good data and information is a well performed and systematically analysis of the actual state of the object or process of interest. [Aggteleky 1990, p.3]

The analysis includes not only technical-functional procedures, it has to consider also the cost structure of the investigated system. At the same time of the analysis, other starting points for improvements are discovered to ensure the flexibility of the operation structure. Particularly for further developments of structures and processes the feasibility study has to use the results of the project study. [Aggteleky 1990, p.3]

For planning of new and innovative industry plants (e.g. diversification, innovation) or for fundamentally changes in production processes, it is necessary to use more abstract approaches. [Aggteleky 1990, p.3]
Figure 2.5 shows methods used in a feasibility study for different planning tasks (e.g. cost reduction, modernization, diversification, innovation, etc.).

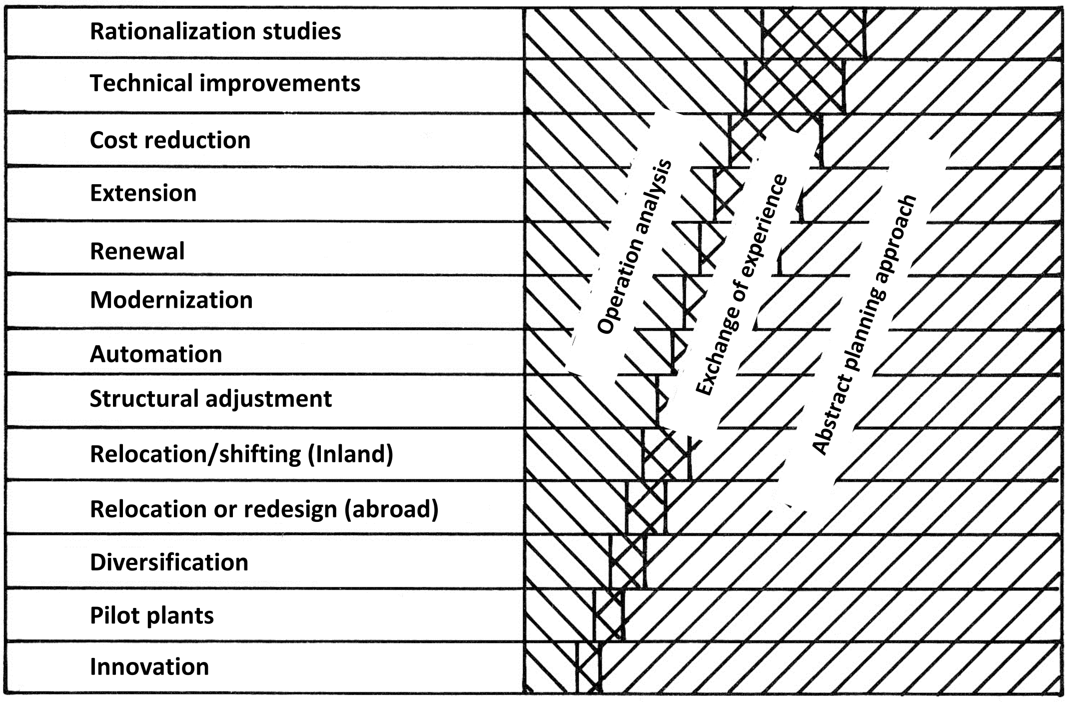


Fig. 2.5: Planning approach in a feasibility study - Methods acc. to planning tasks [Aggteleky 1990, p.4]

Real planning tasks are more or less a mixture of the named planning methods in figure 2.5. The actual state analysis as a rough feasibility study (e.g. for replanning issues) or as basis for a planning study (e.g. for rationalization issues) has an important role in the whole planning approach. [Aggteleky 1990, p.3]

The understanding of the technical-functional processes and the cost analysis, as well as the other tasks is an interdisciplinary task. It is recommended to pick up specialists for specific fields of the study in the planning team. [Aggteleky 1990, p.4]

2.2.2 Feasibility study – Goals and tasks

A feasibility study – also named concept study – has to determine the technical, operational and economical conception of complex projects. The following goals and aspects are in the foreground [Aggteleky 1990, p.4]:

i) Technical-functional design of the facilities
ii) Operational flexibility and modularity
iii) Economical advantage like productivity, profitability and competiveness.

The general approach of a feasibility study is shown in figure 2.6 and is driven by the following four main phases:

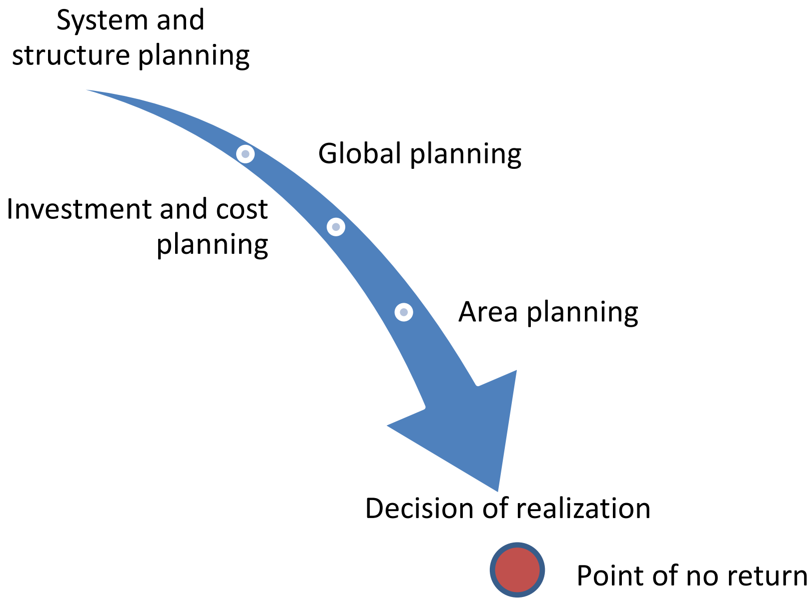


Fig. 2.6: Phases of a feasibility study

After finding a positive decision on the realization of the project, the so called “Point of no return” shows up. At this state of the project, it is decided to go for the new system and to bring it in the next phase – the realization or implementation planning.

Figure 2.7 underlines the impact of a feasibility study on the whole progress of the project. Being able to gain project know how in an early phase of the planning project supports the positive progress of the project.

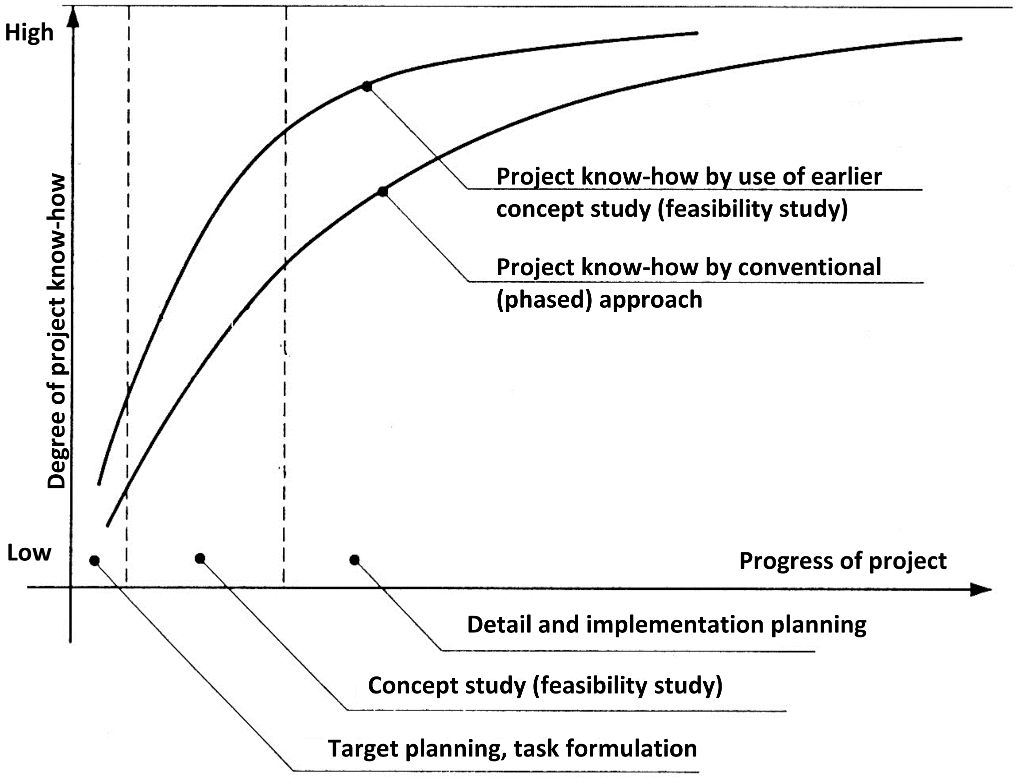


Fig. 2.7: Impact of the approach using a fasibility study [adopted Aggteleky 1990, p.8]

Aggteleky's pyramid model is a well understandable entry in the field of factory planning. The next chapter will figure out fields of interest for factory panning in general. Grundig provides with a planning method one approach of a factory planning project. He defines conditions and objectives which have to be considered throughout a planning process.

2.3 Factory planning method according Grundig C.-G.

A factory planning process includes the solution of problems rising up in the fields of planning, realization and implementation of factories. The factory itself has to be considered as a global system which is specified by the following planning fields mentioned in figure 2.8. [Grundig 2009, p.11f]

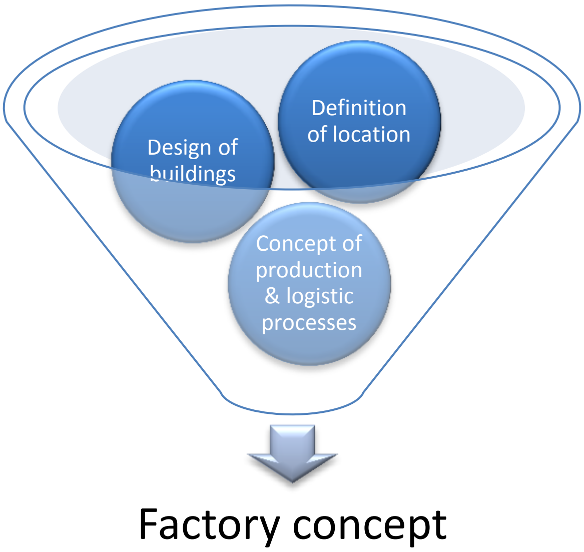


Fig. 2.8: Planning fields of factory planning [adopted Grundig 2009, p.11f]

This factory concept underlies different objectives, which can be focused to three main target fields: [Grundig 2009, p.12]

i) **Secure high efficiency** – Products with low lead time, delivered on time in the right quality. Highest degree of usage of production facilities, rooms and personal.

ii) **Secure high flexibility and versatility** – Equipment, processes, room structures and organizational flexibility ensure adaptability in turbulent times (e.g. market difficulties, product ramp up).

iii) **Secure high attractiveness** – Motivated personal, human working conditions and salary. Modern industry architecture with respect to the economical footprint.

2.3.1 Planning conditions and target fields of factory planning

The following figure shows the planning conditions and the target fields of factory planning according to Grundig C-G.

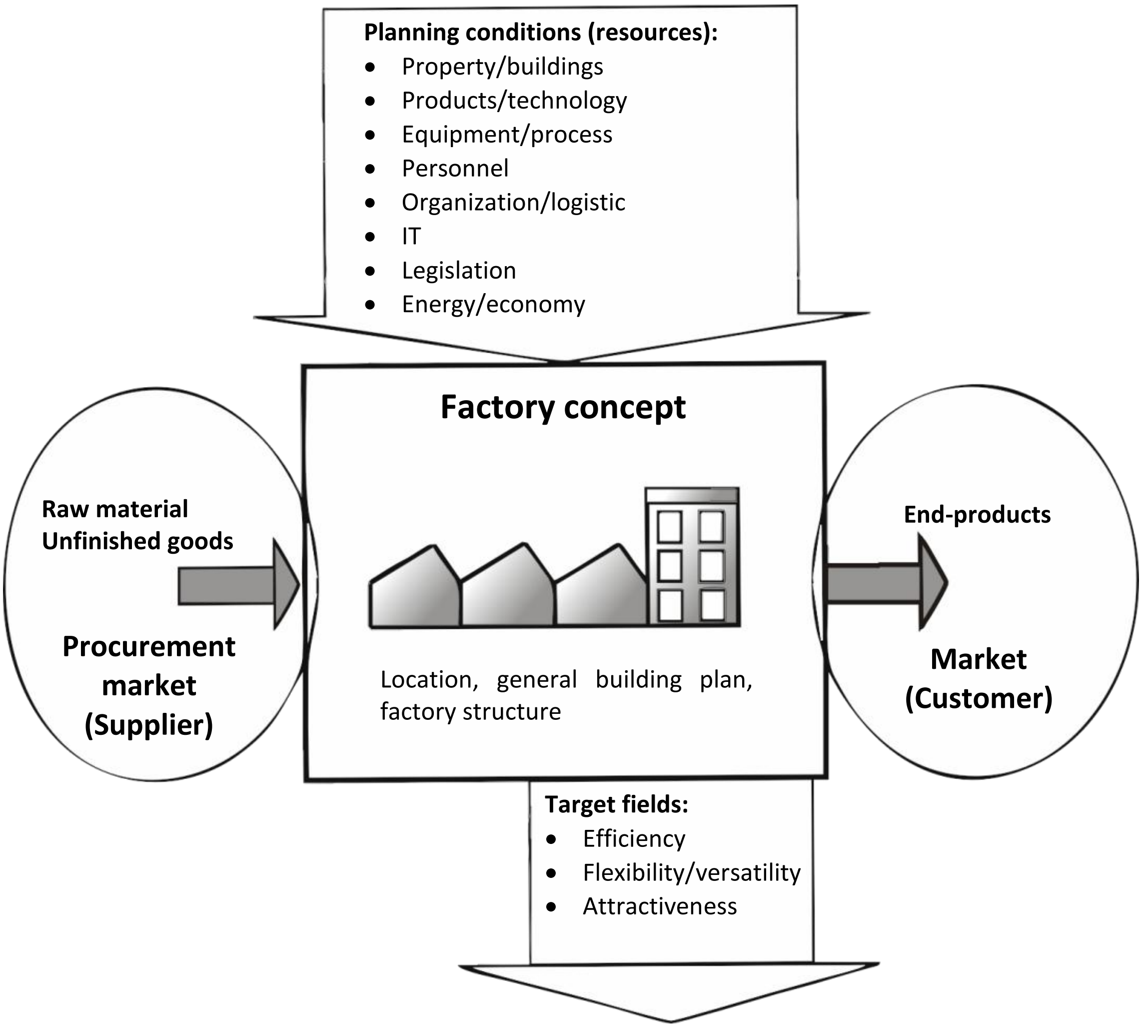


Fig. 2.9: Factory planning conditions and target fields [adopted Grundig 2009, p.13]

The factory planning has to consider all three target fields shown in the picture above. Basis for the factory planning is the specific work on the topics of these three objectives with all available resources (Invest-, equipment-, building- and property-potential) [Grundig 2009, p.12].

Figure 2.9 underlines that the factory concept is significant driven by the production process. The production process itself is formed by the production program which has to be fulfilled. The production program is the core function of a modern factory planning process. Therefore, it is necessary to have a good and reliable forecast of the production program to ensure a well-founded factory planning process. [Grundig 2009, p.13]

2.3.2 Planning approach

The factory planning process is differentiated in textual and methodical planning phases. Basics therefore where: [Grundig 2009, p.37]

i) Industrial practical requirements and operating methods of planning objects

ii) System orientated methods and principles of general problem solving cycles.

Planning phases include well defined content and have an iterative process character. This means that the results of the previous phase are the basis for the following phase. These results are concretized or even iteratively corrected. The phases are chronological staggered and may have different levels of detail. [Grundig 2009, p.37]

The following figure shows the six phase model of a planning approach. This six phase model was originally based on the model of Kettner H. Further details according to the original model can be read in Kettner et al. 1984, p.11.

As shown in the picture 2.10, the feasibility study is in the rough planning phase of the model. In this phase of the planning approach, an optimal technical-economic solution will be defined. [Grundig 2009, p.51]

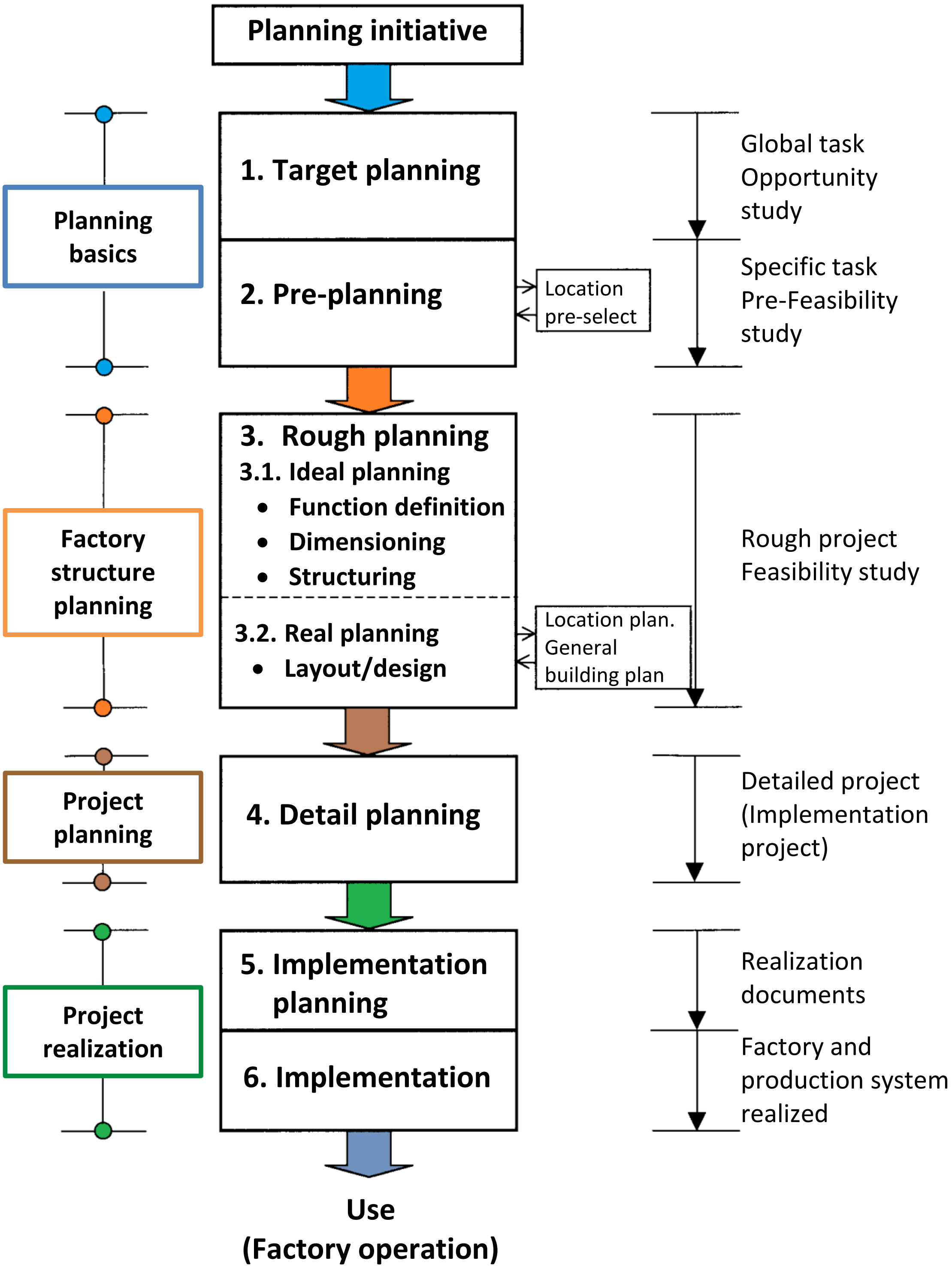


Fig. 2.10: 6 Phases of factory planning [adopted Grundig 2009, p.47]

This model is a bright way to show the overall structure of a factory planning process.

Every step has its own targets and content. A short brief introduction in the six phases can be found below: [Grundig 2009, p.50f]

1. **Target planning:** Introduction and presentation of the planning initiative. Defining the tasks and the targets of the planning objective.

2. **Pre-Planning:** Planning basics are defined by analysis of the initial situation. Substantiation of the tasks and definition of the specifications.

3. **Rough planning**

3.1. **Ideal Planning:** Planning of idealized solution concepts as a result of function definition, dimensioning and structuring.

3.2. **Real planning:** Finding of realizable solutions out of the ideal planning results. Consider the planning environment which is physical available (logistics, buildings, ect.). Find and evaluate variants of possible solutions.

4. **Detail planning:** Consider the best evaluated realizable solution and bring it to a ready-to-run version.

5. **Implementation planning:** Planning and arrangement of all needed processes to realize the planning project.

6. **Implementation:** Leadership and monitoring of the implementation/realization process including the commissioning.

2.3.3 Core functions of factory structure planning

The following picture combines the core functions of the factory planning with its approach until the implementation planning. It is easy to see which kind of topic or content is considered in the different planning phases. The four core competences are – **Function definition – Dimensioning – Structuring – Layout/design.** [Grundig 2009, p48f]

It is recognizable that the solution principle starts at a rough level and ends with a detailed and realistic solution. This principle meets a so called stepped planning. The rough planning phase with its content and targets is also called the factory structure planning. [Grundig 2009, p.48]

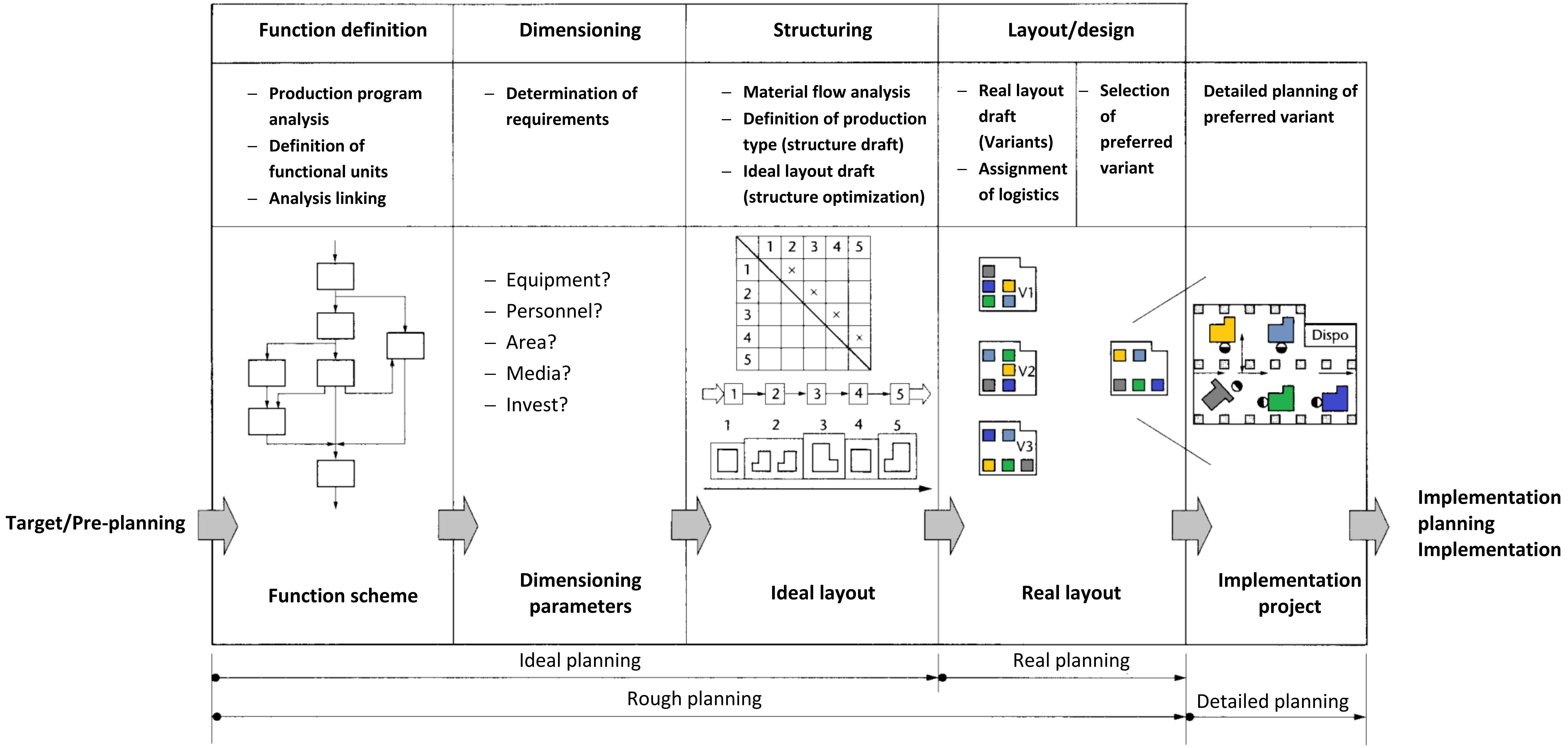


Fig. 2.11: Core functions of factory planning [adopted Grundig 2009, p.49]

2.4 Planning models according to Schenk M. et al.

Schenk M. et al. defines the two basic planning models:

i) Systematic planning models
ii) Situation-driven planning models

Ad i): Systematic planning model [Schenk et al. 2010, p.18ff]

- Rough sequence of the planning processes and manufacturing plants

- Project design takes place in the following sequence: **main processes** → **1st periphery** → **2nd periphery** → **3rd periphery** and must be implemented in the required planning stages (e.g. target planning), figure 2.12.

- The complex planning model ("0+5+X") consists of following planning phases: **I Project definition**, **II project development**, **III project implementation**, figure 2.13.

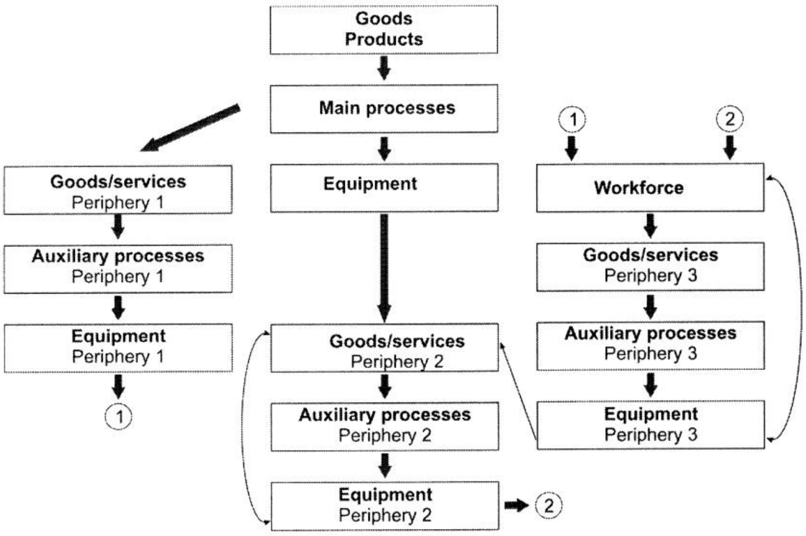


Fig. 2.12: Rough sequence of the planning of processes and manufacturing plants [Schenk et al. 2010, p.20]

Ad ii): Situation-driven planning model [Schenk et al. 2010, p.21]

This type of model differs from systematic or algorithm based planning models. It is a result of operational decisions like changes of targets, data, product, technology and so on. If those changes happen, all or parts of the planning sequence have to be changed. This pertains to levels, stages and steps of planning, as well as to resources. The model is adopted operationally and redeveloped based on the given situation.

2.4.1 The 0+5+X planning model

The complex planning model, as named in the chapter before, is the so called 0+5+X planning model according to Schenk M. et al. The following figure shows the planning approach which is the outcome of a multitude of projects in different sectors. [Schenk et al. 2010, p.29]

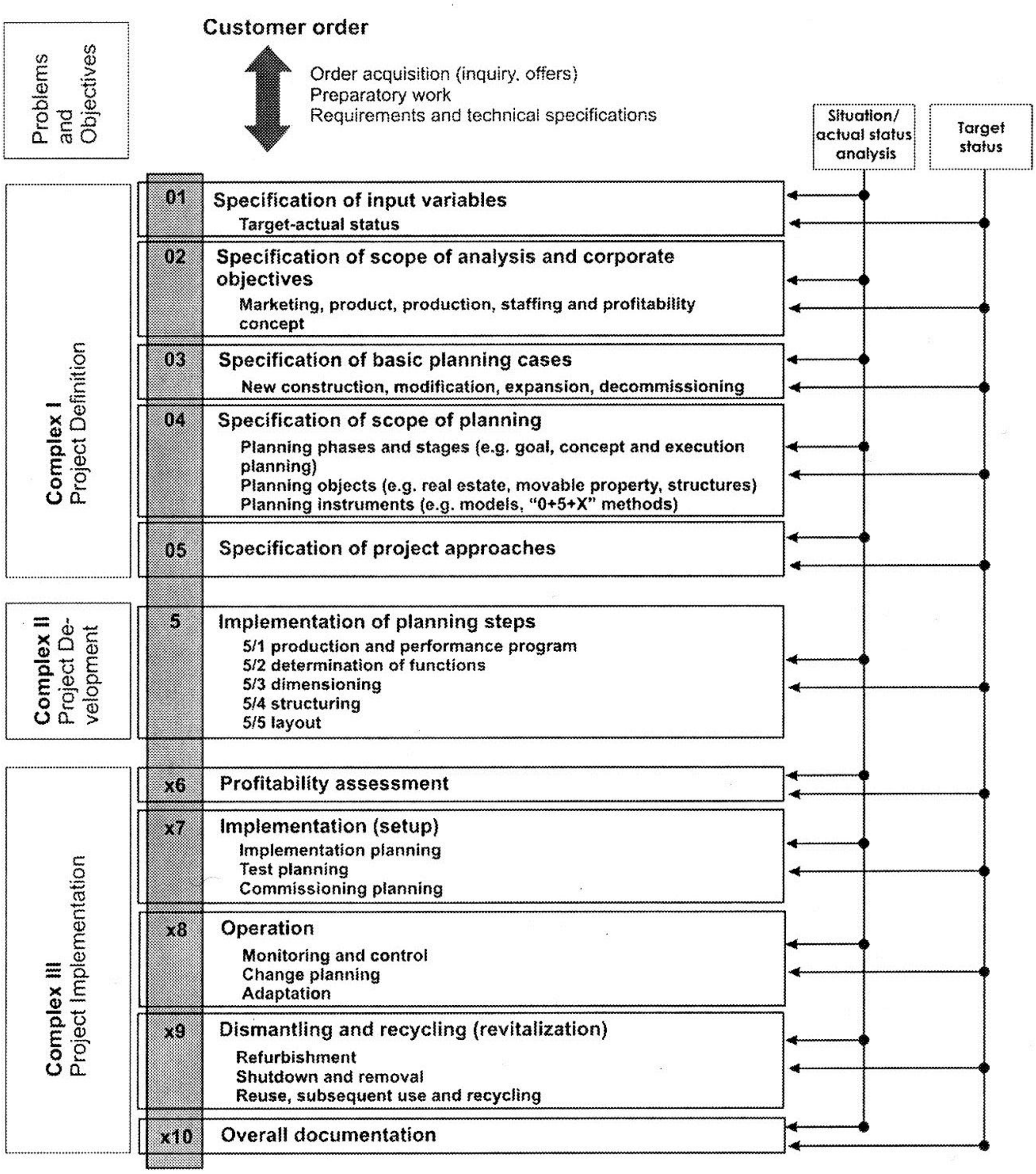


Fig. 2.13: 0+5+X planning model [Schenk at al. 2010, p.29]

The shown model contains complexities that cover areas ranging from problem and task definition to the acquisition of the customer order, project definition, project development, project implementation and execution. [Schenk et al. 2010, p.29]

These complexities define fundamental decision-making levels for completing (exiting) or continuing the planning approach. [Schenk et al. 2010, p.29f]

The planning project is going to be implemented in three stages – the three complexes based on the planning model in figure 2.13.

Complex I:	five specifications (01 – 05) to qualify the definition of the project itself.
Complex II:	five project design steps (5/1 – 5/5) for the development of the project.
Complex III:	five specifications (x6 – x10) for the implementation of the project. [Schenk et al. 2010, p.30]

The three stages are implemented as an iterative process that reevaluates every change and verifies the effect on the whole project. This model is supported with guidelines and checklists to provide a logical sequence of the approach. These guidelines can be found in Schenk et al 2010 based on an example of a worm gear production. [Schenk et al. 2010, p30]

On the following pages the three complexities are described briefly to understand how this model works. To keep it short, the complexities are not described in every detail, for further reading on this topic, see the Factory Planning Manual according to Schenk et al. 2010.

2.4.2 Complex I

Complex I includes five specifications shown in figure 2.14 which are derived from the customer's order. Basically this step of the model is to define the topics and targets of the project. Therefore, it is necessary to do some preparatory work related to development and research as well as to specifications. Examples of development include products, production processes, patents, inventions, forecasts, conceptual studies, technologies and reports. Examples of specifications are the production program, the sales program, quantities, times, quality, restrictions and permits. [Schenk et al. 2010, p.30f]

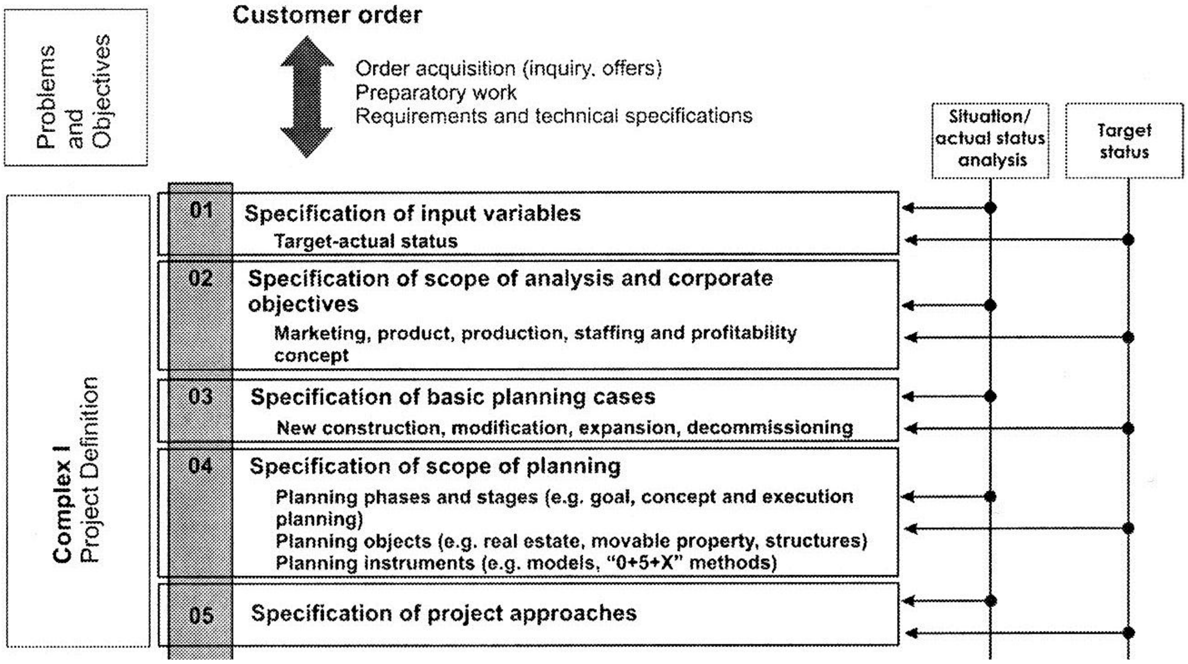


Fig. 2.14: Complex I of the 0+5+X planning model [Schenk et al. 2010, p.31]

After stepping through the phases 01 to 05, the project itself should be defined. The process of planning production facilities is a process of refinement, with iteration steps and decision-making stages. It is a process of continuous improvement and directly related to the Plan-do-check-act (PDCA) cycle. [Schenk et al. 2010, p.42f]

2.4.3 Complex II

The planning activities 5/1 to 5/5 shown in figure 2.15 are based on the project definition deriving from complex I. This is the completion of the project design steps. These steps are carried out systematically and consecutively in a closed feedback loop for the design steps of the project.

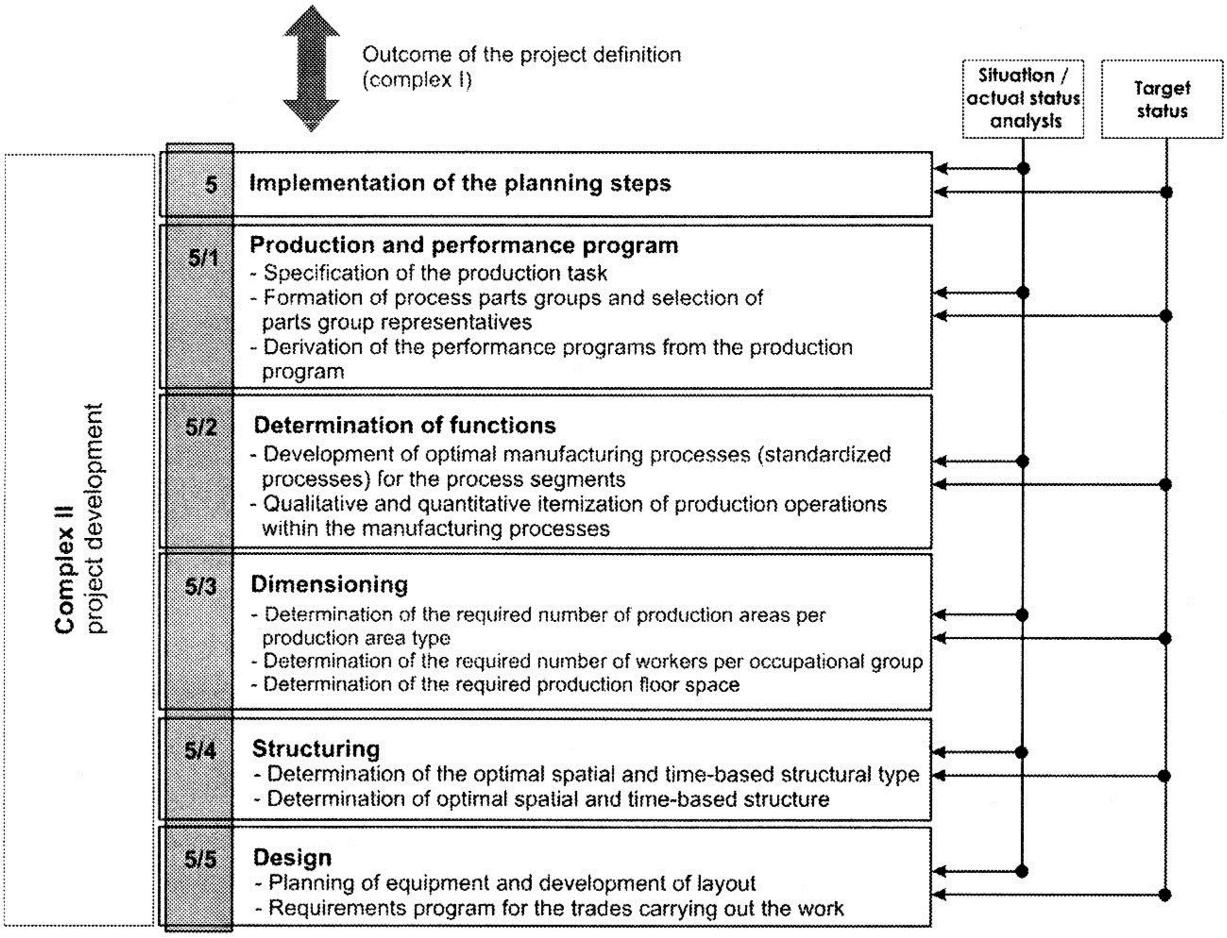


Fig. 2.15: Complex II of the 0+5+X planning model [Schenk at al. 2010, p.44]

This complex is the basis for the implementation complex III. Therefore, there is lots of structure giving steps to be carried out. Starting from 5/1 the production program definition (including make or buy decisions), then continues with 5/2, the determination of functions. Finding processes, equipment and labor force for the production of the goods is next. The dimensioning step 5/3 defines the production itself, like finding the right number of machinery, the required production area and the investments. Structuring answers the questions of how to set up a supply chain network and to find the right organizational structure (buildings, divisions, etc.). The design step 5/5 has to cover the topics layout of the plant/shop floor, define the flow systems and has to consider the working environment. [Schenk at al. 2010, p.43ff]

2.4.4 Complex III

The last complex of this model is the project implementation stage. In this phase of the project the execution planning and the implementation itself are done.

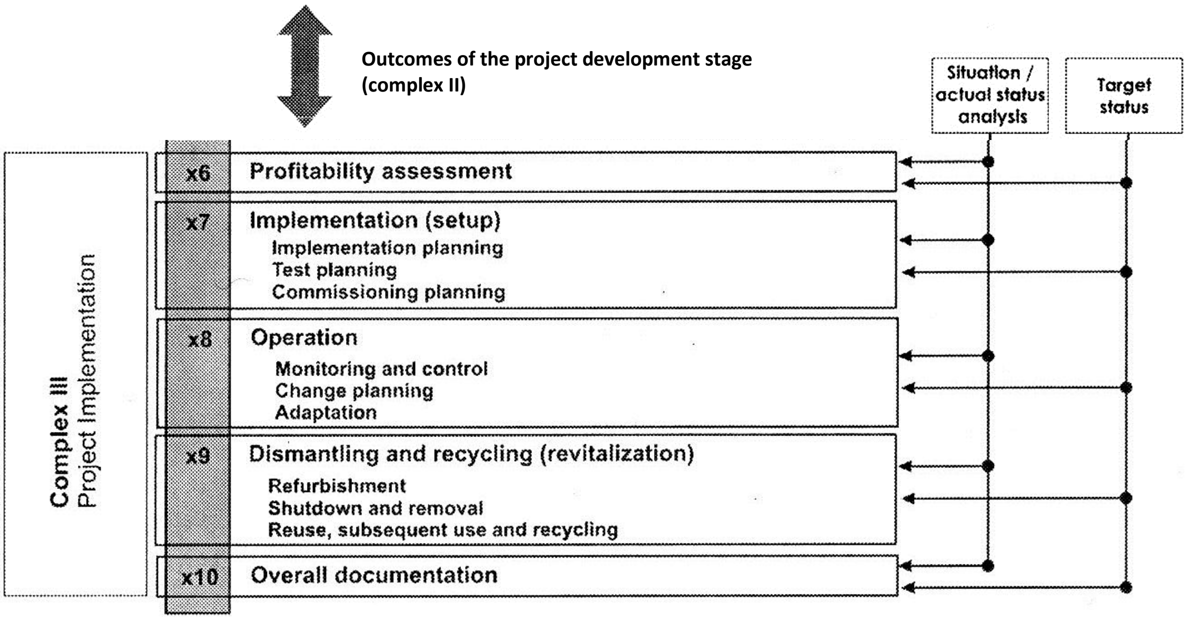


Fig. 2.16: Complex III of the 0+5+X planning model [adopted Schenk et al. 2010, p.196]

Based on the profitability assessment and the decision of realization the project is going to be implemented. This includes the implementation planning – the implementation project from the material and technical realization of all objects. Thus contains the testing and commissioning as well (x7). [Schenk at al. 2010, p.196] With everything in complex II identified, facility outfitter and supplier (machinery, plant, installations, trades), a binding order and agreement must be concluded. Costs, shipping and implementation times, as well as technical specifications must be strictly regulated. In the realization stage, the occupational safety has to be approved and affecting regulations on the machinery, equipment or the plant have to be obtained. [Schenk et al. 2010, p.198f]

The operation of the facility starts with a test run, commissioning and a start-up planning. The processes will be monitored and adopted by day to day operation. After the operational time the resources like equipment, plants and buildings may be reused in the following order: remediation, decommissioning, reuse, further use recycling. The documentation includes the most important documents of the entire implemented facility. Examples of these are process flows, individual projects, decision-making steps, and approvals. Documents according to cooperation partners, clients and contractors are also part of the documentation step x10. [Schenk et al. 2010, p.220f]

2.5 Derivations from the factory planning principles

Throughout the named principles of factory planning it showed that a factory planning process is a complex and wide project with lots of parameters to be defined and evaluated.
These principles show clearly that it is necessary to find a structure and to divide a factory planning process in different phases. It is helpful and important to gain knowledge in specific fields and tasks during the process and also to understand how the sub processes and tasks are linked together.

Aggteleky named the feasibility study as one basic instrument to get a deeper understanding of the given problem or task. This thesis does not cover a whole feasibility study, but it shows one way to estimate the potential of a new production process. The definition and evaluation of the process- and technology improvement, the cost estimation and the proof of realization is the problem which will be discussed in this thesis.

A new production process and all needed sub processes are defined and evaluated according to the circumstances of Mülheim plant.
This thesis is the preliminary work for the implementation of new structures within the plant and to provide fundamental information for further, decision-making steps and to demonstrate the potential of the new system.

3 Production process of welded steam turbine rotor shafts

Figure 3.1 shows the footprint and layout of the factory buildings of Mülheim plant. One important workstation of the production process is the welding center in building 81. There the whole welding process and the post weld heat treatment (PWHT) of the welded turbine rotors are carried out. For mechanical treatment like the welding seam preparation and for ultrasonic testing (UT) the parts have to be moved to building 80. To assemble the rotor shaft with turbine blades it has to be carried into building 62. This building is the largest production hall within the facility. After a balancing test in building 77 (balancing tunnel) the rotor is ready for shipping in building 62. The shipping can be done on streets or via the Ruhr River.
The investigated and introduced production process in chapter three does not cover all steps of producing a whole steam turbine. All needed process steps which are linked to the production of a steam turbine rotor e.g. welding seam preparation, the welding steps, the PWHT and the UT step are explained and investigated among the circumstances in Mülheim.

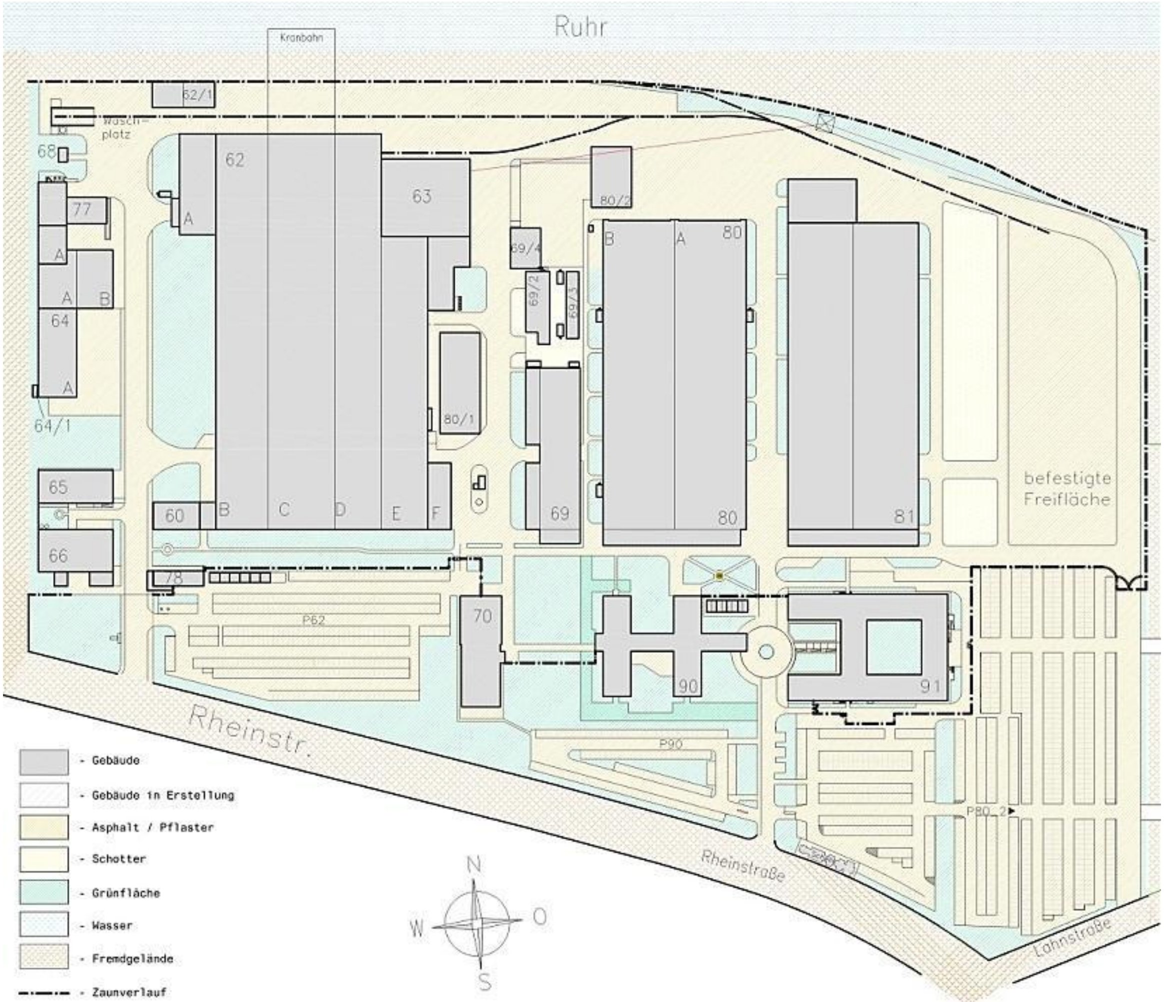


Fig. 3.1: Site plan - Siemens Energy Mülheim an der Ruhr [Kretschmann 2010/1]

Sourcing of big monoblock steam turbine rotor shafts is expensive and becomes more and more difficult. That is because of the small number of big forging factories which are able to manufacture huge forged turbine rotor shafts. In the case of Mülheim plant there is only one supplier available for manufacturing big forged monoblock rotors. Less competition and the fact of single sourcing of forged parts are key drivers for innovations in the field of production of steam turbine rotors.

One possible solution is to reduce the size of forged parts to modules and weld these modules together into a complete rotor shaft. This technique is not new, as competitors like Alstom have been using welding technology since 1929.

Being competitive in the future, Siemens drives their technology and schedules the implementation of a new welding production process. The currently implemented welding process, introduced in 1999, and the application of narrow gap technology show huge potential for innovations.
The new production process explained in this thesis is using a Siemens invention on the new production technology. This is a major innovation in the production of steam turbines.

The following chapters describe the common production processes roughly to understand how steam turbine rotors are currently manufactured. The following figure shows an example of a welded steam turbine rotor.

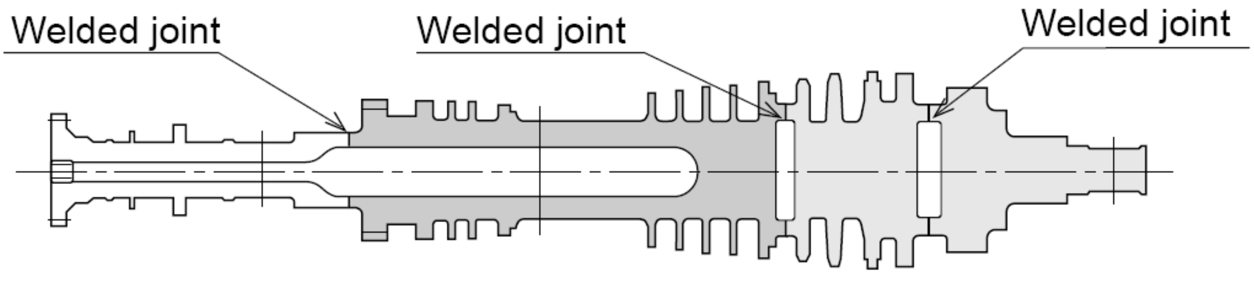


Fig. 3.2: Welded steam turbine rotor – Mitsubishi Heavy Industry Ltd. [Takashi et al. 2001]

As shown in the picture above, this rotor design is different from the shown rotor in chapter two. To be able to produce such kind of rotors it is necessary for Siemens to think about an alternative production strategy so that they can meet their customer needs in the very best way.

Basically there are three different types of manufacturing concepts possible. Figure 3.3 demonstrates possible setups for producing welded steam turbine rotor shafts.

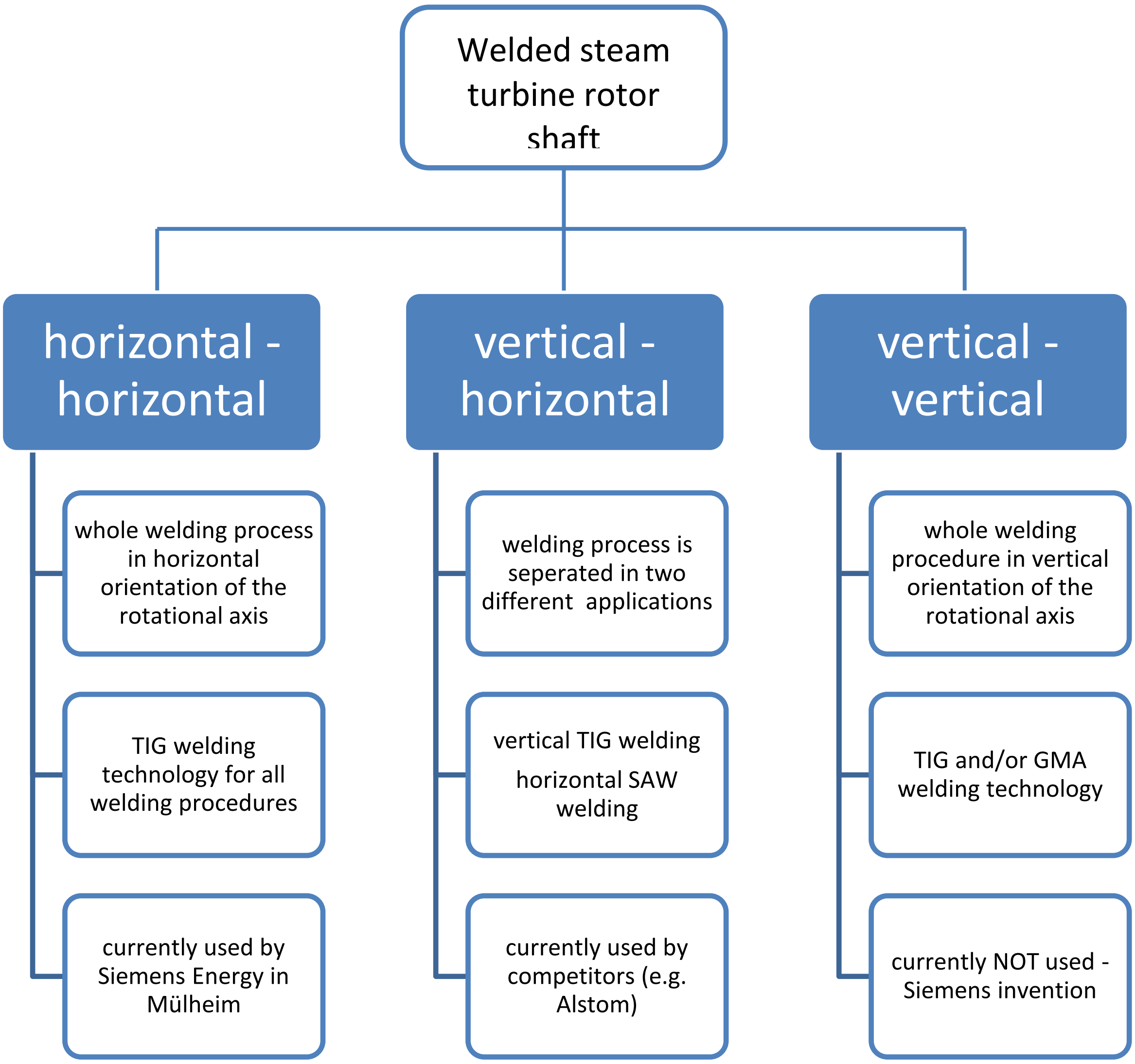


Fig. 3.3: Possible manufacturing concepts of welded steam turbine rotor shafts

The three mentioned possibilities in figure 3.3 will be worked out in the following chapters. The horizontal-horizontal version as implemented in Mülheim plant has been investigated. Vertical-horizontal will be explained and vertical-vertical is going to be set up as the new manufacturing process.

To define the possibilities of the production of steam turbine rotors, a production process notation is implemented. This notation is easy to read and describes different processes in a simple way.

3.1 Production process notation

The production process has its own form of notation, as shown in figure 3.4, to clearly define the orientation of the rotational axis and the used welding principle.

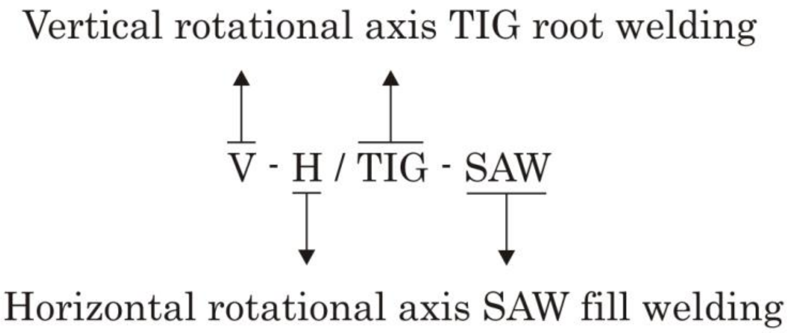


Fig. 3.4: Process notation

This is one way to describe briefly the production process of welded steam turbine rotors. The notation used in this thesis and internally within the project has no right of a general process notation at all.

Due to the fact that this thesis describes several process types, it shows that this is one simple but effective way of describing the complex production process.
The lower picture shows an example of the orientation of the rotational axis during the production process in order to understand the process notation.

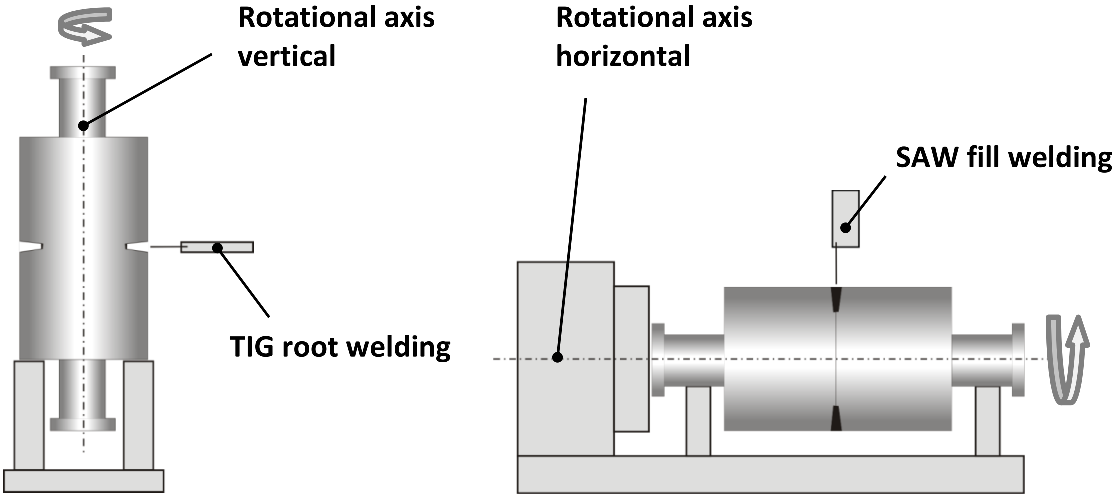


Fig. 3.5: Example of V-H/TIG-SAW process notation

The V-H/TIG-SAW example in figure 3.5 shows in a simple way the process notation in order to understand, that the rotational axis is the main part of interest. The analysis of the implemented production process is the basis for further development of the process.

3.2 Analysis of the introduced horizontal production process

The H-H/TIG-TIG process is the standard process used at the Mülheim plant and is going to be analyzed and described in the following pages in order to understand the used production process.
The horizontal production process is characterized by the following:

i) The root and support welding seam process is done in horizontal orientation of the rotational axis by use of tungsten inert gas (TIG) welding.

ii) The fill welding seam process is done in horizontal orientation of the rotational axis by use of TIG welding.

All process steps are carried out in the horizontal orientation of the rotational axis of the rotor. Therefore an old turning lathe ("Deutschland") has been retrofitted and redesigned for the usage as welding stand. The picture below shows the actual setup of the horizontal welding stand in Mülheim.

Fig. 3.6: Horizontal welding stand "Deutschland"

The process view in figure 3.7 is a rough sequence of the most important steps of H-H/TIG-TIG process. A detailed description of the sub-processes like pre-heating, X-Ray testing, UT, PWHT, etc. can be found in the next chapters.

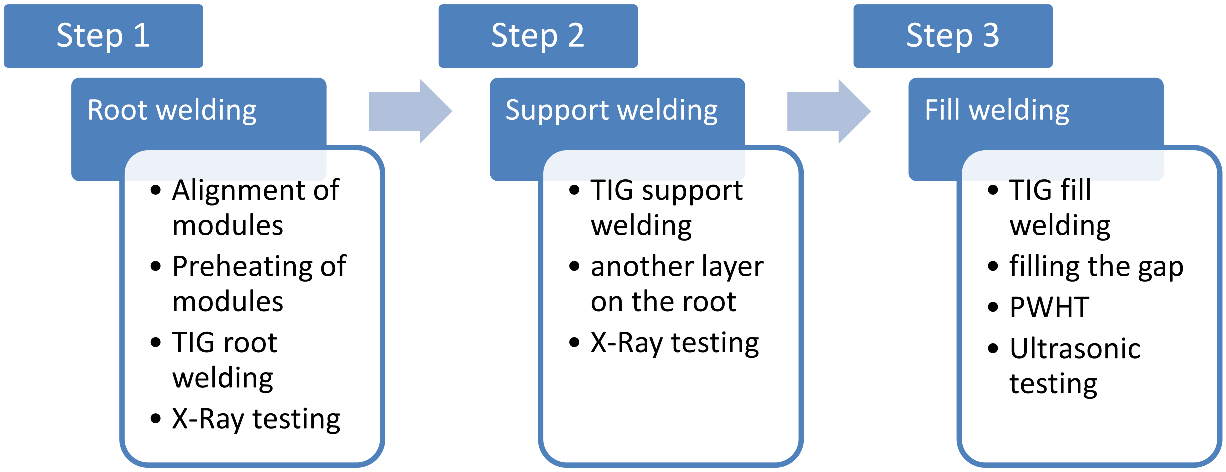


Fig. 3.7: Rough process sequence - H-H/TIG-TIG

Within the main production steps (root-, support-, fill welding), main sub-process steps are listed in the box. In order to become familiar with the current manufacturing process, this process has been investigated during visits in Mülheim plant.

The following pages explain the required sub-processes for a horizontal-horizontal process setup.

3.2.1 Root welding – H-H/TIG-TIG

The first step after the alignment of the modules is the TIG root welding to secure the first joint between the welded modules.

Fig. 3.8: Alignment of rotor modules

Figure 3.8 above shows the alignment sequence in horizontal orientation. With the use of roller blocks the rotor is positioned on the welding stand.
After measuring the concentricity of the rotor the preheating elements are going to be fixed on the modules as shown in figure 3.9.

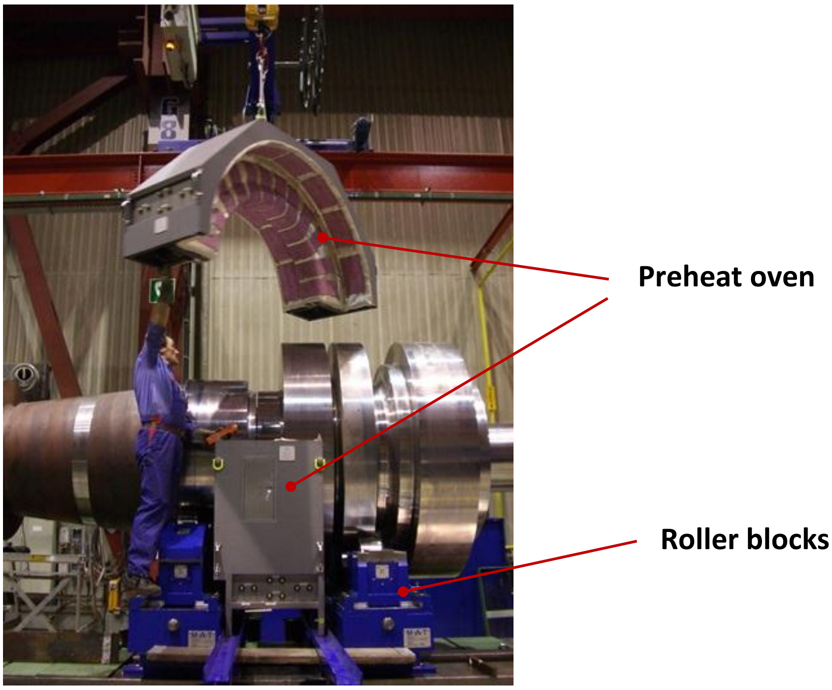


Fig. 3.9: Assembly of preheat oven

For the preheating process a resistance heating method is used. This oven is a special shape for the individual rotor geometry. After reaching the preheat temperature level (approx. 250°C) the rotor is ready for the root welding step.
This process step is the most critical one. The root welding process has to ensure a closed welding joint of the root.

Figure 3.10 shows the principle of the horizontal process setup.

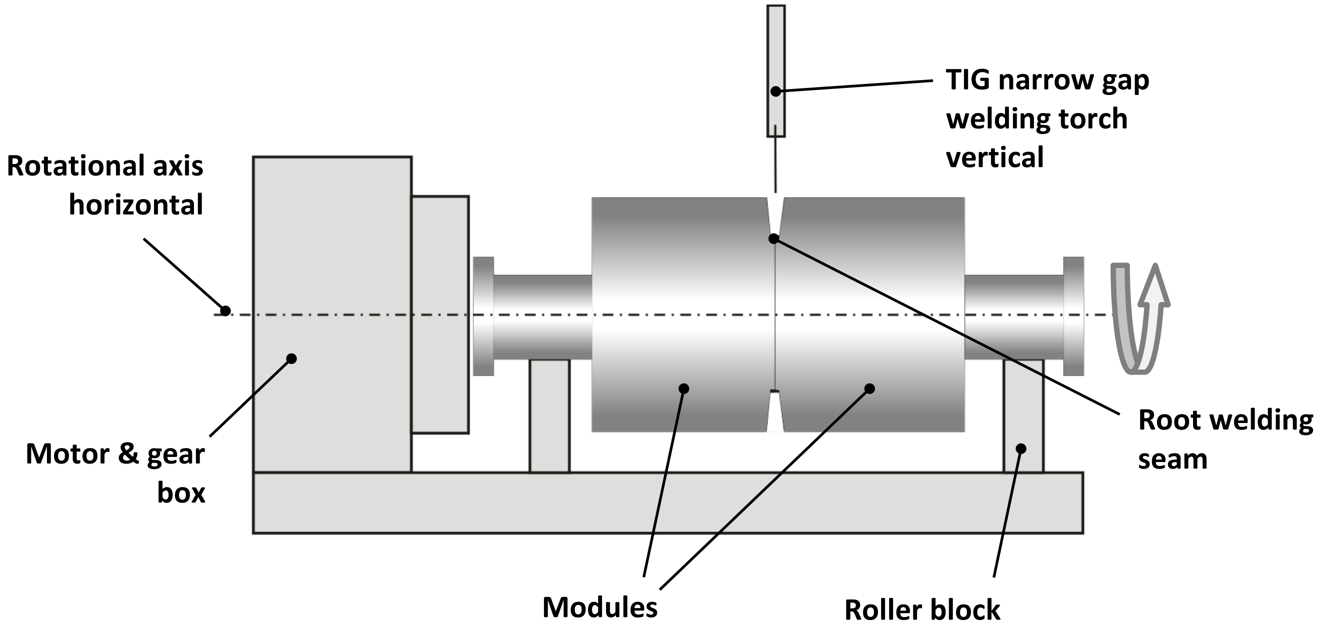


Fig. 3.10: Root welding scheme - H-H/TIG-TIG

With the use of a TIG narrow gap welding torch the root welding seam is processed. This welding torch is a special Siemens in house development, using the TIG welding method with the use of additional filler material. This method guarantees a high quality welding joint, but is one of the slowest welding procedures according to the melting deposition rate combined to gas metal arc welding (GMAW) and submerged arc welding (SAW) process.

The following picture shows the application TIG narrow gap welding torch at Mülheim plant. Further information according the welding torch can be found in Schreiber 2008 and Gunzelmann et al. 2008.

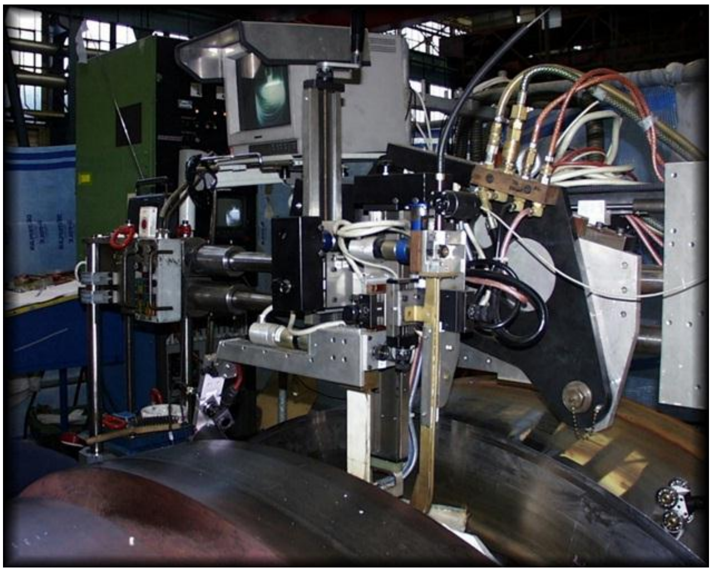


Fig. 3.11: TIG narrow gap welding torch

3.2.2 X-ray testing

After finishing the root welding step a non-destructive X-ray test is done in order to check the root welding seam. This testing is done by a service provider to Siemens with conventional analog X-ray film technology.
"Therefore the rotor has to be cooled down to 50°C and heated up again for the support welding step." [Schreiber 2008, p. 23]
Among this technology Siemens Corporate Technology is developing a new technology for the digital testing procedure. Background of research in HOT X-ray is that the rotor modules do not have to be cooled down for the X-ray check. This allows shorter lead times due to eliminating the cooling- and pre-heating cycle (after X-ray test).

This type of X-ray testing is part of the new production process and is shortly explained in chapter four.

3.2.3 Support welding – H-H/TIG-TIG

Step two is the support welding process, shown in figure 3.12, to put additional layers on the root seam before fill welding starts.

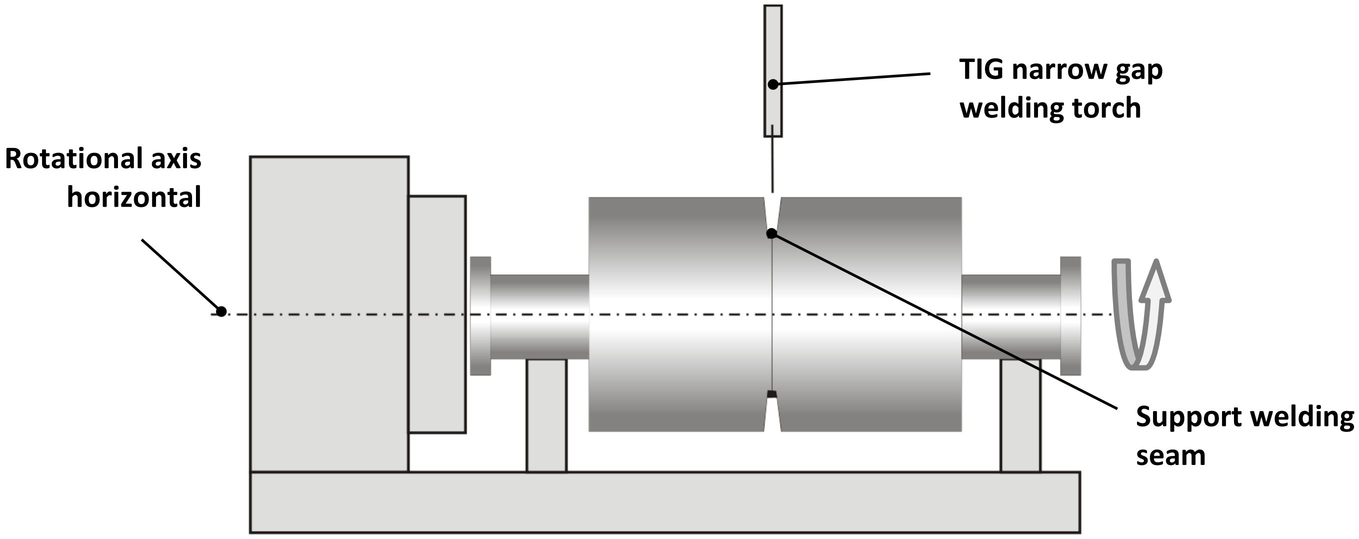


Fig. 3.12: Support welding scheme - H-H/TIG-TIG

After the support welding process a second no-destructive X-ray test is carried out to ensure the quality of the welding seam. The rotor has to be cooled down to 50°C due to the testing procedure.

3.2.4 Fill welding – H-H/TIG-TIG

The third main step is the fill welding process of the narrow gap illustrated in figure 3.13. There the gap is closed and after this the rotor is ready for post weld heat treatment and ultrasonic testing.

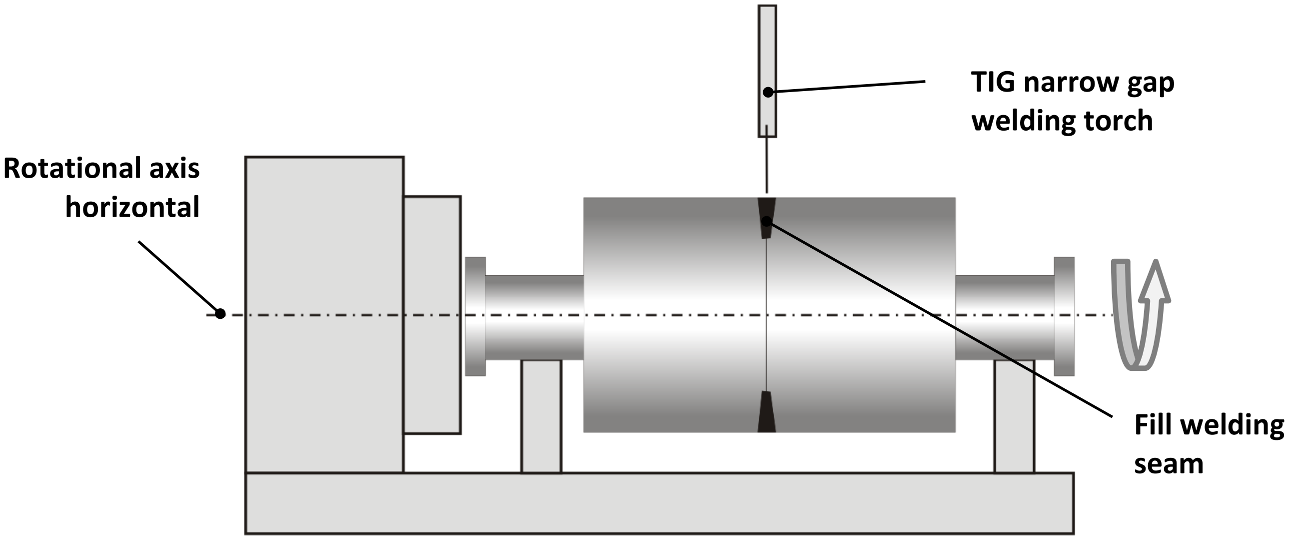


Fig. 3.13: Fill welding scheme - H-H/TIG-TIG

3.2.5 Post weld heat treatment process

After fill welding a post weld heat treatment of the welding joint has to be carried out. This reduces the residual stresses occurred during the welding process of the rotor. The PWHT has the same technical setup as the pre-heating (resistance heating). The annealing of the welding seam is defined by a Siemens welding procedure and carried out from a local service provider. Figure 3.14 shows the final setup of a steam turbine rotor during the PWHT process carried out in building 81.

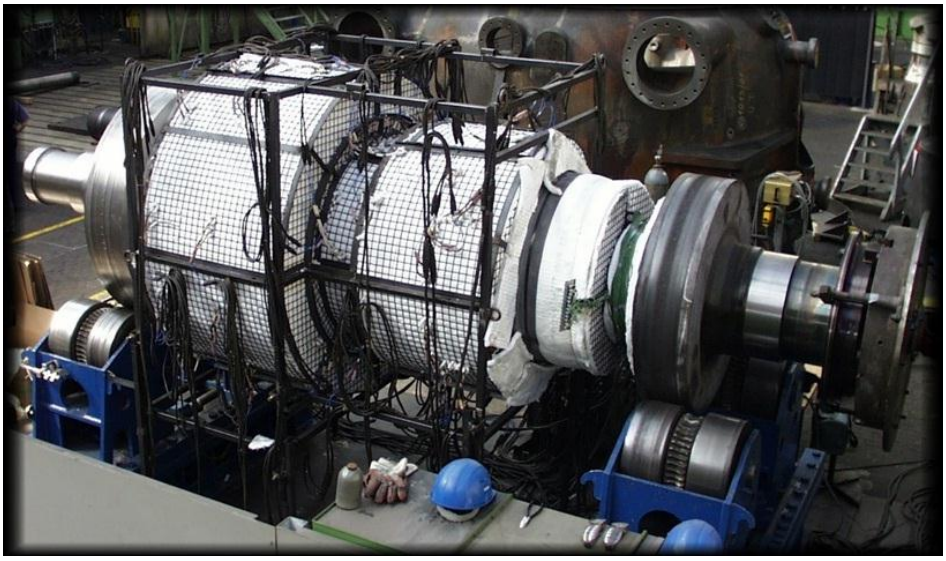


Fig. 3.14: Post weld heat treatment of rotor

To avoid permanent deflection during annealing it is required to rotate the rotor shaft, which achieves a better temperature distribution. After the PWHT process the rotor has to be moved to building 80 to continue with ultrasonic testing.

3.2.6 Non-destructive testing (ultrasonic testing)

After PWHT the welding seam is machined on a turning lathe in order to get a testable surface for the ultrasonic head.

The ultrasonic testing is necessary due to ensure the quality of the fill welding seam. It has to detect failures among the fill welding. [Schreiber 2010, p.24]

Because of the long process time of this step, one department of the plant is doing research and development in the field of UT. This knowledge should be implemented in the new production process.

3.2.7 Pros and cons of the current production process

As briefly shown, the process itself is not rather complicate to set up, but it has several disadvantages listed below which have to be overcome.

Pro

- all process steps in horizontal orientation
- no additional handling steps
- minimun invest - old turning lathe retrofitted
- best welding position for all welding technologies

Contra

- single welding torch
- pre-heating on welding stand
- form-shaped pre-heating and PWHT elements for each rotor design
- Analog X-ray testing
- long fill welding process times
- additional roller blocks
- limited dimensions of the rotor
- complex setup of PWHT
- long alignment times

Fig. 3.15: Pros and cons of the horizontal process

An application of multiple welding torches is not possible, because of the orientation of the rotational axis and the construction of the welding stand itself. The only accessible position for welding is from the top as shown in figure 3.15.

After assembling the rotor modules pre-heating of all rotor modules is done on the welding stand. This is a non-productive time (auxiliary process time) for the welding stand. The form shaped pre-heating and PWHT elements can only be used for an individual type of rotor. If the portfolio of the welded rotors changes, the need of other form shaped elements arises, which require additional investments. The PWHT process is complex in setup due to the need of a rotational movement of the rotor during the annealing process. All wires of the thermo elements have to be long enough to take multiple rotations of the rotor. Then the next rotation has to be in the reverse direction.

The fill welding process has, in order to use the TIG welding method, long process times and is the bottleneck of the whole process.

Also the amount of roller blocks is directly related to the design of the total rotor shaft. With more than two modules of the rotor shaft the horizontal alignment becomes more complicated.

All three major steps are carried out in the same orientation of the rotational axis. This is an advantage as it reduces the additional handling steps to a minimum. The setup of the welding stand by using an old turning lathe is a good and cheap idea. But there is limitation in the design of the rotor, so not the whole portfolio can be covered.

It is necessary to find other ways of producing rotor shafts more efficiently. The next chapter describes process alternatives on the production process of rotor shafts for steam turbines.

Competitors all over the globe have different manufacturing strategies. For example Alstom, as one strong competitor, has implemented a vertical-horizontal production process from early on. Alstom demonstrates that vertical-horizontal is a technique which works.

To define the differences between the implemented process and the competitors', the next chapter describes the main process steps of the vertical-horizontal production process version.

3.3 Production process alternatives

Competitors like Alstom are using a different production methodology. The general idea of the alternative is to put the alignment of the modules, the root and support welding step into the vertical axis. This allows more possibilities in aligning and welding processes in general.

3.3.1 Vertical – horizontal production process

Alstom has been welding rotors since 1929 and pushing their technology. They have set up a production process, which is now state of the art in welding rotors all over the portfolio of steam turbines. [Keller S., Balbach W. 2007]

The used process is characterized by the following:

i) The root and support welding seam process is done in vertical orientation of the rotational axis by use of TIG welding.

ii) The fill welding seam process is done in horizontal orientation of the rotational axis by use of SAW.

In order to understand how this process works, the picture below shows a vertical welding stand. It illustrates the fully prepared rotor on a vertical welding stand and the process principle used in a facility of Alstom in Birr/CH.

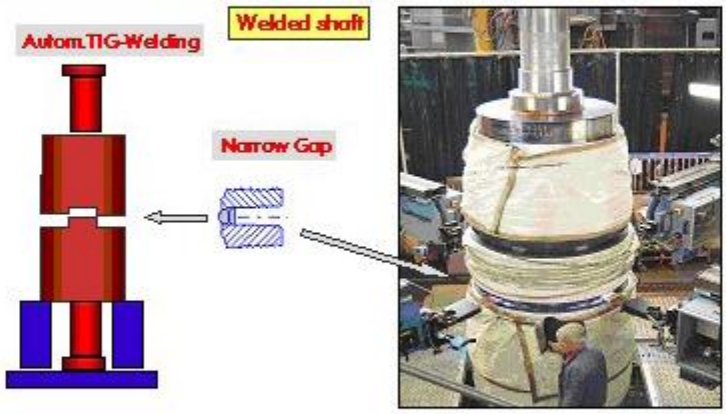


Fig. 3.16: Vertical welding process [Kellner S., Balbach W. 2007]

As shown in figure 3.16, this concept differs from the mentioned H-H/TIG-TIG process before. A detailed description of such a production platform is done in chapter four. The first two steps of the production process are completed on the shown vertical welding stand. Then a flipping of the rotor from the vertical to the horizontal orientation is necessary in order to keep on with the SAW process.

Figure 3.17 shows the major process steps of the V-H/TIG-SAW production process.

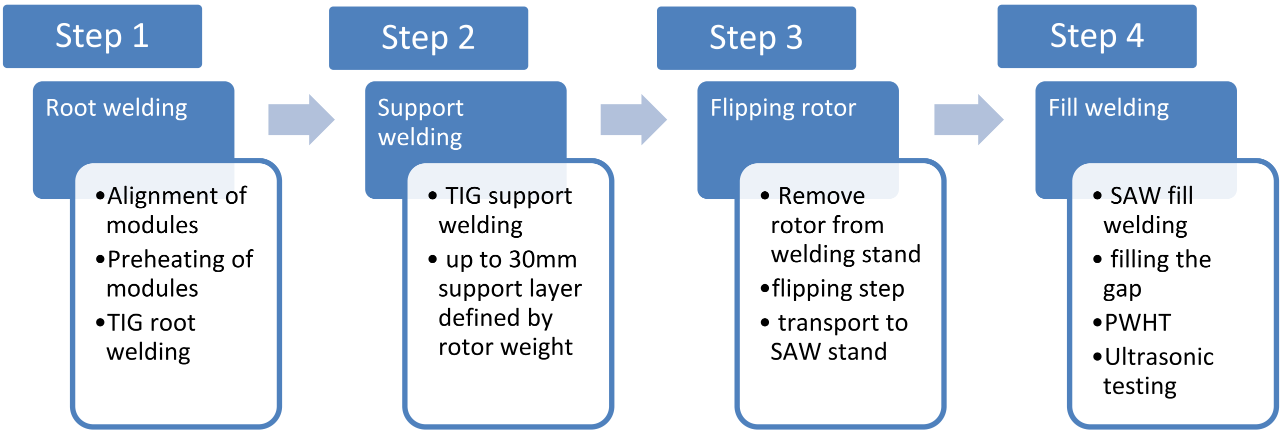


Fig. 3.17: Rough process sequence - V-H/TIG-SAW

3.3.2 Root welding – V-H/TIG-SAW

The first step after the vertical alignment of the modules is similar to the H-H/TIG-TIG process. There is a TIG root welding carried out to ensure the first connection of the modules. The direction of use of the narrow gap welding torch has changed into the horizontal position as demonstrated in figure 3.18

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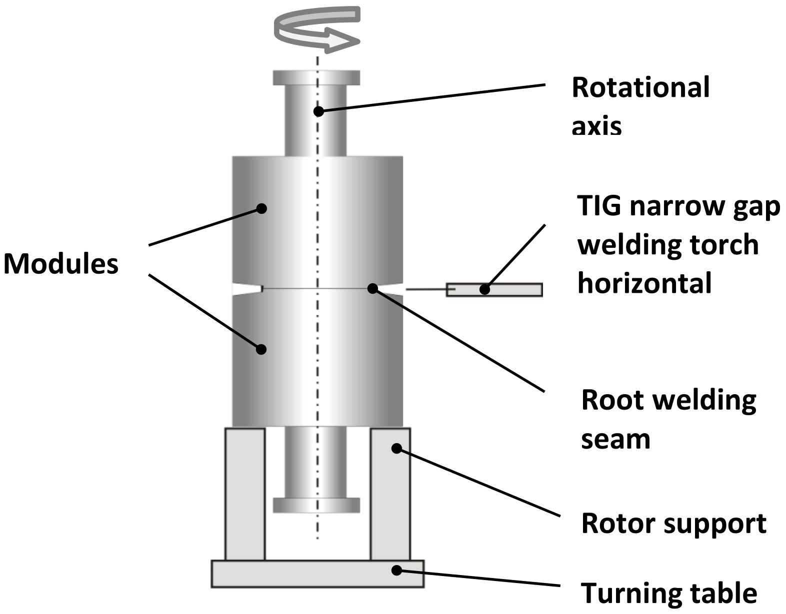


Fig. 3.18: Root welding scheme – V-H/TIG-SAW

Alstom is able to use four TIG torches simultaneously, which reduces the long TIG welding times. After the root welding seam has been processed, the support welding step continues. [Keller S., Balbach W. 2007]

3.3.3 Support welding and flipping – V-H/TIG-SAW

The second step, shown in figure 3.19, is the support welding seam process where additional layers are deposited onto the root weld. The thickness of the whole support welding seam is defined by the weight of the rotor. The support seam has to withstand all stresses during flipping.

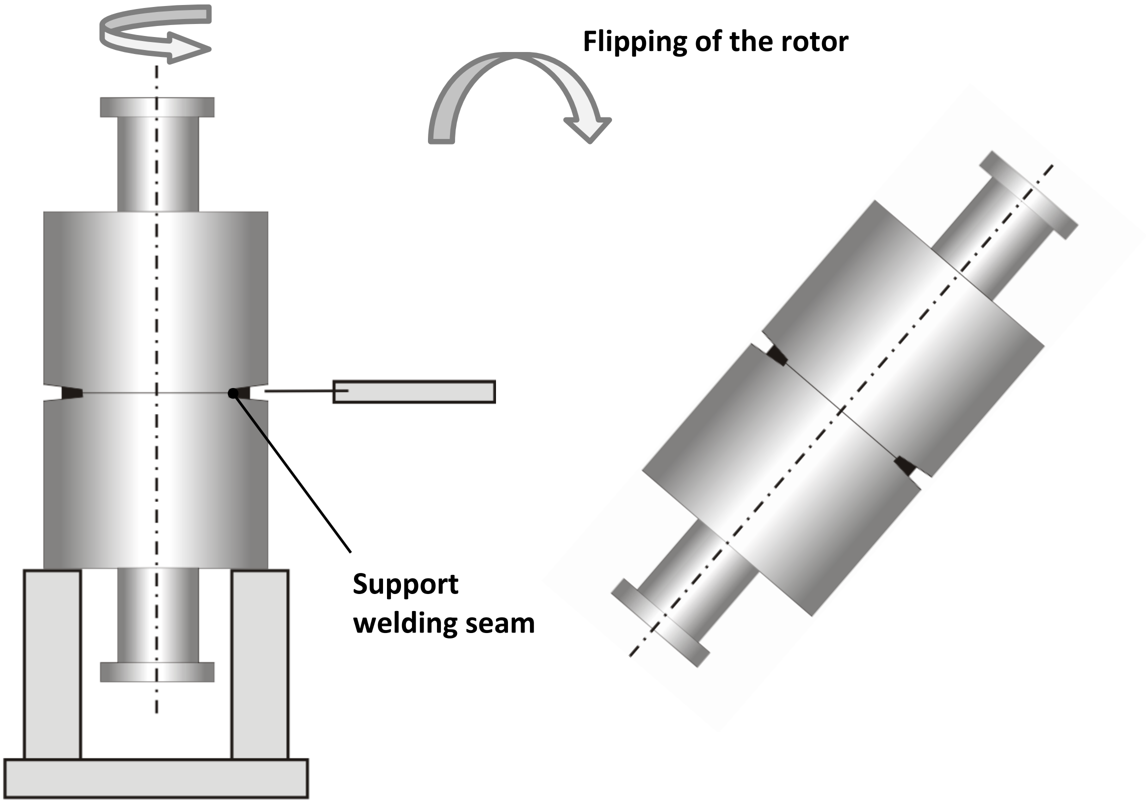


Fig. 3.19: Support welding and flipping scheme – V-H/TIG-SAW

After flipping, the rotor is put on an automated SAW facility. There the fill welding is done. [Keller S., Balbach W. 2007]

3.3.4 Fill welding – V-H/TIG-SAW

The last major step of this process is the fill welding step where a SAW narrow gap torch is used for filling the gap. The setup (figure 3.20) of the welding stand is similar to the horizontal process version H-H/TIG-TIG. The SAW process has a higher deposition rate and therefore shorter process times compared to the TIG procedure.

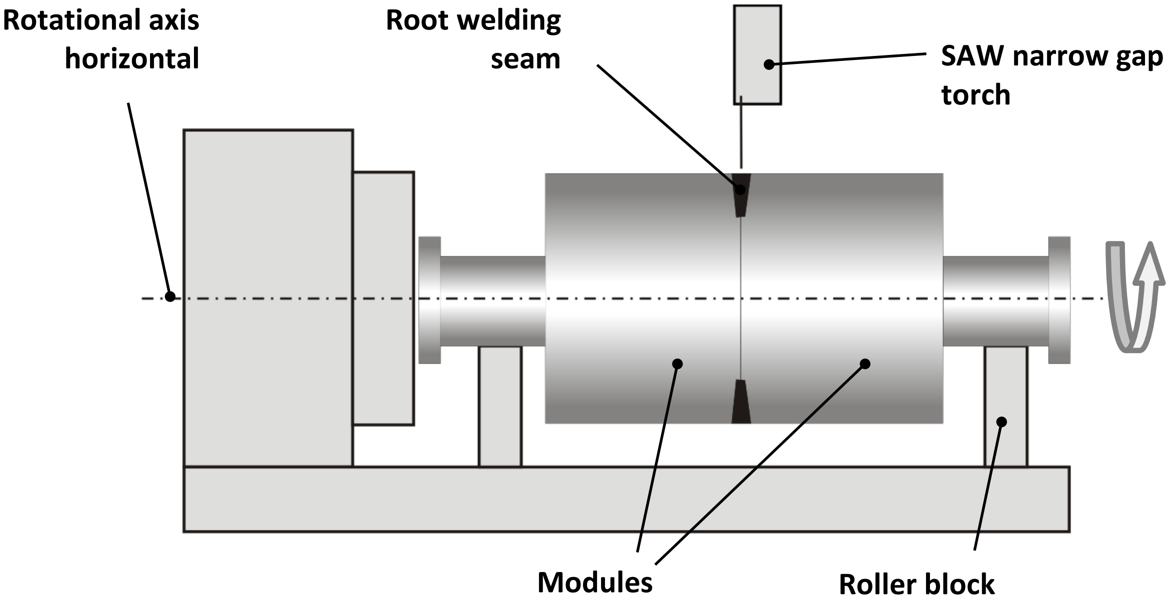


Fig. 3.20: Fill welding scheme - V-H/TIG-SAW

A possible configuration of such a SAW facility is shown in the picture below. This is the production machine used in Birr/CH by Alstom.

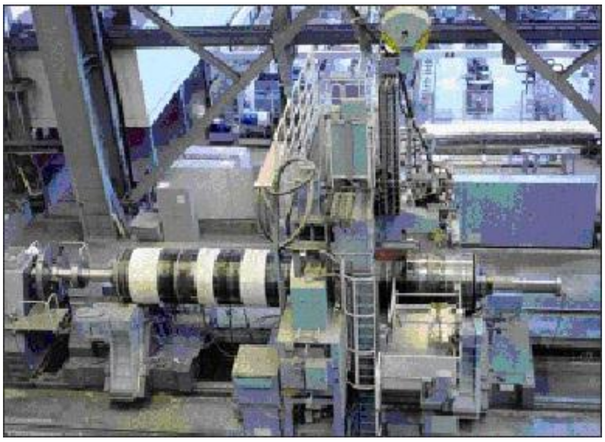


Fig. 3.21: SAW facility by Alstom [Keller S., Balbach W. 2007]

3.3.5 Pros and cons of the V-H/TIG-SAW process

Although this kind of process is used by competitors for years it has some major disadvantages too listed in figure 3.22.

Pro

- use of multiple TIG welding torches
- no additional roller blocks in vertical orientation
- scalable platform for variety of rotor protfolio
- standardized and aproved process
- pre-heating beside the welding stand before root welding

Contra

- additional handling steps - flipping etc.
- SAW welding technology causes invest in second welding stand
- addtional equipment for second welding stand
- long TIG process times according high ammount of support welding
- SAW in vertical position not possible

Fig. 3.22: Pros and cons of the vertical-horizontal production process

The requirement of a second welding stand due to the combination of two different welding technologies (first TIG then SAW) causes higher investment (additional roller blocks, welding equipment, etc.). Additional handling steps are necessary in order to keep on with the SAW welding procedure.

The advantages are the possibility of using multiple welding torches and to remove the roller blocks in the vertical direction. Also the scalable production platform which can deal with the whole portfolio is a strong argument for this type of process.

3.4 Conclusions on rotor shaft production processes for steam turbines

The question for Siemens is how to develop their production process further by using the advantages of both concepts.

Milestones for the development of a new production process are:

i) Reduce handling steps to a minimum
ii) Use of the latest technology like GMAW for the fill welding step
iii) Welding of the whole portfolio of rotor shafts for steam turbines
iv) Economic advantage of new production process
v) Reduction lead time
vi) Becoming a technology leader

Being innovative in production techniques and using the latest technology for developing a new way of producing steam turbines are key drivers for Siemens.
The introduced production process has a limited number of rotors which can be produced in one year. TIG technology within the fill welding step is the limiting factor on the whole process chain. Also the limitation in size of the rotors shows not really competitiveness. Being able to weld all rotors throughout the whole portfolio would increase the competitiveness and economic advantage tremendously.
Aggteleky mentioned in chapter two that the feasibility study has to deliver a technical functional design of the facility including the system and structure planning on the production processes. Also the economic advantages like productivity, profitability and competitiveness are the main goals such a study.

Due to the fact that Siemens has lots of licensing on their products, it becomes much more important to develop the production technology further and to offer the latest technology to their licensing customers.

The next chapter takes a deeper look into a new production process. It tries to eliminate the disadvantages, mentioned before, as much as possible.
A new production process is set up and investigated in order to find the first decision of the next step in the factory and technology planning approach.

4 Development of new production process and procedure

In order to overcome the disadvantages of the implemented H-H/TIG-TIG process and the V-H/TIG-SAW process, a new production process is going to be described on the following pages. This chapter covers the system and structure planning step in a feasibility study according the theory part in chapter two (Aggteleky).
Within the new introduced production process the main production hall changes from building 81 to building 62. Here the crane capacities and the height of the hall ensure an implementation of the new welding stand. A possible new configuration of building 62 is shown in figure 4.1.

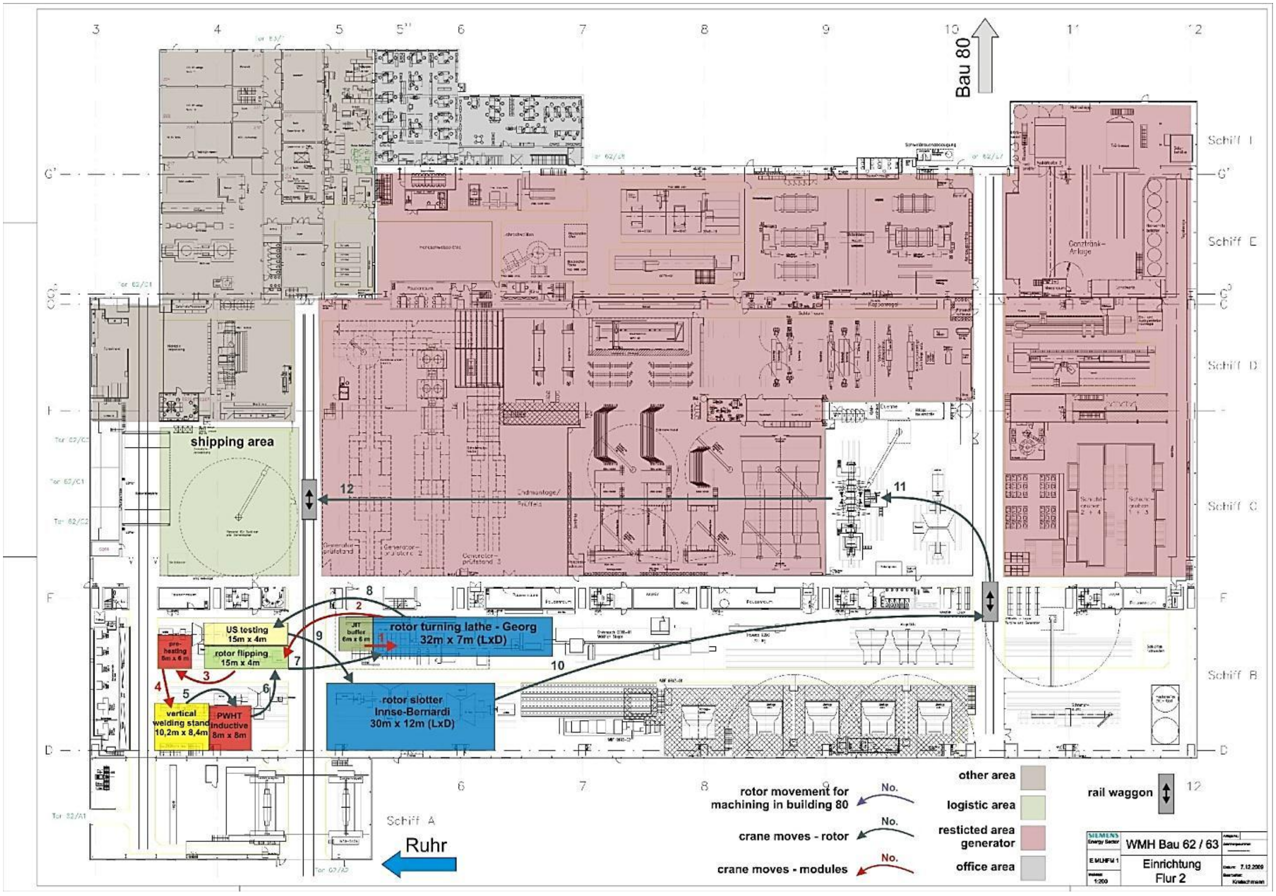


Fig. 4.1: Possible integration of new production process in building 62

The suitable solution of the new production process in building 62 is one main factor for innovations in the field of steam turbine production. Because of the huge potential of the new process and the suitable production hall 62, the implementation of the new process will be also one big investigation project itself. Chapter four provides the discussion basis for an implementation as a global planning part referred to Aggteleky.

To be a strong competitor among the others like Alstom, Mitsubishi, General Electric, etc. Siemens has to find an innovative way of producing steam turbines. The following production process is based on a Siemens invention PTC/EP2010/058088. The idea behind the invention mentioned in Gunzelmann 2010 is to get rid of the horizontal process step in the production process. This can be achieved in order to process the fill welding step also in the vertical orientation of the rotational axis as shown in the picture below.

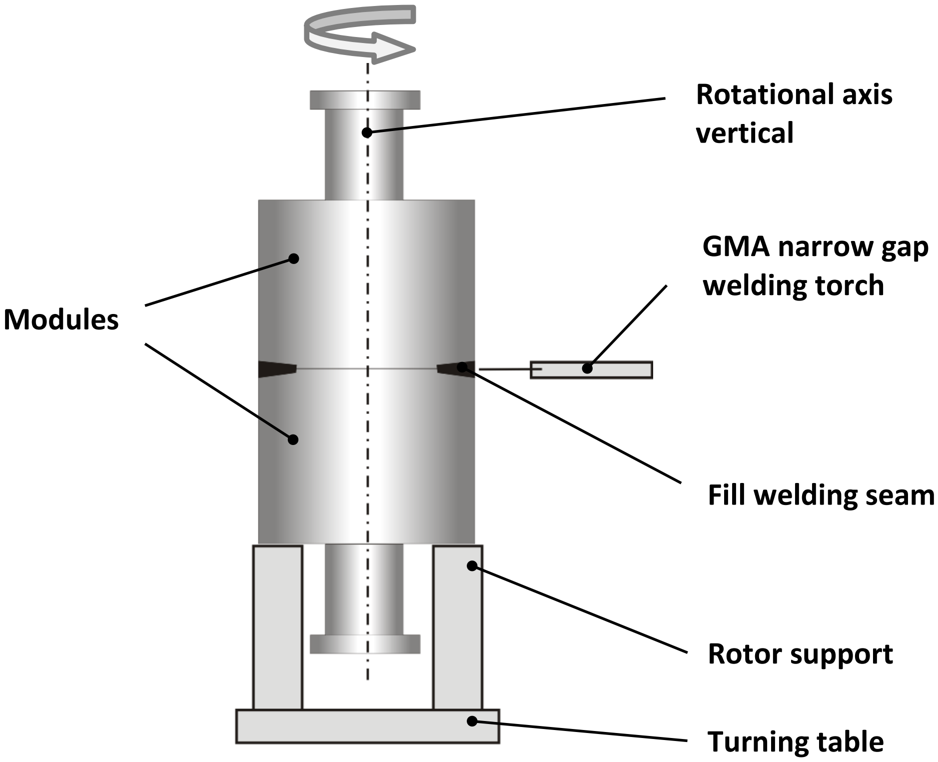


Fig. 4.2: Vertical fill welding setup

The use of the GMA narrow gap welding torch, shown in figure 4.2, is also one basic element of the Siemens invention. The next pages describe the new features and the process itself. Driving the technology from TIG fill welding to GMA fill welding is the biggest innovation step in producing welded rotors for turbines. This innovation step will be completed by the next fiscal year of Siemens. Corporate Technology plays the key role within the research and development of the GMA narrow gap technology. Further details on the GMA technology cannot be published due to intellectual property of the Siemens AG.

The implementation of the key features and the description of the new production process are depicted on the following pages.

4.1 New production process planning and definition

To use the Siemens invention, a new production process chain will be set up and described. All new key features of the production process will be implemented and investigated according to the circumstances within the plant in Mülheim.
The new production process combines several new key features shown in figure 4.3.

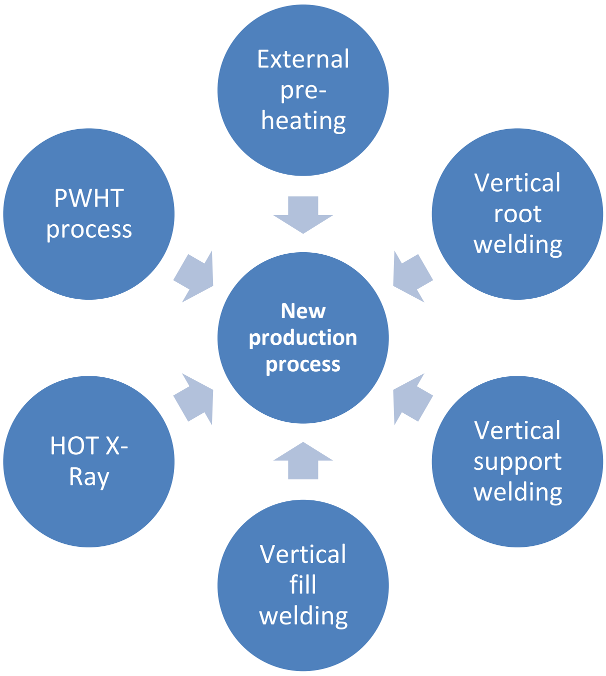


Fig. 4.3: Combination of key features in new production process

The new process follows a V-V/TIG-GMAW systematic. This combination of features is unique in the production of steam turbine rotors. Competitors like Alstom are using a V-H/TIG-SAW systematic as mentioned in chapter three.
The welding stand for such kind of process differs completely from the implemented version, shown in chapter three. To get an idea of how the new production facility looks like the next chapter describes the new welding stand. The named key features like vertical root-, support- and fill welding steps as well as the HOT X-ray process can be performed on the new production platform.

4.2 Possible configurations of the vertical welding stand

To meet the demand of the new process the vertical welding stand has to satisfy lots of different points:

i) Easy assembling of the rotor modules
ii) 360° accessible welding platform
iii) Up to four simultaneous used narrow gap welding torches
iv) Support of the whole rotor portfolio (smallest and biggest rotor types)
v) Solid construction to avoid vibrations during welding
vi) Top feeding/removing of rotor modules and rotor itself
vii) Integrated control for welding equipment, rotational desk, etc.

In order to fulfill all mentioned requirements and to become familiar with the complex facility, the picture below and the following pages explain how this welding stand works.

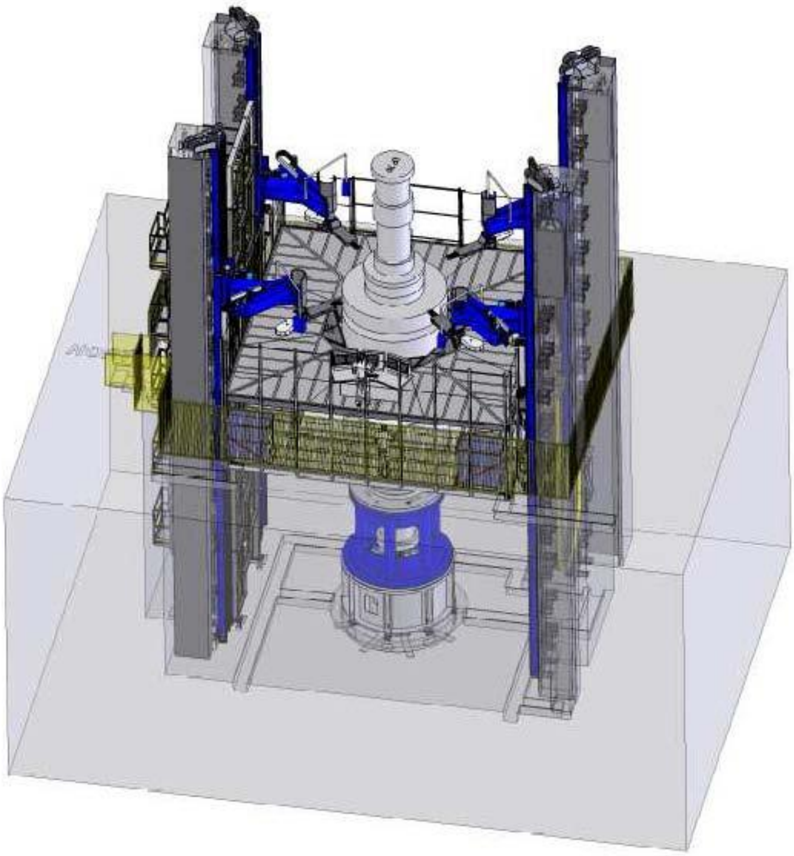


Fig. 4.4: Example of a vertical welding stand [Polysoude 2010, p.56]

As shown in figure 4.4, the welding stand for the new process has four columns and a vertical adjustable production/welding platform.

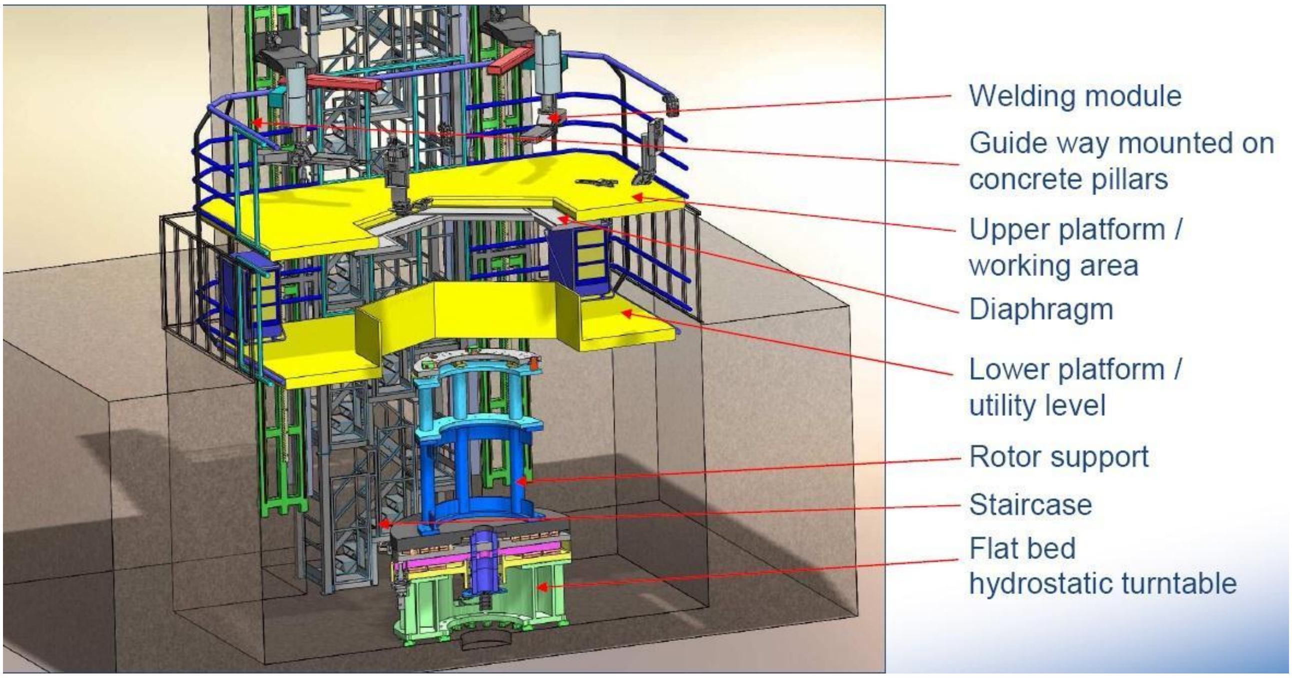


Fig. 4.5: Cross section of a vertical welding stand [Polysoude 2010, p.67]

Figure 4.5 shows a cross section of the vertical welding stand. Four concrete pillars are carrying the whole two-level welding platform. The upper level is used as the working area for the employees and the lower area is used as a utility level. There is all necessary production/welding equipment like induction equipment, welding current sources etc. situated. The platform can be moved up and down ensured by the guide way on the pillars. The lower part (dark blue) of the rotor support ensures a safe alignment and the upper part (cyan) is interchangeable for all rotor shafts along the portfolio. The staircase is used to reach every level of the welding platform. This type of welding stand uses a flatbed hydrostatic turntable for the required rotational movement.

Thus every rotor has its individual shape and diameter the adjustable diaphragm ensures the workers security and full access to the rotor on the welding platform. The following picture shows the adjustment of the diaphragm.

In figure 4.6 the left picture shows the fully opened diaphragm and on right side it is partly closed.

Fig. 4.6: Example of adjustable diaphragm [Polysoude 2010, p.71]

The supplier of the welding stand for Siemens is not Polysoude S.A.S because of the fact, that they are developing and selling their own narrow gap welding equipment. One potential supplier is the company DEUMA (Deuzer Maschinenfabrik). Deuma is using a mechanical turntable instead of the hydrostatic version from Polysoude. The following picture shows a vertical welding stand from Deuma.

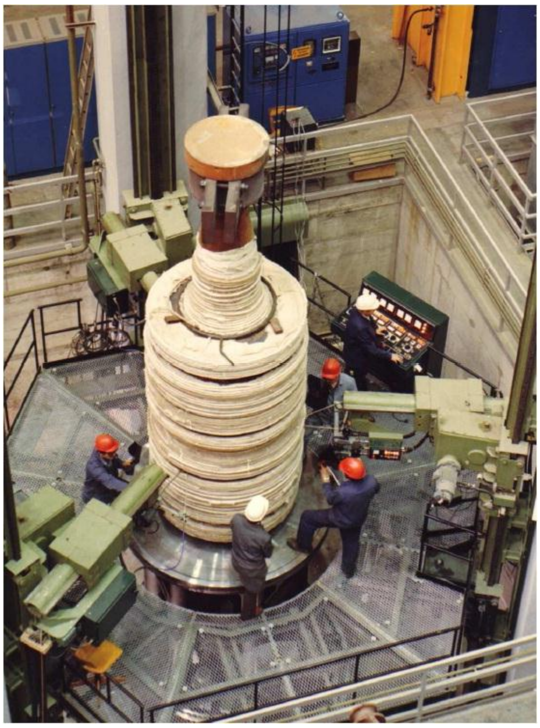


Fig. 4.7: Vertical welding stand [Deuma 2010, p.4]

The functions of the system from Deuma are the same as from Polysoude for the setup of the welding platform, the diaphragm and the rotor support. Polysoude is using their solution for its own narrow gap welding torch.

Deuma is able to integrate the Siemens narrow gap welding torch mentioned in chapter three. Therefore, a combined interface of the welding stand and the narrow gap welding torch has to be defined. The maximum number of simultaneous welding heads is four as shown in figure 4.8. Further information on the Deuma system is mentioned in Deuma 2010.

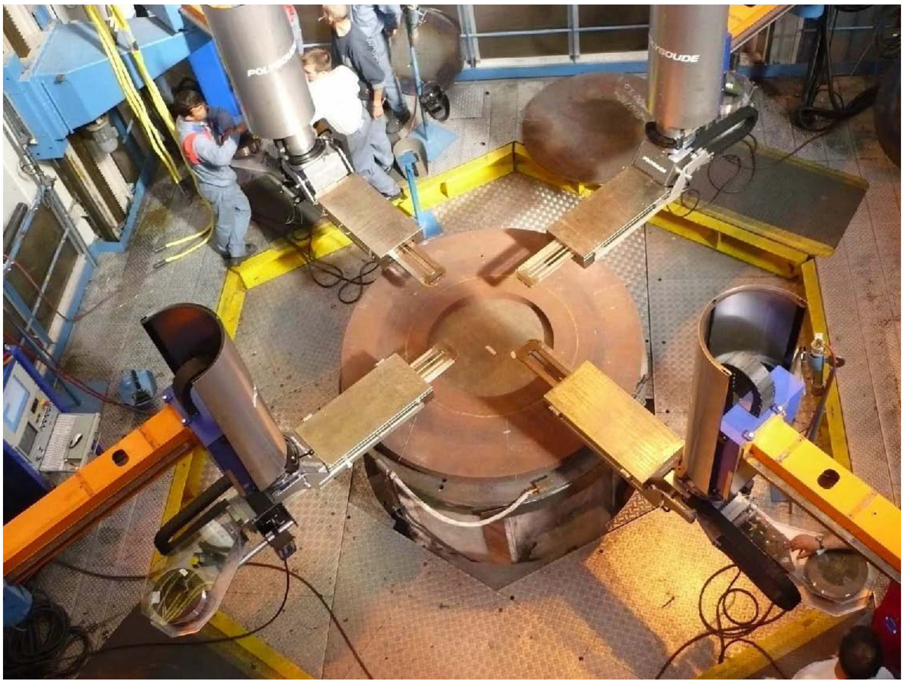


Fig. 4.8: Demonstration of 4 TIG narrow gap heads [Polysoude 2010, p.63]

In the picture above, the welding platform is on its lower end and the four TIG narrow gap welding torches are positioned for demonstration purposes. This is exactly the same setup as it is provided by Deuma and Siemens. Four narrow gap heads can be positioned individually on the platform.

The diaphragm is closed and the welding platform is ready to start with the first alignment of the rotor shaft (first module).

With this kind of production facility Siemens is able to produce the welded steam turbine rotors. How to produce them in a new innovative way is shown in the upcoming chapter and the detailed production process will be explained.

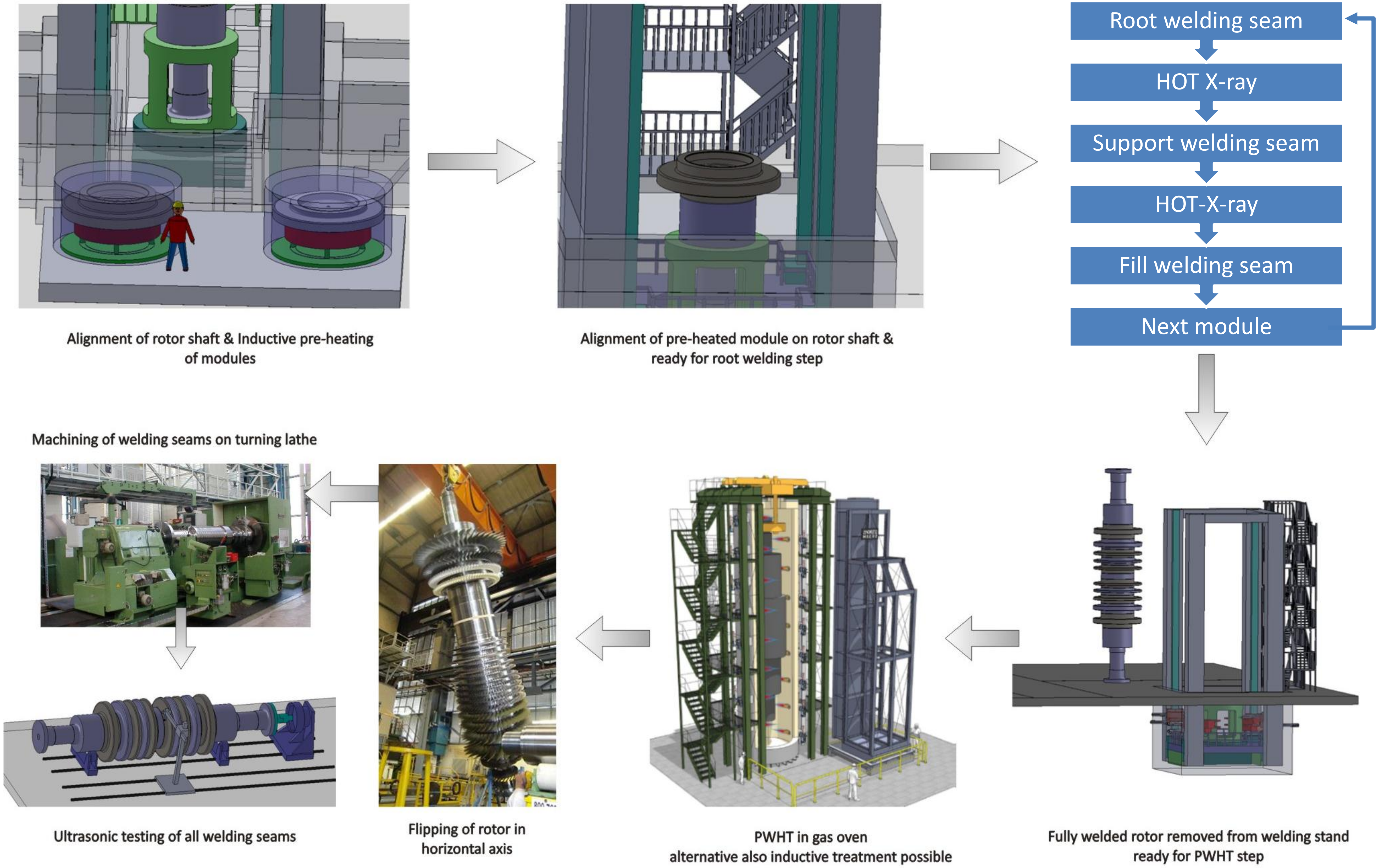
4.3 The vertical – vertical production process sequence

Figure 4.9 on page 63 demonstrates the new production process as a sequence of pictures, which provides an easy to follow principle of the complex process itself. The shown sequence is the outcome of the analysis of the introduced process (chapter three), the study of the process alternatives and the implementation of the invention named in chapter four. According to the theoretical part in chapter two, this refers to the system and structure planning to Aggteleky, the factory structure planning according Grundig and to the complex II point 5/2 (determination of functions) based on Schenk.

4.4 Detailed process view of the V-V/TIG-GMA process

For the production of steam turbine rotor shafts a new production process has been set up and evaluated. The picture 4.9 is the demonstration of the process in a sequence of pictures. To identify all required process steps a detailed version of the production process has been developed. The outcome of this new production process is shown in figure 4.10 on page 64.

The main steps of the process are the welding seam preparation (WSP), the inductive pre-heating, the root, support and fill welding steps, the post weld heat treatment (PWHT) and the ultrasonic testing (UT) step.



Alignment of rotor shaft & Inductive pre-heating of modules

Alignment of pre-heated module on rotor shaft & ready for root welding step

Fully welded rotor removed from welding stand ready for PWHT step

PWHT in gas oven
alternative also inductive treatment possible

Flipping of rotor in horizontal axis

Machining of welding seams on turning lathe

Ultrasonic testing of all welding seams

Fig. 4.9: New vertical-vertical production process sequence

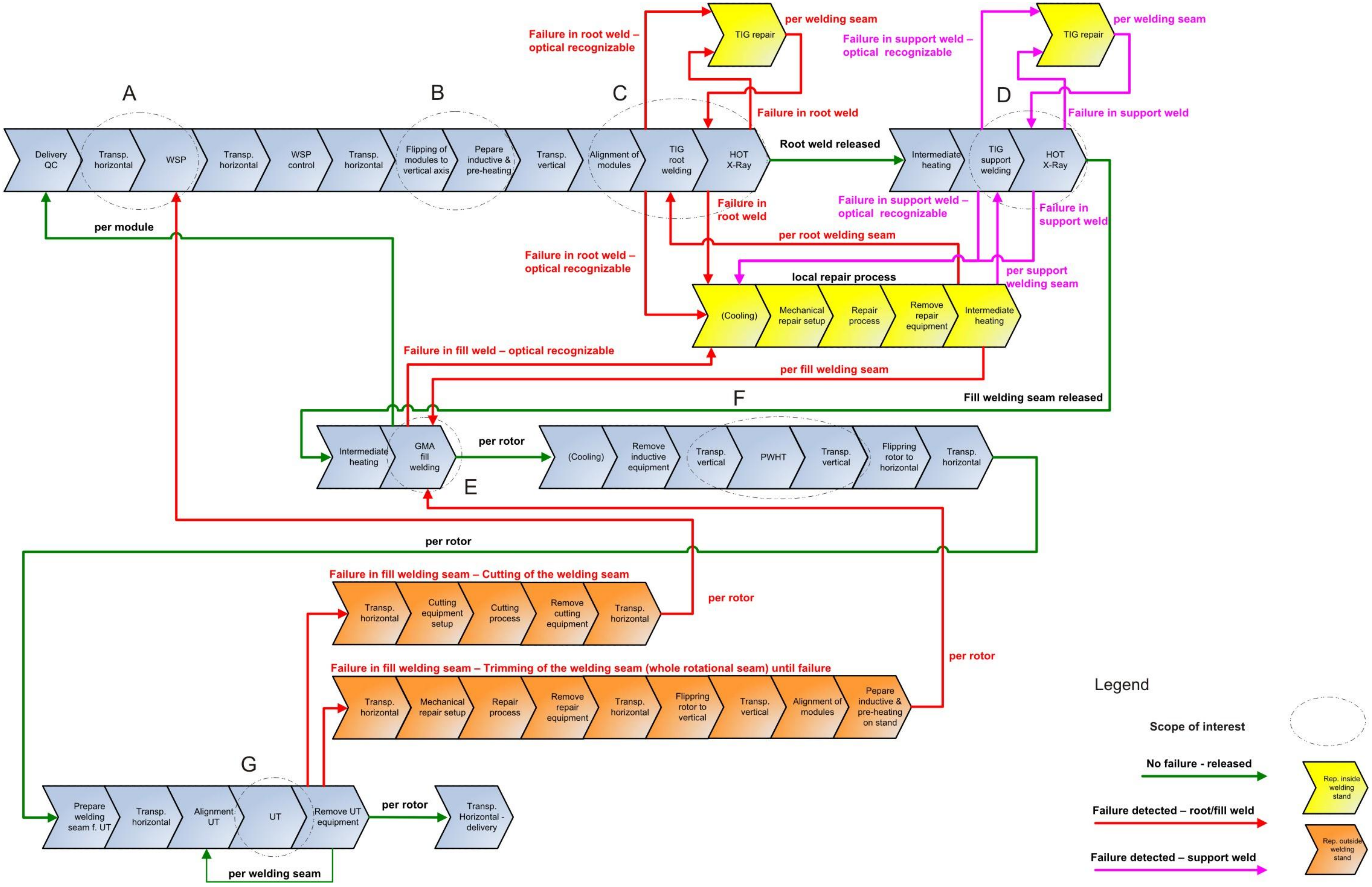


Fig. 4.10: Detailed process view of the V-V/TIG-GMA production process

This setup of the production process has been developed out of the implemented process version and the invention according to Gunzelmann 2010. The usability of the process chain has been reviewed by experts within Corporate Technology and Siemens Energy during the visits in the plant in Mülheim. All needed decisions for the setup has been carried out in cooperation with experts from Siemens Energy, Corporate Technology and visits of potential suppliers for the facility.

The description of the important sub-processes and the idea behind the process is worked out in the next few pages. Not every process step is described in detail, only the scope of interest and the innovative elements of the process chain are pointed out.

4.4.1 Transportation within the plant – Process detail A

The transportation of the modules between the different production halls is done with heavy duty vehicles. These vehicles ensure a maximum of flexibility in order to deliver the components of the rotor in the different production halls. The transportation within the production halls is done with indoor overhead cranes. Due to the fact of missing statistical records, the transportation and buffer times could not be evaluated during the visits in the plant. One suggestion for further investigation is to perform a multi-moment analysis (work-sampling studies) for data collection.

4.4.2 Welding seam preparation – Process detail A

To ensure a shrinking of the modules during the welding process a special welding seam preparation is necessary (figure 4.11). *"The area of the root welding seam is the most critical one because after the welding step a mechanical treatment of the root is not possible anymore."* [Schreiber 2008, p.17]

The necessary machines for this step are a turning lathe and a milling machine. On the turning lathe, the welding seam preparation geometry is machined. *"To ensure a good root welding result, the tolerances of the connection area have to be tight."* [Schreiber 2008, p.17]

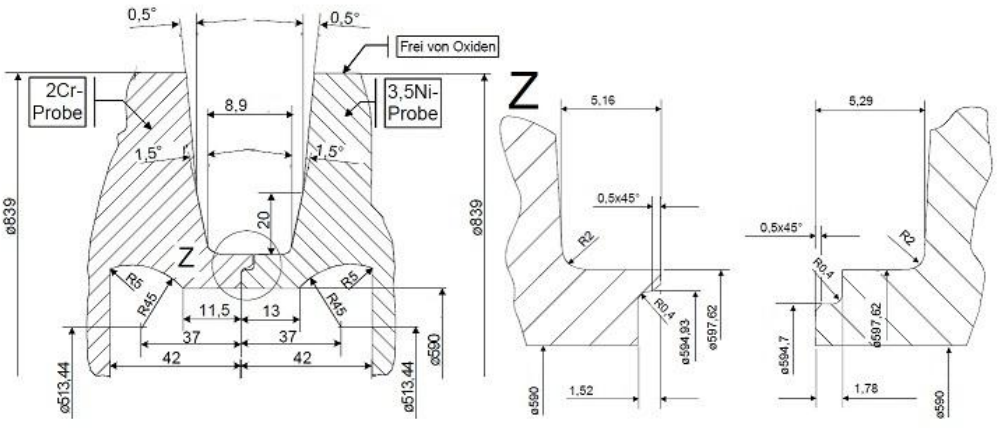


Fig. 4.11: Welding seam preparation [Schreiber 2008, p.18]

The geometry of the vertical welding process is not finally defined at this point of time during the thesis. For the evaluation in chapter five the basic knowledge about the already existing WSP is used. Process setup and times of the new geometry are derived from the existing geometry shown in figure 4.11 by experts in Mülheim and Corporate Technology.

4.4.3 Flipping of rotor/rotor modules – Process detail B

The flipping of the rotor modules for the alignment is a new process step compared to the introduced H-H/TIG-TIG process. Due to the fact that the alignment of the rotor modules is now in vertical orientation of the rotational axis the need of special handling equipment occurs. This equipment has to ensure that the modules can be flipped up in vertical position and to transport the fully equipped pre-heated modules.

The possible configuration of this equipment depends on the portfolio of the produced rotor types. Among the evaluated portfolio (chapter five), every type of rotor has to have its own type of flipping equipment for flipping the modules. The flipping of the rotor can be done with one general flipping equipment for rotors. Because these steps are not implemented currently in Mülheim, there are no data available according these handling procedures. For evaluation purposes in chapter five the basis was the experience of the blue colored workers and the crane operators in Mülheim.

For flipping a rotor as shown in figure 4.9, the basis was the experience from the gas turbine production at the Berlin plant.

4.4.4 Inductive pre-heating of rotor modules – Process detail B

Instead of using resistance heated pre-heating equipment, an inductive pre-heating method is used. Thus provides a variety of individual rotor shapes and an efficient heating method of the rotor modules. A potential supplier for inductive heating and annealing processes is the company SMS Elotherm. They are able to provide solutions for the inductive pre-heating and also the inductive annealing (inductive PWHT) process step implemented in the new production process.

With the inductive technology it is possible to reduce the pre-heating times in comparison to the resistance pre-heating method mentioned in chapter two: The setup of the new pre-heating step is similar to the figure 4.12. Water cooled induction cables are mounted around the rotor modules and are able to cover the whole portfolio of the rotors. In order to reduce pre-heating times, additional heating from one front side can be performed. The pre-heating is performed in front of the alignment step and close to the welding stand. This guarantees short auxiliary times and a high availability of the vertical welding facility.

Figure 4.12 shows a heating procedure to remove a press-fitted rotor from the coupling.
The same setup is used in the new production process for pre-heating of rotor modules. Figure 4.7 in chapter 4.2 shows a fully equipped rotor in a vertical welding stand of Deuma.

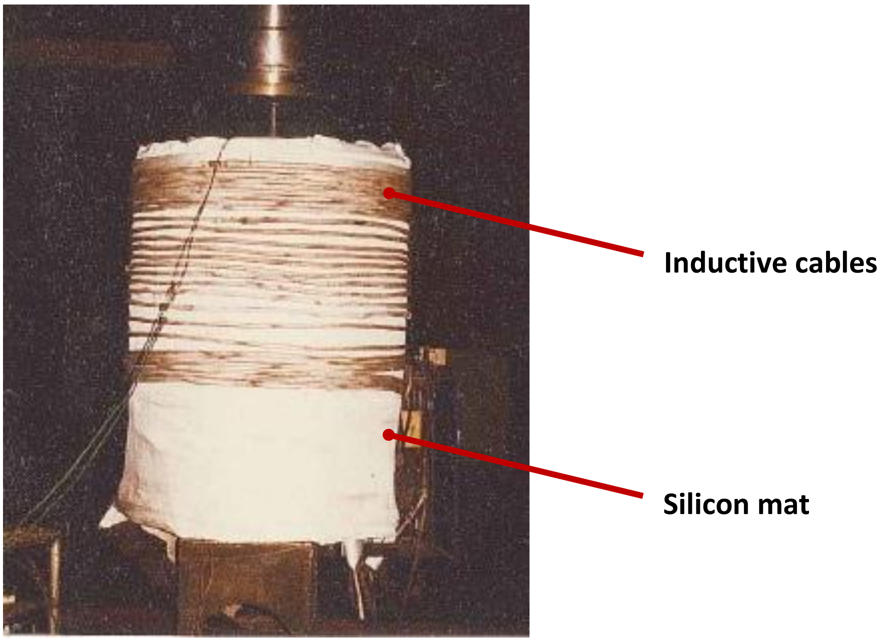


Fig. 4.12: Inductive heating of rotor modules [SMS Elotherm 2010]

The silicon mat is used for protecting the cables from slipping of the rotor. Another layer of this silicon mat (not shown in figure 4.12) covers the cables and the top of the rotor module to ensure a proper insulation and a minimum of heat loss.

4.4.5 Aligment of modules and TIG root welding– Process detail C

The alignment of the individual rotor modules is done with the pre-heated and fully equipped (inductive equipment is not removed) modules. The alignment process step is in vertical orientation of the rotational axis and carried out by the crane operator and additional workers. For evaluation of this step, it was not possible to try this step during the thesis. A mock-up procedure of this step is planned by the engineers in Mülheim. The experience of the employees has been the basis for the evaluation in chapter five.
The TIG root welding step is fully implemented in the current production. All experience and knowhow can be transferred from the existing process to the vertical welding process. Every required process data during the evaluation has been provided from the actual database. Further information on the root welding step can be found in Schreiber 2008 and Gunzelmann 2008.

4.4.6 HOT X-ray – Process detail C

The implemented conventional X-ray technology mentioned in chapter two will be replaced by a new technology. The new process is called "HOT X-ray" due to the fact that the rotor does not need to be cooled down after a welding step. With the use of a digital line-detector it is possible to X-ray the root welding seam in pre-heated form.
A conventional film needs to be developed after X-ray testing. This additional step will be eliminated by the use of HOT X-ray technology.
The research and development of the technology is done by Corporate Technology in cooperation with the plant in Mülheim. With this technique it is possible to reduce testing times. More important are the auxiliary times because of the cooling down and heating up steps in order to X-ray the rotor. These times will be eliminated with the use of HOT X-ray technology. The implementation of this procedure is scheduled for the first quarter of 2011. Due to intellectual property rights no further information about this technique can be published. After testing the joint the process continues with the support welding step.

4.4.7 TIG support welding and HOT X-ray – Process detail D

After root welding of the modules and the first HOT X-ray test a second TIG support welding step is performed. This procedure puts additional layers on the root welding joint. The maximum thickness of the support welding joint is limited by the HOT X-ray technology. Within this study the additional layers have a maximum thickness of about nine millimeter. After support welding a second HOT X-ray test is carried out. This step has to prove the total quality of root- and support welding. The next processed procedure is GMA fill welding of the remaining gap.

4.4.8 GMA fill welding – Process detail E

GMA fill welding of the remaining gap is the biggest innovation in the new production process. The technology and economic advantage of this technology offers Siemens the position as a technology leader. Being able to implement the GMA welding technique in the vertical production process is unique in producing steam turbine rotor shafts. The developed welding equipment named in chapter two is developed further for using GMA technology. The achieved process times, evaluated in chapter five, are 6 – 10 times lower than those of the TIG technology. This allows Siemens to produce their rotor shafts more cost efficiently. Tests and mock-up studies within CT T DE HW1 are underlining the potential of using GMA as new welding technology. Further information on the GMA technology cannot be published in case of intellectual property. After fill welding the rotor is removed from the welding stand and moved to the post weld heat treatment.

4.4.9 Post weld heat treatment – Process detail F

After filling the gap the rotor shaft has to pass an annealing process like mentioned in chapter two.
Two technologies for annealing are of interest for Siemens Energy:

i) Inductive annealing of welding joints
ii) Gas-fired heat-treatment furnace

The inductive version does not differ strongly from the mentioned pre-heating process in chapter 4.4.4. To achieve the required annealing temperatures within the welding joints, additional induction cables are assembled on the rotor shaft. This allows accurate overheating of the heat affected zone.
An alternative to the previous technology annealing can be done with a gas-fired heat-treatment furnace as shown in figure 4.9. This is a so called “integral” heat-treatment process where the whole rotor shaft is heated up. The oven is able to set up different temperature levels along the whole height of the oven. [Andritz-Maerz 2009, p.10]
It could be possible as well to mount additional heating elements on the rotor shaft to get an overheating in the heat affected zone. This is not evaluated yet and needs further information from suppliers. Figure 4.13 shows the shaft furnace in cold and heated condition.

Fig. 4.13: Gas-fired heat-treatment furnace [Andritz-Maerz 2009, p.3]

With this application it is possible to anneal all evaluated rotor types mentioned in chapter five.
The last process step of interest after the PWHT is the non-destructive ultrasonic testing procedure.

4.4.10 Non-destructive testing (ultrasonic testing)

The last step of interest is ultrasonic testing in general. Chapter three named the long process times among UT. The enhancements of the phased-array technique are evaluated by experts in Mülheim. For this thesis results and expert knowledge is used to define the benefit in the new production process in chapter five.

4.5 Process implementation – global planning

This chapter refers to the global planning part of a feasibility study mentioned in the different planning methods in chapter 2.1.
Among the circumstances within Mülheim plant an implementation study of the new production process is carried out. Based on the information sharing with Mülheim plant a block layout of possible solutions is going to be worked out. During the visits in Mülheim suitable production halls have been evaluated.

Constraints of the evaluation for the whole portfolio are:

i) crane hook heights
ii) crane loads
iii) suitable foundations within the production halls
iv) changeable layout of the current production

4.5.1 Suitable facilities/ production halls

Within the shown plant layout in figure 3.1 there are three main production halls available. Building 81 is the main building of the introduced process. Building 80 is used for mechanical treatment and building 62 for generator- and nuclear turbine rotor shaft manufacturing. In building 62 there is the final assembly of the steam turbines and the shipping preparation located as well. All steam turbine rotors have to pass building 62 and the preparation area for shipping. The largest building within the plant is building 62. All required constraints can only be achieved in this hall. Figure 4.14 shows the suitable crane hook heights and the crane capacities.

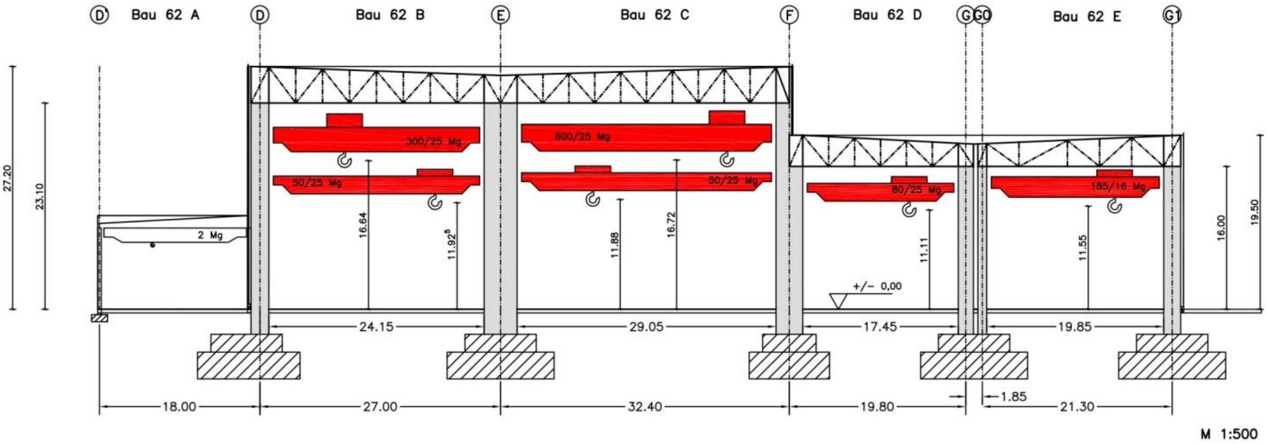


Fig. 4.14: Cross section – production hall 62 [Kretschmann 2010/1]

Production hall 62 is suitable for the realization of the new production process within the plant. Aisle “B” and “C” fulfill the mentioned requirements for implementation. The crane hook height is 16.640 mm and the crane load capacity is 300 t. The existing layout of the aisles “B” and “C” is shown in figure 4.15.

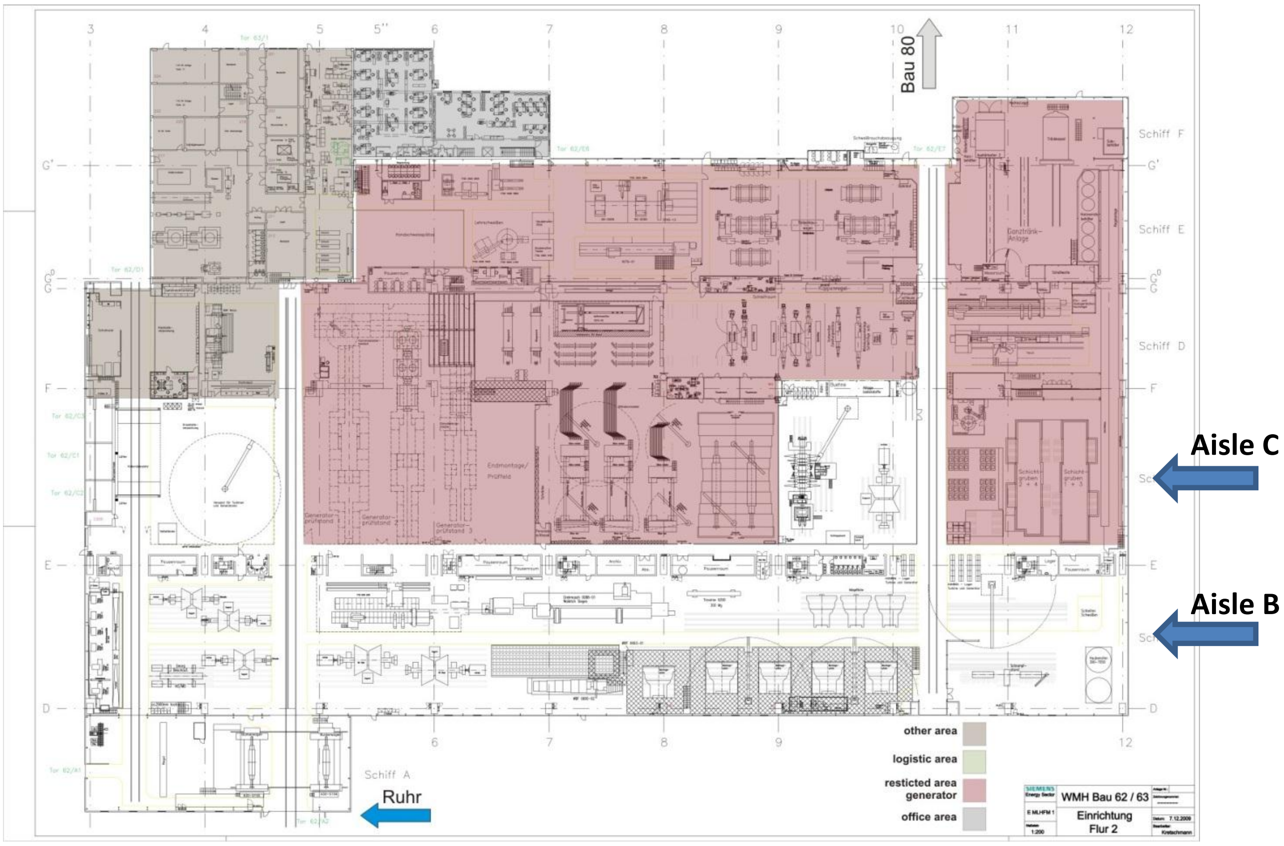


Fig. 4.15: Restricted area in building 62

Red marked areas on the shown layout are restricted for changings due to the generator production- and testing facilities. No changes can be done on that configuration of the layout. Therefore the aisle “C” is also not available for implementing the new production structure. Grey shows the office area and the brown colored area indicates other not usable areas within the building. As a result of the investigation, aisle “A” is left for realization of the new production concept.
Page A4 of the appendix shows a drawing of a possible implementation of a vertical welding stand. [Kretschmann 2010/2]

The layouts in the next chapter show one suitable way of the realization of the new production model in building 62 at Mülheim plant. Two scenarios are defined to point out the difference of the production layouts.

4.5.2 Possible realization solution in production hall 62

For the realization of the new production consepts two different scenarios are defined in figure 4.16 in order to point out a new possible factory structure:

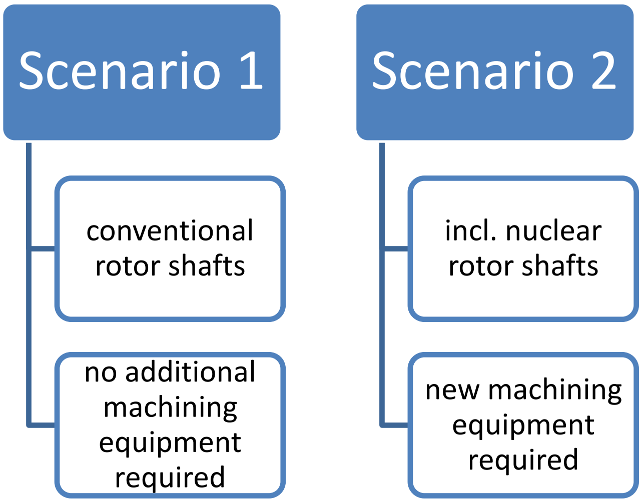


Fig. 4.16: Definition of scenarios

These scenarios are separated in order to show the difference between the implementation of the new production structure of the mentioned portfolio in chapter five. Scenario 1 is the "conventional" version without any nuclear turbine rotor shafts. So there is no need of additional machining equipment. The actual portfolio can be machined with the current setup of the machine shop in building 80. Taking the nuclear rotor shafts into account, the current available machining equipment is not able to process large nuclear rotor shafts. New machining equipment is required, therefore scenario 2 is created.

The following pages discuss a possible integration of these two scenarios in building 62 and a green field version.

4.5.3 Scenario 1 – implementation building 62

Page A5 of the appendix shows the implementation of scenario 1 within the production hall 62. There are two possible setups of the PWHT (inductive or gas fired oven) process. The layout of the current production has to be changed as shown in the figure. Alternative areas for the existing machines or blading stands have to be found within the plant. The new production facilities are situated in the blading area of the building, providing easier movement of the existing blading stands. The area is suitable for all required manufacturing processes like pre-heating, vertical welding and post weld heat treatment. Machining and ultrasonic testing of rotor shafts is carried out in building 80.

With no need of additional machining equipment the setup of the new structure could be implemented more easily than the configuration of scenario 2. Another solution is to build a new production hall to separate the new production processes from the existing ones.

4.5.4 Scenario 2 – implementation building 62

On page A7 of the appendix the implementation of the nuclear scenario is demonstrated. New machining equipment due to the large dimensions of the nuclear rotor shafts is needed. This causes a bigger production area. The existing machining equipment is substituted with new equipment. This requires also foundations which have to be applied. These machines have to be placed in building 62 because the crane loads in building 80 are insufficient. In fact machining and ultrasonic testing moves from production hall 80 to 62. This allows a tighter process setup and reduces additional logistic steps.

4.5.5 Green field planning – Szenario 1 & 2

To determine the required area for a new production hall a block layout is defined. The planned layouts are shown on page A9 and A10 in the appendix. These layouts provide the smallest possible production area. The estimated production area for scenario 1 (without nuclear) is calculated by 730 m² including the gas oven for PWHT and 483 m² using inductive PWHT. Scenario 2 (incl. nuclear) requires approximately 1.700 m² for the gas oven version and 1.200 m² including inductive PWHT.

4.5.6 Investment planning

Realization of the new production strategy needs investments and time. In order to get an overview of the major investments and the realization times a Gantt chart is shown in page A11 of the appendix.
The realization timeline of the welding stand has been evaluated to approximately 2 -3 years (times for technical specifications need further negotiation and investigation). The critical path of the implementation starts with the technical specification of the welding stand. It continues with the engineering and the manufacturing by a supplier. The last step is bringing into service by Siemens Energy. During the first step additional places for the existing production facilities can be found and the machines can be moved.

Investing in new production facilities needs long term preparation and negotiation with potential suppliers. The investment volume depends on the defined scenarios (conventional and nuclear). Although there are two scenarios, a basic setup of the new welding stand can be defined and the welding stand itself is built up for the maximum dimensions of a nuclear rotor type.

One basic setup of the welding stand could be following:

- i) Welding stand (for maximum dimensions of nuclear rotors)
- ii) One TIG narrow gap welding torch
- iii) One GMA narrow gap welding torch
- iv) Inductive pre-heating devices
- v) HOT X-ray equipment

For the whole process chain there is more investment required. Figure 4.17 illustrates a solution for scenario 1 with the use of a gas fired furnace of PWHT.
The first column (machine tools) represents the required invest in machining equipment. For welding equipment (second column) for example, approximately 2,4 Million Euro have to be planned for realization.

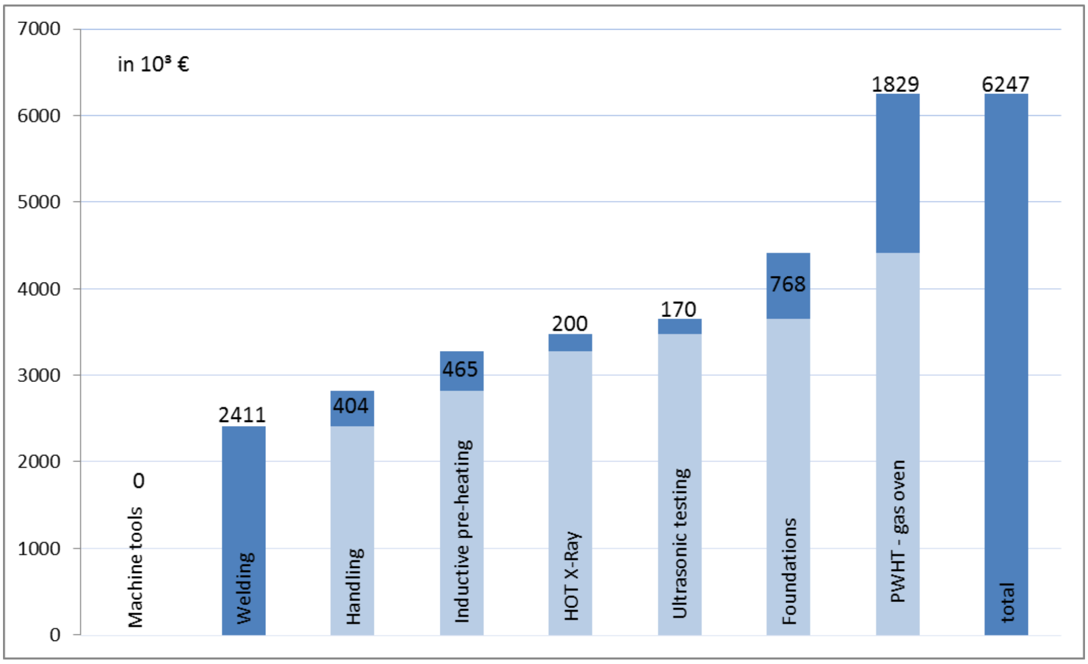


Fig. 4.17: Inevestment planning example - scenario 1 (PWHT - gas oven)

The investigated total amount for realization is approximately 6,25 Million Euro. This does not include setting into service, required audit of procedures and further developments on the vertical welding process itself. This investment is needed for the welding stand and all required equipment for production (handling accessories, welding- and pre-heating equipment, fundaments and PWHT). These values have been evaluated in cooperation with potential suppliers, experts from Mülheim plant and Corporate Technology. Other configurations of the investment planning are listed in the appendix on page A18.

The combination of all required data for the new production process is focused in the following chapter. There an evaluation model is set up and the new process is evaluated among the new process steps and circumstances in Mülheim.

5 Methodology of investigation

To gain knowledge of the new production process, as described in chapter four, an evaluation model is to be set up. The idea behind the model is to separate the whole process chain in sub-processes and evaluate them among the circumstances within the plant. New invented technologies by CT T, like HOT X-ray or GMA narrow gap welding, are transferred into the calculation model. Expert knowledge from Siemens Energy and Corporate Technology has been evaluated during discussions, interviews and factory visits in Mülheim plant. The experience of suppliers and of the employees in Mülheim is also taken into account.

This model was the first trial of focusing all new technology know how and data, the experience of all involved employees and the information from suppliers. The result is a basic data package of the new production process “vertical rotor welding”. The gained information during this study is transferred to Mülheim and will be used as a basis for further investigations and discussions.

5.1 Definition of the evaluation model

Figure 5.1 (blurred due to intellectual property) shows the interface of the calculation tool. The load of the named rotor portfolio in chapter five is the basic input. All four rotor types have been evaluated among their requirements.

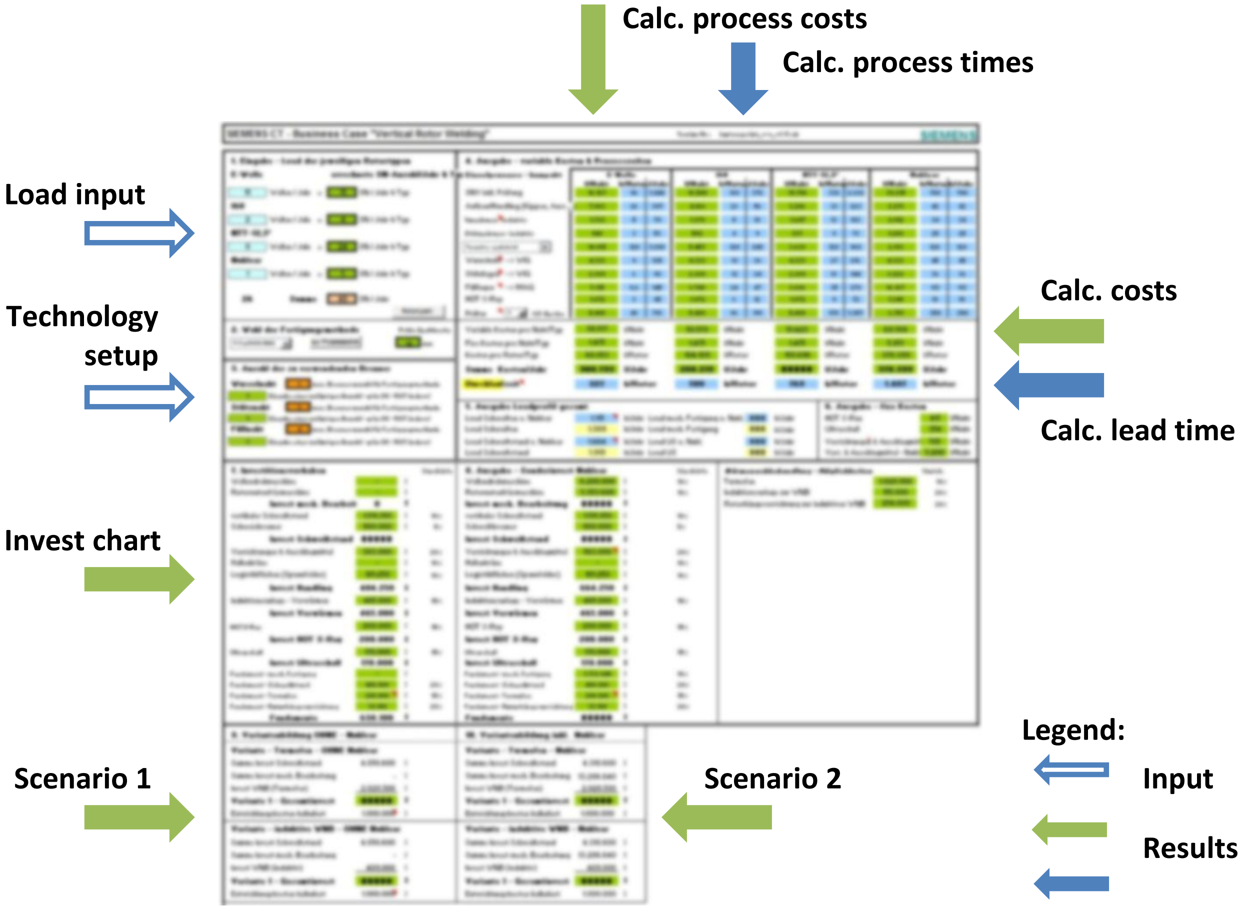


Fig. 5.1: Evaluation model

This interface is the basic screen of the evaluation model. There the data is focused and the results of the whole feasibility study are printed out. The load input allows a user to choose the expected demand of the rotor production for one fiscal year. To individualize the technical setup, such as using more welding torches or changing the welding technology, it is possible to choose the technology setup.
Basis of the calculation within MS Excel is the new defined V-V/TIG-GMA production process. The technology setup allows switching to a V-V/GMA-GMA method as well. The process structure of the GMA-GMA version is similar to TIG-GMA and has been evaluated as well. As a result of the investigation of all required sub-processes the gained data are put into the calculation sheets of the evaluation model. The possibility of calculating new process costs and the expected lead time (no parallelization) is the main focus of the calculation tool. The needed investments due to the rotor portfolio are printed out in the investment chart of the tool. The named scenarios (1 & 2) printed on the model show the difference of required investments for realization. As an example of data collection and calculation, figure 5.2 shows one calculation chart of the tool (blurred due to intellectual property).

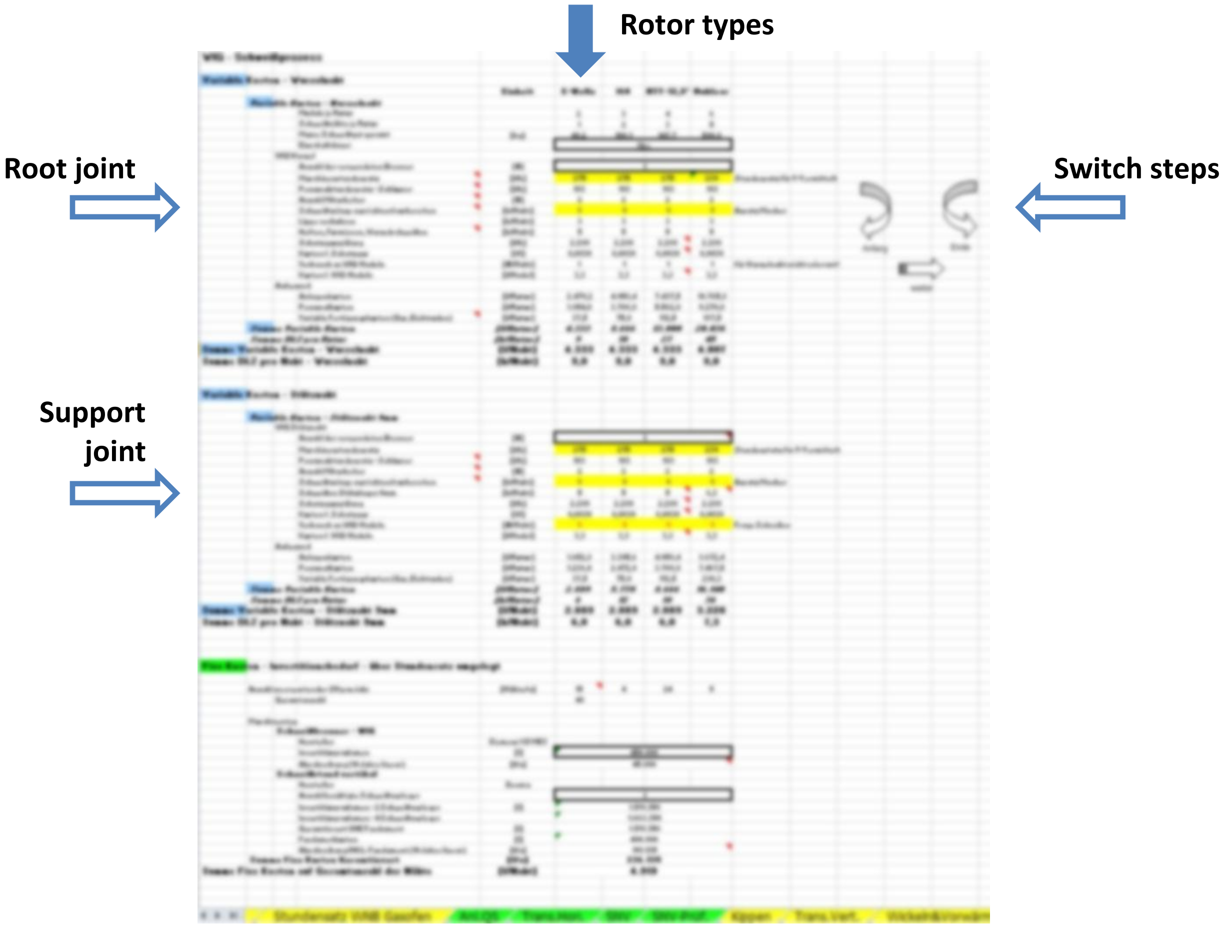
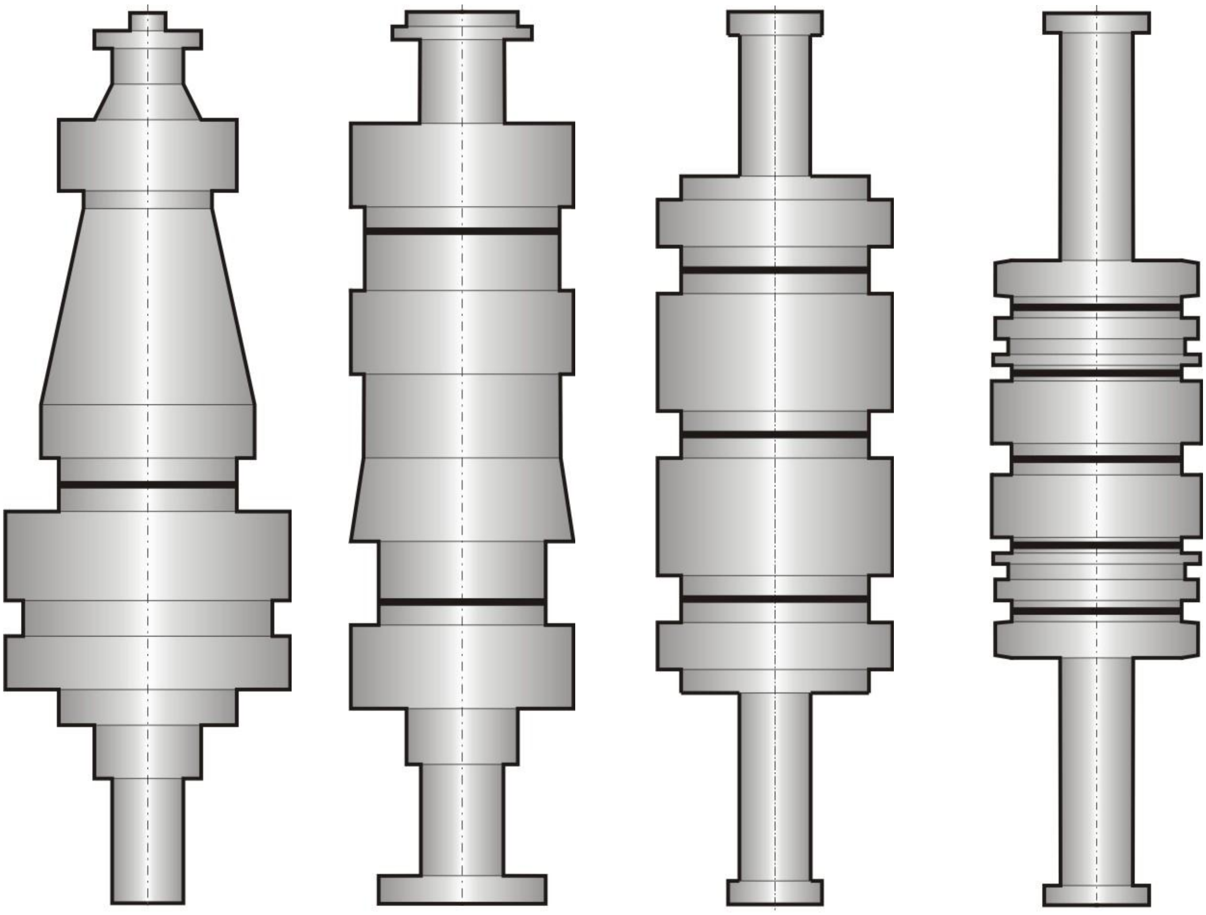


Fig. 5.2: Calculation chart example

The individuality of rotor types has been considered in the calculation model. The difference between the models is the amount of welding joints on one rotor shaft. On the following pages all four types of the rotor design are mentioned.

5.2 Evaluated rotor portfolio

Among the mentioned procedure, the production process is evaluated with four different rotor types of the portfolio. The shown types in figure 5.3 have different shapes and different numbers of welding seams. The idea behind was to find results depending on the number of welding seams on one rotor.



E-type
1 welding joint
Length: ~6.000mm
Max. Ø 1.900mm
Weight: 50.000kg

I60
2 welding joints
Length: ~6.200mm
Max. Ø 1.200mm
Weight: 40.000kg

NTT 12,5^2
3 welding joints
Length: ~8.000mm
Max. Ø 1.900mm
Weight: 106.000kg

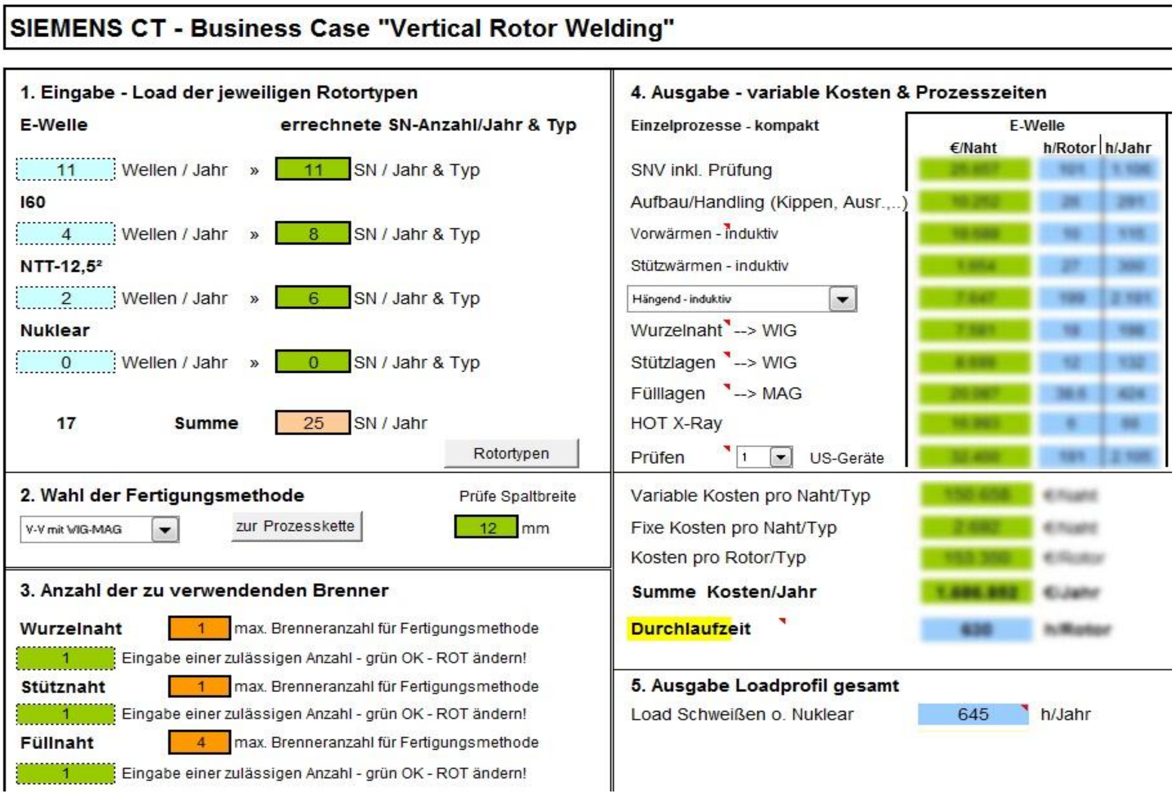
Nuclear
5 welding joints
Length: ~12.000mm
Max. Ø 4.000mm
Weight: 270.000kg

Fig. 5.3: Evaluated rotor portfolio

Every process step has been evaluated according to the individual rotor types shown in figure 5.3. All required information has been worked out during the visits in Mülheim, by visiting the potential suppliers Deuma and SMS Elotherm and in interviews and conference calls with experts from Siemens Energy in Mülheim and researchers within Corporate Technology.

5.3 Evaluation example – E-type rotor

As an example of the evaluation an E-type rotor with one welding seam is described. This E-type version of a steam turbine rotor shaft is produced in Mülheim as mentioned in chapter two. In order to secure the intellectual property of Siemens this example is not displayed with all evaluated process data (data falsified).



SIEMENS CT - Business Case "Vertical Rotor Welding"

1. Eingabe - Load der jeweiligen Rotortypen

E-Welle			**errechnete SN-Anzahl/Jahr & Typ**	
11	Wellen / Jahr	»	11	SN / Jahr & Typ
I60				
4	Wellen / Jahr	»	8	SN / Jahr & Typ
NTT-12,5²				
2	Wellen / Jahr	»	6	SN / Jahr & Typ
Nuklear				
0	Wellen / Jahr	»	0	SN / Jahr & Typ
17	**Summe**		25	SN / Jahr

Rotortypen

2. Wahl der Fertigungsmethode

V-V mit WIG-MAG

zur Prozesskette

Prüfe Spaltbreite: 12 mm

3. Anzahl der zu verwendenden Brenner

Wurzelnaht	1	max. Brenneranzahl für Fertigungsmethode
1	Eingabe einer zulässigen Anzahl - grün OK - ROT ändern!	
Stütznaht	1	max. Brenneranzahl für Fertigungsmethode
1	Eingabe einer zulässigen Anzahl - grün OK - ROT ändern!	
Füllnaht	4	max. Brenneranzahl für Fertigungsmethode
1	Eingabe einer zulässigen Anzahl - grün OK - ROT ändern!	

4. Ausgabe - variable Kosten & Prozesszeiten

Einzelprozesse - kompakt	E-Welle €/Naht	h/Rotor	h/Jahr
SNV inkl. Prüfung	[redacted]	[redacted]	[redacted]
Aufbau/Handling (Kippen, Ausr.,..)	[redacted]	[redacted]	[redacted]
Vorwärmen - induktiv	[redacted]	[redacted]	[redacted]
Stützwärmen - induktiv	[redacted]	[redacted]	[redacted]
Hängend - induktiv	[redacted]	[redacted]	[redacted]
Wurzelnaht --> WIG	[redacted]	[redacted]	[redacted]
Stützlagen --> WIG	[redacted]	[redacted]	[redacted]
Fülllagen --> MAG	[redacted]	[redacted]	[redacted]
HOT X-Ray	[redacted]	[redacted]	[redacted]
Prüfen 1 US-Geräte	[redacted]	[redacted]	[redacted]

Variable Kosten pro Naht/Typ	[redacted]	[redacted]
Fixe Kosten pro Naht/Typ	[redacted]	[redacted]
Kosten pro Rotor/Typ	[redacted]	[redacted]
Summe Kosten/Jahr	[redacted]	[redacted]
Durchlaufzeit	[redacted]	[redacted]

5. Ausgabe Loadprofil gesamt

Load Schweißen o. Nuklear: 645 h/Jahr

Fig. 5.4: Evaluation example (falsified) - E-type rotor

With the chosen load of the rotor shafts, the selection of the V-V/TIG-GMA technology and the definition of the amount of narrow gap welding torches the calculation input is defined. Among the new production philosophy all major process parameters are printed out on the right side of figure 5.4. In this case one welding joint of the E-type rotor costs about 153.350 € (falsified) in production. Due to the load profile this results in a total sum of about 1.686.852 € (falsified) of production costs for 11 E-type rotors. The evaluated costs per every main step are marked in green. Process times are printed out in the blue boxes in figure 5.4. The sum of all welding steps, the busy time, of the new welding facility is calculated to approximately 645 hours per year (falsified). These times are needed for the availability check and the hourly rate calculation of the welding stand. The shown data example does not have any right of correctness due to the real production of E-type rotors. This is an evaluation example within the thesis. The result of the investigation (feasibility study) shows, that the bottleneck of the new production structure moves from the TIG welding process to the machine shop and is discussed in the next chapter.

6 Discussion

TIG narrow gap welding of turbine rotor shafts, as implemented in Mülheim, is done by Siemens Energy in Mülheim for more than 10 years now. In chapter 3.2.7 the pros and cons of the H-H/TIG-TIG production strategy are pointed out. Due to the fact of the increasing demand on rotor shafts and the individuality of their design it is required to seek alternative production possibilities.

The implemented process is currently used only for E-type rotors which is the limitation factor in flexibility and scalability of manufacturing rotor shafts. For the new developed structure this main disadvantage is eliminated and a deeper understanding of the alternative V-V/TIG-MAG technology is created.

As a result of the evaluation process the current bottleneck is the welding center in building 81. Long process- and setup times are responsible for longer lead times of the E-type rotor. In fact of the H-H/TIG-TIG circumstance the welding facility itself is not used optimally from the production perspective. The setup times and all other auxiliary times are keeping the availability of the welding stand low. As a result the maximum number of produced rotor per year is limited by 30 pieces.

6.1 Evaluated cost distribution for V-V/TIG-GMA

Using the new V-V/TIG-GMA production process the named limitation of production has to be overcome and the whole portfolio has to be produced. A cost distribution (per welding joint) of an E-type rotor with the new setup is shown in figure 6.1.

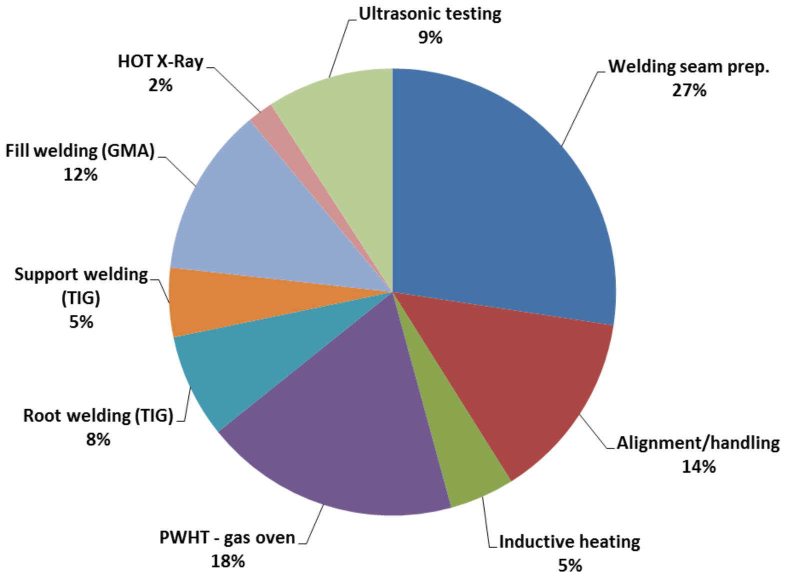


Fig. 6.1: Evaluated cost distribution - E-type rotor (PWHT - gas oven)

The distribution is calculated with the evaluation model mentioned in chapter five and based on the assumed load profile by Siemens Energy. In comparison with Schreiber 2010 the fill welding is now reduced from 31% to 12% of the whole production costs. The welding seam preparation with 28% is nearly constant and PWHT with the gas fired furnace is 19% of the sum. Figure 6.1 shows that the welding seam preparation (mechanical treatment in machine shop) and post weld heat treatment are the main cost drivers for the new production process. In comparison to the current process fill welding is reduced dramatically due to the implementation of GMA fill welding technology. Post weld heat treatment with 19% is the second largest percent in the diagram. This is driven by high investment costs of such a heating facility.

Another possible configuration of the annealing process is the inductive version shown in figure 6.2.

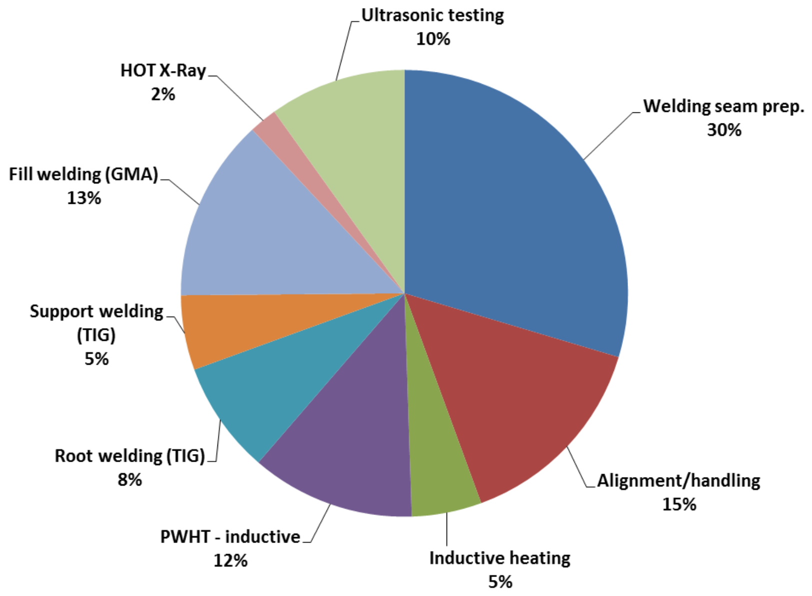


Fig. 6.2: Evaluated cost distribution - E-type rotor (PWHT - inductive)

Using inductive PWHT reduces the costs from 19% (gas oven) to 12% of the total sum (assuming that process times are not changing due to the used technology). Further configurations are shown in the appendix on page A12ff.

One big part in the diagram is the welding seam preparation. It covers about 30% of the total costs. This sub-process has not only a big cost driver it is also one basic element for the lead time of the rotor within the new production structure. Reducing welding process times is a question of the used welding technology. This is done within the new production setup using GMA technology. Implementing GMA narrow gap welding technology shifts the lead time driver to the mechanical treatment of the rotor modules (welding seam preparation) within the new process perspective.

6.2 Evaluated process time distribution

Before the implementation of the new V-V/TIG-GMA process design the welding center in building 81 has been the bottleneck of the production. With the change of the current process to the new one the machine shop in building 80 becomes the bottleneck of the V-V/TIG-GMA process. Figure 6.3 demonstrates the evaluated process time distribution (per welding joint) of a NTT 12,5² rotor type.

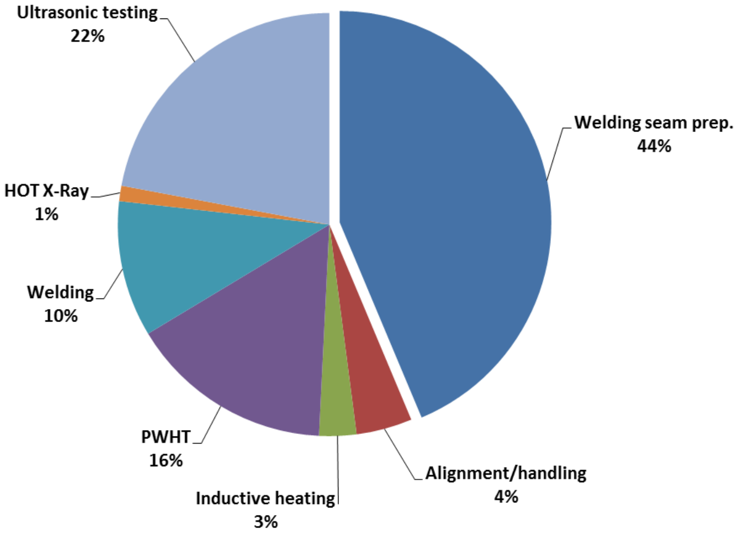


Fig. 6.3: Evaluated process time distribution - NTT 12,5² rotor type

The total production time in the picture has been evaluated for a NTT 12,5² rotor type but is not shown to protect the company's know how. As shown in figure 6.3, 44% of the lead time is found in welding seam preparation. The times for machining of rotor modules have been evaluated in cooperation with the machine shop in Mülheim plant. Ultrasonic testing is the second biggest part in the picture. The reduction of the ultrasonic testing times can be achieved with the use of multiple UT heads. The whole welding process times are evaluated to 10% of the sum. In comparison to Schreiber 2008 a reduction of more than 20% has been achieved. This is a result of the change from TIG to GMA fill welding technology. Reduction of machining times shows huge potential. The achieved effect is seen for the whole process chain.

The named evaluation model is the first model which combines all sub-processes of the production process together. This allows the direct print out of bottlenecks and cost drivers among the new manufacturing structure. Also the potentials can be figured out easily. This allows a broad discussion basis along the whole process chain of the new and even the current production setup.

An example for reduction of manufacturing times within the machine shop (welding seam preparation) is named in Wimmer 2009. Figure 6.4 demonstrates an example of reducing machining times for a "SGT – front hollow shaft".

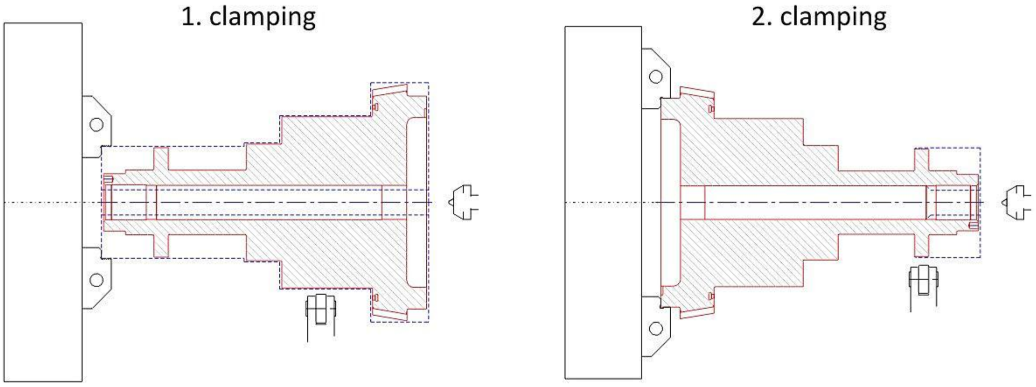


Fig. 6.4: Reduction example of mechanical machining times [Wimmer 2009]

The shown front hollow shaft of a Siemens gas turbine (SGT) can be machined with modern machining equipment in two clamping modes. A reduction of 80% for process time can be achieved within the study. [Wimmer 2009] The limitation factor of these reductions is the maximum module diameter and the weight of the machined parts. Due to these factors it has to be investigated how much of the current machining time can be reduced.

6.3 Realization of the new production process

Chapter four describes a feasible way of a realization scenario. Dividing the scenarios in a "conventional" and in a "nuclear" version allows a different point of view and discussion basis. The implementation of scenario 1 (conventional) can be done without any investment in machining equipment. All required machines are capable of machining the welded rotor shafts. Scenario 2 requires investments in heavy machine equipment which is able to machine nuclear rotor shafts with 12.000mm length and a weight up to 300 tons. Those machines have to be placed in building 62 due to available crane loads. Mülheim plant is located beside the Ruhr River. The limiting factor of the implementation is the groundwater level which is approximately at three to four meter depth. The required foundation needs a depth of 7,5 meter. In that case a special foundation construction is required for the welding stand. [Kretschmann 2010/2]
The shown PWHT process in chapter two can be replaced by two different technologies named in chapter four:

i) Gas fired oven (integral annealing)
ii) Inductive annealing (differential/integral)

Both versions of annealing are currently not done in Mülheim. Within the visits of potential suppliers the inductive version showed big potential in the new process structure. The possibility of integration in the current production is of additional interest. The generator manufacturing within the plant is already using inductive technology for shrinking and their know-how could be transferred to steam turbine production. Using the inductive pre-heating devices for annealing processes is another possible application. Figure 6.5 shows the required investments for realization within the current production.

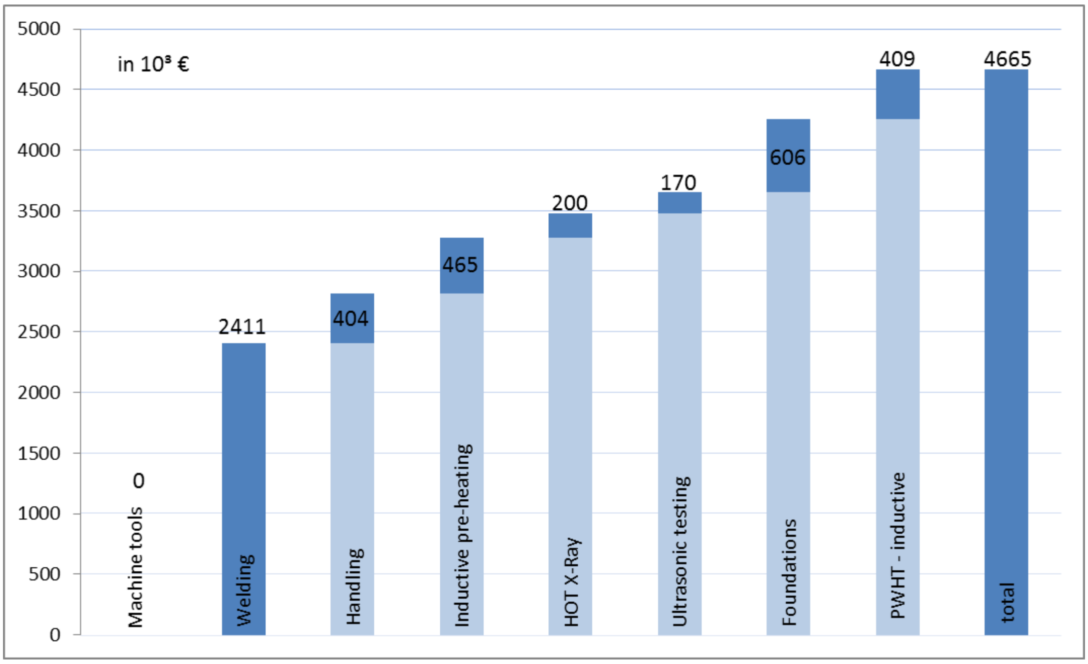


Fig. 6.5: Investments - Realization of inductive PWHT

The fact that post weld heat treatment with a gas fired furnace requires approximately two Million Euro of investment, inductive PWHT and is much cheaper (approx. 60%). Taking into account that the inductive version needs a miner amount of production area (appendix page A6) this setup is a feasible scenario for Mülheim plant. Investment in production facilities of approximately 4,7 Million Euro is required. In addition, 1 Million Euro for further developments is required.

With the possibility of the integration of scenario 1 (conventional) in the current production situation of Mülheim plant, it is conceivable that the realization can be planned within the next two years. Possible configurations of the process are shown in this thesis. Further investigations of the process are needed to refine the data set of the evaluation model. Implementing the GMA narrow gap and the HOT X-ray technology within the current H-H/TIG-TIG process is the field of actual research and development. This is done in cooperation with Siemens Energy and Corporate Technology.

7 Conclusion and outlook

Among the investigations and evaluations in the chapters before the following key features in figure 7.1 have been figured out for Siemens Energy and especially for Mülheim plant:

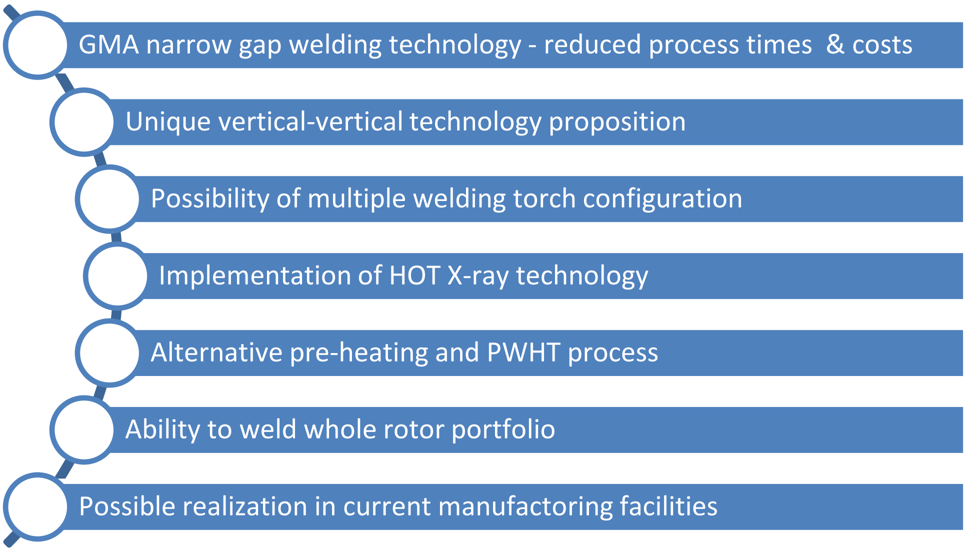


Fig. 7.1: Key features of vertical rotor welding technology

A realization of the new production facility enables Siemens Energy as a strategic role of a technology leader. Total welding of steam turbine rotor shafts in vertical-vertical setup is unique. Root- and support welding in vertical orientation of the rotational axis has been done by competitors for years. Fill welding in the same alignment of the rotor shaft will be done for the first time. The implementation of HOT X-ray is a strategic step within the fiscal year. Implementation of this technology in the current production will provide experiences for transferring it into the new process setup. Using multiple narrow gap torches in the vertical position is state of the art technology and done by several competitors using TIG torches.

With the application of GMA narrow gap technology it has to be investigated if multiple torches are required furthermore. GMA narrow gap technology is field of current research and development. Current trials within CT T show high potential for realization of GMA in the current production

Induction technology as alternative pre-heating process reduces the pre-heating process times significantly. This available technology can be adapted to the current horizontal-horizontal production setup as well to the postulated new vertical-vertical technology.

Becoming a technology as well as a cost and production process leader in the field of manufacturing welded steam turbine rotor shafts has a strategic role within

Siemens Energy. The shown processes and the implementation study provide the basis for further investigations.

The actual research on GMA narrow gap welding allows Siemens Energy to reduce the current lead time. The realization of this technology within the current production will be the first step of further research of welding processes. For refining data among the evaluation model additional investigations are optional possible.

Short term activities:

The mechanical treatment (welding seam preparation) of rotor modules shows the highest potential of short term advancements. Time studies for optimization of the process times according to the welding seam preparation and also for machining of the final rotor geometry can be carried out. Further investigations in the field of mechanical treatment may deliver optimized machining parameters according to the specifications of the given rotor portfolio. These data can be put into the evaluation model and the gained process knowledge becomes more precise.

Another short term activity is the research of inductive pre-heating of rotor modules. The proof of implementation within the current production continues the development of the current pre-heating process. Current pre-heating times with resistance heating elements could be reduced significantly. The named PWHT process (using resistance heating elements) can be investigated furthermore. The use of induction technology may provide an immediate benefit for pre-heating and even more for PWHT.

Middle term activities:

In order to get more precise data along the current process chain a value stream mapping should be carried out. The gained information will be implemented in the evaluation model as well.

Resistance heated post weld heat treatment of E-type rotors is currently done by a service provider. Using inductive PWHT as an alternative will be developed and implemented in the new manufacturing process. Investigations on this technique have to be performed in order to become familiar with the process. Labs within Siemens provide equipment for studies in the field of inductive annealing.

Due to the fact that the rotor modules will be aligned in vertical orientation of the rotational axis, studies and experiments in handling should be carried out. Experience from suppliers and experts from Mülheim and CT can be concentrated and a vertical mock-up in case of alignment should be performed. The impact of the different rotor designs (mentioned in chapter five) has to be evaluated. Fixtures and handling equipment may vary strong and can’t be used for every type of rotor shaft.

Long term activities:
In the long run the realization of the new manufacturing process has to be scheduled. To meet all requirements, technical specifications have to be evaluated and worked out.
Due to the estimated realization time of two to three years, a detailed realization plan has to be worked out. After the decision of realization two possibilities have to be considered: Implementation in current production halls or a green field scenario.
For the implementation of the process in Mülheim plant, the current production setup has to be evaluated. For all necessary machines and equipment which have to be removed from building 62 additional production space has to be found or created. They could also be substituted by other machines which have enough production capacity left.

A possible future scenario is that TIG root- and support welding is substituted by the GMA technology. This causes only a single investment in welding equipment. All welding joints among the portfolio have to be harmonized. The V-V/GMA-GMA process will become state of the art in the production of welded steam turbine rotor shafts. Siemens Energy will be the technology leader in producing welded rotors and is able to license this technology to customers. Siemens Energy has the cost and process leadership in the field of producing steam turbine rotor shafts. This technology will also be capable of welding other types of rotor shafts (e.g. gas turbine, compressors, generators).

This thesis provides the thoughts for the future of manufacturing steam turbine rotor shafts within Siemens in general. As a discussion basis for further decisions and investigations it shows one possible way for how such a realization could look like. Beside the evaluation, the implementation of the vertical-vertical welding process might also be a strategic decision for Siemens Energy to be pioneer in technology driven markets.

8 Indices

8.1 List of figures

8.2 List of references

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8.4 Table of abbreviations

CT T	Corporate Research and Technology
DE	Deutschland
HW1	Hardware 1
TIG	Tungsten Inert Gas
GMA	Gas Metal Arc
GMAW	Gas Metal Arc Welding
SAW	Submerged Arc Welding
PWHT	Post Weld Heat Treatment
UT	Ultrasonic Testing
WSP	Welding Seam Preparation

9 Appendices

9.1 Published short text (English)

To meet the steady increasing demand of electricity, innovative and more efficient solutions are becoming more and more important. Siemens, as a global player, is present on the global market of producing highly efficient steam turbines. To be present as strong competitor in future, Siemens is seeking for innovative production technologies for steam turbine rotor shafts. Currently there are two different manufacturing technologies implemented within Siemens.

One technology is to machine the rotor shaft from a single piece of forged steel. Sourcing of such big monoblock rotors becomes more and more difficult and expensive.

The second technology is to weld smaller rotor modules together. The used welding technology is the narrow gap welding technique. Smaller parts and the possibility of joining different materials is one big advantage of that technology which has been introduced by Siemens in 1999. The technique shows huge potential for further innovations in the field of manufacturing steam turbine rotor shafts.

This thesis explains one feasible way of the implementation of a new production technology. The current production process has been evaluated. With the use of a Siemens invention a new production process has been defined. This new process has been evaluated among the circumstances within one Siemens plant. The analysis figured out, that it is possible to integrate the new production facility within the plant. The demonstrated advantages enable Siemens the role of a technology leader in the future.

9.2 Published short text (Deutsch)

Um die stetig steigende Nachfrage an elektrischer Energie auch in Zukunft noch decken zu können, werden innovative und effizientere Lösungen immer wichtiger. Siemens, als Global Player, ist mit hocheffizienten Dampfturbinen am derzeitigen globalen Markt vertreten. Um auch in Zukunft ein starker Wettbewerber zu bleiben investiert Siemens in innovative Herstellungsverfahren moderner Dampfturbinenrotoren. Derzeitig finden sich innerhalb des Siemens Konzerns zwei typische Herstellungsverfahren solcher Rotoren.

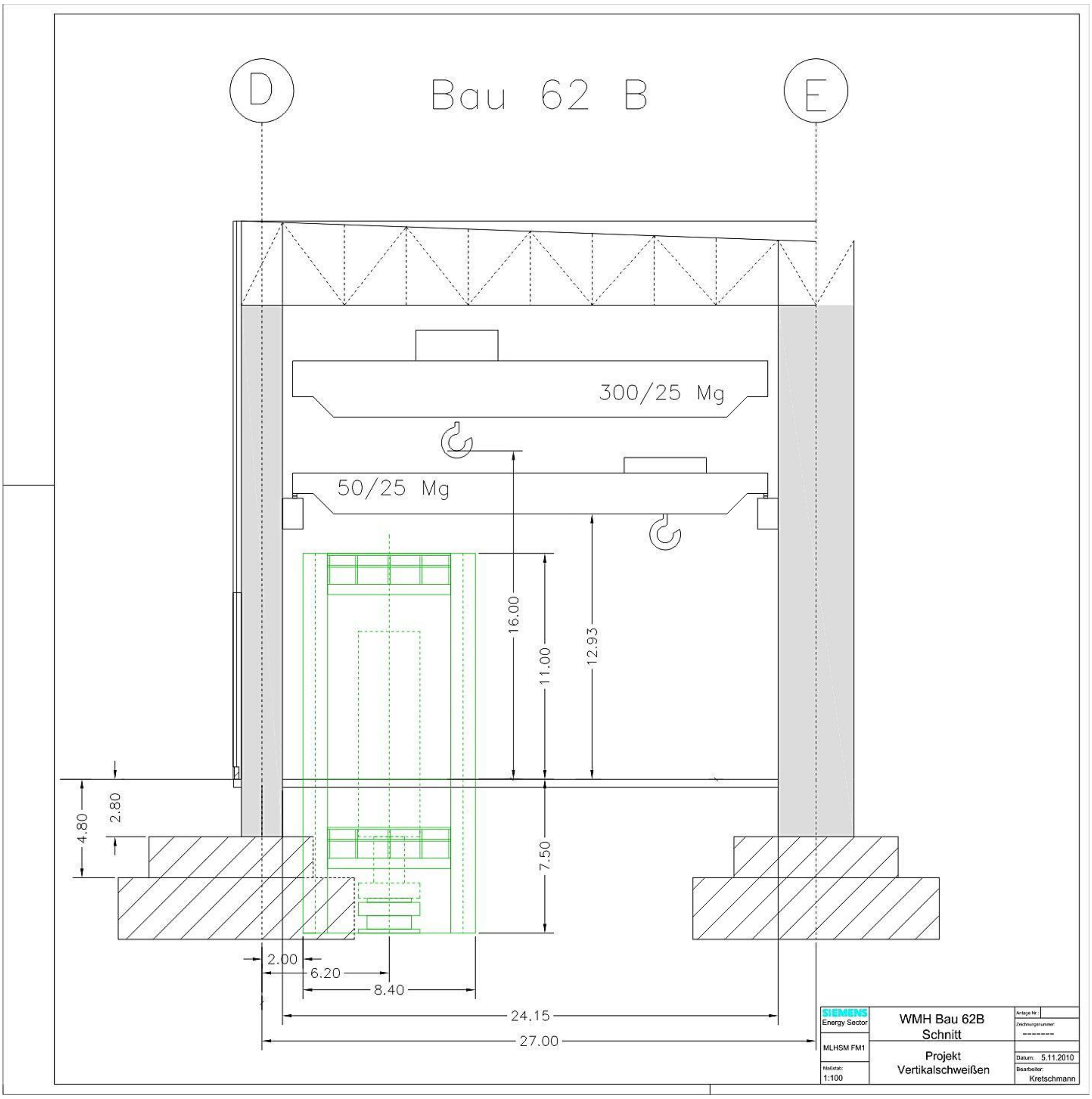
Eine bewährte Technologie ist die Drehbearbeitung von geschmiedeten Monoblock-Rotorrohlingen. Nachteil jener ist jedoch die immer schwieriger und teurer werdende Beschaffung der Rohlinge.

Die zweite Technologie ist ein Engspaltverbindungsschweißverfahren von dickwandigen Werkstücken. Hierbei werden kleinere Rotormodule miteinander verschweißt, um die jeweiligen Anforderungen an den Dampfturbinenrotor gerecht zu werden. Ein weiterer Vorteil besteht darin, dass verschiedene Werkstoffe miteinander verschweißt werden können. Diese Technologie wird von Siemens seit 1999 verwendet und bietet großes Potential für Innovationen im Bereich der Herstellung von Dampfturbinenrotoren.

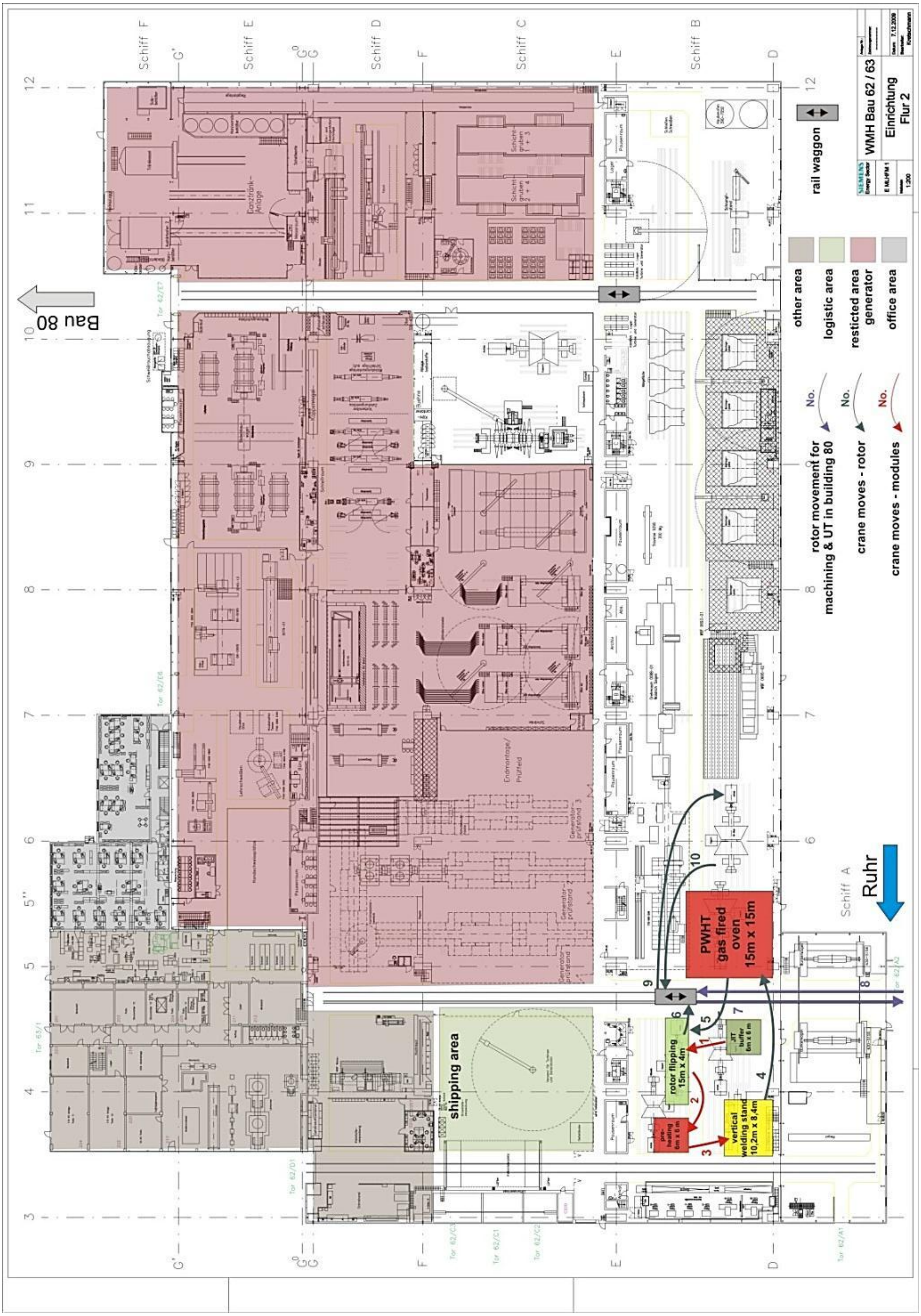
Diese Arbeit zeigt einen Weg auf, wie der derzeitige Produktionsprozess abgeändert werden kann, um eine Effizienzsteigerung in der Herstellung von Rotoren zu erzielen. Hierzu wurde die derzeitige Fertigung analysiert und aufbauend auf einer Siemens Erfindungsmeldung ein neuer Produktionsprozess abgebildet. Jener neue Prozess wurde anhand der Gegebenheiten in einem Siemens Werk untersucht. Es hat sich gezeigt, dass eine Integration einer neuen Produktionsanlage im Werk machbar ist und deutliche Vorteile in der Herstellung von Dampfturbinenrotoren mit sich bringt. Die Einführung dieser neuen Technologie ermöglicht Siemens die Position eines Technologieführers in der Zukunft.

9.3 Additional information – implementation

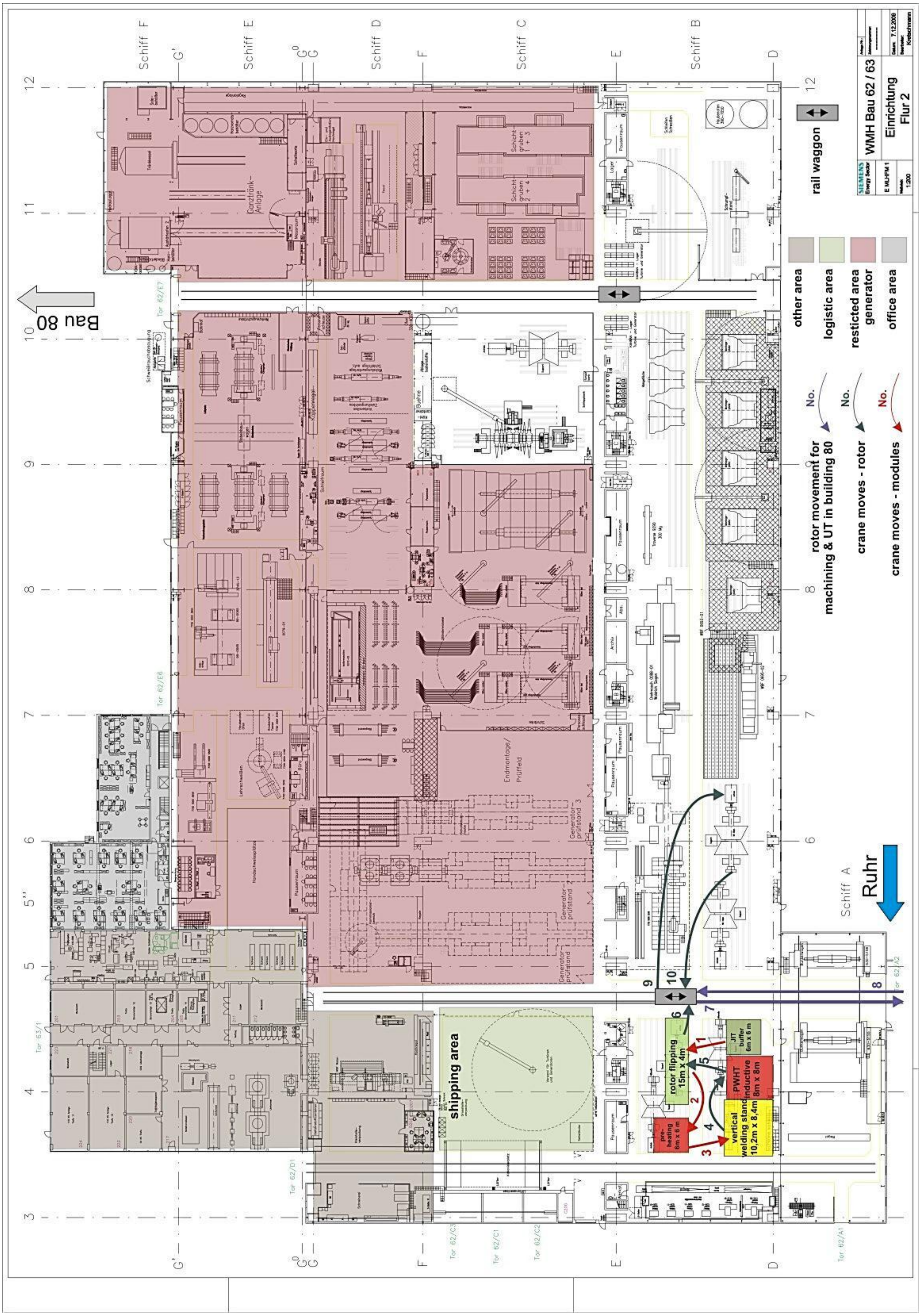
To underline the possibilities of the implementation of the welding stand, this chapter provides further layouts of production hall 62.
A green field planning scenario (block layout) is created in order to determine the minimum required production space.



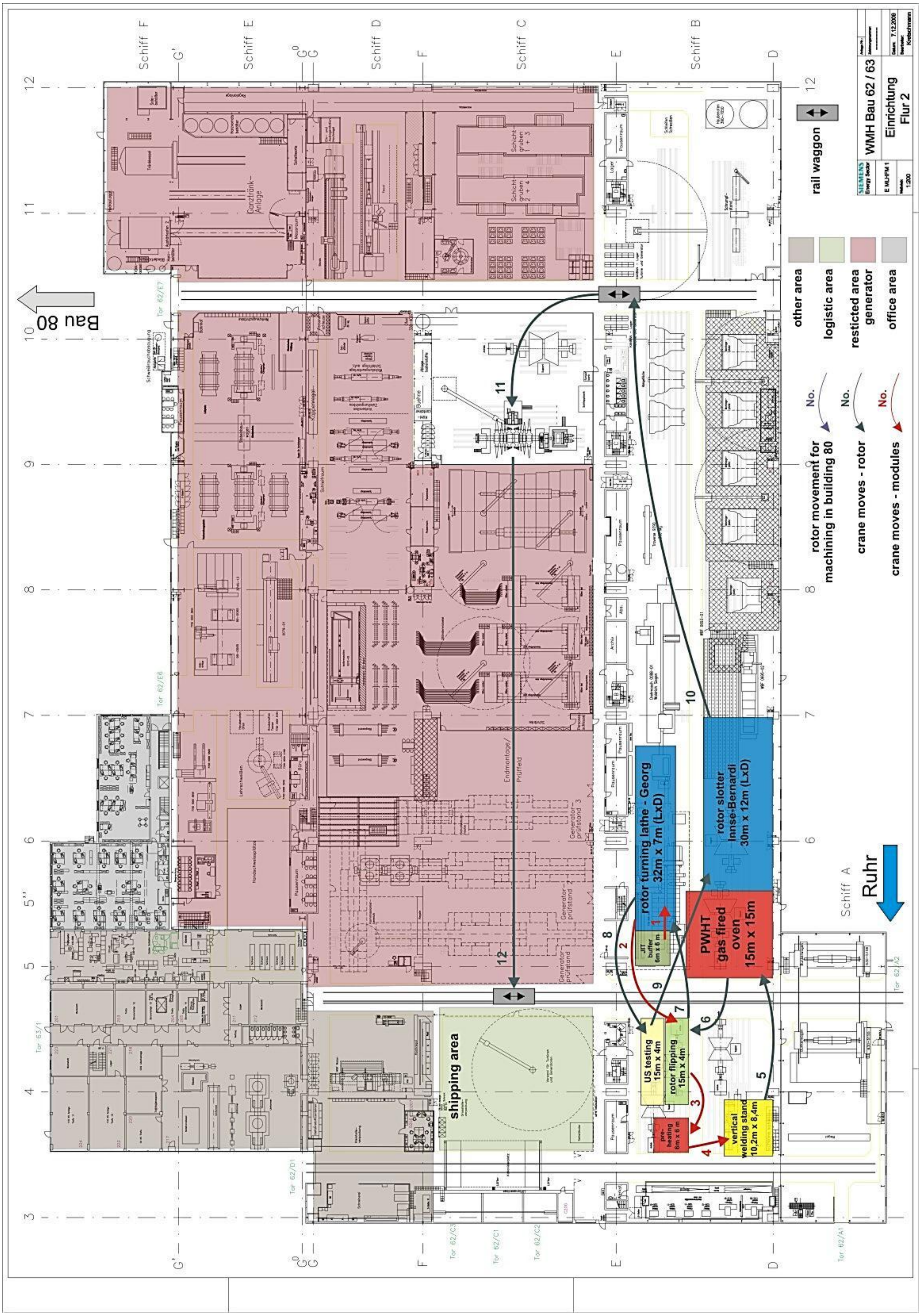
Appendix 1: Implementation of welding stand in building 62



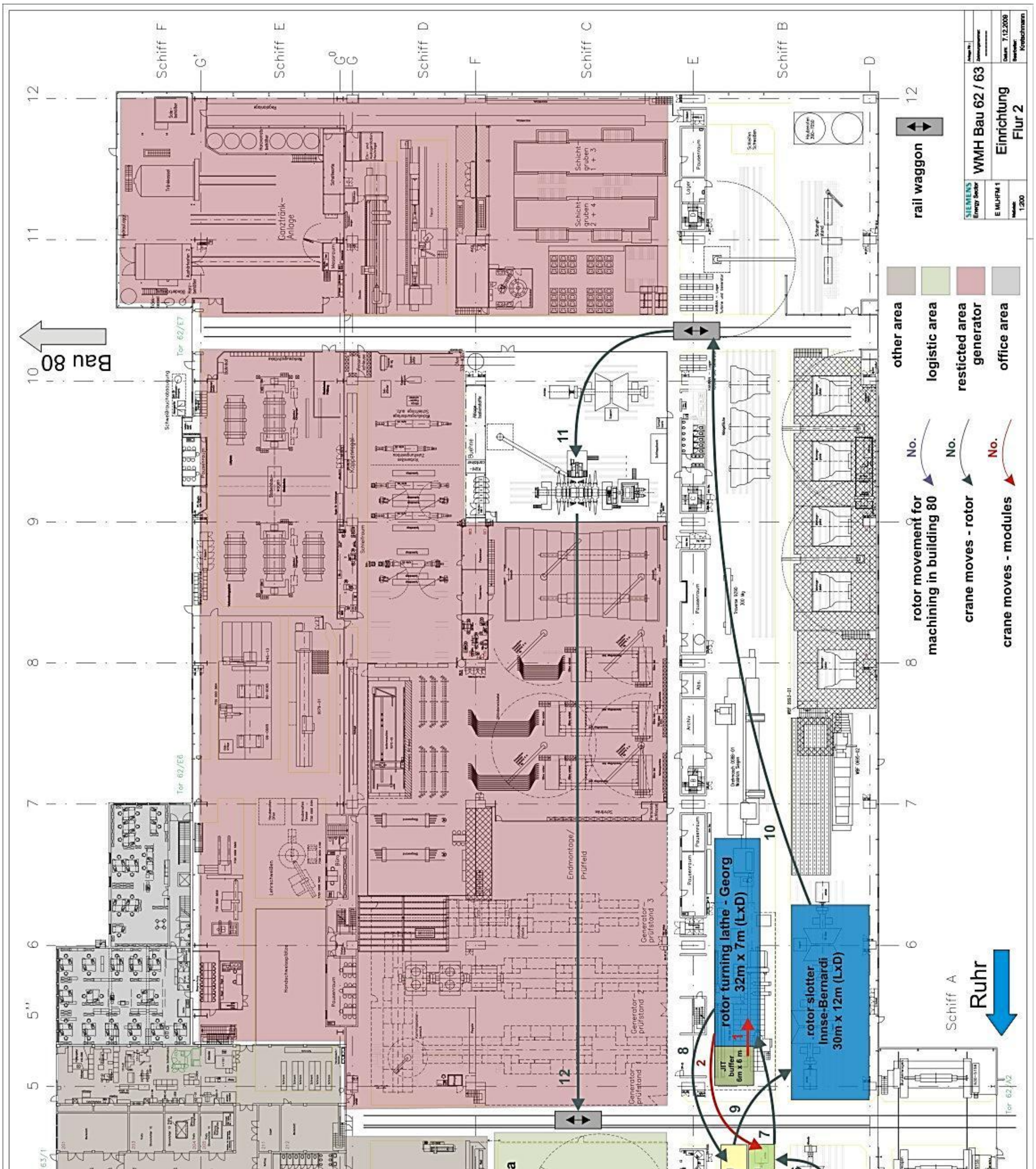
Appendix 2: Layout building 62 (scenario 1) - PWHT gas oven



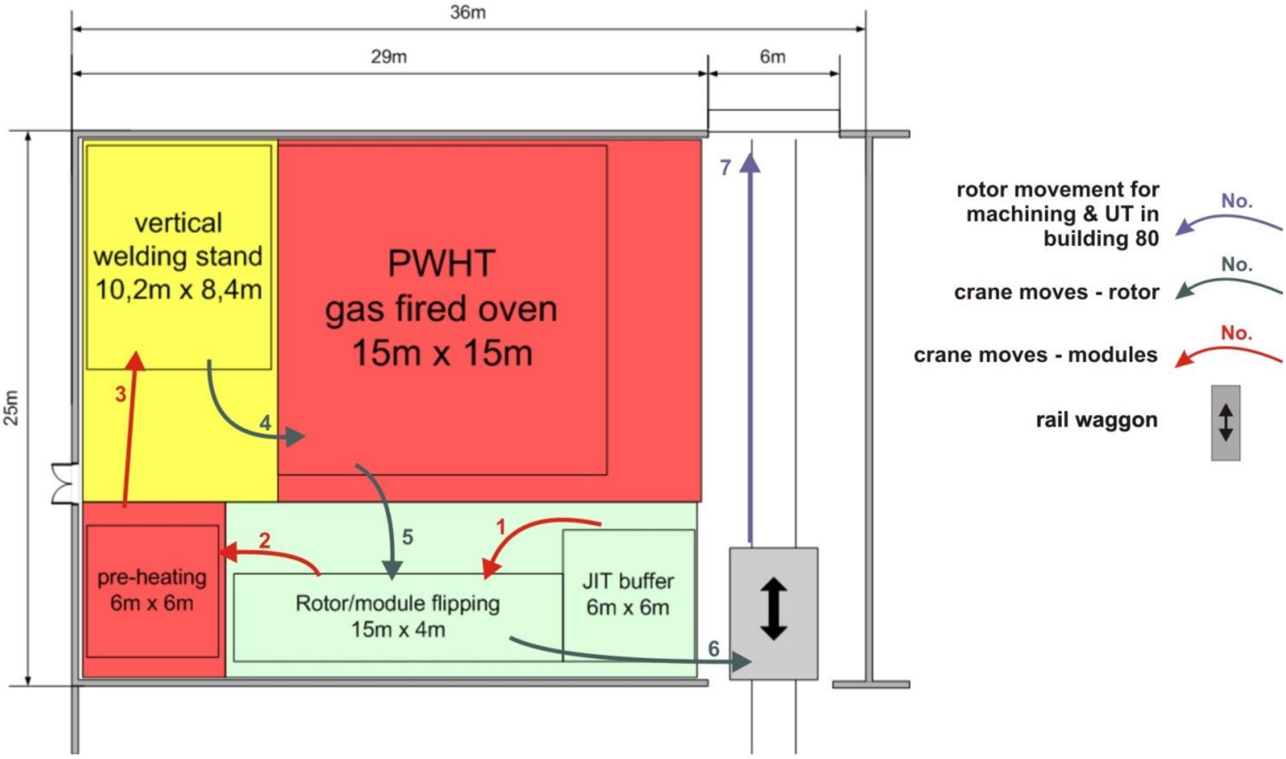
Appendix 3: Layout building 62 (scenario 1) - PWHT inductive



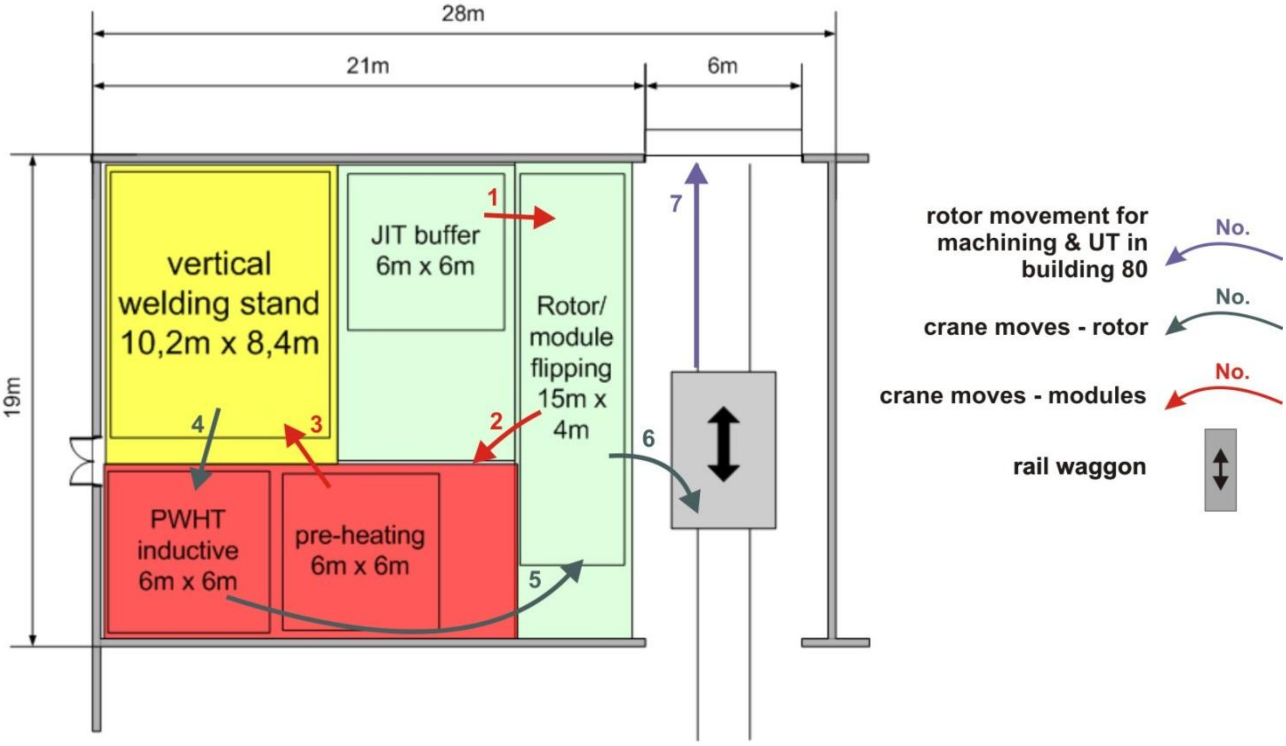
Appendix 4: Layout building 62 (scenario 2) - PWHT gas oven



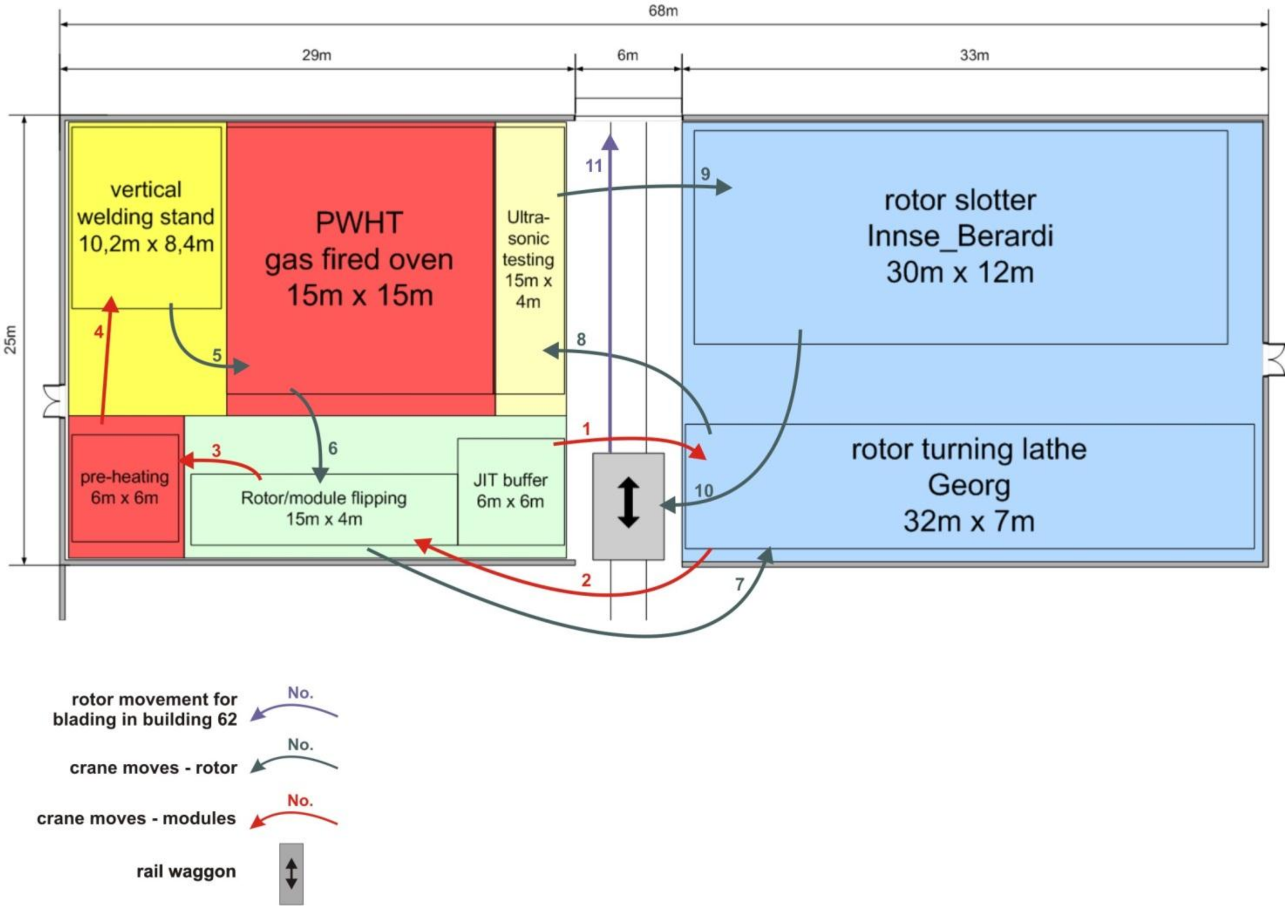
Appendix 5: Layout building 62 (scenario 2) - PWHT inductive



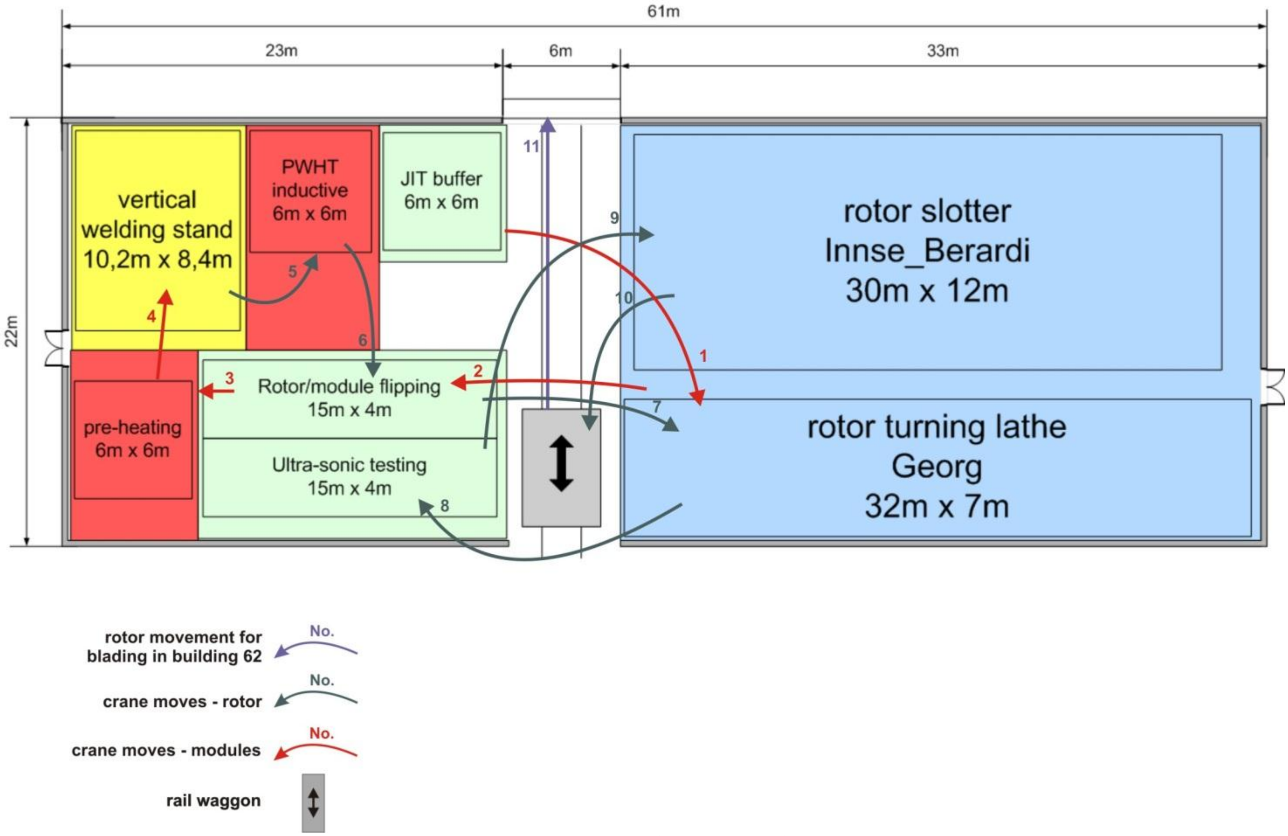
Appendix 6: Green field planning (scenario 1) - PWHT gas oven



Appendix 7: Green field planning (scenario 1) - PWHT inductive



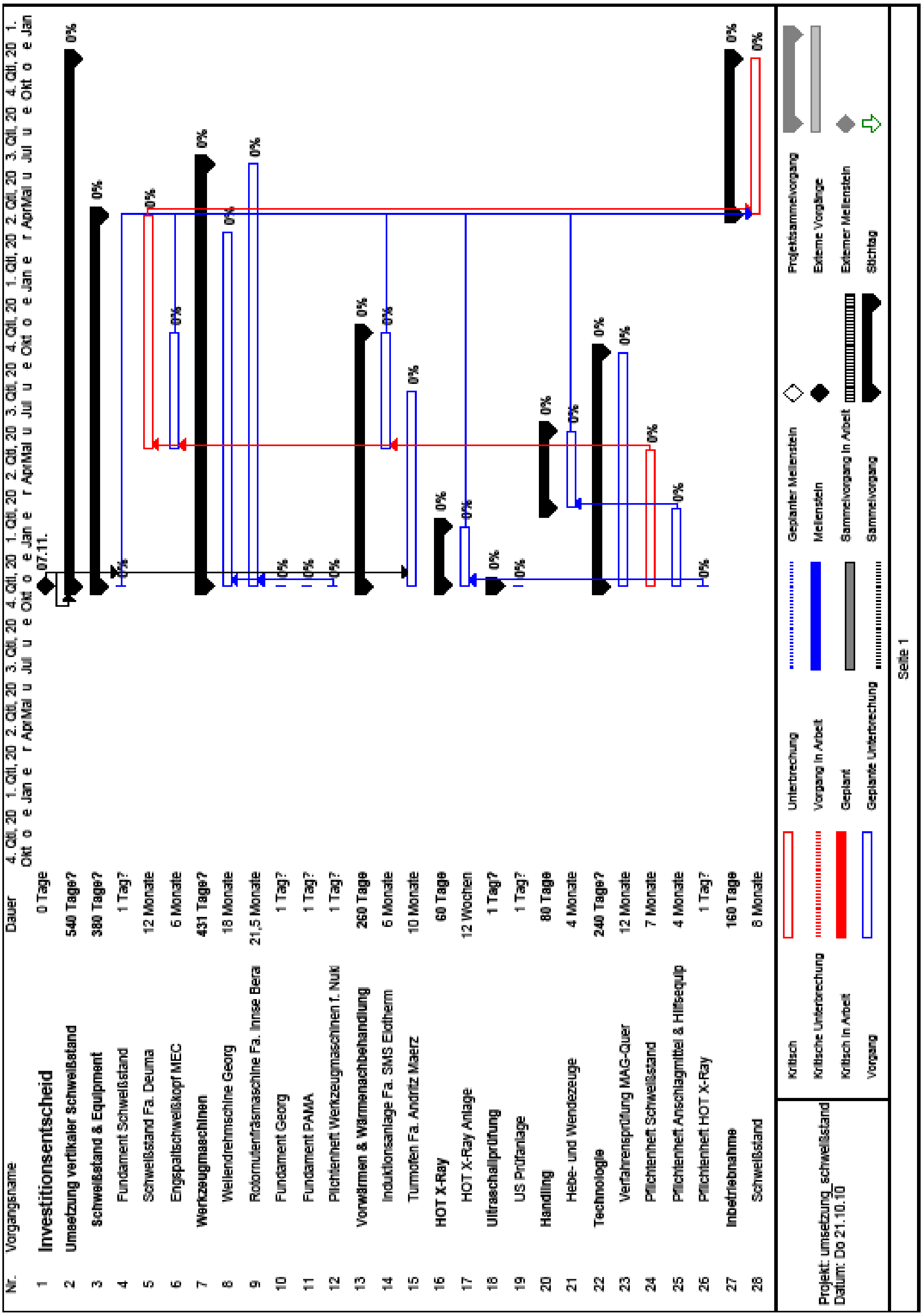
Appendix 8: Green field planning (scenario 2) - PWHT gas oven



Appendix 9: Green field planning (scenario 2) - PWHT inductive

9.4 Additional information – realization Gantt chart

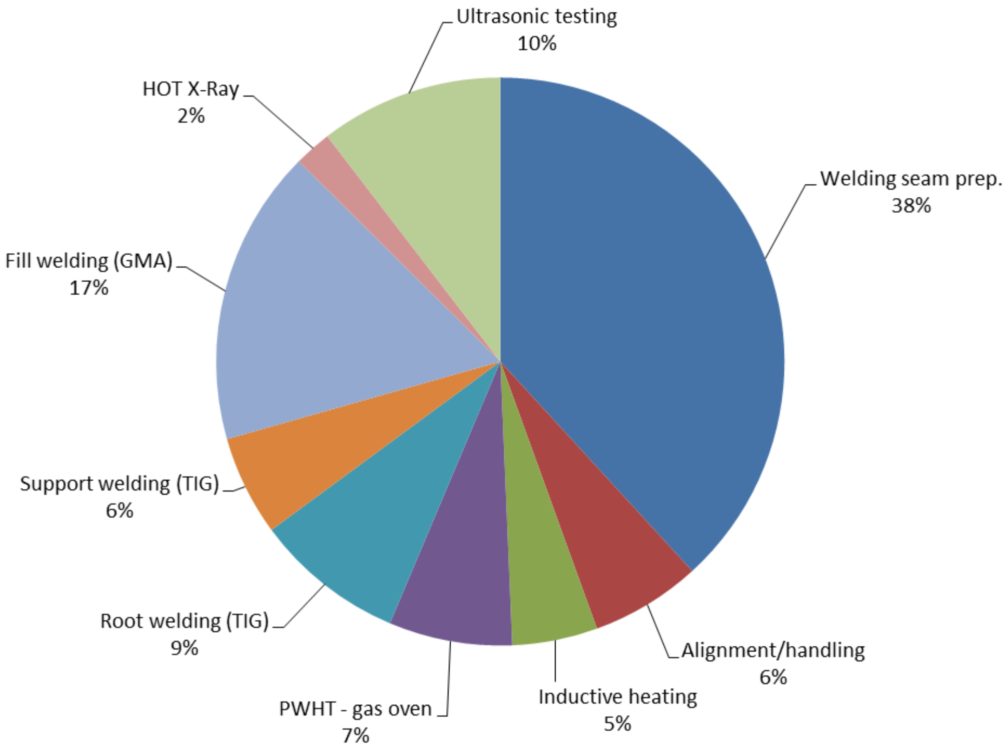
For determination of an estimated realization time, a Gantt chart has been set up. The critical path of the chart is marked in red.



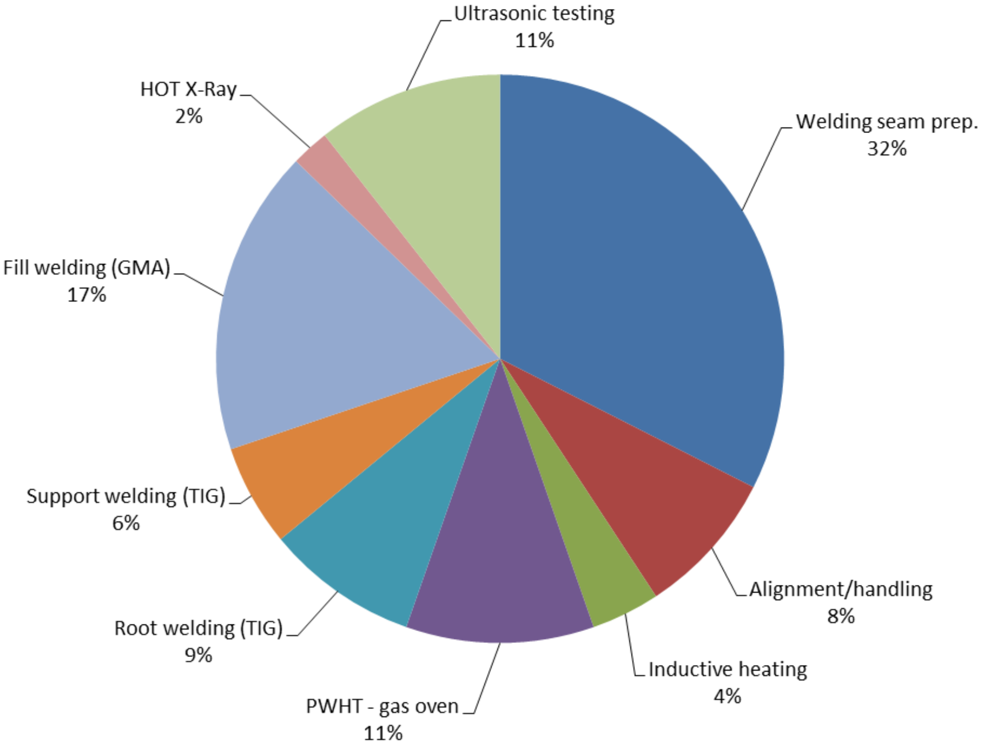
Appendix 10: Realization Gantt chart

9.5 Additional information – evaluated cost distribution

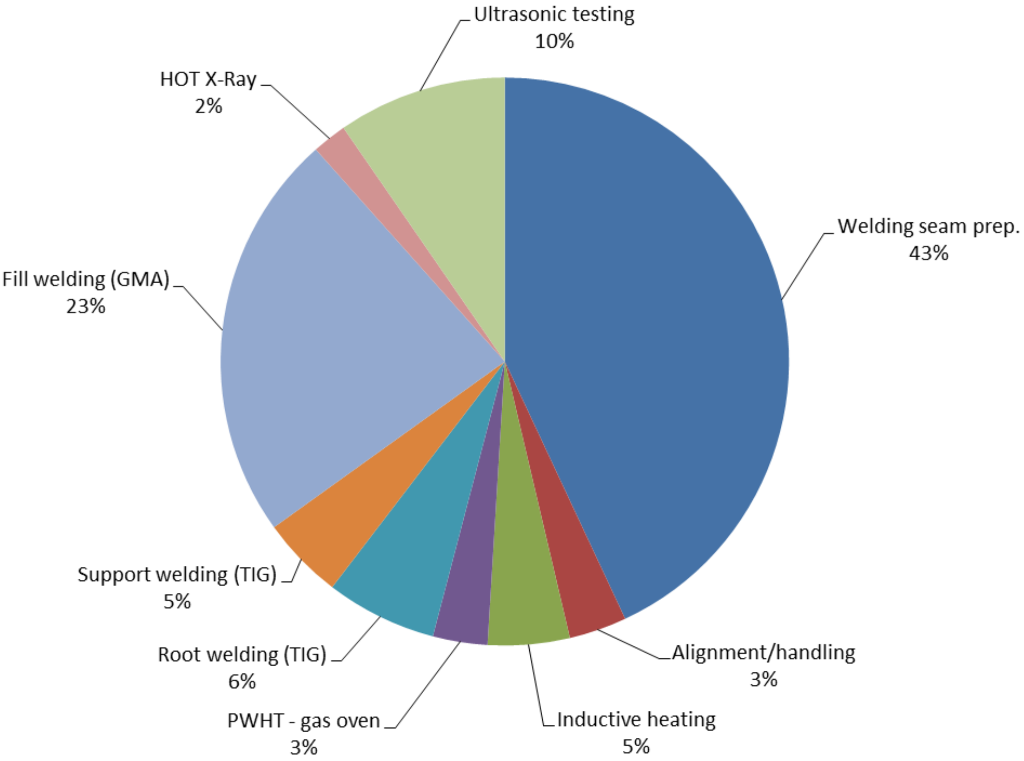
The following figures show the evaluated cost distribution (per welding joint) for further rotor types to point out the differences between the rotor design and the post weld heat treatment technology (gas fired oven or inductive).



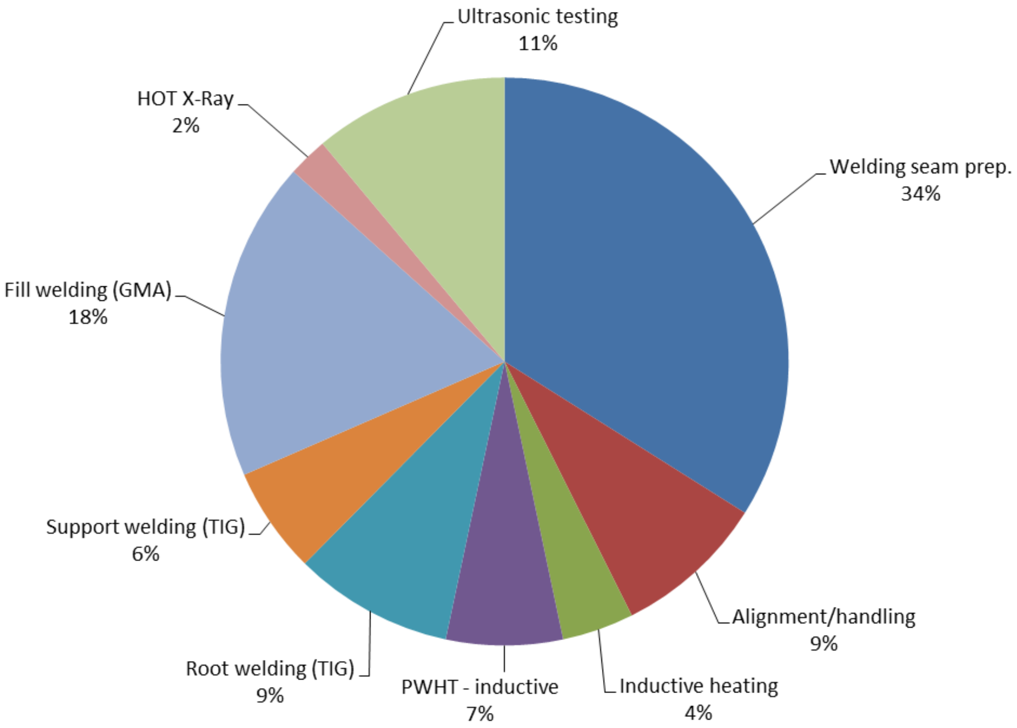
Appendix 11: Cost distribution - NTT 12,5^2 -PWHT gas oven



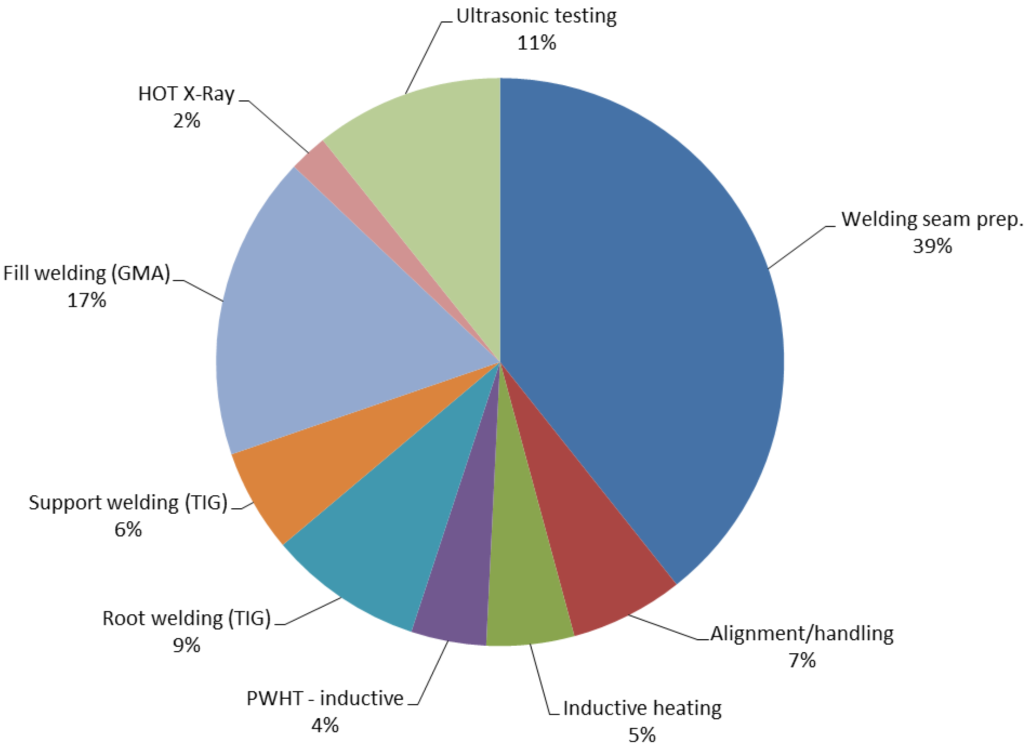
Appendix 12: Cost distribution - I60 - PWHT gas oven



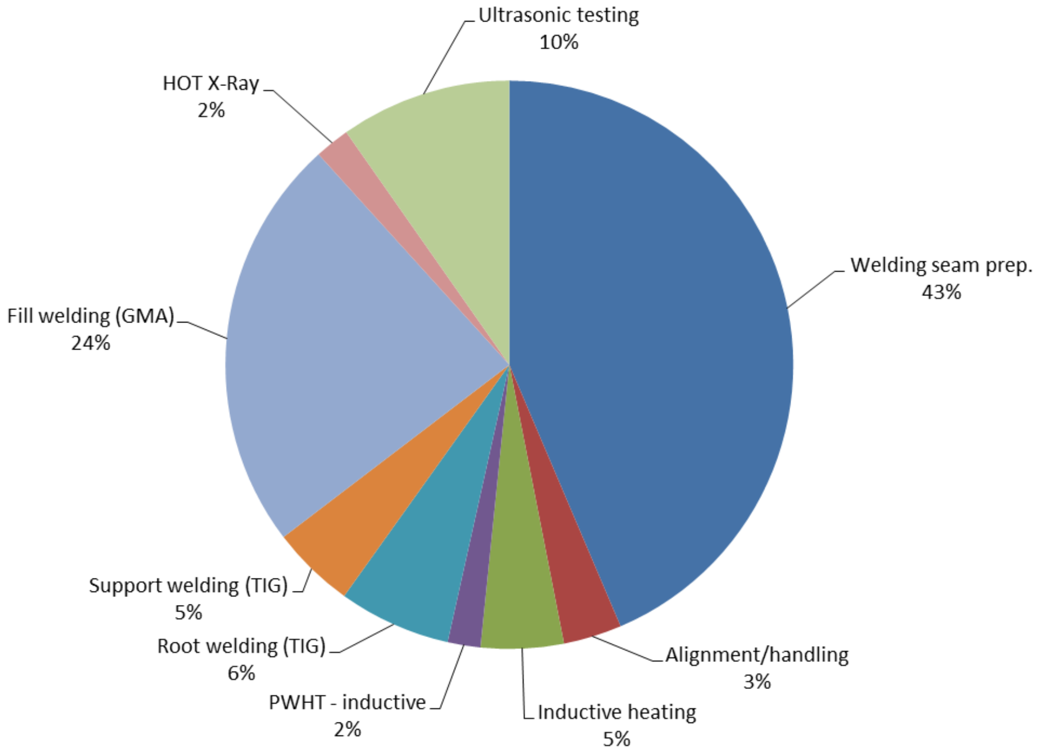
Appendix 13: Cost distribution - Nuclear - PWHT gas oven



Appendix 14: Cost distribution - I60 - PWHT inductive



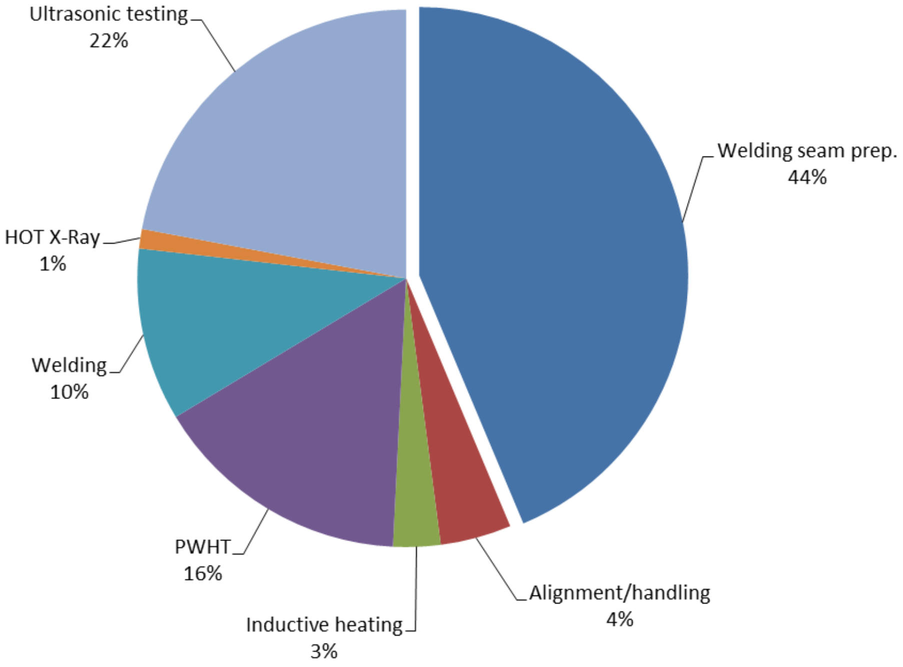
Appendix 15: Cost distribution - NTT 12,5^2 - PWHT inductive



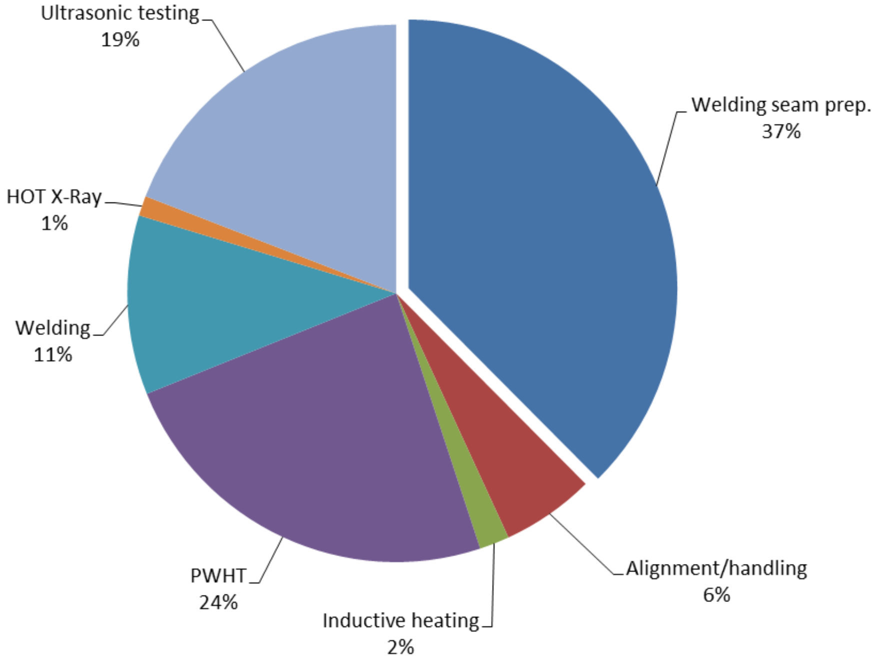
Appendix 16: Cost distribution - Nuclear - PWHT inductive

9.6 Additional information – evaluated process time distribution

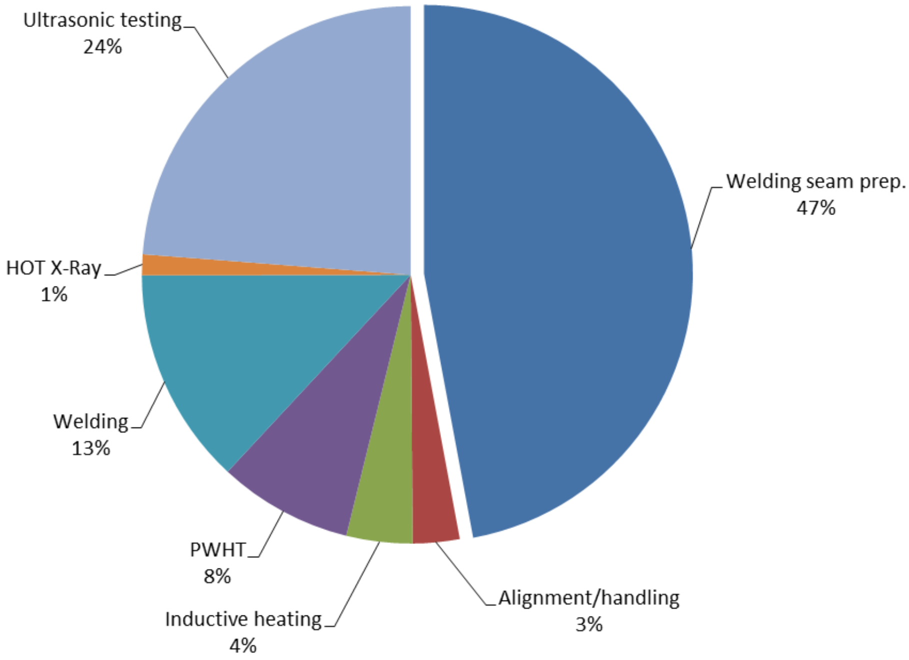
The following figures show the evaluated process time (per welding joint) distribution for further rotor types to point out the differences between the rotor designs. All figures are calculated with the standard welding stand setup (1 TIG head, 1 GMA head, HOT X-ray, 1 UT head).



Appendix 17: Process time distribution - E-type rotor



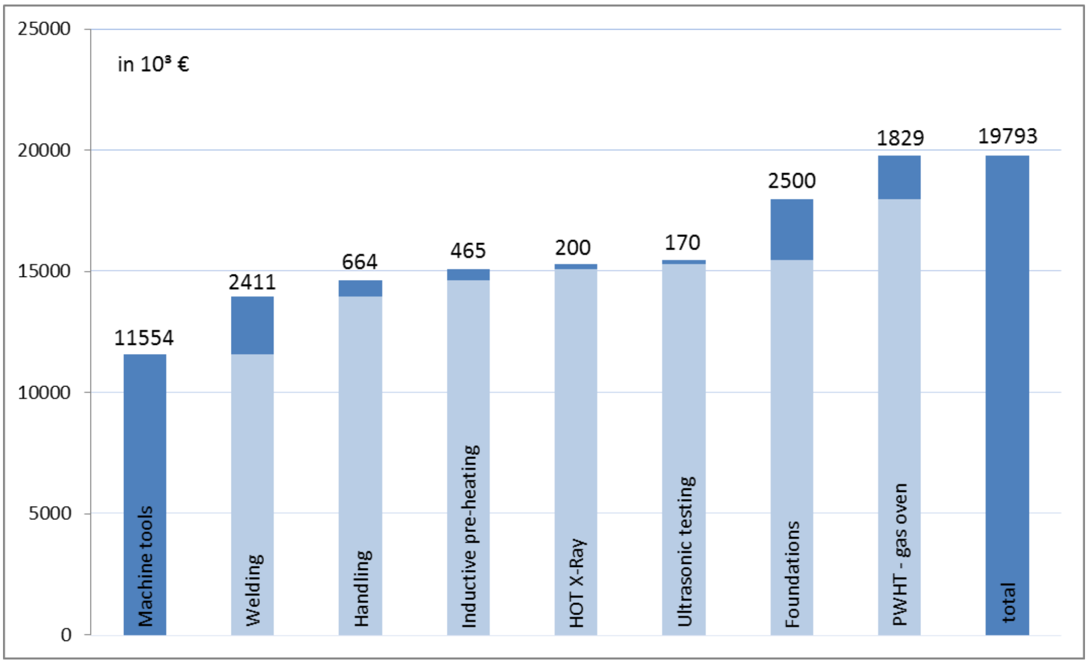
Appendix 18: Process time distribution - I60 rotor



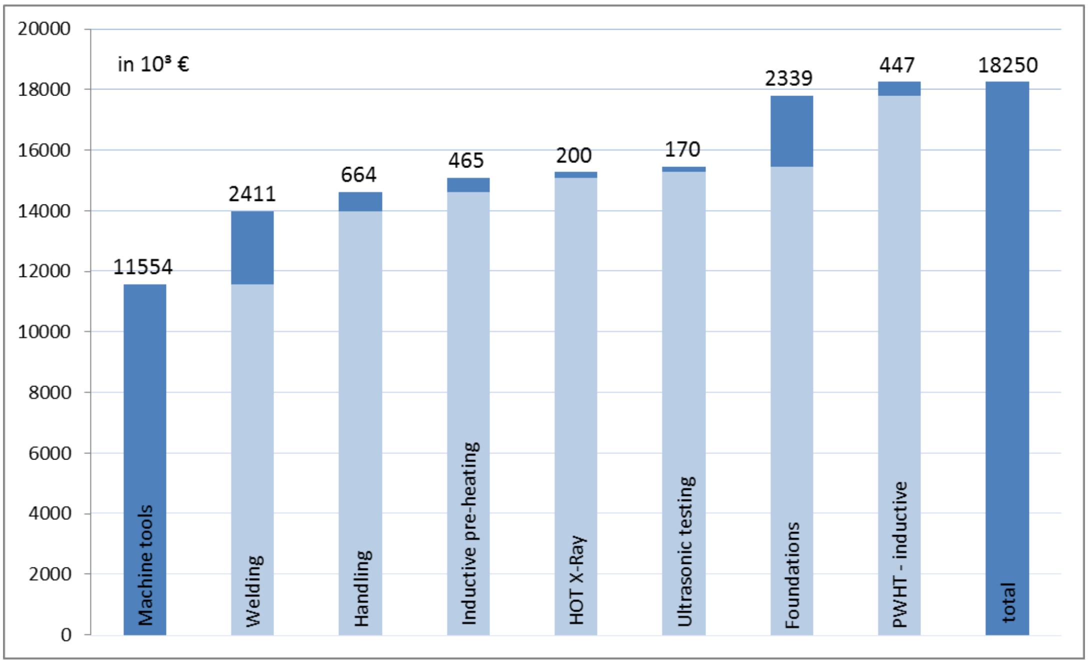
Appendix 19: Process time distribution - Nuclear rotor

9.7 Additional information – investment planning

The following figures show the evaluated investment planning for scenario 2 (nuclear version) and different PWHT technologies.



Appendix 20: Investment planning - scenario 2 (PWHT gas oven)



Appendix 21: Investment planning - scenario 2 (PWHT inductive)