Development of an Automated Split Log Feeding System

Master Thesis at Graz University of Technology
Institute of Logistics Engineering

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Graz, March 2013

Statutory Declaration

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Abstract

In this thesis a new design for the automated feeding of gasification boilers with split logs was developed. One of the main drawbacks of split log gasification boilers is the relatively uncomfortable requirement to manually execute the feeding process. The new system is able to automatically fill a gasification boiler with split logs of a specific size over a period of ten to fourteen days.

The new system's design was guided by a systematic step-by-step approach. First, a series of experiments regarding the physical properties of split logs was conducted in order to provide valuable data for each of the development steps of the new design.

Required system functions then were determined with respect to specific project demands. Among these functions were the storage of split logs, the collecting process and transportation, the accurate positioning of split logs, and the termination of the feeding process at a desired moment. Then solution principles for each function were determined, selected and combined with project requirements.

Thereafter, common methods of evaluation were applied to find an optimal solution. The next step was to determine realizable modules. To minimize the costs of production standardized technical components were preferably selected for each of these modules. After a first layout of the key modules was created and agreed on, a complete layout was developed. The layout, every important technical characteristic and all installed components were documented and described. Furthermore, an estimation of costs and a list of materials were provided.

Acknowledgement

It is important to me to take this opportunity to thank all those people who supported me throughout the process of writing my thesis. I am very grateful that I was given the chance to dedicate my time reasonably to a task that I am very interested in. I am also very happy that I worked together with positive and knowledgeable people who enabled me to gather valuable experiences for my future career.

I am very thankful to Mr. DI Bauer of Heiz- & Energietechnik Entwicklungs-GmbH (HET) for a very interesting collaboration, financial support and a very positive atmosphere during the entire project phase. He assisted me in every way possible and shared first-hand experience whenever needed.

Furthermore, I am greatly indebted to the team of the ITL department. Special gratitude belongs to my supervisor AP DI Dr. techn. Christian Landschützer. He gave advice and practical support as well as useful technical and organizational directions.

Lastly, I would like to extend my sincerest gratitude to my family and friends. They supported me throughout my time in Graz as well as during my exchange year at the University of Tennessee and thereby largely contributed to achieving my goals.

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1 Introduction

A growing demand for energy and steadily increasing energy prices are some of the major problems our society has to deal with. The shortage of fossil fuels and an ever-growing population furthermore intensify this issue. Austria greatly depends on energy imports and certainly must gain greater independence. It is important to use energy economically and to find new ways of harnessing local energy resources.

Wood is an important source of renewable energy in Austria and it constitutes the most commonly used fuel for domestic heating systems. Due to increasing energy prices, consumers find it more and more attractive to invest in heating solutions that reduce both their energy demand and their expenses for fuel.

Wood pellet, wood chip and split log heating systems are the three predominant biomass technologies in the domestic heating sector. Biomass heating systems are especially well established in rural regions because local supply of biomass is easier and more convenient. Moreover, particulate matter is not as pressing an issue as in and around large cities. In contrast to split log heating systems, wood chip and wood pellet heating systems are automated and provide a high level of comfort. Needless to say, the purchase price as well as the fuel price per kilogram is higher compared to that of a split log heating system. Although log wood gasification boilers are comparatively cheap, the feeding process, with very few exceptions, is still carried out manually. This represents one of the main disadvantages of the split log heating technology.

1.1 Initial Situation

Heiz- & Energietechnik Entwicklungs-GmbH (HET), located in Seekirchen am Wallersee in Salzburg, is a technical design office for mechanical engineering with a main focus on energy technology solutions. HET took up this issue and built a first prototype of an automated split log feeding system which is illustrated in figure 1-1. It was designed in cooperation with students of the local HTBL Salzburg.

Figure 1-1: Prototype of an automated split log feeding system

A second project, also in cooperation with students of that school, resulted in a prototype for a rotary feeder that constitutes the interface between an automated feeding system and a log wood gasification boiler (see figure 1-2). It ensures a smoke-free split log feeding process and by its design is also compatible with a range of different wood gasification boilers.

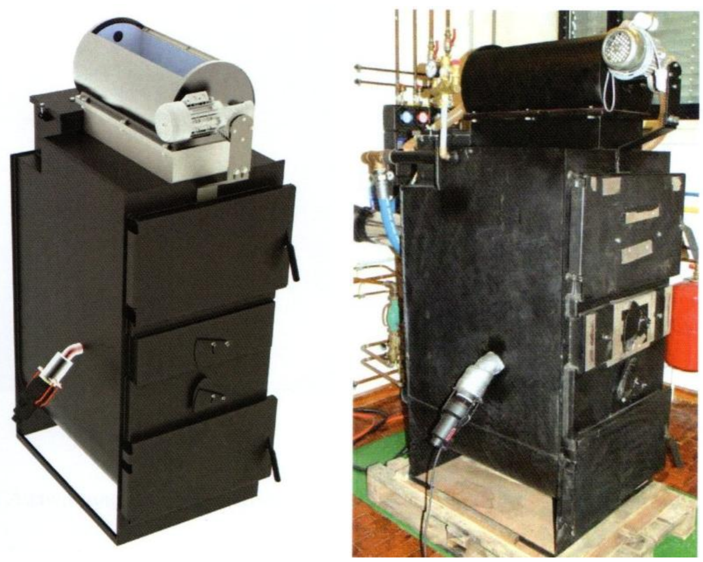


Figure 1-2: Rotary feeder on top of a boiler

1.2 Objectives

The main objective of this thesis is to develop a new, innovative design of an automated split log feeding system, or else to optimize and improve the initial prototype. Technical as well as economic aspects and requirements will be considered in order to develop a reasonably priced product. The automated feeding system has to fulfill a number of different functions, which range from the appropriate storage of split logs in the boiler room to the final, accurate placement into a rotary feeder that is connected to the log wood gasification boiler. Depending on available storage capacities the heating system with a power range of 25-35 kW is able to maintain a controlled heating process over a period of ten to fourteen days. During this period a control unit regulates the boiler. The fuel combustion of the boiler runs through different phases. At first the formation of a glow nest in the combustion chamber requires several layers of split logs. Then the combustion is regulated with single pieces of split log. In average the fuel amount fluctuates from three to six pieces of split log per hour, depending on type and size of the wood that is used. Split logs are produced in different sizes ranging from 25-100 cm. In order to develop an automated system that is as simple and cost-effective as possible, however, our decision is to design a prototype for a constant split log length of approximately 50 cm. The feeding system needs to be very flexible regarding the amounts and characteristics of used split logs to ensure the most accurate quantity for the combustion.
A holistic process design requires a good coordination between the ancillary transfer of energy and signals and the material flow, which constitutes the transport within the feeding system. To address the economical aspect of the new design, it is also necessary to incorporate ideas about predefined system requirements, customer wishes and preliminary work. Based upon these considerations, the product design has to be tailored to a certain target group. The new design, therefore, should not only offer a viable alternative to automated wood chip and wood pellet heating systems, but also enter the market with a competitive price-performance ratio.
The result is an overall layout that illustrates the system with all components necessary to fulfill the functions of the product. Furthermore an estimation of the production costs and a bill of material are required. The resulting layout is then finalized in more detail by the specialized design engineers of HET themselves.
Finally, another important objective is to carry out the engineering design process in accordance with a systematic step-by-step approach. This guarantees a traceability of each decision and each design step throughout the process as well as it provides the design engineer with a guiding framework.

2 Problem Analysis

This chapter sets out to detect and analyze main difficulties encountered with respect to the product design. Here the interaction between goods in transit, the transportation system and the interface, which connects feeder and boiler, is of particular interest. An accurate analysis of these three system components is a prerequisite for a further elaboration of the objectives stated in chapter one. Additionally, relevant theoretical basics regarding the related subject and subordinated system components, such as sensor technology, are explained. Finally, this chapter describes the applied, systematic design approach and the selected evaluation methodology.

2.1 Goods in Transit

This subchapter gives a brief overview of the different types of goods in transit and their classification. A special emphasis is given to split logs and in particular their production, accurate storage and material characteristics. This information is essential for the subsequent design and development processes.

Goods in transit are generally categorized in two groups, bulk and piece goods. According to [DAN01] piece goods are defined as goods with a solid shell, which have an unalterable form / shape during storage and transport processes. Another definition of piece goods is stated in [DINISO3569], which classifies piece goods according to its different properties and offers the following three categories:

- Heavy individual pieces.
- Containers and tanks for bulk material, fluids and gases.
- Loading units consisting of several individual units, which are fastened together.

Some properties for the classification of piece goods are form, center of gravity, orientation, mass, volume, material, form and properties of the footprint, special properties, and sensitivity with regard to external influences.
On the other hand, bulk material is defined as fragmentary, grainy or dusty good with a flowing characteristic that commonly changes its form during transport and requires auxiliary means to be collected, [MAR11]. Some important properties of bulk material are grain texture, bulk density and temperature.
As mentioned in chapter 1.2, to facilitate the design process, the general length of split logs will be approximately 50 cm. Throughout the system's entire operation pieces of such a size are handled individually, from the moment of initial storage to their placement in the rotary feeder. In this case, thus, split logs are considered as piece goods.

2.1.1 Split Logs

For the development of an automated system, the goods in transit are of particular interest. Split logs have manifold and varying characteristics and are difficult to implement in an automated process. The purpose of this subchapter is to analyze the production processes of split logs, their storage as well as characteristics, with the aim to provide a thorough knowledge base for the product design.

2.1.1.1 Production and Storage

Apart from wood chips and wood pellets, split logs are the most common form of biomass used for domestic heating systems. Split logs are generally made from residual forest wood or timber after thinning. Figure 2-1 illustrates the overall energy consumption in Austrian households. Fuel wood, which also includes split logs, is ranked third and had a share of 19.7% in 2010. It is the most favored biogenic fuel, and compared to wood chips and wood pellets, has a higher significance.

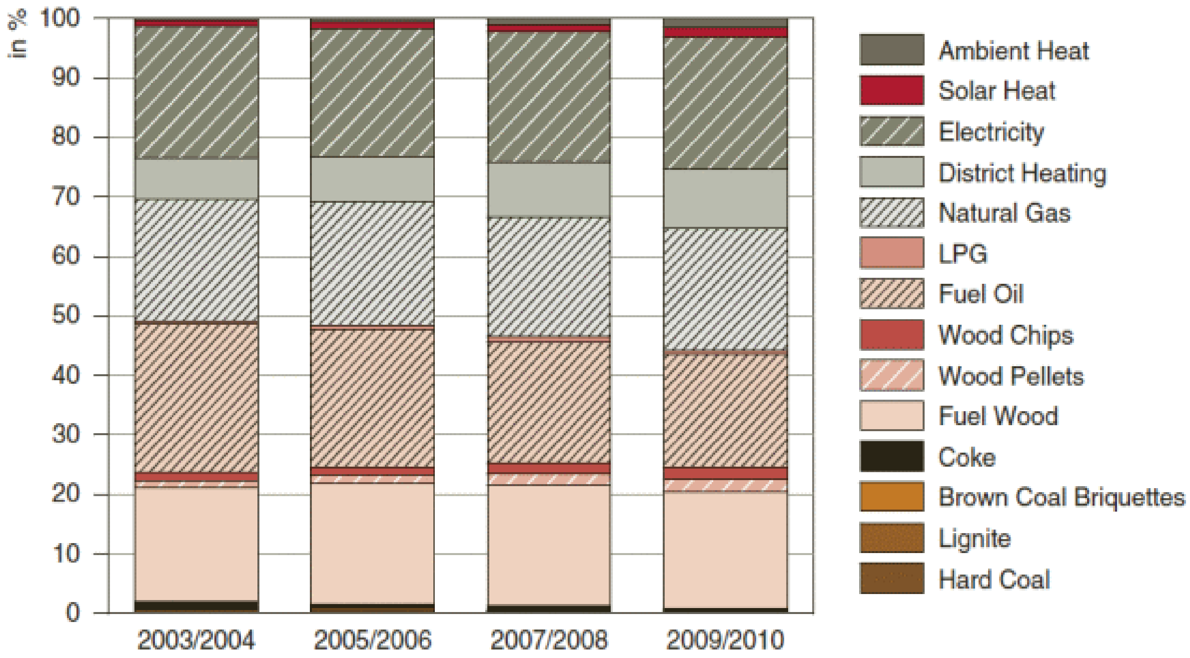


Figure 2-1: Fuel shares from 2003 to 2010

(Source: http://www.statistik.at, 15.11.2012)

The production of logged wood consists of particular process steps. Even though all steps are applied during the processing, the sequence of the steps may vary if necessary, [KHH09].

The production steps for split logs are listed and described below:

- felling
- collecting
- drying
- storing
- chopping (splitting/sawing)
- transport to final or intermediate storage facility
- final storage

The first process step is felling and it can be carried out manually as well as partly or fully mechanized. Manual felling with axes and chainsaws has the least harmful effects on the forest's soil. Then the timber is collected. Depending on where the further process steps are carried out, the timber remains at the felling site or is transported to a centralized processing location, to skid roads as well as to forest roads. This step can be done in an industrialized manner or by end users themselves. The water content of timber after felling can be over 50%. Therefore, timber has to be air-dried for about one to two years to lower its water content to less than 20%. Ideally the wood is stacked and covered, and best located in a sunny and wind exposed area. Depending on available storage space timber is stacked directly in the forest or at the customer's site. The final processing steps consist of splitting and cutting the timber into an individual size required for the heating system. Generally, logged wood is produced in lengths of 20, 25, 33, 50 and 100 cm. For delivery purposes, moreover, it is available in packaged form, wrapped, loose in containers or stacked on pallets, [KHH09].

2.1.1.2 Characteristics

The highly irregular properties of logged wood and the availability of different sizes make it difficult to directly implement transported goods in automated systems. Form, size, weight and impurities are just a few of the many variables which considerably influence the processing. On the one hand, these characteristics depend on the condition of the logged wood itself. On the other, every further processing step has an impact on the logged wood's condition. Due to these factors, it is rather difficult to develop a simple automated system, which is technically suited for all different characteristics of logged wood at a reasonable and competitive price. Depicting the process variables and constants should facilitate the detection of properties, which are either harmful to or beneficial for the design. Such a depiction, furthermore, enables us to deliberately use or avoid certain properties of split logs, some of which are potentially influential for the whole process:

Geometrical properties:

- length (20, 25, 33, 50, 100 cm)
- diameter
- curvature
- twist

External properties:

- cleavage plains (round wood, split log)
- branches
- surface (abrasive, smooth)
- impurities (bark, resin, fungus)
- irregularities (chipping, holes, tail end of branches)

Internal properties:

- fiber orientation
- mass
- hardness
- type of wood (softwood, hardwood)
- water content

Some of these properties are influenced substantially during the growth phase as well as each of the processing steps, not to mention the overall storage conditions. Figure 2-2 illustrates log wood which is not suitable for the split log feeding process due to undesirable characteristics.

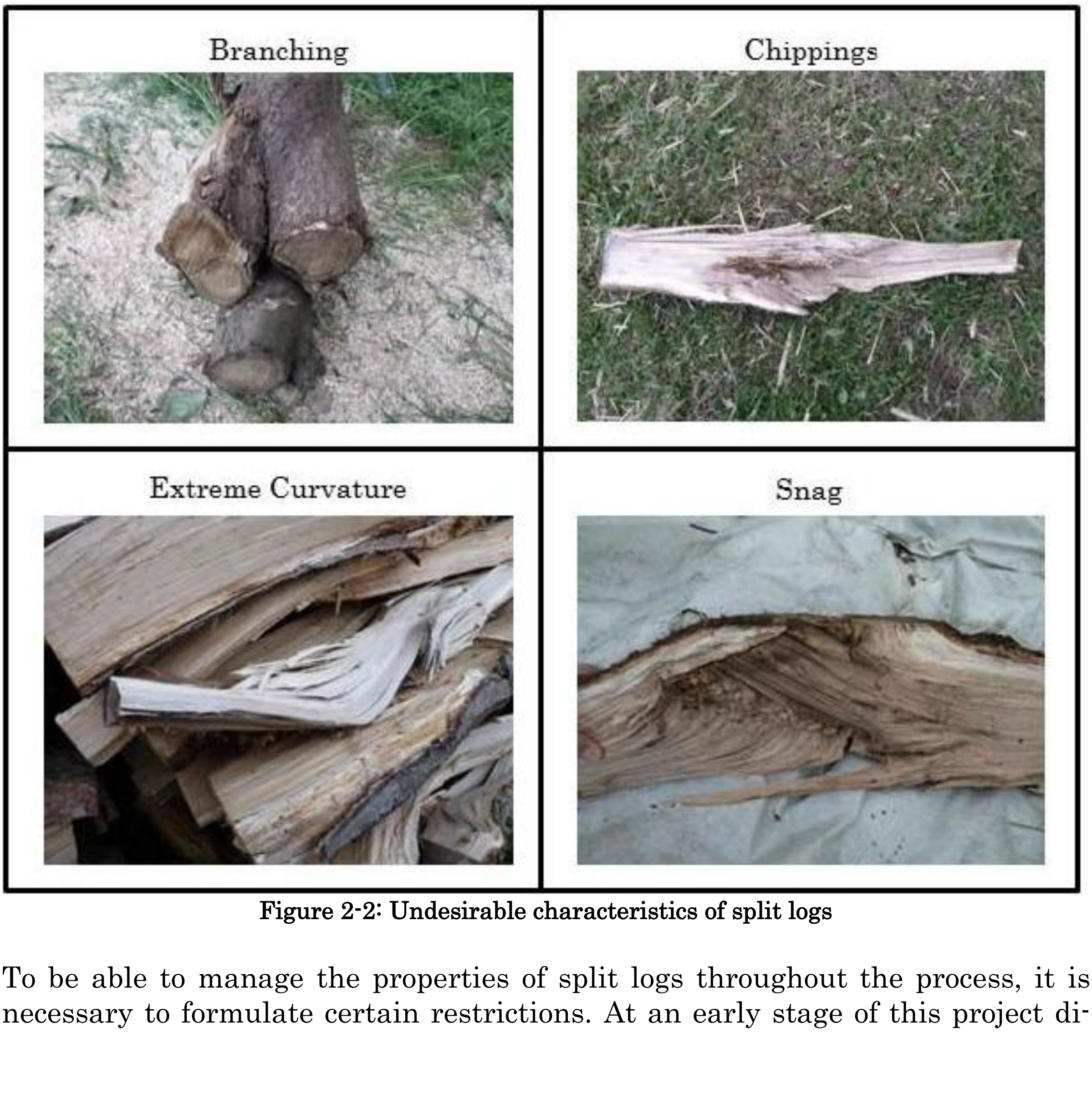


Figure 2-2: Undesirable characteristics of split logs

To be able to manage the properties of split logs throughout the process, it is necessary to formulate certain restrictions. At an early stage of this project dimensional and geometric restrictions have a major influence on further design steps. As already stated in chapter 1.2, the split log's length is set to 50 cm with a tolerance of plus or minus 7 cm. Furthermore, split logs have to have a shape that is approximately straight and free of extreme curvature, major twists and branches. Further detailed restrictions and requirements will be noted at a later stage of the design process, at which point some of the remaining properties will be of greater influence, too.

Constants are easier to manage in a process and have a facilitating effect on the product design. One major discovery of the problem analysis is the fact that split logs consistently have a plain and perpendicular cut surface. Although it differs in size, it can serve as a contact surface for handling operations. This is of particular interest for the transport of single split logs and therefore to be considered in the further development stages of the product design.
As depicted in figure 2-3, split logs have many different appearances, which are all suitable for the process. The illustrated split logs, furthermore, have a plane and perpendicular cut surface and an appropriate size, which is required for the use in the rotary feeder (see chapter 1.1).

Figure 2-3: Suitable forms of split logs

2.2 Material Handling and Transportation

One of the automated split log feeding system's main tasks is to transport material to a determined position. This can be carried out in different ways. The technical field of material handling specifically provides numerous options for potential applications. Therefore, it is important to emphasize relevant theoretical basics of conveying, handling and gripper technologies. This information then supports the analysis and selection of potential technology with respect to the suitability for the task. During the first stages of a design process for a new product it is important to consider a wide range of possible solutions and therefore not to exclude any of them at an early project stage. As soon as a broad base of information is established, the gradual narrowing-down with the help of systematic elimination in subsequent steps can begin.

Material handling includes organized transportation of goods in various directions over limited distances. Conveyors are machines, which transfer goods or individuals. According to [BAA11], they can be grouped as follows:

- Regarding temporal functioning, i.e., conveying systems that work continuously or discontinuously.
- Regarding operational degrees of freedom, i.e., one-dimensional operated conveyors, two-dimensional operated conveyors, or three-dimensional operated conveyors.
- Regarding conveying direction and loading paths, i.e., conveyors that are aligned horizontally or slightly sloping, strongly sloped conveyors, vertical conveyors, or lifting conveyors.

As outlined above, conveyors can be classified in most different ways. Figure 2-4 illustrates a classification of material handling systems by differentiating between continuous and discontinuous conveyors at the first level, and a further differentiation at the second level between possible forms of conveyed goods (e.g., bulk and piece goods). Both technologies have practical applications, which are partly or entirely suitable for the automated feeding process. An assessment of all potential systems will be carried out later on in the development process.

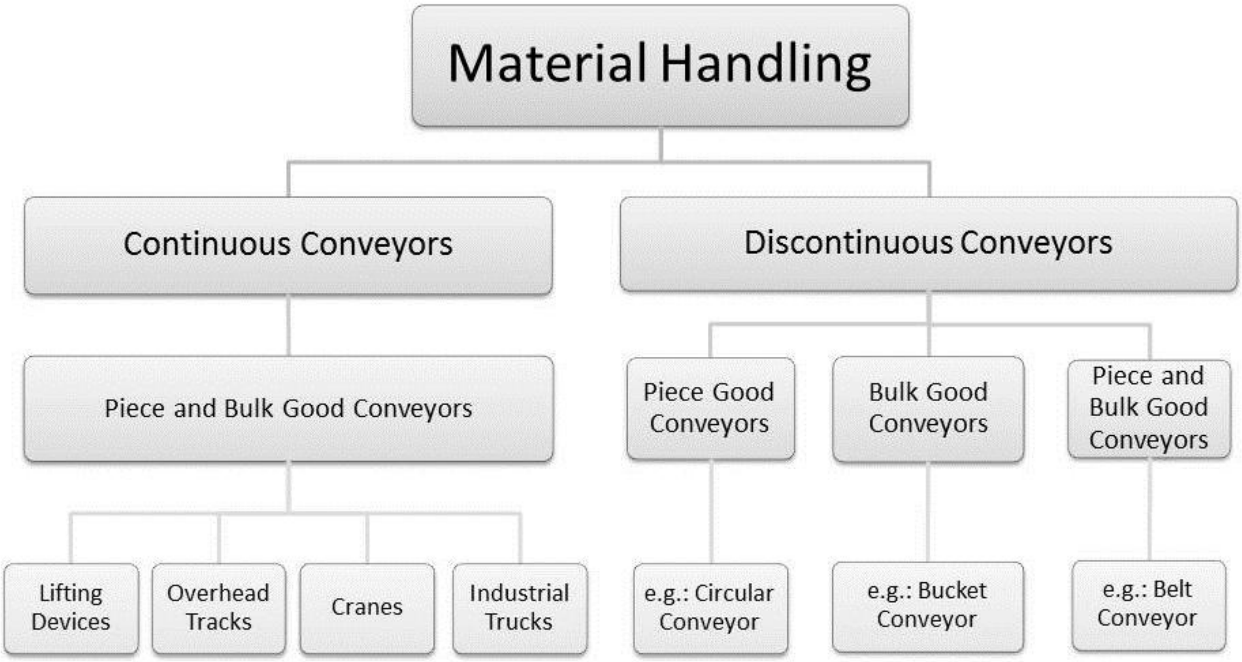


Figure 2-4: General classifications for material handling, [MAR11]

Continuous conveyors operate in steady motion and create a continuous flow of goods in transport. Thereby they can operate uninterruptedly over longer periods of time. Loading and unloading goods can take place during operation at all sections of the transport line. Continuous conveyors are easier to automate than discontinuous conveyors and do not require operating personnel for transport operations. They can be used for bulk and/or piece goods with mass flows ranging from very small to very large quantities. Transportation distances along a certain transport route can also vary from middle to very high. Due to their characteristics, continuous conveyors are used in all branches of industry, [MAR11].

Regarding the definition of goods in transit, stated in chapter 2.1, split logs with a length of approximately 50 cm can be categorized as piece goods. To be able to load the rotary feeder of a gasification boiler with the help of a continuous conveyor, it is necessary to separate split logs into single pieces at the end of their transport route to a determined position. This helps to avoid getting split logs wedged together before or during their entrance into the rotary feeder. In contrast, discontinuous conveyors are able to collect individual pieces of split log as well as they do not require a singulation process. Handling single pieces, moreover, reduces possible forces and momentums during operation and enables an economical design.

Discontinuous conveyors transfer bulk or piece goods from a loading to an unloading point in discontinuous motion. The discontinuous motion commonly takes place in operating cycles. Further characteristics of their operation are changes between loaded and empty runs, loading and unloading downtimes, and connection runs. Loading and unloading takes place at certain points in standstill position with the help of so-called load handling devices. Costs are relatively high due to mainly manual operation. In comparison to continuous conveyors, it requires more effort to automate operations for discontinuous conveyors. The particular advantage of the latter is an overall high degree of flexibility in its application. The transportation of piece goods is carried out in single pieces or in loading units, [MAR11].

For a new product development it is of special relevance for the design engineers to have a holistic and broad understanding of the topic. According to [BAA11], material handling from the perspective of a design engineer not only consists of installation engineering, but to an equal extent of component and system technology. These three categories are illustrated below in figure 2-5.

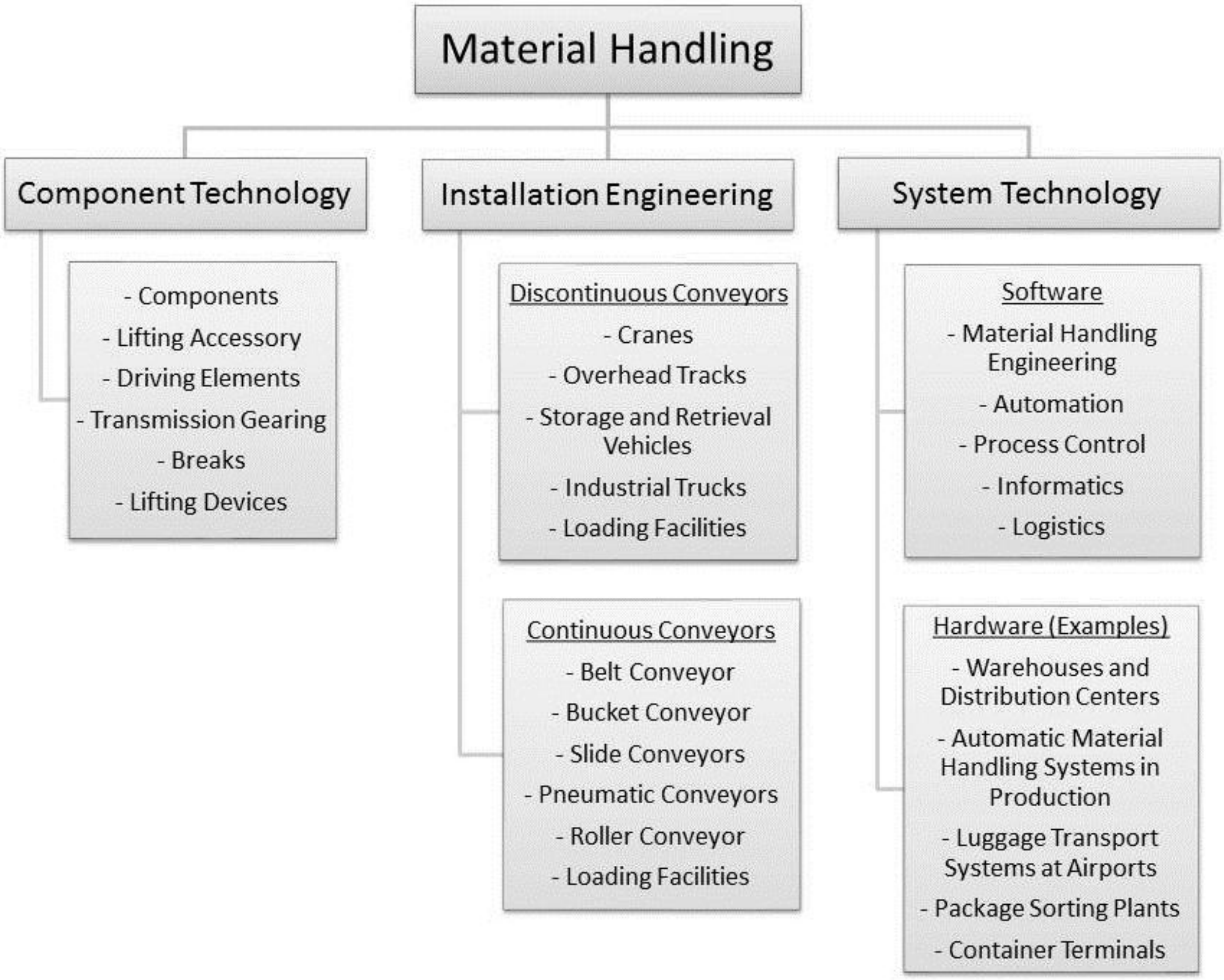


Figure 2-5: Material handling classification from a design engineer's perspective, [BAA11]

2.2.1 Gripper Technology

Discontinuous transport of material in combination with gripper technology constitutes a potential solution for the design of the automated split log feeding system. Therefore, this chapter elaborates on relevant information regarding gripper technology.

The design engineer's goal is to develop an automated system that operates as flexible, safe and independent as possible. It is crucial to find out, which means of transport and which technologies are the most adequate to reach this goal. One of the first steps of the design engineer is to assess, if gripper technology is applicable for the given task.

Grippers are the most important components of manipulating machines. In most basic terms, a gripper and its functions replace the human hand in an automated process. The design of a gripping system is mainly influenced by its application, which has to be assessed based on parameters like performance or flexibility. Considering the geometry of the goods in transit and the task's description, high system versatility is desired. Gripping is defined as temporarily establishing a connection between one or multiple working surfaces of the gripper and an object through the use of force. In the first place, it is important to analyze the gripping task in order to determine whether or not it is possible to hold the object automatically and safely. Secondly, it has to be figured out, which speed, accuracy and reliability are possible to achieve during the application of the handling process, [HES11].

Important characteristics of gripping systems are, [HES11]:

- number of gripping jaws
- force, material, or form closure
- freedom of movement
- actuation and gripping force
- dimensions and weight
- length and speed of gripping jaws
- sensor equipments
- durability

There are certain process steps that a technical gripper carries out during operation, [HES11]:

- Establishing contact between the gripper and the object.
- Securing the contact throughout the movements in every direction.
- Accurate positioning of the object in place with a minimum expenditure of time.

With respect to relevant physical principles, grippers are selected according to the given task's description. Figure 2-6 illustrates three different gripper technologies, which are grouped according to the different physical principles involved. Grippers for solid objects operate with friction and vacuum forces as well as magnetic fields. For textile materials grippers with so-called surface interlocking technique are used, which function by way of needling, scraping or burling. Freezing grippers are suitable for handling processes with high retention forces and for objects with sensitive surfaces. Depending on the task's description various working principles for grippers are possible.
Before any further considerations regarding a suitable gripper technology are made, it is important to assess, if it is generally possible to grab an object under prevailing conditions. The requirements and conditions to successfully grip an object are, [HES11]:

- The object is accessible.
- The object is able to be carried.
- The gripper is opened.
- The gripper is positioned at the reference point.
- The clamping jaws are suitable for the process.

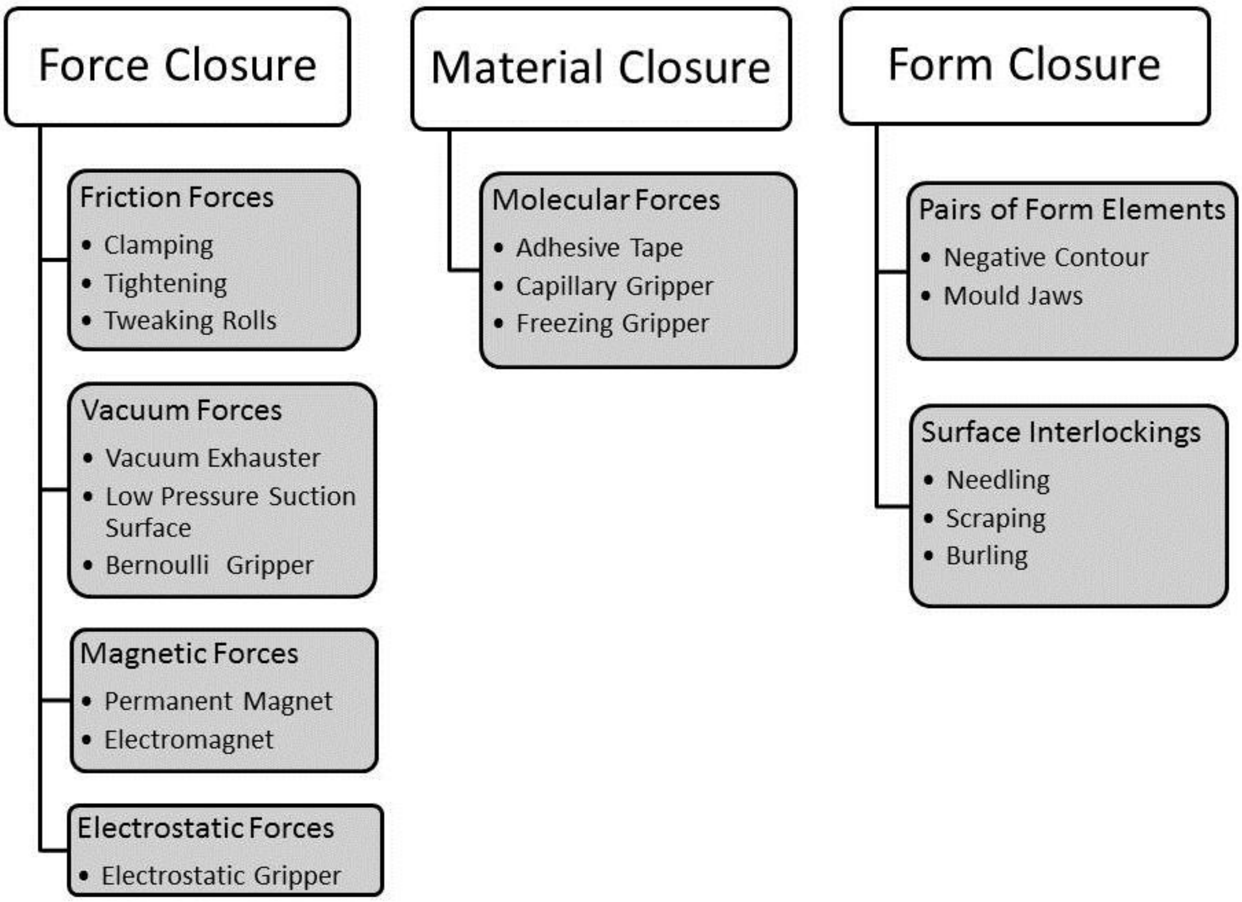


Figure 2-6: Principles to establish a connection, [HES11]

In case the gripper is able to successfully hold the object, further considerations regarding the type of connection between the gripper and the good can be made. As depicted in figure 2-6, there generally are three different ways of how a connection between gripper and object can be achieved. According to [HES11], these can be defined as follows:

- Force-fit Grip:
  Gripper and object are connected tangentially via forces applied punctual or planar, i.e., either through friction, vacuum or magnetism. The force-fit grip is the most frequently used form of gripper technology.

- Form-fit Grip:
  The closure of the gripper's jaws has the same form as the object it should hold, which guarantees a sustained grip. Gravity is causing low reaction forces at the bearings. The object is bedded loosely between the gripper jaws.

- Adhesive Bond Grip:
  An adhesive bond uses atomic and molecular forces to maintain the connection between objects and the gripper. Adhesives or liquid bridges are used for capillary and freezing grippers. A singular surface is often sufficient for gripping an object.

All three forms of gripping substantially differ from each other, and thus have to be assessed and selected based on the individual task.

An essential factor in gripping technology is the gripping force. Technical grippers can apply forces punctually or planar. Clamping is the most common principle used for grippers. During the handling process of objects in three-dimensional space, different forces are at work:

- weight
- inertia forces
- process forces

Inertia forces, for instance, occur during the acceleration of objects. The gripping force has to be laid out to absorb all other appearing forces. Thereby influencing parameters, such as static friction coefficient μ_0, safety factor S, the kind of work pairing and the handling sequence have to be considered, [HES11].

$F_G = m \cdot g$ [N] Formula 2-1

$F_I = m \cdot a$ [N] Formula 2-2

m mass [kg]
g gravitation [m/s²]
a acceleration [m/s²]

Table 2-1 illustrates static friction coefficients for materials that are relevant for gripping applications.

Combination of Materials	dry	greasy
Steel - Steel	0.45 – 0.8	0.10
Steel - Cast iron	0.18 – 0.2	0.10
Cast iron - Cast iron	0.2 – 0.3	0.1 – 0.15
Steel - CuSn alloy	0.18 – 0.2	0.1 – 0.2
Wood - Metal	0.5 – 0.6	0.10
Wood - Wood	0.4 – 0.6	0.15

Table 2-1: Static friction coefficients

The required force for a gripper with two parallel jaws to hold an object can be estimated as follows:

$$FG = \left(\frac{m \cdot g \cdot S}{2 \cdot \mu 0}\right) \qquad \text{Formula 2-3}$$

Thereby the safety factor S considers common operational values for acceleration and momentum. Table 2-2 includes safety factors for different applications, [HES11].

full form-fit grip of the object	S=1,5
normal applications	S=2
frequently used safety factor	S=2,5
Movements in multiple axial directions with low accelerations and axial decelerations.	S=3
Movements with high accelerations and high decelerations as well as for hits and bounces during train rides.	S=4 (to 8)

Table 2-2: Safety factors for gripping force calculation, [HES11]

2.3 Technology and Patents

A further step in the development process of a new product is to analyze current, state of the art technologies that are relevant for the design. First and foremost it is necessary to find out about the patent situation and patent claims. Searching online patent databases is free and depending on the inquiry often only requires a moderate expenditure of time.

2.3.1 Patent Research

As previously mentioned, special attention has to be paid to an early and thorough search for patents regarding related technologies. The design of a new product is a time consuming task and all efforts made need to be as practical as possible. Therefore, it is essential to clarify the as-is situation in order to eliminate the risk of infringement of existing patent rights. For this purpose numerous web pages provide free online access to publication servers and databases.

There are different databases available for national, European and international patents. Some databases used for patent research are:

Austrian patent publication server:
- http://pubserv.patentamt.at

Database of the German patent office:
- http://depatisnet.dpma.de

EU patent database:
- http://www.espacenet.com

US patent database:
- http://patft1.uspto.gov/

Additional online sources:
- http://freepatentsonline.com
- http://www.google.com/patents

These web pages usually have certain attributes in common. They provide different search modes and search functions for people with different levels of experience as well as they enable one to search for miscellaneous entries with the help of key words. They also provide instructions for effective search strategies and other useful tips. Depending on the publication of a certain patent the specifications are released in different languages. Hence, it is advisable to not only search for patents in one language. To search most efficiently, it is also advisable to get accustomed with the expert search modes of the patent search engines and to use them together with synonyms and meaningful word combinations.

The documentation of the completed patent research helps to keep track of accomplished search results and potentially reduces the research effort. An extract from a list with English and German keywords and synonyms used for patent research on the relevant topics, i.e., automated split log feeding system and gasification boiler, is depicted in table 2-3 below.

Automated Split Log Feeding System	Wood Gasification Boiler
automated, automatic, steady, continuous	gasification boiler
log wood, split logs, firewood, fuel wood, stick wood, cord firewood	log wood boiler
conveyor, feeder, loading unit, self-feeding	self-feed furnace
feed, load, charge, supply	automatic stove feed
automatisiert, automatisch, selbsttätig	Holzvergaserkessel
Scheitholz, Rundholz, Stückholz, Holzscheit	Scheitholzkessel
Förderer, Zubringer, Beschicker, Nachladesystem, Beschickvorrichtung	Heizkessel
beschicken, befüllen, zuführen, beladen, fördern	Holzofen

Table 2-3: English and German key words used for patent research

The patent research with online databases resulted in finding numerous relevant patents from various technical fields, such as combined storage and feeding systems, gripping systems, singling-out of split logs, and others. Some of these relevant patents are illustrated and explained in the following paragraphs.

The invention depicted in figure 2-7 illustrates a boiler with an attached automated feeding system. The boiler gets charged with split logs by lifting a loop that surrounds the stored fuel wood. The length of the loop can be shortened and thereby the split logs get lifted to the fuel lock situated at the top right corner of the storage.

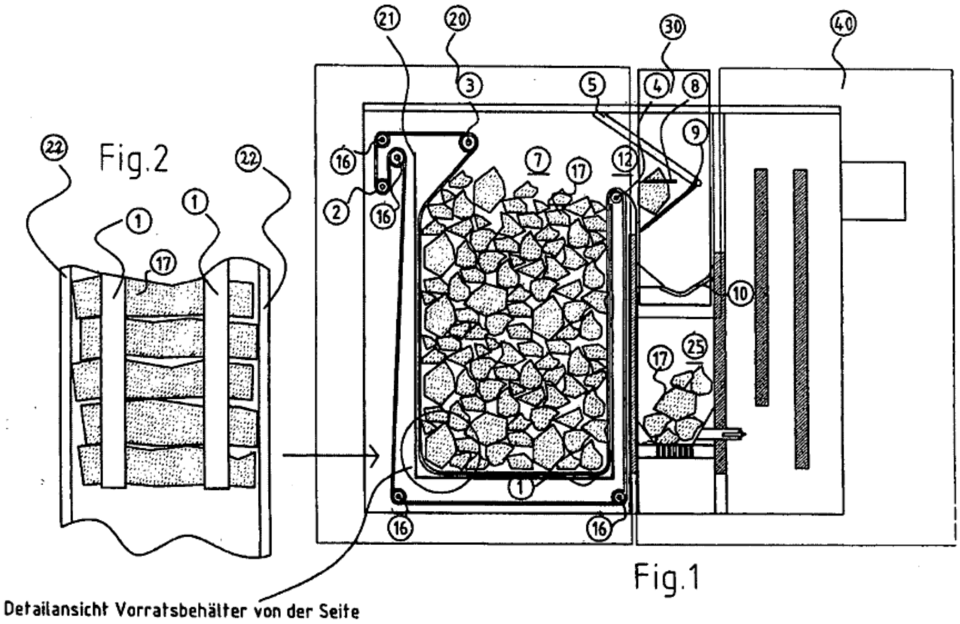


Figure 2-7: Storage container and boiler
(Source: patent AT502491B1, 2007)

Another relevant patent is depicted in figure 2-8. A gripper head is located directly above an unordered pile of split logs and mounted on a crane trolley. The device can be controlled and is mechanically driven, which enables it to collect small amounts of split logs from the pile, vertically transport the material and then place the split logs at an end position. From this position split logs are transported to the fuel lock of a boiler.

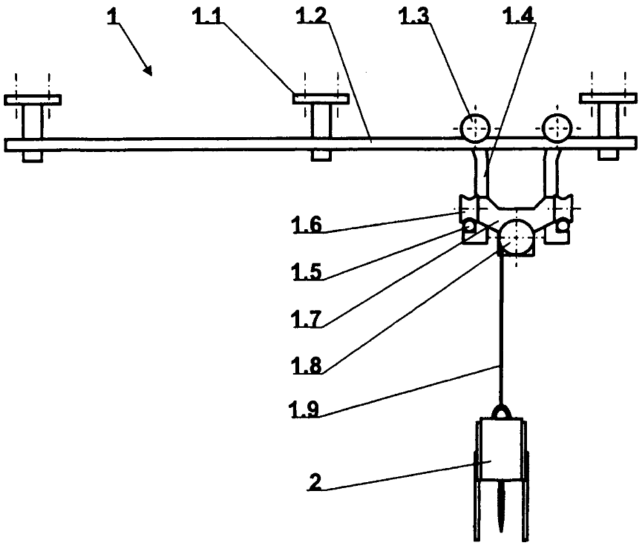


Figure 2-8: Automated feeding system for boilers with split logs
(Source: utility model document AT010296U1, 2008)

2.3.2 Log Wood Gasification Boiler

The development of the automated split log feeding system requires relevant characteristics of the log wood gasification boiler to be incorporated into the product design. Therefore, this chapter gives an overview about relevant information concerning the technology as well as about specific achievements in the history of the gasification boiler.

The gasification boiler is a further developed variant of a regular firewood boiler. An Austrian company named Fröling invented the first gasification boiler in 1988. The newly invented boiler, FHG Turbo, enabled an economical and more efficient combustion of firewood at high temperatures and was a major step in the development of firewood boilers, [FRO12].

In a gasification boiler the process steps of gasification and combustion are spatially and temporally separated. Thus, high degrees of efficiency and low pollutant emissions can be attained compared to regular firewood boilers, [WAT09].

A typical gasification boiler is separated into an upper and a lower chamber and gets charged with firewood in batches. These batches of wood are stacked inside the boiler on a burner plate, which constitutes the separation of the two chambers. During the combustion, the gasification phase takes place after the firewood releases its remaining moisture. Pre-combustion already takes place above the burner plate, when light gas components arise. The resulting flue gases move together with unconsummated gas components through the glowing charcoal down into a turbulence chamber. There the hardly combustible gas components combust at high temperatures of about 1,100°C. This process step is followed by an afterburning. Depending on the boiler design combustion either is supported by an induced draught fan, which is situated in the exhaust gas stream, or by a pressure blower that operates in the fresh air duct. Air is supplied in two different ways. Primary air is supplied to the upper chamber to control the gasification process and therewith the boiler output. Secondary air gets supplied into the lower chamber for complete combustion of the wood gas, [WAT09].

Today the main technology for firing up manually charged boilers almost exclusively is the lower combustion system. Pieces of wood in the form of split logs get filled into the feeding chute. Thereby boilers with a common capacity of about 20 to roughly 40 kW get charged with a typical filling volume of about 30-50 kg fuel per charging. Since the air for combustion is supplied by an induced draught fan, or less commonly by a pressure blower, the combustion in the combustion chamber takes place at either excess pressure or negative pressure. Today systems that operate only with regular natural draught are very rare. One of the major advantages of systems equipped with fans is that the combustion operates almost independently from any external influences, such as the draught condition in the chimney. It is also possible to overcome greater losses of pressure in the combustion chamber. Such pressure losses are necessary to attain an appro-

priate mix of combustion air and flammable gases by creating turbulences due to diminutions and deflections, [KHH09].
Figure 2-9 illustrates a state of the art log wood gasification boiler with lower combustion. It operates with negative pressure and the induced draught fan is situated in the exhaust gas stream.

Figure 2-9: Log wood gasification boiler
(Source: http://www.kwb.at, 20.12.2012)

To prevent the formation of aggressive condensates and tar deposits, gasification boilers require a return temperature raising facility to avoid return temperatures below 55°C. Due to the application of controlled fans, gasification boilers achieve high degrees of efficiency in addition to low pollutant emissions compared to regular, natural draught boilers. It guarantees a correct air supply for the combustion process. After fully charging a gasification boiler, combustion lasts for several hours. Gasification boilers ideally are coupled with a large hot water storage cylinder to guarantee that the boiler is constantly running at full-load operation. The stored energy then is used over a longer period depending on daily demand, [WAT09].

2.4 Sensor Technology

To develop a controlled and automated split log feeding system, it is necessary to install appropriate sensor technology. Thus, this chapter elaborates on aspects of sensor technology that are relevant for the design of the split log feeding system.

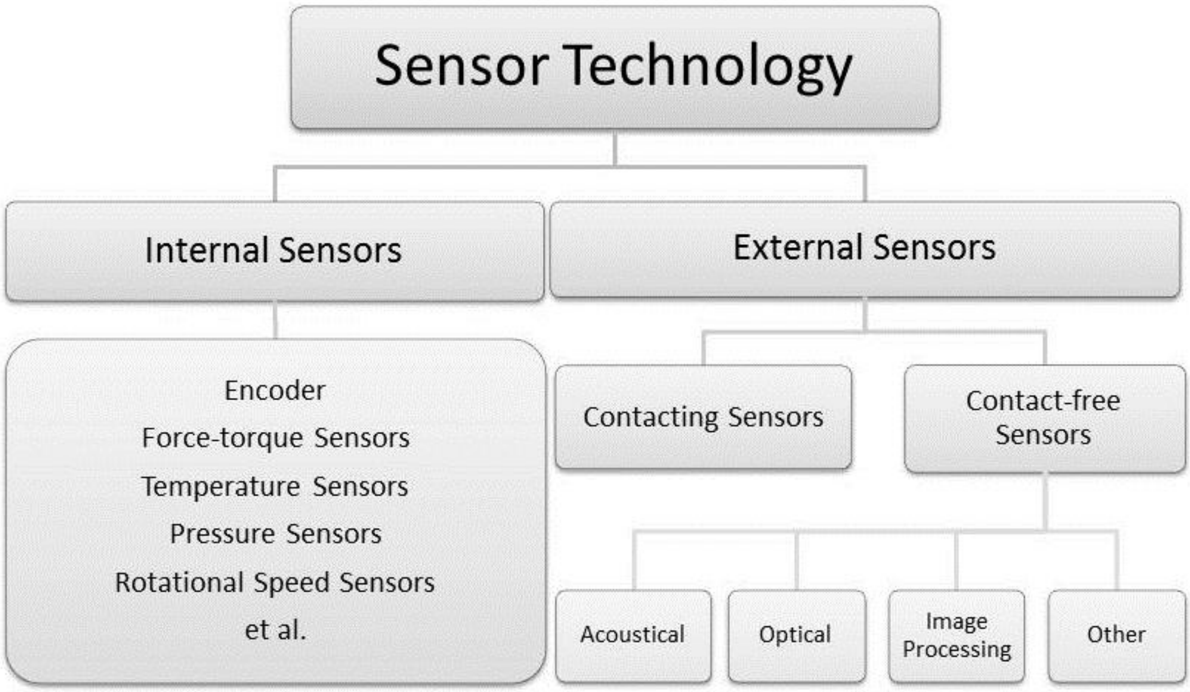


Figure 2-10: Sensor technology, [HSC09]

Sensors are technical components that detect time variables and physical or electro-chemical values and convert them into clear electrical signals. A sensor system consists of a sensor and a measuring object, which both are furthermore connected to their environments, [HSC09].

The grouping of sensor technology as seen in figure 2-10 is used for robotic systems. The two categories are internal and external sensors. The former detect internal conditions, such as position and orientation, speed, internal temperature, forces, torques, and others. The latter detect signals from the environment, such as light and heat as well as physical values in technical processes, distances, object contours, and others.

Measurement parameters can be determined in the following ways:

- Tactile sensors operate through direct mechanical contact or a mechanical coupling system.
- Approximation sensors use close-up effect operating principles.
- Cameras with image processing systems. The distance between the measuring object and the sensor does not directly influence the sensorial interpretation.

The selection process of sensors for automation purposes requires a determination of the following aspects, [HSC09]:

- demand of certain sensorial functions
- requirements for each sensor
- uncertainties during the process
- uncertainties that are not tolerable and to be controlled with sensors
- considerable environmental conditions
- means of information transfer
- physical principles with the highest expectation for success
- required auxiliary energy

Depending on the task description the first phase of the selection and evaluation process regarding sensor systems focuses on functional requirements, such as resolution, linearity, response time, and repetition accuracy.
Suitable sensor systems for the elaborated principle solutions described in chapter 3.3.3 are based on distance measuring. Therefore, relevant parameters are depicted in table 2-4 below:

Sensor Parameter	inductive	optical	acoustical
Measuring Distance	0 - 10 mm	15 – 1000 mm	20 – 2500 mm
Resolution	0.1 µm	2 µm	0.3 mm
Repetition Accuracy	1 µm	2 µm	0.5 mm
Linearity	0.4 - 4 %	0.1 – 1.2 %	0.5 %
Response Time	0.35 ms	0.9 ms	50 ms

Table 2-4: Distance measuring parameters, [HSC09]

2.5 Methodic Procedures in Systematic Design

The goal of a methodic design approach is to develop solutions for problems that are traceable due to an accurate documentation of process steps and decisions. Documentation is also necessary to fulfill ongoing iterative process steps throughout the design process and to avoid that relevant information gets lost. Therefore, the development of the split log feeding system, as described in chapter 1.2, is based on VDI guidelines to ensure an appropriate traceability and documentation of all steps throughout the entire design process.

2.5.1 VDI Guidelines

VDI guideline 2221 discusses general basics regarding methodic design and development, which are generally applicable for different technical systems and products. It is based on a general design approach, which consists of seven stages.

1. Clarify and define the task.
2. Establish functions and their structures.
3. Search for solution principles and their combinations.
4. Divide into realizable modules.
5. Develop layouts of key modules.
6. Complete overall layout.
7. Prepare production and operating instructions.

Figure 2-11 illustrates the previously listed stages of the systematic design approach. The VDI guidelines 2222 and 2223 complement guideline 2221 and discuss the individual stages in further detail. VDI guideline 2222 covers stages 1 to 3, all of which concern the methodical development of solution principles. VDI guideline 2223 deals with the remaining stages 4 to 7 and is about methodical design.

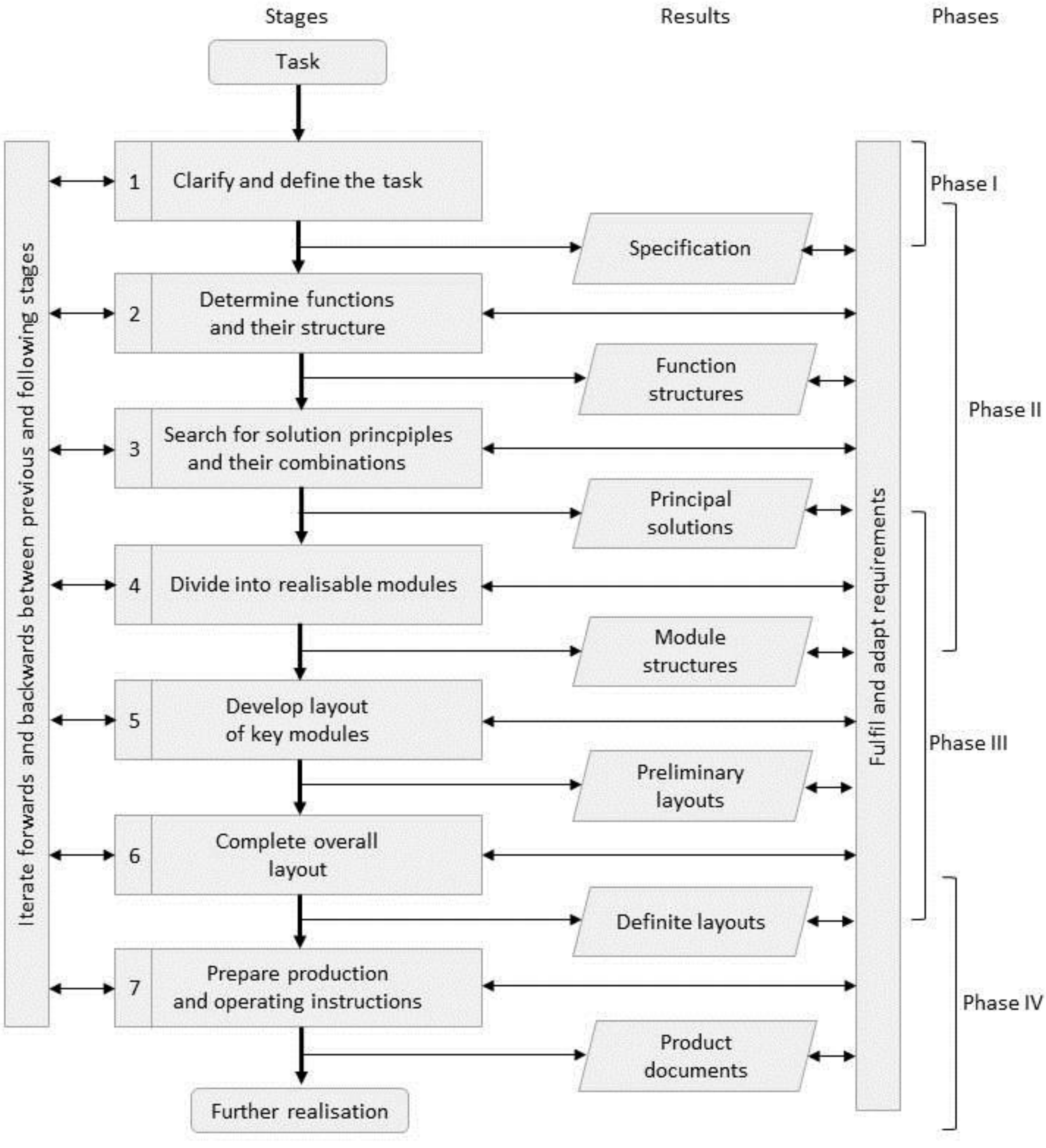


Figure 2-11: General approach to design according to VDI 2221

The development process is divided into four phases and consists of seven stages altogether. The process also includes a forward and backward iteration between all stages to allow a dynamic process execution and a continuous alteration of contents.

Stage 1:
This stage clarifies and defines the requirements of the given task and thereby provides an improved understanding of the topic for all parties concerned. The result of the first stage is a list of specifications. This list constitutes information, which supports all the following stages, and thus requires constant updates. In practice, it is common to stop changing the list of specifications at a certain time by creating a final mutually agreed-on version.

Stage 2:
Here all functions are determined that the underlying system or product has to fulfill. These functions consist of an overall function and the most essential sub-functions. The result of this second stage is a function structure. The higher the scope and the inherent complexity of the system is, the more detailed the structure has to become and the more structures are required.
It is also beneficial to conduct an analysis of the functional relations and of task-related conditions in combination with a step-by-step abstraction of the task, [PBF+07].

Stage 3:
In this stage solution principles for each determined function of the previous stage are to be detected. The solution principles of each sub-function are connected with each other with respect to the overall function structure. Thereby they form the working structure. It is possible that auxiliary functions are detected during this process, which can be substantial for the realization of the solution principles and underlying effects. A high quantity of solution principles is desirable and allows for a large number of possible results. After the selection, one or more solution principles are chosen, which are suitable to fulfill the functions of the product.

Stage 4:
The solution principles acquired in stage 3 are divided into realizable modules in order to form a modular structure. This modular structure, then, reveals out of which groups and elements the product consists.

Stage 5:
In this stage the design of key modules further specifies the product. The results of this first rough design process are preliminary drafts, which are relevant for the final key modules.

Stage 6:
This stage is about finalizing and refining the design of the modules. Modules that did not get developed in stage 5 are defined by selecting standard components and elements. The result is a complete, overall layout that illustrates and contains all relevant design features and specifications.

Stage 7:
The aim of the last stage is to prepare a product documentation, which consists of production and operating instructions.

2.6 Solution Finding Process

In order to come up with optimal solutions for the task, it is recommended to strive for a large quantity of solutions at the beginning of the solution finding process. In this case, quantity ultimately leads to higher quality. For this purpose, there are numerous methods and tools available that support the generating of ideas and enhance a creative thought process.

One of the main advantages of generating ideas systematically is that design engineers continuously elaborate solutions in the course of the project, which is bound to a finite timetable. Thereby they can avoid relying on a solution at an unexpected moment. An optimal solution is characterized as follows, [PBF+07]:

- The solution fulfills all demands on the requirement's list and as many additional wishes as possible.
- The solution can be realized under prevailing constraints of the company. Such constraints, for instance, are budget, date of delivery, or manufacturing facilities.

VDI guideline 2221 quotes different methods and techniques for each stage of the methodic design approach. Some of these techniques are better suited for certain process steps than others. Table 2-5 illustrates such idea generation techniques assigned to each individual process step.
Some methods and techniques that were used to generate ideas for the development of the automated split log feeding system are:

Intuitive Idea Generation Techniques
- Brainstorming
- Semantic Intuition

Discursive Idea Generation Techniques
- Morphological Box
- Attribute Listing
- Mind Mapping
- Design Catalogues

Additional Methods:
- Analysis of Technical and Natural Systems
- Measurements and Model Tests
- TRIZ

These methods were selected on the basis of their suitability to the task and individual requirements regarding the execution, such as the required number of participants. The methods can be used individually or combined with each other at different stages throughout the whole project. When successfully applied to the steps of the systematic VDI design approach, these methods facilitate finding an optimal solution.

Methods / Stages	1 Clarify and define the task	2 Establish functions and their structures	3 Search for solution principles and their combinations	4 Divide into realizable modules	5 Develop layouts of key modules	6 Complete overall layout	7 Prepare production and operating instructions
Methodic-intuitive (heuristic)							
Creativity techniques							
• Brainstorming	o	+	+				
• Method 66		+	+	o			
• Method 635		+	+	o			
• Provocation			o		o		
• Delphi	o		o	o			
Systematic-discursive methods							
Morphology							
• Morphological box		+	+	+	o		
• Moderate morphology		+	+	+	o		
• Attribute listing		o	+	+			
Systematic variation		o	+	o	+	+	
Design-, and solution catalogues		+	+	o	+	+	
Design guidelines				+	+	+	+
Modular system		+	o	+	+	+	+
Illustration of solutions with							
• Drawings, models, drafts	o	o	o	+	+	+	+
Combinations (heuristic/discursive)							
Combinations of methods		o	o	o	o	o	o
Synectics	o	+	+				
• moderate synectics		o	+	o	o	o	
(+…well suited; o…suitable) for the individual design step							

Table 2-5: Idea generation techniques according to VDI 2221

2.7 Selection and Evaluation

Goal of the systematic design approach is to generate a wide range of possible solutions. Therefore idea generation techniques as mentioned in chapter 2.6 have to be systematically applied during the project. Next, these elaborated solutions need to be selected and evaluated. Thus, this chapter gives an overview about relevant theoretical basics and methods on completing the selection and evaluation of solutions.

Even though the systematic design approach aims for a high quantity of solutions, it is practically not manageable to consider and make use of all of them. Solutions have to be selected early on in the idea generation process. However, it is crucial to avoid that suitable solution principles get lost due to an imprudent selection. One adequate and commonly used selection method is "elimination and preference."

The first step of this method is to dismiss solutions that are least appropriate for the given task. If the number of remaining solutions is still high, the superior solutions are to prefer. These solutions are then elaborated with greater detail. The designer ought to apply this method at each design step. Criteria for solutions, which are not to be eliminated, are listed below, [PBF+07]:

- Compatibility with the task and/or with one another.
- The solution fulfills the demands of the list of requirements.
- The solution can be realized regarding size, required orientation, etc.
- It can be expected that costs and effort are permissible.

Preferences for solutions are justified, if they fulfill the following criteria, [PBF+07]:

- Solutions allow for direct safety features and ergonomic conditions.
- Solutions seem to be easily realizable due to familiar know-how, materials, procedures as well as favorable patent situation.

After the selection, the remaining viable solutions have to be concretized and evaluated. Goal of the evaluation is to determine the value, usefulness or strength of a solution with respect to the demands stated in the list of requirements. The evaluation must not be based on a single criterion, such as costs or ecological compatibility. All criteria have to be considered in an appropriate ratio to the task's requirements. According to [PBF+07], the two most common methods of evaluation are:

- Cost-Utility Analysis:
  This method defines and evaluates target goals and sub-goals in a hierarchical order. The potential solutions are assessed based on the degree of fulfilling these goals.

- Technical-Economic Analysis (according to VDI guideline 2225):
  In contrast to the cost-utility analysis, this method is based on a direct evaluation of defined criteria without using hierarchically ordered goals.

3 Development of Measures – Systematic Approach

In this chapter the design of the automated split log feeding system is developed according to the systematic design approach described in chapter 2.5.1. Furthermore performed supporting experiments and an analysis for the product development are included.
The main objective is to develop a new concept for the automated split log feeding process and to select and design components that are required for the overall functionality. The resulting concept is then designed in more detail by the design engineers of HET themselves. Additionally the corresponding control system is also elaborated by HET. Thus, the last design stage of the systematic VDI design approach which is about preparing production and operating instructions for the finalized product is not part of this thesis.

3.1 Clarify and Define The Task

This chapter's aim is to capture and formulate all project requirements in a list to base subsequent development steps on.

As already described in chapter 1, the task is to develop an automated split log feeding system for a wood gasification boiler. To get a clearly structured list of requirements, they are organized in different categories.
The first category considers the main flow of material, which consists of split logs. The split logs in use during the process have a maximum length of 50 cm +- 7 cm. The maximum edge length is approximately 15 cm. Round wood without cleavage planes, however, should not exceed diameters of 8 cm due to a different combustion characteristic than that of split logs. Split logs have to have a straight form and no extreme geometric deformation. It is desirable, furthermore, that the number of cleavage planes of every log is greater or equal to one.
The second category concerns the system requirements. The foremost requirement is that the automation of the feeding process results in a level of comfort approximately equal to that of wood chip and wood pellet systems. A reliability threshold value of about 97-98 % is required to fulfill customer satisfaction. The feeding rate for split logs is 3-6 pieces per hour and the capacity of the rotary feeder is 2-3 pieces per revolution. The system has to be designed for a boiler capacity of 25-35 kW, which is common for single-family housing. To attain a sufficient comfort level for the customer, the system's storage has to be laid out for a period of 10-14 days. To facilitate the implementation of the existing rotary feeder, split logs have to be aligned parallel to it as well as alongside the combustion chamber. In Austria the minimum required ceiling height of cellars is 220 cm. The split log storage can be adjacent to the boiler. The minimum height for split logs to be charged into the rotary feeder is 60 cm. The following requirements for the system are formulated wishes, which should be considered in the design process, if possible. Split logs ought to be dosed in single pieces, to reduce potential process errors caused by wedging. The system's operation has

to generate as little noise as possible. Split logs with improper geometry or dimensions should be singled out.
The third category regards the combustion of split logs. The combustion in the chamber runs through different phases. Initially, the chamber is charged with 4-5 split logs to form a glow nest, followed by another 3-4 pieces. Then, the boiler is charged with 3-6 split logs per hour.
Cost attractiveness is one of the major competitive advantages to wood pellet and wood chip heating systems. Hence, the maximum manufacturing costs should not exceed € 1,333-1,600, in order to guarantee that the final retail price is below € 12,000. This represents a competitive market price for an automated wood heating system.
The total initial production volume of the product is set to be several hundred units. It is important to design the product as simple, robust and reliable as possible. Comfortable and simple operation with low actuation forces is meant to ensure the required level of comfort. Finally, it should be possible to carry out all maintenance and installation work exclusively with standard tools.

All the previously stated demands and wishes of the task description are categorized and summed up. Table 3-1 represents the final version of the list of requirements with all agreed-upon changes made and additionally provides the foundation for all further development stages.

LIST OF REQUIREMENTS for an automated split log feeding system		
Category	D W	Requirements
1	 D D D D D W	<u>Split logs:</u> max. length: 50 cm (+/- 7 cm) max. edge length: 15 cm manual stacking straight form round wood diameter of less than 8 cm more than one cleavage plane
2	 D D W W D D D D D D W	<u>System:</u> automated feeding reliability: 97-98 % dosing with single pieces of split log little noise development split log feeding rate: 3-6 #/h (capacity of the rotary feeder per revolution: 2-3 #) boiler capacity: ~ 25-35kW split log storage capacity: 10-14d split log orientation parallel to rotary feeder and alongside the combustion chamber min. ceiling height: 220 cm min. split log lock-in height: 60 cm automatic separation of split logs with improper geometry or dimensions
3	 W W	<u>Combustion:</u> primary charging: 4-5 split logs secondary charging: 3-4 split logs
4	 D D	<u>Costs:</u> max. manufacturing costs: € 1,333-1,600 total boiler price: max. € 12,000
5	 W W	<u>Production:</u> production output of several hundred units simple, robust and reliable design
6	 W W	<u>Operation:</u> low actuation forces simple operation
7	 W	<u>Installation:</u> use of standard tools
D… demands W… wishes		

Table 3-1: List of requirements

3.2 Establish Functions and Their Structures

In this chapter the main and sub-functions of the task, as described in chapter 3.1, and their related function structures are determined. To simplify the extraction of functions from the task, it is helpful to abstract the demands of table 3-1. Then, the functions can be derived from the resulting, neutrally formulated problem statement.
The list of requirements contains detailed information in quantitative and qualitative form. This information is often carefully worded to capture every important aspect of the system and its tasks. However, extensive verbalization aggravates getting a clear understanding of what is essential. Thus, it is appropriate to abstract the demands in a step-by-step approach, beginning at a very low and proceeding to a high abstraction level. The following steps are related to the approach described in [PBF+07]:

- Leave out all formulated wishes and focus on demands required to fulfill essential functions:

  max. length: 50 cm (+/- 7 cm)
  max. edge length: 15 cm
  manual stacking
  round log diameter: < 8 cm
  automated feeding
  split log feeding rate: 3-6 #/h
  split log storage capacity: 10-14 d
  split log orientation parallel to rotary feeder
  min. ceiling height: 220 cm
  min. split log lock-in height: 60 cm

- Convert quantitative into qualitative data and add supportive information reasonably:

  stacked split logs with specific geometry
  automated system
  dosed feeding
  preset storage capacity
  dimensional constraints

- Neutral phrasing of the problem:

  Charge a rotary feeder in a dosed and automated way with split logs of specific geometry considering dimensional constraints.

To leave out all unessential information, the neutrally phrased problem is implemented in a black box, which is illustrated in figure 3-1. Thereby only flows relevant to the technical system are included. The main flow of the system is the material flow with the help of which split logs are transported from their storage place to the rotary feeder. Apart from the main flow, there is a flow of energy and a signal flow. These three flows are put together and visualized alongside the phrased problem, which is surrounded by a system boundary line. Then, the main functions can be derived from the main material flow and the sub-functions from the auxiliary flows.

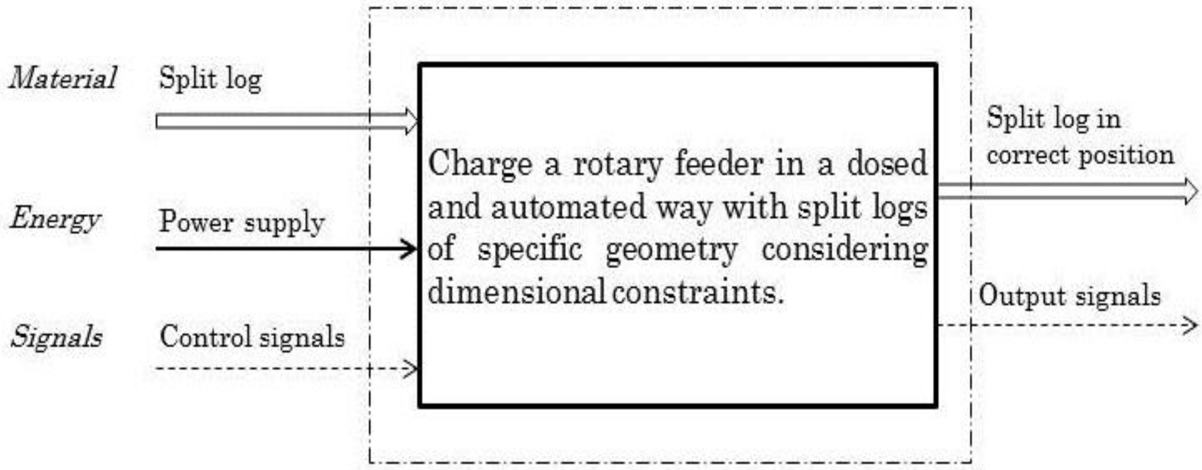


Figure 3-1: Overall function of the automated split log feeding system

In addition to this direct abstraction from the list of requirements, it is also possible to abstract the task according to an approach described in VDI guideline 2222. The approach was carried out and is illustrated in table 3-2. Its main focus, again, is to generate a generally valid problem statement, which allows for the finding of a wide spectrum of different solutions that are suitable for the task. From one step to the next, bits of information are extracted and temporarily neglected to attain a highly abstracted and generalized formulation of the task.

Level of Abstraction	Nr.	Object	Verb	Lost Information	Goal
low	1	split log	feed	____	____
↓	2	solid object	position	inward transfer to rotary feeder; characteristics of split log	generalize the process
↓	3	solid material	move	split log's form; positioning into rotary feeder	describe functions physically
high	4	material	convey	physical condition of the material	describe functions generally

Table 3-2: Stepwise abstraction according to VDI 2222

Problem formulations of all levels of abstraction are equally important to determine the required functions for a successful product design. At the beginning of the design process, a very abstract formulation of the problem facilitates an understanding of the most essential aspects of the process. At a later stage of the process, more detailed information and finer function structures are required.

At a high level of abstraction, the main functions of the split log feeding system are to convey material from the initial storage position to its end position, and subsequently to position the material in the rotary feeder. The according function structure is depicted in figure 3-2 below, in which additional functions and information are deliberately left out.

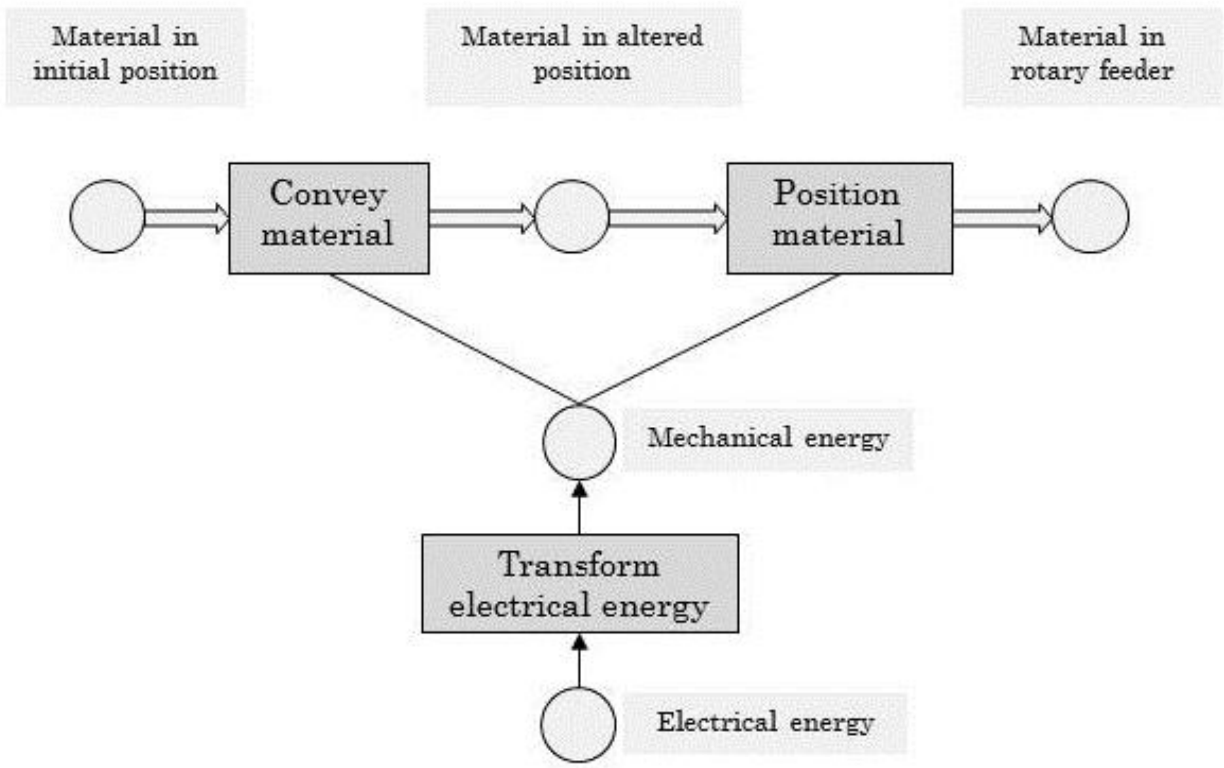


Figure 3-2: Function structure at a high level of abstraction

For a complete product design, however, it is necessary to generate a more detailed function structure. Next to conveying and positioning split logs, the type of storage is an important aspect in the development of the product. Attributes, such as storage position, orientation, size, etc., have a significant influence on the selected conveying system. Therefore, storing split logs appropriately is an additional main function of the automated split log feeding system.
Conveying split logs can be split up into two separate functions. First, split logs have to be gathered by establishing a connection to them. Principles, such as form, force, or material closure can be used. Secondly, the split logs are ready to be transported to their end position either with the help of continuous or discontinuous material handling systems. So, depending on the transport system split logs are positioned at some place favorable for entering the rotary feeder. Finally, the rotary feeder must be charged with split logs at the correct time. Besides, some transport technologies require additional handling processing or the appli-

cation of counter-pressure to terminate the connection. Thus, disconnecting from the transportation system constitutes the last main function.

The main functions determined from the abstracted list of requirements and the problem statement are summarized and listed below:

- Store split logs at initial position.
- Collect split logs and establish connection.
- Transport split logs to transfer position.
- Position split logs.
- Disconnect.

From the auxiliary flow of signals and energy the sub-functions are derived. These functions are necessary to successfully maintain the operation of the main functions:

- Supply electrical and mechanical energy.
- Measure and control process.

In figure 3-3 the detailed function structure with the five main functions and the auxiliary functions are illustrated.

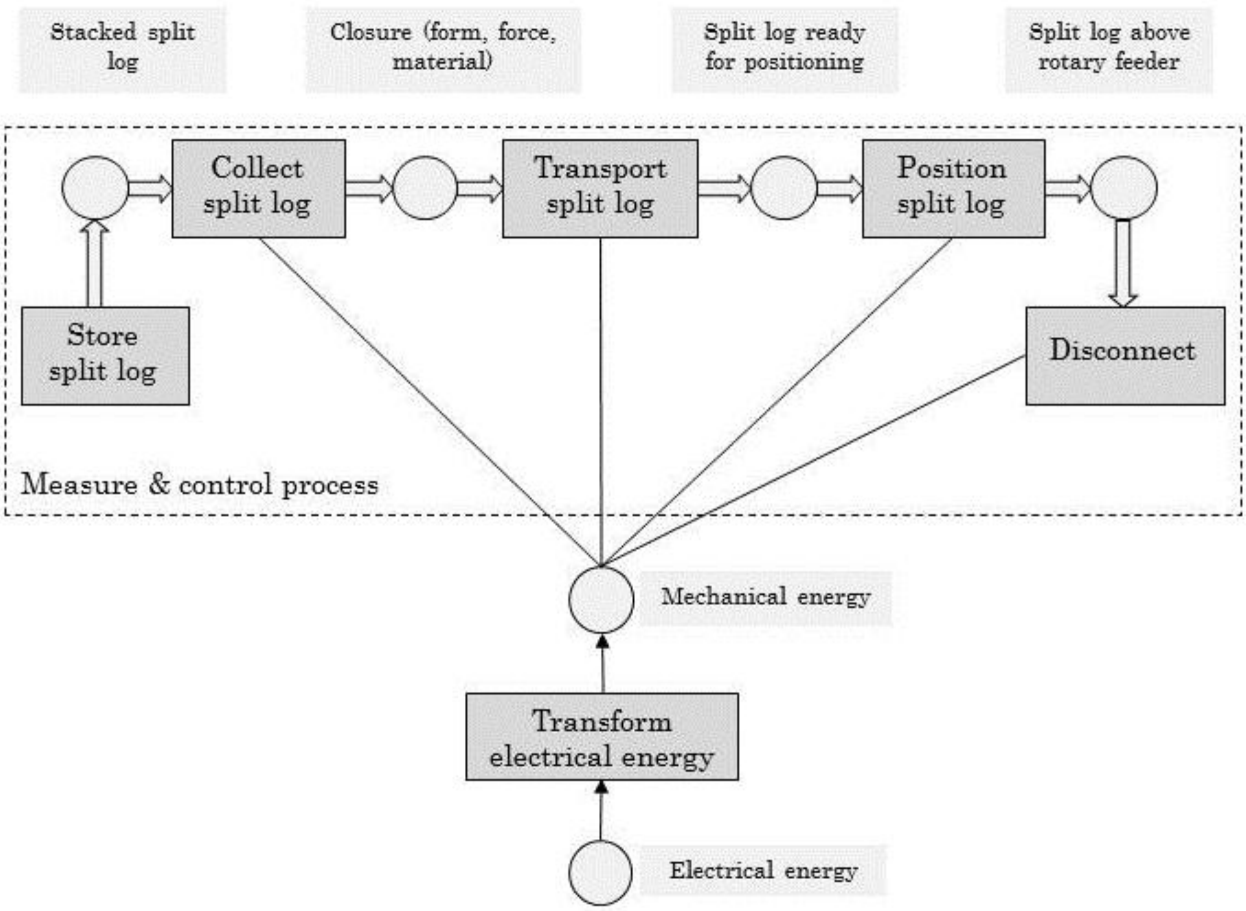


Figure 3-3: Detailed function structure

In the next stage of the systematic design approach solution principles for the functions of the automated feeding system need to be elaborated. Thereby it is important to avoid isolating one function from another. In the design process all functions have significant influence on one another.

3.3 Search for Solution Principles and Their Combinations

In this stage of the systematic design approach the goal is to elaborate principle solutions. Therefore, solution principles for the functions determined in chapter 3.2 need to be found, because only then can the solution principles be selected according to certain criteria. The chosen principles get systematically combined to form a single or multiple working structures. The resulting principle solutions, finally, are evaluated based on criteria, which are discussed by members that are involved in the project. The applied selection and evaluation methodology is based on the procedure described in chapter 2.7.

3.3.1 Preliminary Analysis

This chapter's goal is to analyze properties of split logs that are of particular significance for the design of components of the transport. The analysis thereby contributes to finding optimal solution principles for each function. A special focus of the analysis is to assess physical properties of split log pieces, such as slip angle and slip behavior.

3.3.1.1 Slip Behavior of Split Logs

According to the typical properties of split log, as described in chapter 2.1.1.2, the slip behavior is not expected to be favorable for the design. A rough and rugged surface combined with impurities, such as resin and fungus, causes high friction during the logs' slipping. In order to be able to come up with solution principles for the determined functions, it is beneficial to analyze the slip behavior of split logs. Figure 3-4 illustrates the performed experiment, in which split logs were put on top of an inclined surface.

Figure 3-4: Slip angle experiment with split logs

The angle of the surface, then, was steadily increased until the split logs slipped down. The experiment was carried out several times with surfaces of different material as can be seen in table 3-3, where the various slip angles are gathered.

Slip Angles		
1	two separate planks of wood (rough and dirty surface)	δ = 40°
2	plain chipboard (clean surface)	δ = 35°
3	plain steel plate (clean surface)	δ = 32°

Table 3-3: Slip angles

An additional experiment, based on the previous results of the slip angles, was designed to test the possibility of autonomously leading split logs to a defined gathering position without using additional energy sources. Therefore, a storage system was built that holds the fuel capacity for up to seven days. The storage was filled with stacked split logs of a length of 50 cm. It had to be determined, if split logs slip down along a declining wooden surface to a defined end position until the storage is empty. According to the determined slip angles of table 3-3 the steepness of the sliding surface was set to an angle 35°. The experiment is illustrated in figure 3-5. Although the experiment presented a slip behavior of high reliability during most of the attempts, some experiments ended due to a bridging of split logs. The main problem was caused by the tapering cross section. Even though further adjustments led to improvements of this problem, the required reliability was not attained.

Figure 3-5: Slip behavior experiment with split logs

3.3.1.2 Stacking of Split Logs

In this section a further experiment with respect to potential ways of storing split logs is discussed. The purpose of the experiment is to determine the stability of split logs when stacked to a certain height. Split logs with a length of one meter are commonly stacked on forest soil during the drying process without further concerns. However, this is not certain for split logs with a length of 50 cm. Thus, in the experiment split logs are stacked up to a height of 1.6 meters to be able to visually and mechanically inspect the stability. The result then serves as a basis for decision-making on whether or not it is possible to store split logs only between plates on each side of the stack and without a supporting surface at the front or back side. Such a design maximizes the accessibility for the gathering process of split log. Consequently, this would result in a higher number of solution principles.

The experiment was performed in a standard storage room of a basement and is illustrated in figure 3-6. Split logs only with those characteristics defined in the list of requirements in chapter 3.1 were used for the experiment. Markers on the floor enclosed the storage space and were sufficient to stack split logs to the determined height of 1.6 meters. Both the visual inspections as well as the lateral resistance test were successful. Consequently storing split logs in such a way can also be considered for generating solution principles.

Figure 3-6: Stacking experiment with split logs

3.3.2 Solution Principles

For each function defined in chapter 3.2 solution principles need to be determined. A systematic visualization of these principles enhances the designer's possibility of recognizing essential connections between them. Therefore, classification schemes are used to organize solution related information for each function.
Depending on the function reasonable criteria for classifications are determined, such as working geometry, working surface, or source of energy, [PBF+07].
The resulting schemes serve as a database for solution principles during each stage of the design process and all consecutive iterate process steps.
Only solution principles that are relevant and compatible are further elaborated. Thus, for each function the solution principles are selected. The remaining promising principles are combined and visualized by entering them into a morphological box. Thereby principles of each function are connected to form one or several potential working structures.

3.3.2.1 Storage of Split Logs

The first main function of the system is to appropriately store split logs. As described in chapter 3.3.1.2 storing split logs for a period of ten to fourteen days requires storage space of up to 2.5 m³. The goal is to search for different ways to store the described amount of split logs optimally with respect to structural constraints for the subsequent removal process. Split logs, as specified in the list of requirements, weighs up to four kg per piece. Therefore, when stacked to a pile, there happens to be a high contact pressure on the lowest of its layers. Segmenting the stack is one option to reduce the load as it allows for a more delicate design. The storage's form is also of great importance. Especially when combined with the remaining solution principles of other functions, possible resolutions for an individually adapted design of the storage may come in handy.
Space in storage rooms is very limited. Thus, it is worthwhile to exploit the available storage space as efficiently as possible. Storing split logs close to the ground ensures that full advantage of the available ceiling height is taken.
Split log removal can take place in different ways and from different directions. The storage design has to consider this aspect by limiting potential constraints. An optimal storage design provides free access for the act of removing split logs from as many directions as possible.

It is possible to design the storage system so as to enable the removal of split logs from either a fixed position or from various positions around the object. Certainly, the latter option would ensure more flexibility for the process. Because the transport of split logs inside the storage container overlaps with the third system function, that of transporting split logs, respective considerations have to be made in advance. Possible solution principles for the required transportation are mechanical or electrical drives as well as individually designed containers, which make use of gravitation.
Table 3-4 illustrates and summarizes solution principles for the storage function.

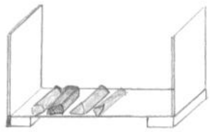
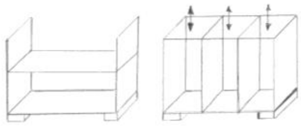
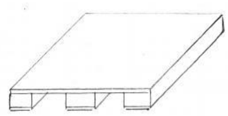
Variant / Attribute	1	2	3
Type	One single pile of split logs stacked between walls. 	Storage container with horizontal or vertical segments. 	Split logs piled on commercially available pallets. 
Form	cuboid 	trapeze 	Individually adjusted to the gathering method.
Location	on the ground	on an elevated platform	recessed in the ground
Size	630 kg hard wood $\triangleq$ 1,3 – 1,7 m^3	630 kg soft wood $\triangleq$ 2 – 2,5 m^3	euro-pallet (800 x 1200 mm): 1,45 m^3
Quantity	one single pile	several segments	Several piles, containers or pallets next to each other.
Gathering	top surface	bottom surface	side cut surface
Gathering Position	from fixed position	from various positions	–
Drive	none / gravity	mechanical drive	electrical drive

Table 3-4: Solution principles for the storage of split logs

3.3.2.2 Establish Connection

The second main system function is establishing a safe connection to the transported goods. Depending on the means of transportation different types of connection are required. For the split log feeding system both continuous and discontinuous conveyors are suitable for the transport of split logs. Handling single pieces of split log with discontinuous conveyors differs greatly from handling a larger quantity all at once with respect to the requirements needed for the connection.

Generally, connections can be established with the help of form, force or material closure. On the one hand, continuous conveyors that are based on the form closure principle can transport split logs in containers, in forms or in a defined volume. Discontinuous conveyors, on the other hand, that work with the force closure technique can be equipped with grippers, mandrels or screws to connect to split logs.

The rotary feeder can be charged with up to two large or three small pieces of split log. Split logs, hence, need to be dosed before entering the rotary feeder. The single transport of split logs makes the aforementioned process step redundant. Table 3-5 depicts and summarizes the solution principles for establishing a connection to split logs.

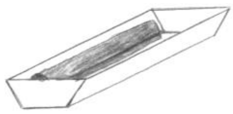
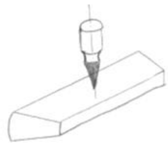
		Variant / Attribute	1	2	3
Working Geometry	Working Surfaces	**Type**	form closure	force closure	material closure
Working Geometry	Working Surfaces	**Form**	container / form / defined volume 	gripper 	mandrel, screw 
Working Geometry	Working Surfaces	**Location**	surrounding container	skin surface	cut surface
Working Geometry	Working Surfaces	**Size**	one split log	two large split logs	three small split logs
Working Geometry	Working Surfaces	**Quantity**	one container, gripper, screw, mandrel	multiple containers, mandrel	–
Working Geometry	Working Motions	**Type**	translation	rotation	translation & rotation
Working Geometry	Working Motions	**Form**	straight motion (horizontal & vertical)	linear motion (inclined)	guided motion (non-linear)
Working Geometry	Working Motions	**Direction**	horizontally	vertically	inclined

Table 3-5: Solution principles for establishing a safe connection

The type of energy required for fulfilling the function depends on the means of transportation. Whereas continuous conveyors almost exclusively use electrical supply for transportation, discontinuous conveyors' force closure also can be generated based on different physical principles, some of which are illustrated below in table 3-6.

Energy / Principle	1 mechanical	2 electrical	3 hydraulic	4 pneumatic
Pot. energy	mass of solid body	–	liquid column	–
Impulse	impact	magnetic field	back pressure	gas pressure
Lever	lever arm	–	–	–
Spring	metallic spring	–	compressed fluid	compressed gas
Upstroke	lifting column, telescopic lift	–	–	–
Wedge Effect	screw, arbor	–	–	–

Table 3-6: Types of energy supply for connection

3.3.2.3 Transport

After a connection is established, the transportation of split logs to a determined position takes place. Even though it is theoretically possible to transport split logs with many kinds of different and innovative technologies, this chapter focuses on conventional transportation systems.
According to the theoretical basics elaborated in chapter 2.2 split logs can be transported with two types of conveyors:

- continuous conveyors
- discontinuous conveyors

For both conveyor types solution principles are elaborated and separately illustrated in classification schemes.

Relevant components for discontinuous transport are linear guide systems, roller guides, spindle drives, and linear motors. The location in storage rooms, where the transport system should be installed, as well as its overall condition and structural constraints need to be adjusted according to the choice made regarding possible ways of discontinuous transport.

Storage rooms quite often are already equipped with installations, especially on ceilings, which also need to be considered. Table 3-7 illustrates four relevant solutions for the discontinuous transport.

		Variant / Attribute	1	2	3	4
Working Geometry	Working Surfaces	**Type**	linear guide system	anti-friction guide way, roller guide	spindle drive	linear motor
		Form	linear slide bearing	rail guide systems	telescopic slide (square / round)	trapeze & ball spindle, steep-spindle drive
		Location	cealing installation	on the ground	–	–
		Quantity	single system	multiple systems	–	–
	Working Motion	**Type**	translation	rotation	translation & rotation	–
		Form	straight (vertical & horizontal)	linear (inclined)	guided (non-linear)	rotation
		Direction	x, z direction	x, y, z direction	–	–

Table 3-7: Solution principles for discontinuous split log transport

Split logs can be transported from the storage location to the rotary feeder in different ways. In comparison to a system with guided non-linear motion, the combination of continuous vertical and horizontal motion requires a different set of technical components and drives. A belt conveyor, for example, is able to transport split logs in a guided continuous motion from the storage location to the rotary feeder. Continuous conveyors, hence, commonly use electric motors as drives.

In contrast to this, different types of energy supply for a discontinuous transport are illustrated in table 3-8. Possible principles for the vertical transport of split logs are electric hoists, electric chain hoists, spindle jacks, scissor lifts, etc. Apart from electrical drives for scissor lifts, there are also electro-hydraulic drives available.

Two potential drives for a horizontal transport are chain and toothed belt drives. In contrast to the latter, chain drives require lubrication. This is a major drawback especially in dusty and dirty environments. In split log storage rooms the dusty environment can lead to an increased contamination of components, which, in turn, requires more frequent maintenance measures.

Drive / Principle	1 mechanical	2 electric	3 hydraulic
1	spindle jack	electric motor	scissor lift
2	scissor lift	electric hoist	–
4	toothed belt drive	electric chain hoist	–
5	chain drive	–	–

Table 3-8: Drives for discontinuous split log transport

Continuous conveyors are another alternative for the transportation process. However, to dose split logs and to charge the rotary feeder with the exact amount of fuel at the correct time, an additional process step to singularize split logs is required. Thus, different forms of belt and chain conveyors are viable principle solutions for the transport. In order to transport split logs from the storage location to the rotary feeder these conveyors have to manage different altitudes. With regard to the steepness of the design it has to be guaranteed that split logs do not lose their grip while being transported as well as they should not slip downwards. In other words, form or force closure between split logs and the conveyor have to be maintained until the end position is reached. Table 3-9 illustrates several relevant types of continuous conveyors and related attributes.

Variant / Attribute	1	2	3
Type	belt conveyor	chain conveyor	oscillating convey-or
Form	steep belt conveyor	scraper conveyor	trough conveyor
Location	from storage to top of rotary feeder	–	–
Quantity	one conveyor	multiple conveyors in series	–

Table 3-9: Solution principles for continuous split log transport

3.3.2.4 Positioning

Depending on the type of conveyor split logs have to be positioned in yet a further process step, to ensure that the rotary feeder is charged appropriately. Split logs must be allocated in correct position, orientation and time. One of the demands stated in the list of requirements in chapter 3.1 claims that the split logs' orientation has to be parallel to the rotary feeder and alongside the combustion chamber.
HET's first prototype (see chapter 1.1) uses a take-off tunnel to align and position single pieces of split log directly above the rotary feeder. Split logs are picked and transported with a customized and sharpened mandrel. The mandrel is connected to a floating bearing, which allows the split logs to be turned into the correct position when entering the take-off tunnel.
Another alternative is to position split logs by using a take-off fence. The fence is attached in such a way that split logs are aligned directly above and parallel to the rotary feeder before the single pieces fall off.
A principle solution of continuous conveyors is to use an intermediate container. This facilitates controlling the correct amount and actual position of split logs before entering the rotary feeder. To maintain a continuous operation of the automated feeding process, it is crucial to ensure that split logs do not get wedged together outside of or inside the rotary feeder.
Table 3-10 illustrates potential solution principles to accurately fulfill the positioning function.

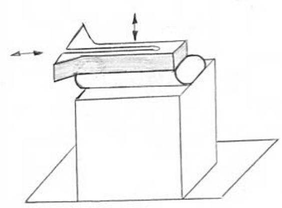
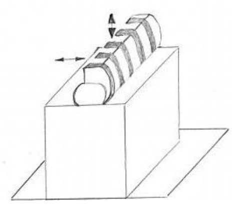
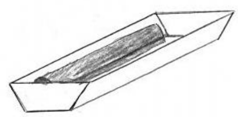
Variant / Attribute	1	2	3
Type	take-off tunnel 	take-off fence 	container, bucket 
Form	alignment and positioning outside rotary feeder	positioning of filled container inside rotary feeder	conveying of loose split logs into rotary feeder
Location	above	inside	circumjacent
Quantity	one single split log	one or two large split logs	one to three small split logs
Principle	electrical drive	mechanical back-pressure	gravity, vibrating or sliding surface

Table 3-10: Solution principles for positioning split logs

3.3.2.5 Disconnect

The last function is to terminate the connection between split logs and the conveying system at the correct position and time.
Material handling systems that use force closure, such as grippers, have to terminate the connection of a gripper or clamp above the rotary feeder. Split logs, then, directly fall into the rotary feeder or onto a chute or funnel, which leads the fuel wood into the rotary feeder.
Split logs can also be transported with additional forms of force closure. A mandrel, for instance, can be used to pierce the split logs and transport them to the rotary feeder. In this case counter-pressure has to be applied in order to strip off the split logs at the desired position. The existing prototype positions split logs inside a take-off tunnel and removes the logs from the mandrel by an upward movement of the mandrel through a stripper plate.
Conveyors that work with a form closure technique, as for example the bucket conveyor, by their design either terminate the connection automatically or empty the container at the end position.
Table 3-11 illustrates different ways of terminating the connection between split logs and the conveying system.

		Attribute \ Variant	1	2	3
Working Geometry	Working Surfaces	**Type**	force closure	form closure	material closure
		Form	clear filled container / volume	loosen grip / clamp	remove mandrel / screw
		Location	inside rotary feeder	outside rotary feeder	circumjacent
		Size	one split log	one or two large split logs	one to three small split logs
		Quantity	one container, mandrel, gripper	multiple containers, mandrels	–
	Working Motions	**Type**	translation	rotation	translation & rotation
		Form	straight motion	non-linear	–
		Direction	horizontally	vertically	–

Table 3-11: Solution principles for disconnecting

3.3.3 Systematic Combination of Solution Principles

The goal of this chapter is to elaborate one or more principle solutions. In chapter 3.3.2 solution principles for each individual function were determined. To generate a solution that fulfills the overall function of the split log feeding system, the solution principles of each function are systematically combined.
Only solution principles that were selected according to eliminated or preferable criteria, as described in chapter 2.7, are used for the systematic combination. The solution principles are entered into a classification scheme, which is also referred to as morphological box, and thereby organized according to their related functions. At least one solution principle of each function has to be selected in order to generate a combined solution. Table 3-12 illustrates the classification scheme used for the combination, which resulted in three different solutions that each are represented in a different color. These solutions are specified below.

The first principle solution represents a split log feeding system, which is based on a discontinuous transport of split logs. This means that a mechanical gripper collects split logs from various positions across the stack. In other words, the gripper picks up single pieces by clamping them on both their sides, which have cut surfaces. The transport is executed in horizontal and vertical motions. First, a lifting column elevates a single split log from the stack and transports it horizontally to the rotary feeder with the help of a guide rail system. Whereas the lifting column is driven by an electrical hoist, the rail guide system uses a belt drive for the horizontal transport. To charge the rotary feeder, split logs are aligned and positioned directly above it. The gripper releases the pressure, when a control signal is sent. Figure 3-7 illustrates solution principle Nr. 1.

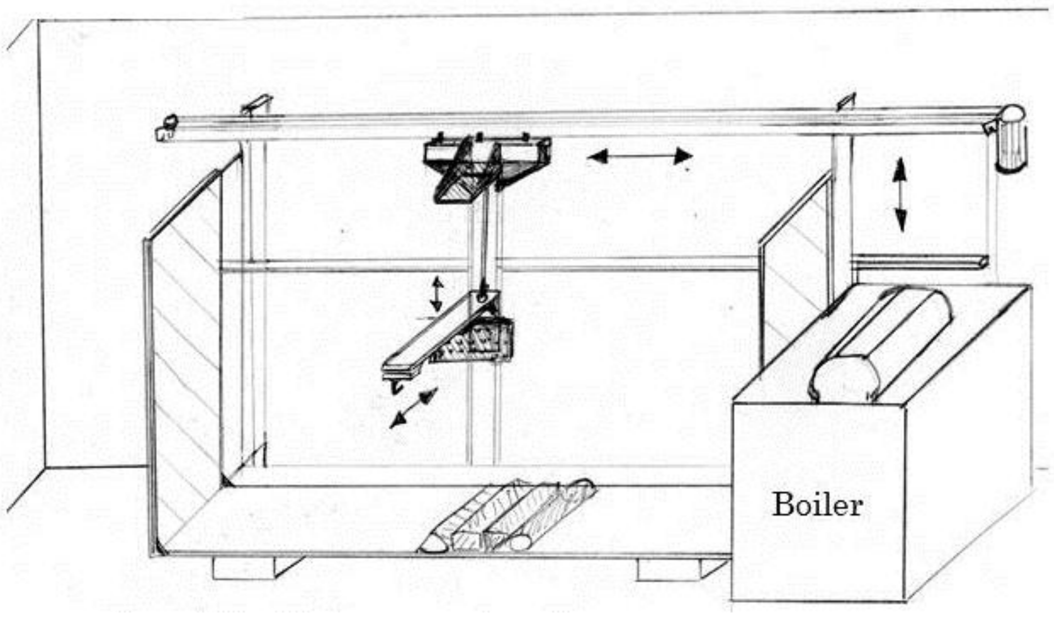


Figure 3-7: Principle solution Nr. 1

The second principle solution is mainly characterized by the utilization of a scraper conveyor for the feeding process by means of a container that stores the split logs with the help of horizontal segments. From each segment the split logs are conveyed horizontally to an intermediate storage container where sensors check for the correct amount that is to be used. As soon as the sensory check is successfully completed and the required control signal sent, a specific amount of split logs is vertically lifted to a determined altitude above the rotary feeder. Then, split logs slip down along a chute or funnel and directly slide into the rotary feeder. The solution principle is illustrated in Figure 3-8.

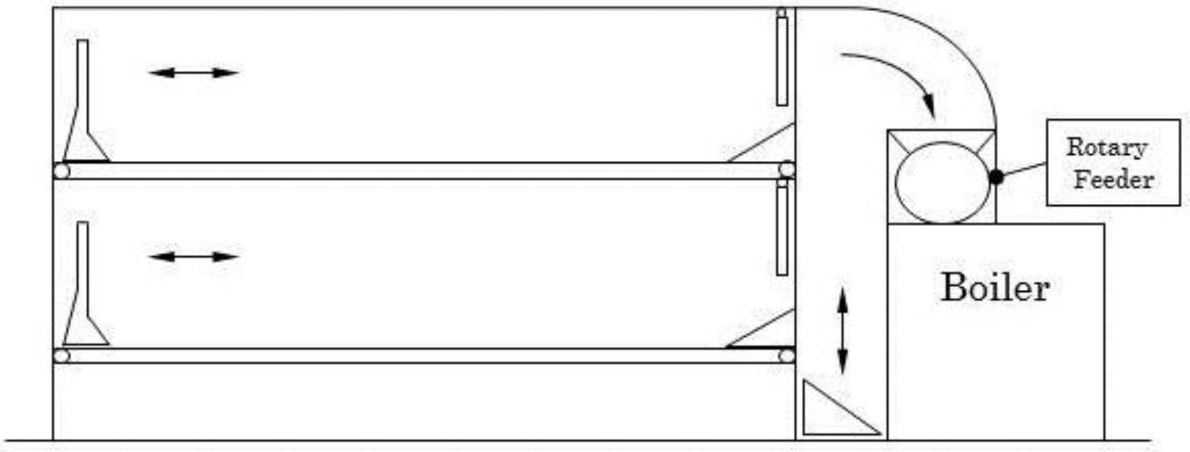


Figure 3-8: Principle solution Nr. 2

The third principle solution also uses a continuous material handling system. Split logs are stored and stacked in a storage container from the bottom of which a first scraper conveyor transports them into a collection container. Thereafter split logs are elevated by a second conveyor. The steepness of the design ensures that only single pieces of split log are transported. The end of the conveyor is connected to the rotary feeder. When the required control signal is sent, single pieces of split log enter the rotary feeder. Solution principle Nr. 3 is illustrated in Figure 3-9.

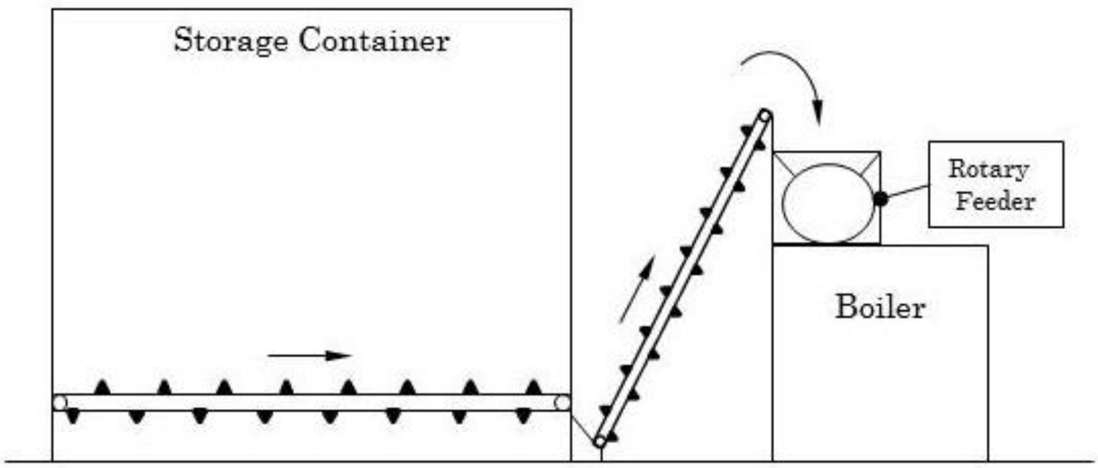


Figure 3-9: Principle solution Nr. 3

1. Store Split Log	stacked split log	storage container	split log stacked on a pallet
	one entire stack	horizontal segments	
	gathering from fixed position	gathering from variable positions	
2. Collect Split Log and Establish Connection	form closure	force closure	material closure
	container / defined volume	gripper	mandrel / screw
	skin surface	cut surface	
	1 single split log	multiple split logs	
	lifting column	telescopic lift	metallic spring
	electric hoist	electric chain hoist	scissor-lift
3. Transport Split Log	horizontal + vertical motion	guided motion	linear inclined
	cealing installation	on the ground	
	linear slide bearing	rail guide systems	spindle drive
	chain drive	belt drive	
	belt conveyor	scraper conveyor	oscillating conveyor
	one conveyor	multiple conveyors in series	
4. Position Split Log	take-off tunnel	intermediate container	take-off fence
	inside rotary feeder	above rotary feeder	
	electrical drive	mechanical back-pressure	gravity+vibrating/sliding surface
5. Disconnect	remove mandrel/screw	loosen grip/clamp	clear filled container/volume
Combined Solutions:	Principle Solution Nr. 1	Principle Solution Nr. 2	Principle Solution Nr. 3

Table 3-12: Morphological Box

3.3.4 Evaluation

The next step is to evaluate the solution principles, which were gathered in chapter 3.3.3. Therefore, a technical-economic analysis according to VDI guideline 2225 is carried out. In order to assess the principle solutions as objective as possible two additional persons, who are familiar with the project, joined the evaluation process. Moreover, before the evaluation took place, criteria for a final decision-making were discussed and agreed upon by the project's team members. Only a small number of criteria were found to be more important than the rest and assigned twice the weight. The evaluation was carried out function by function, in order to be able to compare solutions directly with one other. After the evaluation process had been finished, each solution's score was determined.

VDI guideline 2225 suggests that a solution does not necessarily have to be automatically selected, just because of the highest earned score. If there only is a marginal difference between the scores of the top-scoring solutions, the project team ought to consider these solutions in a second step.

The evaluation of the solutions and their determined scores are illustrated in table 3-13. Overall, solution #3 earned the highest score although the difference to solution #1 was a mere four percent. After a second evaluation of the two remaining solutions and a subsequent group discussion with an additional exchange of preferences, solution #1 was selected. The main reasons for choosing solution #1 were the transport of single split logs with the associated simpler dosage process and lower overall production costs.

Main Attributes	Nr.	Evaluation Criteria	w	1				2				3			
				B.	Pa.	Pe.	øP	B.	Pa.	Pe.	øP	B.	Pa.	Pe.	øP
Functionality	1	split logs are easy to collect	1	2	2	2	1,5	3	3	3	2,3	3	3	2	2,0
	2	efficient use of available space	2	2	2	3	3,5	1	2	1	2,0	2	3	3	4,0
	3	split logs are easy to dose	2	1	3	2	3,0	2	2	2	3,0	3	4	2	4,5
	4	safe transport	1	3	3	3	2,3	3	3	2	2,0	2	2	1	1,3
Working Principle	5	high overall system reliability	1	2	3	2	1,8	3	3	1	1,8	2	2	1	1,3
Image & Design	6	simple / robust / down-to-earth	1	2	2	2	1,5	3	1	1	1,3	3	3	3	2,3
Manufacturing	7	low level of complexity	1	3	2	1	1,5	2	1	1	1,0	3	3	3	2,3
Use	8	simple use & good accessibility	2	3	3	3	4,5	1	2	1	2,0	2	2	1	2,5
Maintenance	9	simple / safe / cheap	2	2	2	2	3,0	1	1	2	2,0	3	3	2	4,0
Costs	10	low operating and ancillary costs	2	2	2	1	2,5	2	1	1	2,0	3	3	3	4,5
	11	low cost of production	2	2	2	2	3,0	1	1	2	2,0	2	2	2	3,0
		Score					28,0				21,3				31,5
		W_t					0,412				0,313				0,463
		Ranking					2				3				1

Scale of values: 0...unsatisfactory / 1...just about acceptable / 2...sufficient / 3...good / 4...very good

Participants: Mr. DI Bauer (B.), Reinhard Pausakerl (Pa.), Boris Petrovic (Pe.)

Table 3-13: Evaluation according to VDI 2225

3.4 Divide Into Realizable Modules

The next design step is to divide the elaborated and selected principle solution of chapter 3.3.3 into realizable modules. The goal is to develop a modular structure of the split log feeding system, which illustrates the major assemblies and elements.

With respect to the list of requirements and the elaborated required system functions the combined solution was determined. Figure 3-10 illustrates a conceptual drawing of the principle solution and the three separate modules of which the system consists. Thereby each module interacts with one another.

The structuring of the product design into modules required a consideration of demands and wishes stated in the requirements list. Some requirements, which were important in this design stage, were simplicity as well as robustness and high reliability of the product.

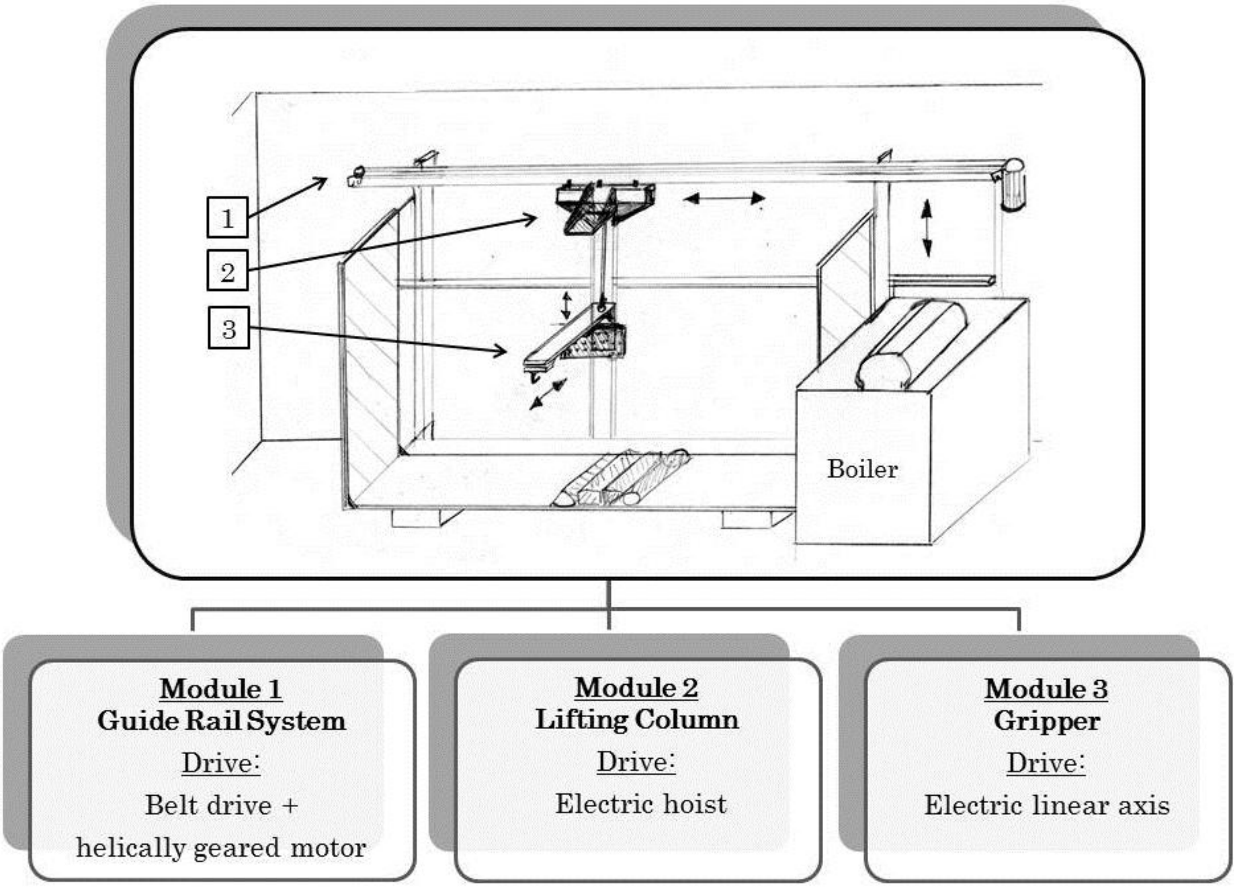


Figure 3-10: Modular product structure

- Module 1: The guide rail system. It is attached to a metal framework and consists of a guide rail and a toothed belt drive.

- Module 2: A lifting column which is used for the vertical transport of split log. An electric hoist which is situated on top of the lifting column constitutes the drive for the vertical motions of the gripper. The lifting column is horizontally guided through the rail guide system.

- Module 3: A mechanical gripper that collects single pieces of split log from the stack and charges the rotary feeder. The technical principle used by the gripper consists of two functions. First, it gathers split logs by punctually establishing a connection on one of their sides, and secondly, clamps the logs by using a counter plate with an abrasive surface. For the drive of the clamping mechanism an electrical linear axis was selected.

3.4.1.1 Functionality Test

Before further effort and time is put into the development of the modules for the split log feeding system, it has to be determined if the system functions are realizable. Therefore, certain process steps and functions, which seem to have a potential for causing issues during operation, have to be tested by performing experiments.
One major function of the split log feeding system is to collect split logs from a stack by establishing a safe connection to it.
In chapter 2.1.1.2 the characteristics of split logs were analyzed in order to be able to deliberately use or avoid certain properties. Thereby it was determined that the plain and perpendicular cut surface of split logs and round wood can potentially be utilized for the product's development. Especially the design of the gripper and its functionality can be simplified when based on a constant parameter, such as the contact surface.
The experiment was set up to test the described gripper functions as well as the design measures for compensating the potential risk of losing grip on one of the split logs during operation. Figure 3-11 illustrates the experiment.

Figure 3-11: Collecting split logs as part of the functionality test

In order to avoid gathering multiple logs, the gripper clamps split logs with the help of a punctual contact surface on one of their sides and a counter plate on the other side.
When clamping split logs, it has to be ensured that the gripper does not lose grip. To remedy such behavior, the counter plate has an abrasive surface to increase friction and edged sides to avoid split logs slipping off sideways.

The experiment was performed as follows:

- First, a framework was built for stacking split logs upon it. In the next step a tube was attached to the framework as vertical guidance for the clamp mechanism.

- In the next step the designed clamp mechanism was lowered to the height of the split logs.

- Then the split log was clamped between the two contact surfaces.

- As depicted in figure 3-12 it was also tested, if it is possible to safely collect split logs from the stack when its position is tilted or inclined.

- Finally the clamp mechanism was checked for accurate fit of the connection.

Figure 3-12: Collecting split logs which are in tilted or inclined position

The evaluation of both the gripper's functionality and the accurate fit of the connection was carried out by a series of ten tests with split logs in regular, tilted and inclined position.
The results of the performed experiment showed that the selected gripper principle, which is based on clamping split logs between a punctual surface and a counter plate, appropriately fulfills its functionality. Due to the abrasive surface and edged sides of the counter plate it was also possible to appropriately collect and clamp the split logs, which were in tilted or inclined position. The whole series of tests was successfully performed.

In addition to the performed experiment, other process parameters and conditions also contribute to ensuring the functionality of the gripping system. The split log's weight of about only 4 kg and the requirement of low transport speed and accelerations decrease accruing operational forces as well as required clamping forces and allow for a safe connection during transport.

Based on the results of the experiment the following conclusions for the operational behavior can be drawn:

- Single withdrawal of split logs is ensured by combining a punctual and a planar clamping surface.

- Due to low operational loads a safe connection can be established and maintained by low clamping forces.

- The abrasive surface and edged sides of the counter plate ensure a safe grip of the split logs during transport.

- Self-locking trapezoidal spindles prevent a loss of clamping force.

- Low operational requirements regarding the acceleration and speed of moving parts favor a safe grip and transport of split logs.

3.5 Develop Layouts of Key Modules

The task of this design stage is to develop layouts of key modules. Therefore components for each module defined in chapter 3.4, need to be designed or selected. The reasoning for the selection and the explanation about the design of each component is then described in the next step. Even though the operational loads during the process are very low, the dimensioning of some critical components is required and therefore part of this design stage. In this development step it is important to make use of standardized components to minimize the total costs of production, if possible. The components of each module are then assembled and illustrated. The purpose of the layouts is to appropriately represent the concept of the system. The layouts need to include all relevant parts, which are required for accurate functionality. Three-dimensional drawings are created by using the design software Creo-Parametric-1.0. Even though it is not a part of this thesis to elaborate the associated control system, considerations concerning required sensor technology are made in order to be able to elaborate a sequence for the automated process.

3.5.1 Guide Rail System

The guide rail system has to ensure horizontal guidance of the lifting column and gripper between split log stack and rotary feeder. It also requires a drive for horizontally moving the lifting column. The system was selected due to its cost-effectiveness and robust design. The guide rail system consists of the following components:

- Guide Rail
- Hangers
- Sockets
- Toothed Belt Drive

For the guide rail standard parts from a company called *Bauernfeind GmbH* were selected. The rails are easy to extend and available as stainless steel variant or electronically galvanized rails. The lifting column is guided in the rail by two single-paired hangers. As depictured in table 3-14 the maximum load per hanger of the selected rail type *A3* is 50 kg.

Guide Rail – Maximum Load per Hanger		
Type	single-paired hanger	two-paired hanger
A3	50 kg	88 kg

Table 3-14: Technical data of the selected hanger type *A3*

With a resulting combined load of max. 100 kg the rail is sufficiently dimensioned for the horizontal transport of lifting column, gripper and transport good. Figure 3-13 illustrates the selected rail type *A3* and its dimensions.

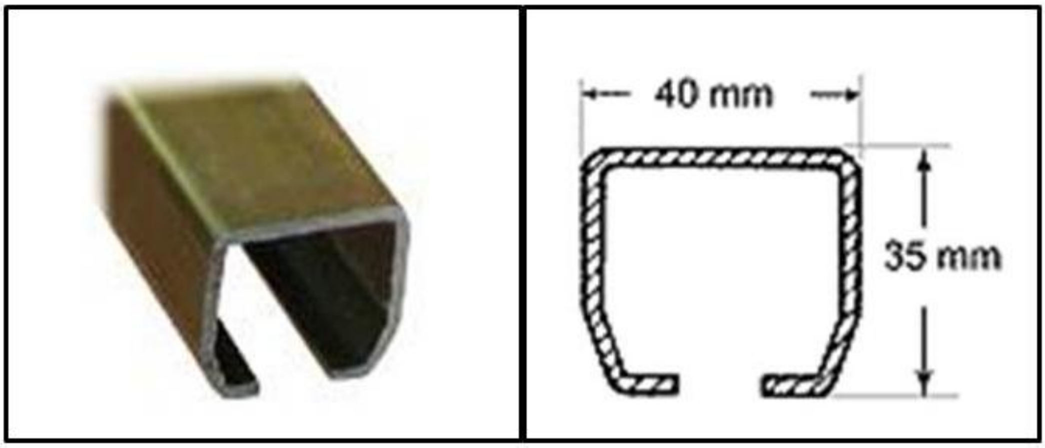
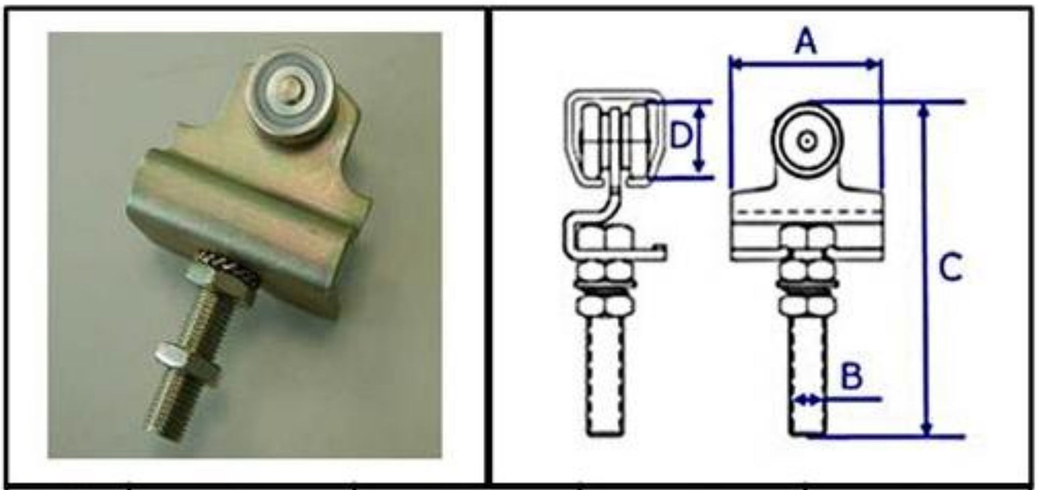


Figure 3-13: Guide rail of type *A3*
(Source: http://www.bauernfeind.at, 11.20.2012)

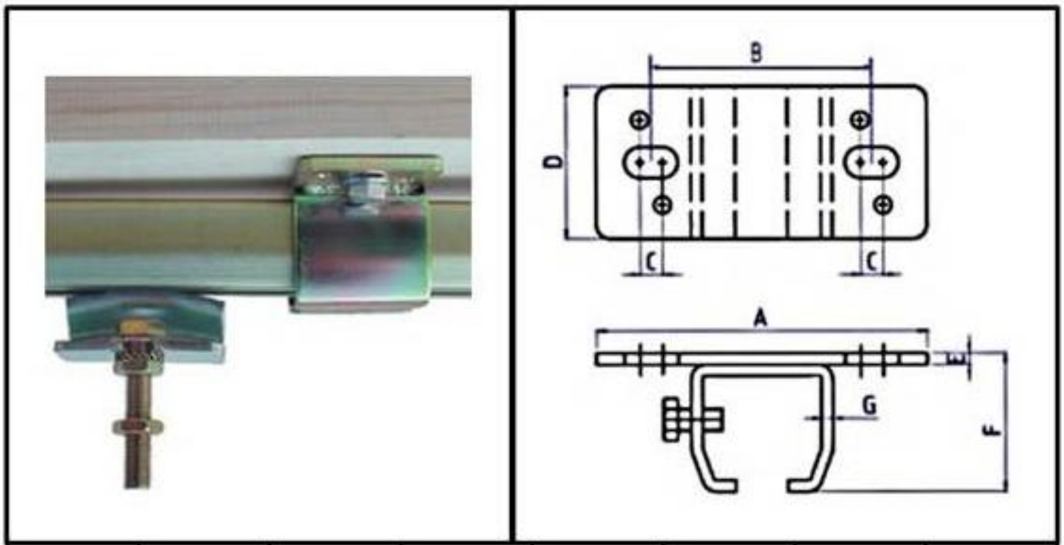
Due to low operational loads, single-paired hangers were selected. With respect to the guide rail type in use the matching hanger type is *A3*. Each hanger has a maximum load of 50 kg. Relevant dimensions for the design are illustrated in figure 3-14.



Type	A	B	C	D
A3	60	M12	124	28

Figure 3-14: Hanger of type *A3*
(Source: http://www.bauernfeind.at, 11.20.2012)

For fixing the guide rail to the metal framework galvanized ceiling sockets of type A3 were used. Relevant dimensions and the correct installation are illustrated in figure 3-15.



Type	A	B	C	D	E	F	G
A3	117	78	8	54	4	49	4

Figure 3-15: Sockets of type *A*
(Source: http://www.bauernfeind.at, 11.20.2012)

3.5.1.1 Toothed Belt Drive

The selected drive for the horizontal guide rail system is a toothed belt drive produced by the company *Lenze*. Its main purpose is to drive the lifting column and gripper along the guide rail. In contrast to chain drives, toothed belt drives do not require lubrication and are therefore suited better for the application in dusty split log storage rooms. The belt drive consists of the following parts:

- Toothed Belt
- Helically Geared Motor with Incremental Encoder
- Belt Pulleys
- Bearing Bushes
- Mounting Plate

Figure 3-16 illustrates the assembled components of the guide rail system. The gearbox's flange enables horizontal installation on the mounting plate. Guide rail and socket as well as the mounting plate are fixed to the metal frame.

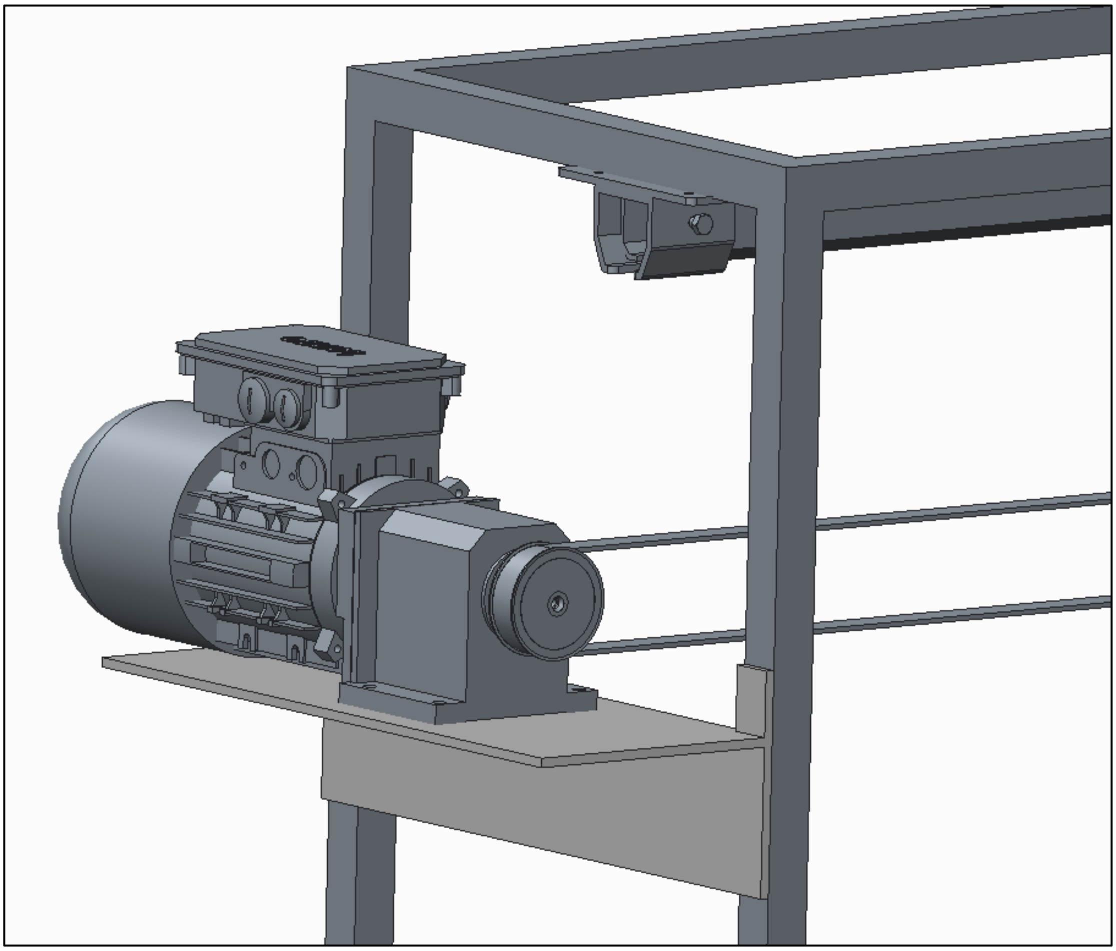


Figure 3-16: Rail guide system

The used belt type is a *PU Powergrip HTD 5M* with a belt width of 15 mm. In addition to that, the drive also consists of two belt pulleys *Powergrip HTD TL34-5M-15/3F* and bearing bushes. With regard to particular suitability for horizontal and linear motion an open toothed belt was selected. Additionally, a mounting plate of type *5M-15* is used to tighten the belt and to connect the belt to the lifting column.

With respect to low system requirements and operational loads a helically geared motor by *Lenze* with a rated power of only 0.09 kW was selected. The rated torque is 0.63 Nm and the rated rotational speed is 1375 min^{-1}. The used transmission with a gear ratio of 10.033 resulted in a rotational output speed of 137 min^{-1} and an output drive torque of 6 Nm.
Relating to the control system, the motor also integrates an incremental encoder for gathering positioning data of the lifting column. The three-dimensional drawing, which was used for the layout of the key module, was also provided by *Lenze*.

3.5.2 Lifting Column

The lifting column is responsible for the vertical movement of the gripper and the collected split logs. The overall design was influenced by an analysis of technical systems and the subsequent combination of applied technical solutions. To comply with the requirements of the split log feeding system, suitable solutions were adapted accordingly. Useful technical systems for the analysis were manipulators and mobile lifting equipment, which is used to facilitate manual handling by mechanically lifting components and heavy machinery.

According to the design's requirements, the goal was to develop a robust and cost effective system. Thus, all parts of the lifting column were selected respectively.

The system comprises of the following parts:

- Supporting Structure
- Electric Hoist
- Linear Guide
- Lower Horizontal Guiding
- Fastening for Toothed Belt's Mounting Plate

The supporting structure of the lifting column consists of standard profiled tubes, flat iron and angle steel. All materials used for the supporting structure are by the company *Bauernfeind GmbH*.

The electric hoist, *Einhell BT 250*, used for driving the gripper, is a standard and reasonably priced bought-in product. Figure 3-17 illustrates the electric hoist and its technical data. It is equipped with a non-rotational wire rope with a diameter of 3 mm and a load hook to connect to the gripper. The product safety and controllability is provided through an automatic break, an automatic limit stop function and a thermo switch.

Electric hoist – Einhell BT 250	
Electric supply	230 V | 50 Hz
Max. power	500 W
Max. load	125 kg
Max. lift height	11.5 m
Max. lift speed	8 m/min

Figure 3-17: Electric hoist

For the vertically installed linear guide a system by the company *IGUS* was selected. The system has a modular structure and features a high level of flexibility of design. Figure 3-18 illustrates the *IGUS* linear guide. Due to its dry-tech technology, furthermore, it is free of maintenance. The selected linear guide type *DrylinW 20-80* comprises of a hard-anodized aluminum double rail and four separately adjustable housings with built-in gliders. The clearance of the bearing was extended from 250 mm to 300 mm in order to accomplish improved vertical guidance.

Figure 3-18: Linear guide

Therefore, the regular *IGUS* mounting plate was replaced by an individually designed part. The system operates without lubrication, and thus is well suited for dusty and dirty environments of split log storage rooms. The linear guide is predrilled and easy to attach to the supporting structure of the lifting column.

Figure 3-19 illustrates the assembled lifting column, which is guided by a rail guide system at the top and a horizontal guiding located lower at the bottom. The design of the lower horizontal guiding for the lifting column was realized by using standard guide rolls in combination with u-shaped section steel. Two rolls are placed on the inside and outside of the section steel. The guide rolls, then, are fitted on a mounting plate on the lifting column, and the sectional steel is attached to the framework of the split log storage. An additional fixing plate is attached to the top of the lifting column. It is used to fix the belt drive's mounting plate on it, which establishes the connection between lifting column and the toothed belt drive.

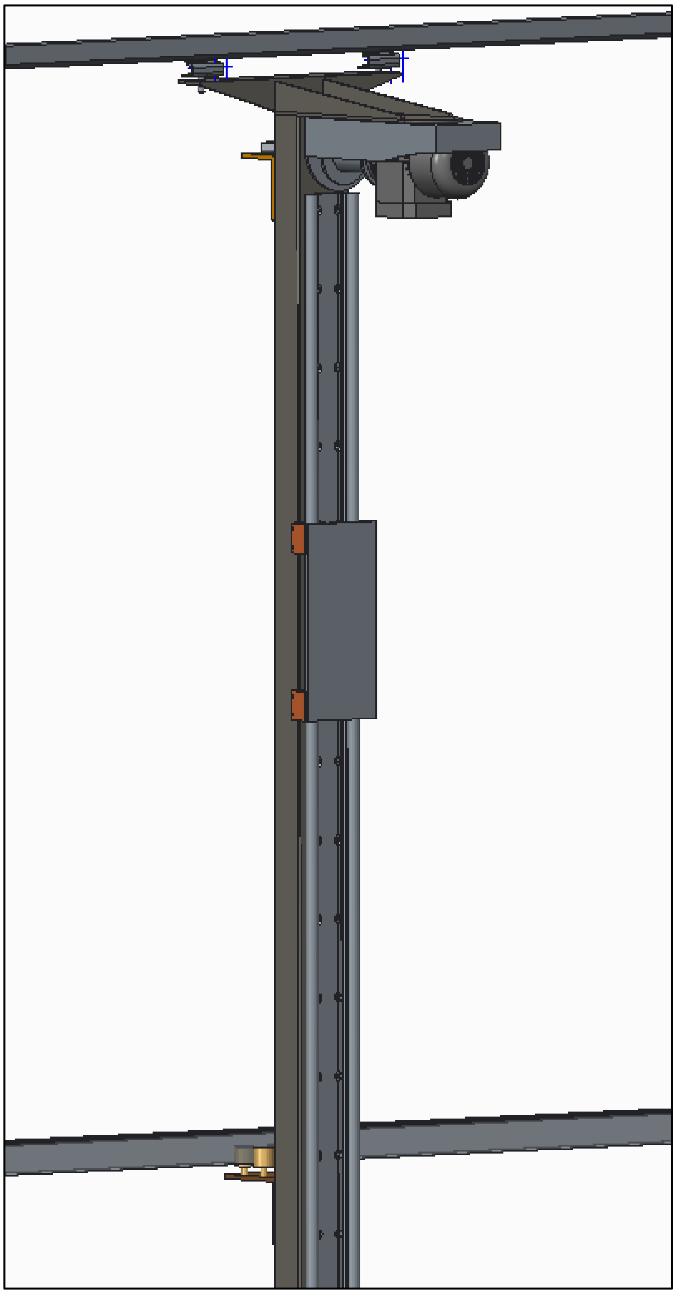


Figure 3-19: Lifting column

3.5.3 Gripper

The task of the gripper is to collect split logs from the stack and to safely transport them to the rotary feeder, where the grip then is released. The gripper is attached to the lifting column by a mounting plate and consists of the following parts:

1. Supporting Frame
2. Electrical Linear Axis
3. Clamping Lever
4. Spring -loaded Clamping Pin
5. Measuring Head
6. Counter Plate

Figure 3-20 illustrates the assembled components of the gripper.

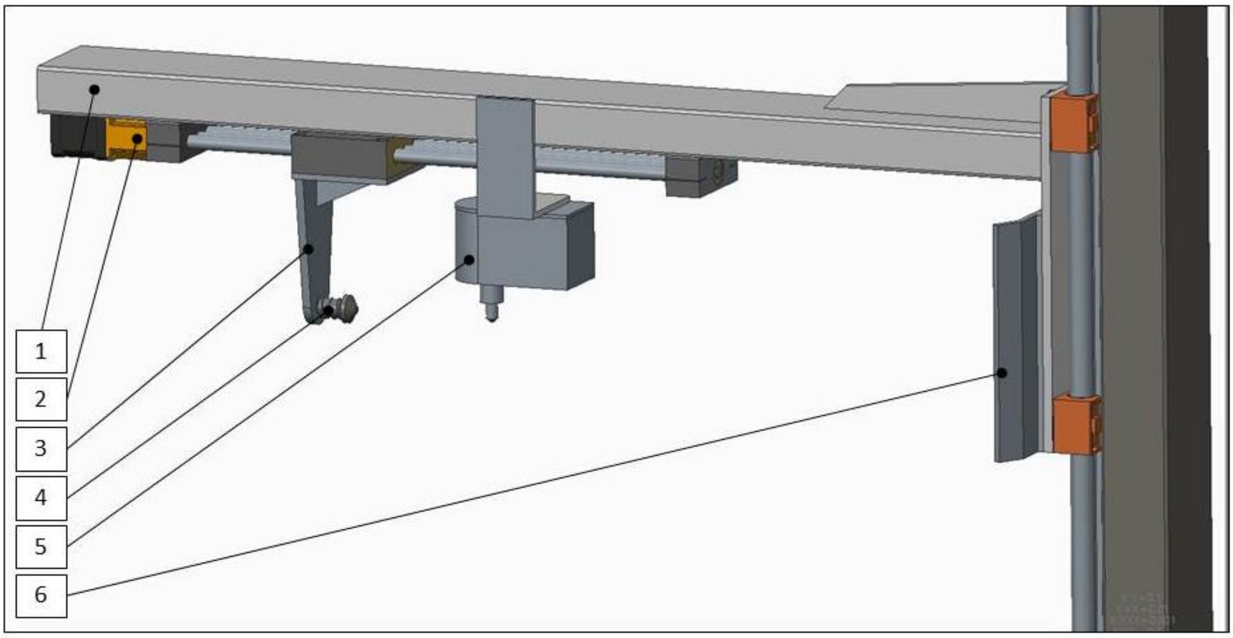


Figure 3-20: Gripper attached to lifting column

The supporting frame is horizontally attached to the mounting plate and comprises of a standard profiled tube and a stiffening plate. To connect the cable wire of the electric hoist to the gripper, the stiffening plate contains a mounting hole which is positioned in close distance to the lifting column.

3.5.3.1 Clamping Mechanism

Split logs are collected from the stack by clamping single logs between the clamping lever and the counter plate. The clamping lever is attached to the carriage of the electrical linear axis. Piece by piece split logs are pushed sideways on the top layer of the stack, that is, from the stack against the counter plate. The spring-loaded pin is part of the clamping lever and its small contact surface ensures that only single split logs are collected. The pin is spring-loaded to ensure a safe connection during transport. Thus, even in case of an electrical power outage, the gripper does not lose split logs. An established connection to the split logs is ensured, as soon as the compressed spring-loaded pin activates the limit switch and stops the clamping process. The tip of the pin was flattened to avoid a piercing into the split logs. Considering the size and different forms of split logs (see chapter 2.1.1.2), it was determined that the contact point of the spring-loaded pin needs to be set two centimeters below the contact point of the measuring head. The required gripping force F_G was determined according to chapter 2.2.1:

- Approximate Mass of Single Split Logs: 4 kg
- Safety Factor S = 3 for Movements in Multiple Axial Directions
- Static Friction Coefficient $\mu_0 = 0{,}5$ (Wood - Metal)

$$FG = \left(\frac{m \cdot g \cdot S}{2 \cdot \mu 0}\right) = 117 \text{ N}$$

A gripping force of 117 Newton is sufficient for a safe and automated transport of split logs. Figure 3-21 illustrates the clamping process as well as the resulting acting forces.

The design of the clamping counter plate was built for high friction and slip resistance. A corrugated sheet metal with edged sides ensures a safe connection and prevents split logs from slipping off sideways. The design also allows for gathering split logs which lie on the stack in tilted or inclined position.

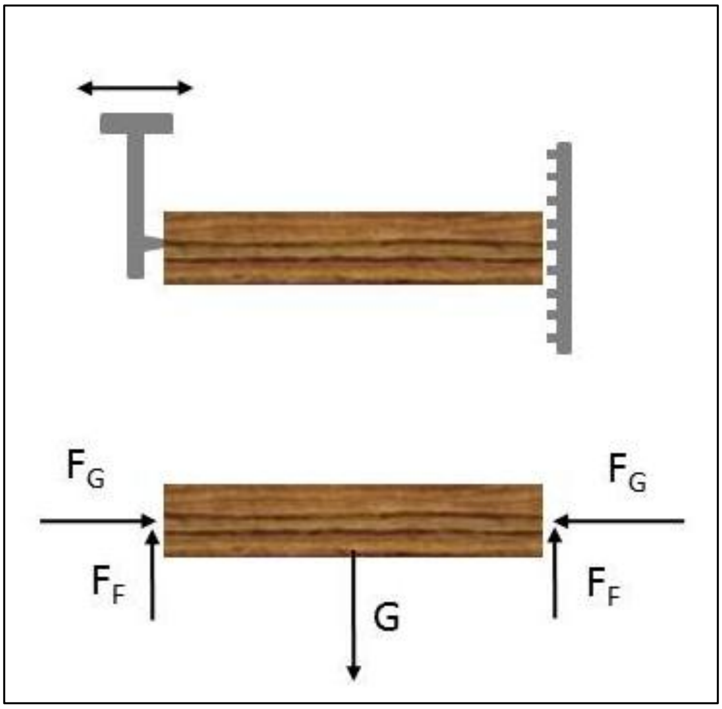


Figure 3-21: Clamping process

3.5.3.2 Electrical Linear Axis

To drive the clamping mechanism an electrical linear axis by the company *IGUS* was selected. The system consists of the following components:

- Stepper Motor Nema 17
- Linear Axis SHT 12
- Motor Flange
- Coupling

The product version *SHT 12* is a standard linear axis from *IGUS*. It is a cost effective solution and was also chosen with respect to its lubricant-free *TR 10x2* trapezoidal spindle. It is free of maintenance, and therefore, suitable for the application in dusty environments of split log storage rooms. For the linear axis a stroke of 350 mm was selected. The maximum axial carrying capacity is 700 N, and thus, adequate for clamping split logs with a required force of 117 N. Figure 3-22 illustrates the assembled components of the electrical linear axis.

Figure 3-22: Electrical linear axis

The motor *IGUS NEMA 17* was also selected according to the required gripping force determined in chapter 3.5.4.1. Stepper motors are cost effective and the small, compact design enables for direct attachment to the supporting metal frame of the gripper. Due to a standardized connector plug, the motor can be connected to common motor control systems. The stepper motor and its technical data are illustrated in Figure 3-23.

Stepper motor – IGUS NEMA 17	
Electric supply	60 V | DC
Holding torque	0.5 Nm
Flange dimension	42 mm
Step angle	1.8°
Product weight	0.32 kg

Figure 3-23: Stepper motor

To ensure a reliable gripping process at the operating points of the motor's characteristic curve, the required driving torque Mt of the motor was determined. The *IGUS* linear axis *SHT 12* with a 18x2 trapezoidal spindle (spindle pitch: p=2) has an efficiency factor η of 20 to 48 percent, when operated under dry running conditions. The required gripping force F_G is 117 Newton. Formula 3-1 was used for the calculation.

$$Mt = \left(\frac{FG \cdot p}{2 \cdot \pi \cdot \eta}\right) \qquad \text{Formula 3-1}$$

The required driving torque for the lowest efficiency factor of 20 percent is 0.187 Nm. The holding torque of the *Nema 17* motor is 0.5 Nm, and thus, sufficient for the appropriate transport of split logs.

3.5.3.3 Measuring Head

The measuring head is responsible for determining the height of split logs along the wood stack throughout the feeding process, in order to be able to collect split logs layer by layer and piece by piece from the stack's top to its bottom. Therefore, the measuring head is equipped with two optical laser distance sensors by *SHARP*, which operate in different measurement ranges. When the gripper is moved from one end of the split log stack to the other, the first sensor *SHARP GP2Y0A02YK* measures a distance ranging from 20 to 150 cm. Then, the second sensor *SHARP GP2D150A* measures in a closer distance of 3 to 30 cm. With the gathered measurement data a control system determines the highest position of split logs on the stack. Thereafter, the gripper is directed to this position accordingly. In the next step, the gripper moves down and approaches the split log's surface to push a contact pin inwards until a limit switch is activated, which stops the movement of the gripper. Figure 3-24 illustrates the measuring head.

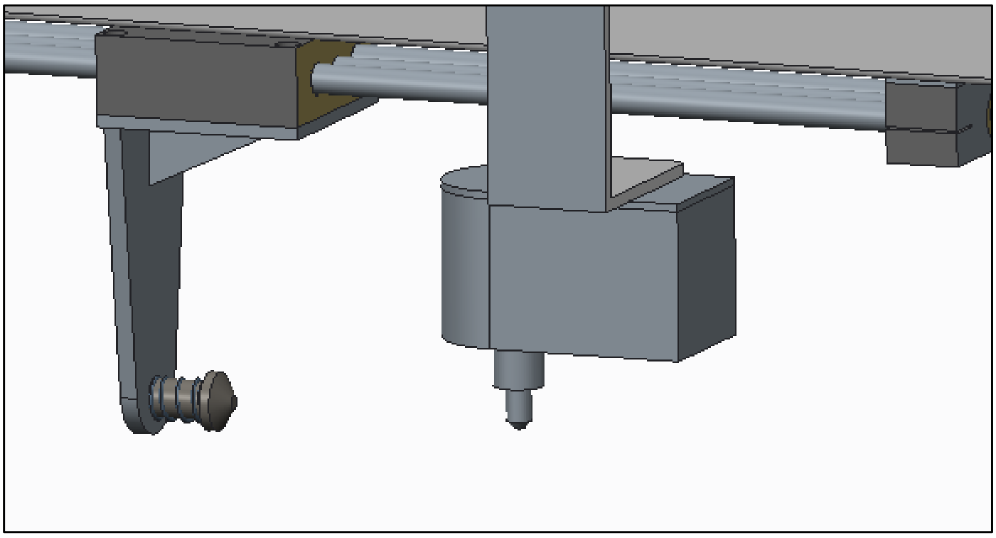


Figure 3-24: Measuring head

4 Results

In chapter three the key modules, which are required for the overall layout of the split log feeding system, were developed according to a step-wise systematic approach. The resulting three key modules were designed based on defined task objectives and derived system requirements. Then, the overall function of the system was elaborated. In the next step a function structure, consisting of all of the system's main and sub functions was generated based on the main material flow, ancillary energy and signal flow. The features of the key modules were then further designed according to these functions. Consequently the results are the combined key modules in form of an overall layout, which is designed to fulfill all functions of the split log feeding system. The results, furthermore, include a list of all relevant components and a cost estimation of the system. The elaborated results and the according documentation then provide *HET* with required data for finalizing the design and developing a control system.

4.1 Overall Layout

In the overall layout the three key modules, which were individually developed for fulfilling the system's main and sub functions, are assembled:

- Guide Rail System
- Lifting Column
- Gripper

The overall layout illustrates the functionality of the split log feeding system with all components of the key modules and puts it into context with the log wood gasification boiler and split log storage. Furthermore, an elaborated operational sequence, step by step, describes the feeding process from the initial storage to the final determined position, where the split logs enter the rotary feeder.

All selected components and individually designed parts of the automated split log feeding system along with the split logs' storage, a log wood gasification boiler, and the attached rotary feeder are illustrated in figure 4-1.

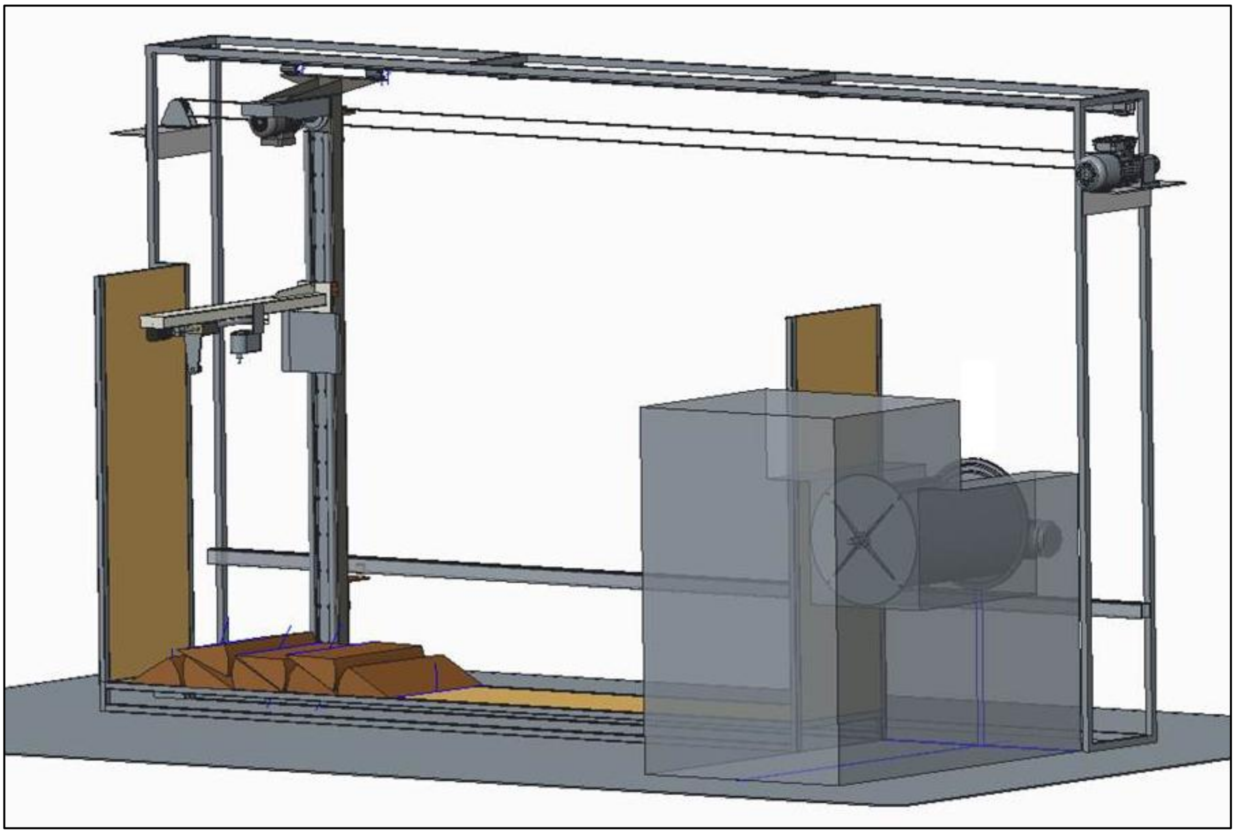


Figure 4-1: Overall layout

During the operation of the automated split log feeding system, the process requires a controlled interaction of all installed mechanical components, sensors, switches and the control system.
As stated in the list of requirements (see chapter 3.1), the wood log gasification boiler is charged with three to six split logs per hour. Thereby the system can operate with three different drives and in three different directions. The horizontal movements of the lifting column correspond to data gathered with the help of the motor's incremental encoder.

The resulting operational sequence is described in the following steps:

1.) **Switch on system:**	System is ready when gripper is in initial position above the rotary feeder.
2.) **Belt drive ON:**	Lifting column moves to the beginning of the stack of split logs. Gripper is at the top position of the lifting column.
3.) **Distance sensors ON:**	Gripper moves along the stack, while distance sensors perform measurements concerning the stack's height.
4.) **Limit switch (#1):**	Stops movement of the lifting column.
5.) **Control system:**	Evaluation of gathered data.
6.) **Belt drive ON:**	Positioning of the gripper above the highest measured point of the stack.
7.) **El. hoist ON:**	Gripper is lowered until contact with split logs is established.
8.) **Limit switch (#2):**	Stops electric hoist.
9.) **El. linear axis ON:**	Clamping process takes place.
10.) **Limit switch (#3):**	Spring-loaded pin activates limit switch and stops clamping process.
11.) **El. hoist ON:**	Lifting column elevates the gripper and turns off automatically at the top position.
12.) **Belt drive ON:**	Loaded gripper is positioned above rotary feeder.
13.) **El. hoist ON:**	Gripper is lowered to the rotary feeder.
14.) **El. linear axis ON:**	Gripper releases pressure of the clamping mechanism. Split log enters rotary feeder.
15.) **El. hoist ON:**	Gripper returns to initial position.

4.2 Estimation of Costs

In this chapter the costs for the main bought-in components, which are essential for the overall functionality of the system, are evaluated. Only in-house manufactured parts, components for the control system, and components, which result from a further detailed design, are not yet part of the cost estimation.

The components are structured in the modules rail guide system, lifting column and mechanical gripper. The estimation of costs includes a product description, the required amount of units, the item number, the supplier and the price per unit. The structured costs per module are illustrated in table 4-1, table 4-2 and table 4-3.

Module 1: Rail Guide System				
Product	**Unit(s)**	**Item Number**	**Supplier**	**Price/Unit**
Helically Geared Motor: *GST03-2M VBR 063C12*	1	15603700	*Lenze*	€ 363,14
Toothed Belt: *POWER-GRIP HTD 5M15,* 8500mm	1	50000036	*Lenze*	€ 59,70
Belt Pulleys: *POWER-GRIP HTD TL34-5M-15/3F*	2	13393636	*Lenze*	€ 4,56
Bearing Bushes: *Type 1008,* Bore14mm H7	2	13075508	*Lenze*	€ 2,40
Mounting Plate: *TYPE 5M-15*	2	13074081	*Lenze*	€ 8,52
Guide Rail: *A3* (3850 mm) 6m bar	1	LS36	*Bauern-feind*	€28,80
Socket: *A3*	4	LDM3	*Bauern-feind*	€ 6,50
Hangers: *A3* (single-paired)	2	LRE3	*Bauern-feind*	€ 11,90
			Subtotal 1:	**€ 532,40**

Table 4-1: Structured costs for the guide rail system

Module 2: Lifting Column				
Product	**Unit(s)**	**Item Number**	**Supplier**	**Price/Unit**
Electric Hoist: *Einhell BT250*	1	2255117	*Einhell*	€ 80,00
Linear Guide: *IGUS – Drylin W* (1850mm)	1	WS-20-80	*Igus*	€ 166,32
Guide Rolls (Ø30x40)	4	964163	*Bima*	€ 7,95
			Subtotal 2:	**€ 278,12**

Table 4-2: Structured costs for the lifting column

Module 3: Mechanical Gripper				
Product	**Unit(s)**	**Item Number**	**Supplier**	**Price/Unit**
Linear Axis *SHT12* Stroke: 350 mm	1	SHT-12-AWM-R-350	*Igus*	€ 200,70
Stepper Motor + Connector Plug: *NEMA 17*	1	MOT-AN-S-060-005-042-MA-AAAA	*Igus*	€ 116,40
Motor Flange: *NEMA 17*	1	MF-2040-NEMA17	*Igus*	€ 71,86
Coupling	1	COU-AR-K-050-100-32-32-B-AAAA	*Igus*	€ 35,88
Distance Sensor #1: *SHARP*	1	GP 2 Y0A 02 YK	*Conrad*	€ 24,54
Distance Sensor #2: *SHARP*	1	GP2D150A	*Conrad*	€ 26,72
			Subtotal 3:	**€ 476,10**

Table 4-3: Structured costs for the gripper

Overall Costs – Bought-in Components	
Module 1: Rail Guide System	€ 532,40
Module 2: Lifting Column	€ 278,12
Module 3: Mechanical Gripper	€ 476,10
Total:	**€ 1286,62**

Table 4-4: Total costs for bought-in components

The overall costs for the main bought-in components are summed up in table 4-4 and amount to € 1286,62. This estimation of costs does not consider quantity discount. According to the planned total production volume of several hundred units, a quantity discount of up to 40 percent is possible. Taking this into consideration, the maximum overall manufacturing costs of € 1600, which include the costs for all product parts and labor time, are achievable.

5 Summary

The main task of this thesis was to develop an automated split log feeding system for log wood gasification boilers. Furthermore, it was important to carry out the design process in accordance with a systematic step-by-step approach (VDI).

With very few exceptions, the feeding process of gasification boilers until today is executed manually due to the complex implementation and handling of split logs in automated processes. In the first stage of the development, these difficulties were limited by restrictions on the transport material. Only split logs, which fulfill the elaborated criteria, stated in the list of requirements in chapter 3.1, are used for the feeding process.

In addition to aforementioned agreed-upon requirements for split logs, the remaining demands of the system guided the design process from the first design stage on into a certain direction. The system's environment constituted one of the main restrictions for the design. The most common places for installing automated split log feeding systems are boiler rooms in the basement of detached houses. The storage space in such rooms is limited. Therefore, stacking of split logs in an organized way efficiently utilizes the available space. Furthermore, the choice of installed components was influenced by the dusty and dirty conditions in boiler and storage rooms. Thus, parts with dry-running technology and lubricant-free drive systems were preferably selected.

The low split log feeding rate of three to six pieces per hour in combination with discontinuous transport of single split logs called for a simple and cost-effective design. Therefore, all components as well as the supporting structural elements could be selected and designed based on low operational loads, which in turn minimize production and operational costs.

Collecting and transporting single split logs also facilitates charging the rotary feeder appropriately with the required quantity at the right time. It, furthermore, prevents possible system errors. Charging the rotary feeder with multiple split logs at once can cause a blockage of the feeder, if split logs are wedged together. To ensure the functionality of the gripper and the process of collecting single split logs, an experiment according to the system's requirements was set up and a series of tests was successfully performed.

Regular project meetings were hold to support the exchange of information and to give updates on the current state of the design process. Furthermore, the list of requirements was continuously updated until a final version could be generated. Group members also performed an evaluation of the elaborated principle solutions.

The estimation of costs listed in chapter 4.2 illustrated, that with respect to generated economies of scale, the production costs of the automated split log feeding system do not exceed the maximum threshold of € 1600.

In order to develop the product to a level of maturity, i.e., for it to enter the market (see figure 5-1), further measures are recommended. First, a final completion of the developed overall layout is required. Then, a practical realization with a prototype and complementary experimental setups are necessary to test the operational behavior as well as all functions of the automated split log feeding system. Based on these results the decision has to be made, whether or not further changes at the level of the product or its conceptual design are required, before the product finally can be released for production.

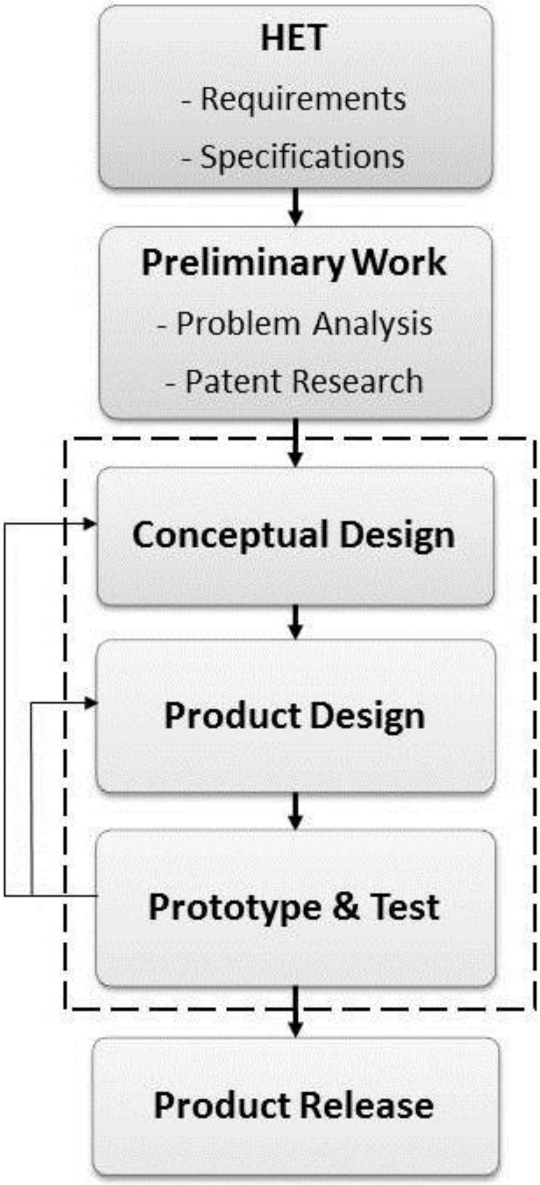


Figure 5-1: Further development steps

6 Directories

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6.2 List of Figures

6.3 List of Tables

7 Appendix

7.1 Appendix A – Technical Data

Technical data of the selected linear axis *DryLin SHT*.

DryLin® TR leadscrew drives

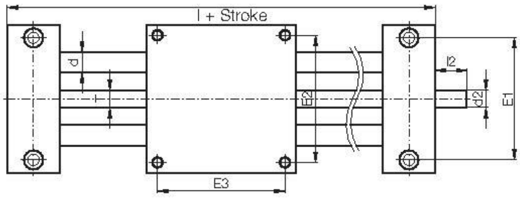
DryLin® SHT | Product Range | Trapezoidal Leadscrew

SHT – Standard

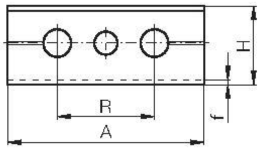
- Solid design
- Three different installation sizes
- Various materials for shaft and leadscrew
- Maintenance-free and corrosion-resistant
- TR 10 x 2, TR 18 x 4, TR 24 x 5
- Temperature-resistant up to +80 °C
- Available accessories ▶ page 922

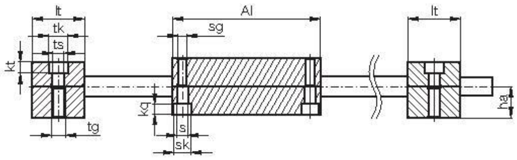
Order key
complete ▶ page 897

SHT-12-AWM



red dot design award winner 2006





Technical Data

Part number	Max. length of stroke	Aluminum shaft		Steel shaft		Max. static load-bearing capacity	
		Weight	Additional (per 100 mm)	Weight	Additional (per 100 mm)	axial	radial
	[mm]	[kg]	[kg]	[kg]	[kg]	[N]	[N]
SHT-12-AWM	750	1.1	0.1	1.3	0.2	700	2,800
SHT-20-AWM	1,000	3.2	0.3	3.9	0.6	1,600	6,400
SHT-30-AWM	1,250	8.6	0.6	10.9	1.4	2,500	10,000

Dimensions [mm]

Part number	A –0.3	Al –0.3	H	E1 ±0.15	E2 ±0.15	E3 ±0.15	l	R	f	lt ±0.1	tk	ts
SHT-12-AWM	85	85	34	70	73	73	145	42	2	30	11	6.6
SHT-20-AWM	130	130	48	108	115	115	202	72	2	36	15	9.0
SHT-30-AWM	180	189	68	150	158	158	280	96	4	50	20	13.5

Part number	tg	kt ±0.1	s	sk	sg	kq	d	T	l2	d2 Standard	ha
SHT-12-AWM	M8	6.4	6.3	10	M6	6.0	12	TR 10 x 2	17	TR 10 x 2*	18
SHT-20-AWM	M10	8.6	6.4	11	M8	7.0	20	TR 18 x 4	26	12 h9	23
SHT-30-AWM	M16	12.6	11.0	18	M12	10.6	30	TR 24 x 5	38	14 h9	36

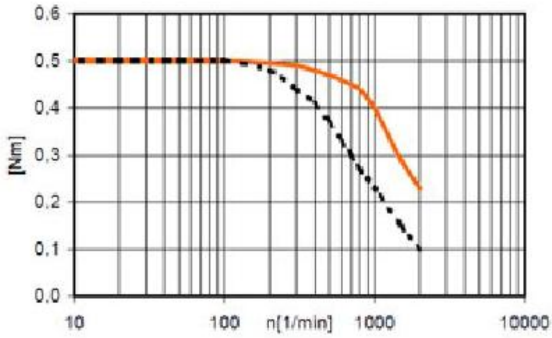
Linear axis *Drylin-SHT* (Source: http://www.igus.at, 11.15.2012)

Technical data of the selected stepper motor *Nema 17*.

drylin® step motor NEMA17

igus® stepper motors are well suited to drylin® linear axes well. They distinguish themselves by their cost-efficiency, precision and simple control. They work reliably under varied environmental conditions (depending on the selected protection class IP). Due to the standardized power connection the igus® step motors can be connected to the most popular motor control systems.

characteristic



dashed: 24 V DC
orange: 48 V DC
characteristic based on quarter step mode

part no

MOT -	MOT = motor
AN -	AN = design
S -	S = stepper motor
060 -	060 = 60 V DC
005 -	005 = 0,5 Nm
042 -	042 = flange dimension 42 mm
M -	M = metric plug L = stranded wire (optional)
A -	A = without C = incremental encoder D = incremental encoder and brake
AAA	AAAA = standard AAAC = encoder AAAD = encoder and brake

Motor with connector plug

Motor with connector plug and

Motor with plug, encoder and brake

Stepper motor ***Nema 17*** (Source: http://www.igus.at, 11.16.2012)

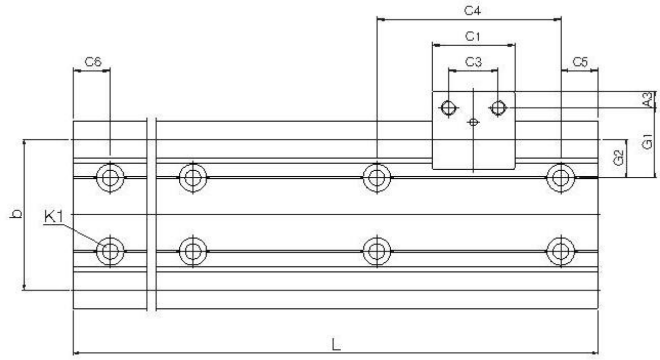
Technical data of the selected linear guide system *DryLin W*.

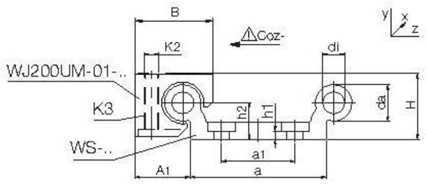
DryLin® W Modular Guide Systems | Product Range

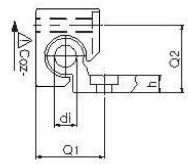
DryLin® W modular guide systems

Double rail and housing bearing, round

Order key
complete ▶ page 785







Displayed assembling position not possible for WS-10-40 and WS-10-80

DryLin® W Guide Rails – Dimensions [mm]

Part number	Weight	H	da	di	L	a	b	h	h1	h2	G1	G2	a1*
	[kg/m]	±0.07	–0.1		max.	–0.3							
WS-10-40	1.00	18	10	–	4,000	40	40	5.5	5.5**	9	27	17	–
WS-10-80	1.50	18	10	–	4,000	74	74	5.5	5.5**	9	27	17	40
WS-16-60	1.96	27	16	8.0	4,000	54	58	7.5	3.5	14	33	19	–
WS-20-80	3.30	36	20	10.2	4,000	74	82	9.5	4.5	20	38	21	40

* WS-10-40 and WS-16-60 a single row of mounting holes down the centreline;
** WS-10-80 and WS-20-80 two parrellel rows of mounting holes

Part number	C4	C5		C6		K1 for Screw	Iy	Iz	Wby	Wbz
		min.	max.	min.	max.	DIN 912	[mm⁴]	[mm⁴]	[mm³]	[mm³]
WS-10-40	120	20	79.5	20	79.5	M6***	91,000	5,100	3,600	590
WS-10-80	120	20	79.5	20	79.5	M6***	388,000	6,100	9,200	650
WS-16-60	120	20	79.5	20	79.5	M8	367,600	26,100	9,900	1,900
WS-20-80	120	20	79.5	20	79.5	M8	1,080,000	78,700	21,000	4,000

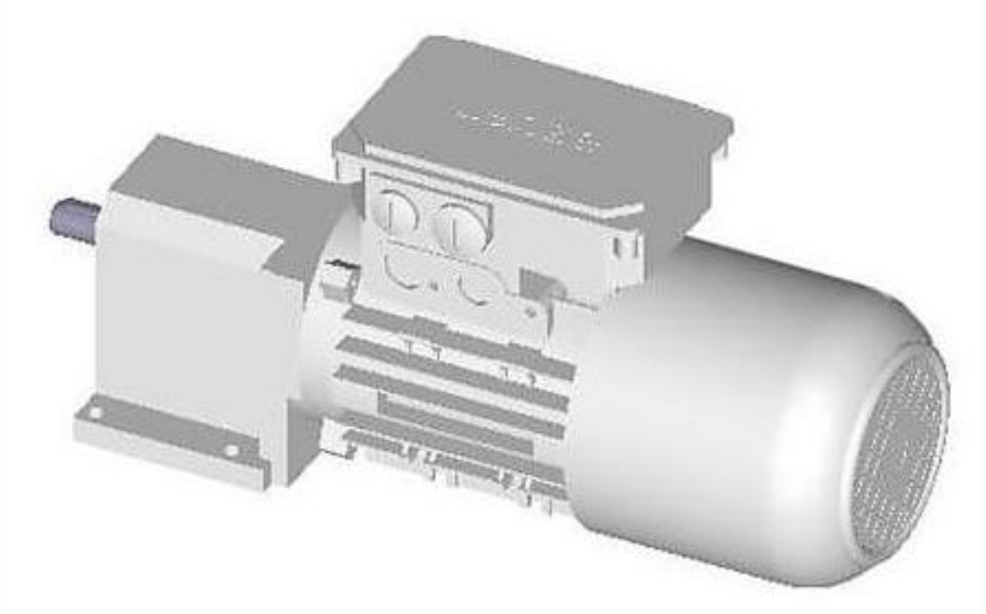
Standard bore pattern symmetrical: C5 = C6; please order C5 ≠ C6 with drawing *** Trough bore

Load Data and Dimensions [mm] – DryLin® W Housing Bearings – Round

Part number	Weight	B	C1	C3	A3	K2	K3	Stat. Load Capac.		
								Coy	Coz+	Coz–
	[g]							[N]	[N]	[N]
WJ200UM-01-10	41	26	29	16	6.5	M5	M5	1,200	1,200	250
WJ200UM-01-16	100	34.5	36	18	9	M8	M6	2,100	2,100	400
WJ200UM-01-20	190	42.5	45	27	9	M8	M6	3,200	3,200	500

Linear guide system *DryLin W* (Source: http://www.igus.at, 11.15.2012)

Technical data of the selected helically geared motor by *Lenze*.



Motor type	Three-phase motor
Rated power	0.090 kW
Rated torque	0.63 Nm
Rated rotational speed	1375 1/min
Rated voltage	230 / 400 V +-10%
Rated current	0,48 / 0,28 A
Rated freuquency	50 Hz
Power factor	0.71
Gear ratio	10.033
Output speed	137.0 1/min
Drive torque	6 Nm
Feedback	Incremental encoder
Connection feedback	Plug M12

Helically geared motor (Source: http://www.lenze.at, 11.18.2012)

7.2 Appendix B – Assembly Drawings