Energy Efficiency Manual
Guide with Examples from Practice

Imprint

Energy Efficiency Manual

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Preface

Dear reader,
with the dawn of the 21st century, the topic of energy efficiency, which represents the second large pillar of the energy revolution next to regenerative power generation, increased in importance such that hardly any company today is not working on increasing energy efficiency.
As a provider of drive and control systems, Bosch Rexroth AG has numerous innovative solutions in its product portfolio for electrical and hydraulic drives and control systems. For many years many solutions have been developed and introduced with the Rexroth-4EE system (“The Entire Machine in a Virtual View” on page 93).
Bosch Rexroth AG has also committed to reducing the relative CO_2 emissions world-wide by 20 percent by 2020 and set up the “GoGreen” project team in 2011 to achieve this goal. This goal was intensified to 35% in 2016. The main focus from the start was on increasing energy efficiency. The second focus was on increasing the proportion of regenerative energy. The newly set up “GoGreen” project team was to ensure the deployment of the goals at the different locations, uncover potential, accompany the implementation and ensure the implementation of innovative solutions.
Initially, the central core team of GoGreen had developed and implemented suitable methods and techniques. These included

- holistic analyses of potential at the locations,
- target development and controlling processes,
- the development of technical solutions as well as
- accompanying the project, including change management.

In order to implement the methods and techniques in the organization, extensive training was carried out for those involved in the project and the position of energy manager of the plants was created. The modular training materials have steadily evolved into a “best practice” over the seven years of the project. The maturity of the training materials has now reached a level where an edition in book form makes sense.
With this book, we would like to make the findings gained accessible to a broader public and show you methods for how you can integrate the topic of energy efficiency in your company. Rexroth's approach to implementing CO_2 goals has also become known beyond the company's boundaries and has made specialists from other companies interested in our course of action. The “GoGreen” project team gladly accepted external training participants in the internal training.
Rexroth is ready to pass on the gained knowledge by publishing this book and by providing a corresponding training offer to other energy managers and environmental officers from industrial companies as well as to testing and consulting companies.
Entrepreneurs and plant managers who also see the reduction of CO_2 emissions or energy costs as a necessary field of action and who are looking for professional support for goal planning and change management can find suggestions and support in this book. In addition to this book, we are also happy to accompany the process in an advisory capacity. Project management employs certified project managers.
This book is ideal for project managers who are pursuing the company-wide implementation of energy efficiency goals. Our project managers from the “GoGreen” project are happy to discuss their project experiences.
The “GoGreen” project team has already recognized a considerable gap between the technically and economically feasible and the generally available state of the art during the pilot potential analysis at the Elchingen plant (products: hydraulic pumps and motors). The innovative η-research plant (ETA-FAB) of the Technical University of Darmstadt was initiated and successfully established together with professor Abele

from the PTW Institute [Institute for Production Management, Technology and Machine Tools] at TU Darmstadt and manufacturers of production facilities as we utilize them in our plants. Scientists and developers will find numerous suggestions for additional developments of energy-efficient innovations in this book.

The scope of the book is not limited to the industrial sector, because the methodological approach can be transferred to other sectors. We would be pleased if you can get some suggestions for your company from this book, hope you enjoy reading and wish you success in implementing the measures presented.

Rolf Najork (Chairman of the Executive Board)
Dr. Bertram Hoffmann (Member of the Executive Board)
Bosch Rexroth AG, Lohr am Main

1 Holistic Approach to Energy Management

Author: Leo Pototzky

As described in chapter “Implementation Concept of Bosch Rexroth AG: Project GoGreen and Energy Efficiency with Rexroth 4EE” on page 11, Bosch Rexroth has launched the GoGreen project in order to pursue and implement the climate protection goals and dual strategy. This chapter explains how this project “works” and how it was generally organized. The chapter “Project Management for Holistic Energy Efficiency Potential Analyses” on page 29 then follows and discusses the project management methods.

1.1 Rules for Calculating CO_2 Emissions

Nothing works without a target and without key figures

In order to measure the performance of CO_2 emissions or their reduction, Bosch defined the key figure CO_2rel:
CO_2rel = CO_2total / NGU – MAT [t CO_2/million €]
The CO_2 emissions in tons are calculated using emissions factors and are composed, for example, of the combustion of energy carriers, such as gas, or also from the consumption of electricity. These emissions are related to the value added (NGU – MAT = net total turnover minus material). The value added expresses what value was “added” to a product in the plant. This economic formula shows on the one hand the reduction of the emissions and on the other hand takes into consideration changes, such as the growth of a company. However, it must also be taken into consideration in the process that the key figure may change due to economic factors (prices, relocation to countries with high emissions factors, such as China). This is why it may make sense to use other technical key figures, which will be discussed later.
Bosch has set itself the goal of reducing the key figure CO_2rel by 35% by the year 2020.
In addition to the calculation of CO_2 emissions explained above, Bosch has also defined a number of additional rules in a guide, such as the restriction (scope) of emissions from various polluters.

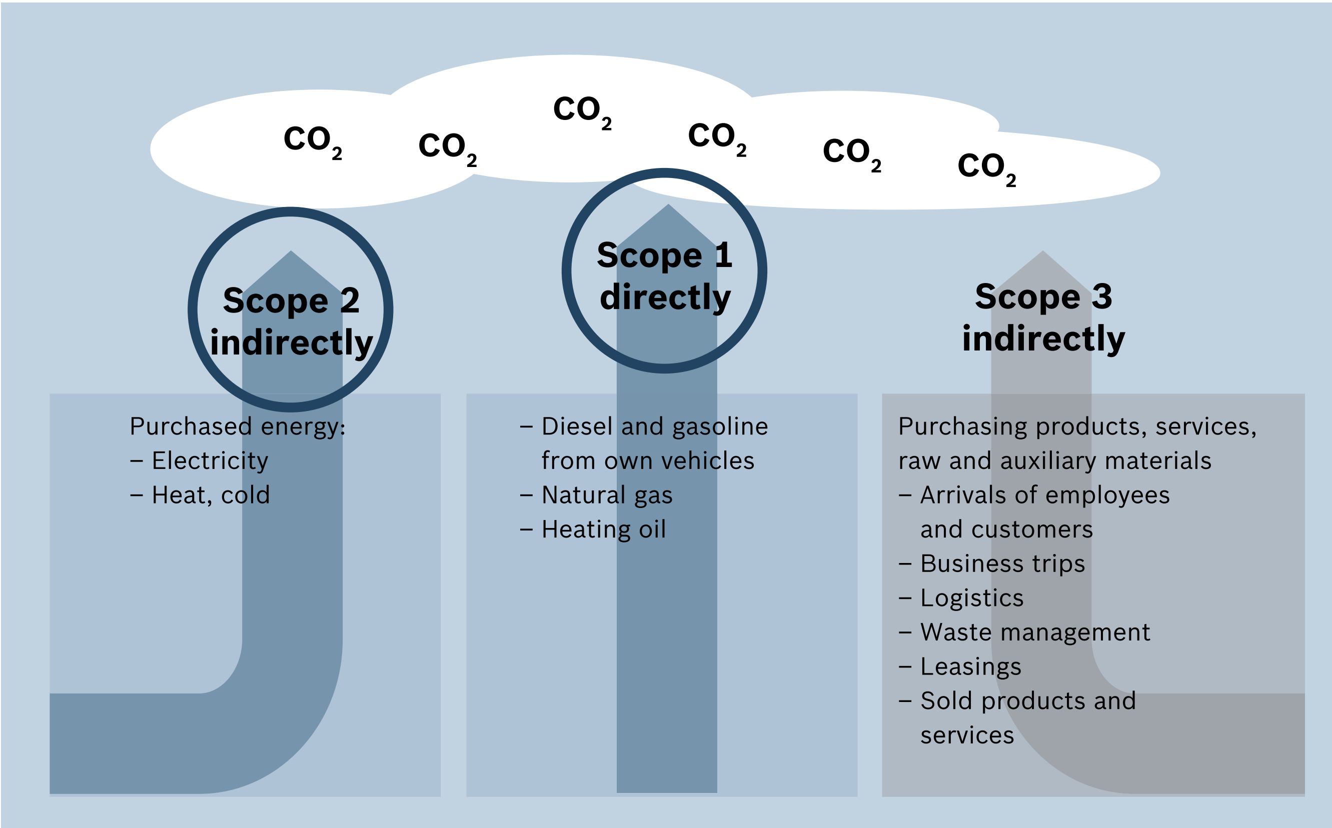


Fig. 2: Scope 1 and 2 describe the framework of CO_2 accounting at Bosch

The Greenhouse Gas Protocol provides the basis for the calculation

Bosch's rules for climate protection and greenhouse gas / GHG management are based on the guides of the Greenhouse Gas Protocol Initiative of the World Business Council for Sustainable Development (WBCSD), of which Bosch is a member, and the World Resource Institute (WRI).
Climate protection at Bosch and the associated CO_2 management refer to the scope 1 and scope 2 of the GHG Protocol for greenhouse gas / GHG emissions. The main basis for calculating the CO_2 emissions is thus the combustion of gas or oil and purchased electricity. For a purchased kilowatt hour of electricity, country-specific CO_2 factors are used to calculate CO_2 emissions, which result in power-generating power plants, but that were caused by the demand in the plants and therefore are attributed to the plants.
The energy consumption in the production of preliminary products or in the use of products (scope 3) is not incorporated in the calculation.

1.2 Target Derivation, Finding Potential and Monitoring in an International Group – the Core of the GoGreen Project

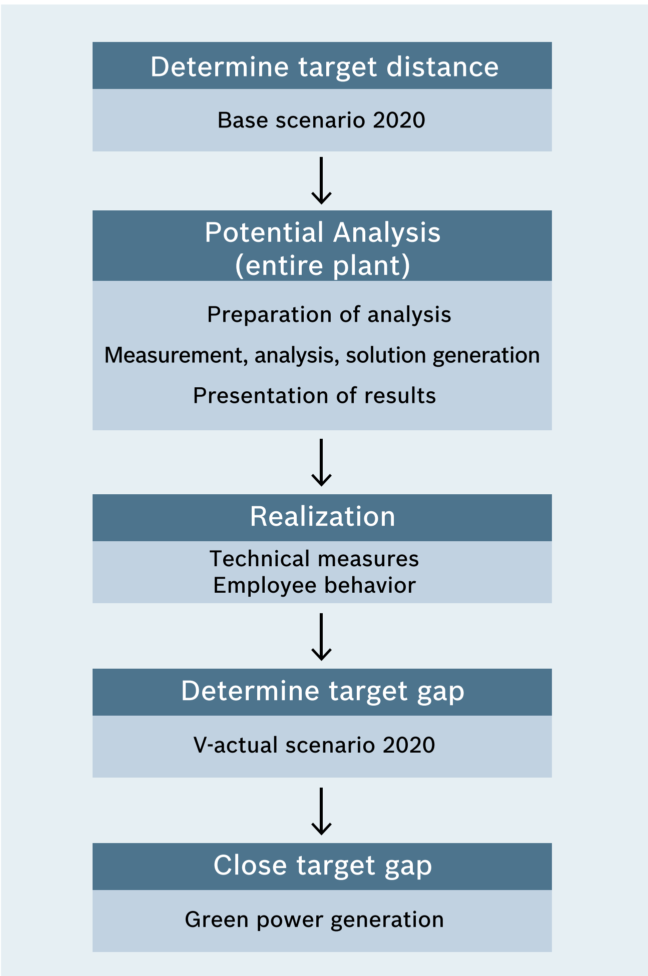


Fig. 3: Line of action in the GoGreen project

When applying a key figure like CO_2rel where country-specific key figures have a major impact, long-term forecasts must be used to determine how the key figure for the entire company responds to the development of different regions of the earth. After all, nearly twice as much CO_2 is generated to use a kilowatt hour of electricity in China (788 g/kWh) as in Germany (404 g/kWh) (data from the GHG Protocol). It is only with a scenario calculation that the actual target route needed to achieve the company goal is achieved.

To find out where improvements are possible, the potential of the plants needs to be taken into consideration. A standardized line of action was developed and applied at Rexroth in the GoGreen project for this purpose. Based on this analysis, each plant receives an individual goal that takes its potential into account.

After implementing the measures, possible goal gaps are calculated again and closed with measures to produce regenerative energy.

The holistic potential analysis of plants

What is aken into consideration in the potential analysis in the plants?

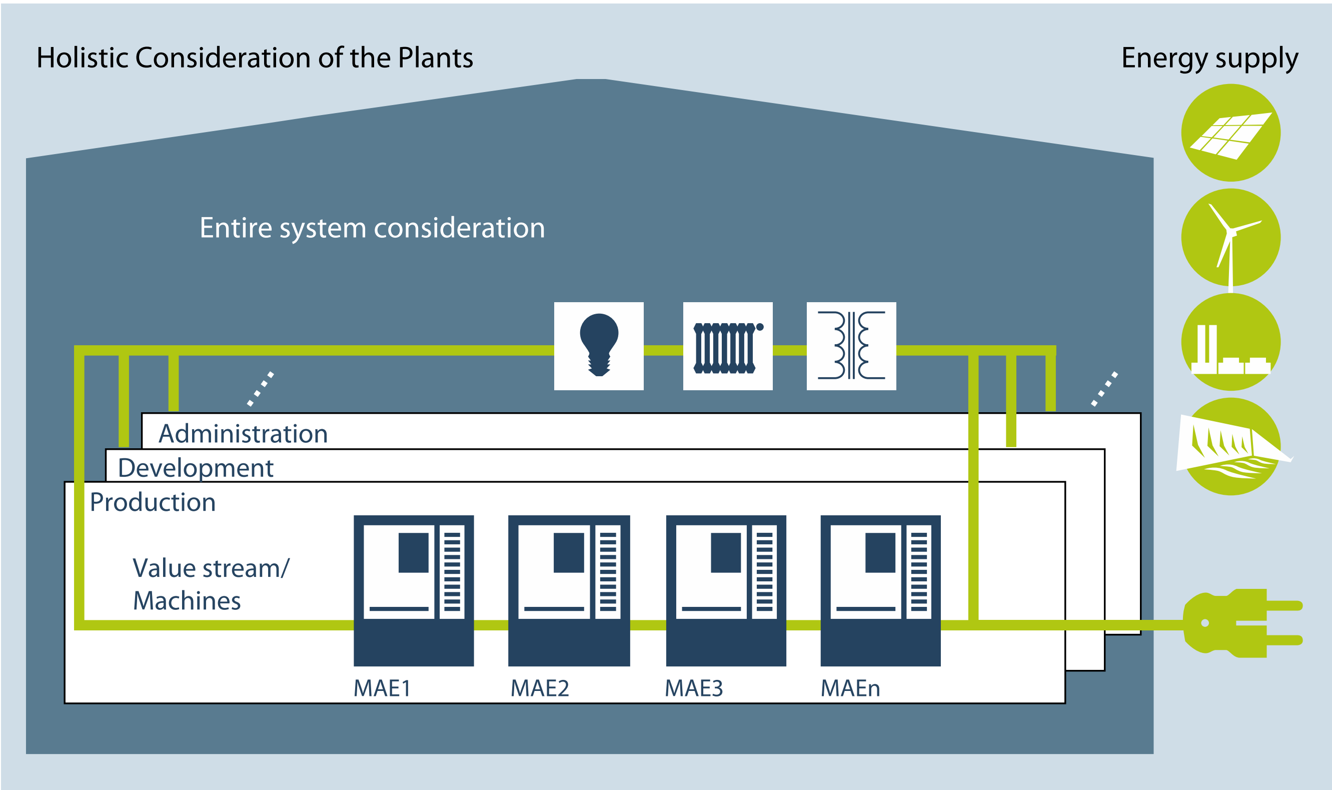


Fig. 4: Holistic Consideration of the Plants

Since many different energy consumers exist in a production plant, a holistic analysis should be used to record the majority of them. Unlike with "common" energy consulting, it is not just about the classic questions of infrastructure, such as building, heating and air conditioning, but rather is above all about the production processes. In the process, the individual energy-consuming components as well as the entire production line are both examined. This includes the interaction between machines or even buildings and other infrastructure. The holistic analysis is intended to provide an overview that allows us to focus on the right potential. This then provides the necessary knowledge basis to be able to start projects.

The following "process" shows this approach from the individual component to the consideration of the entire plant:

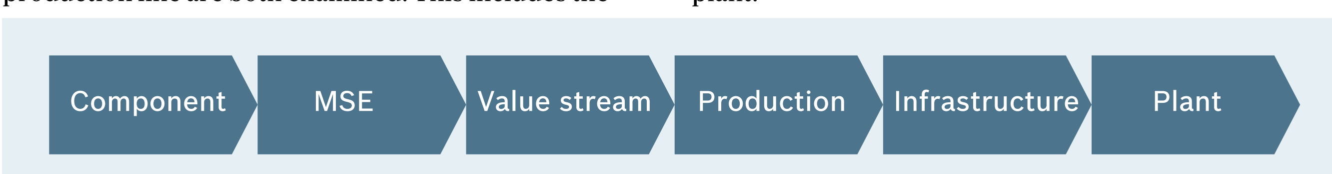


Fig. 5: Elements of the Production Process that are Analyzed

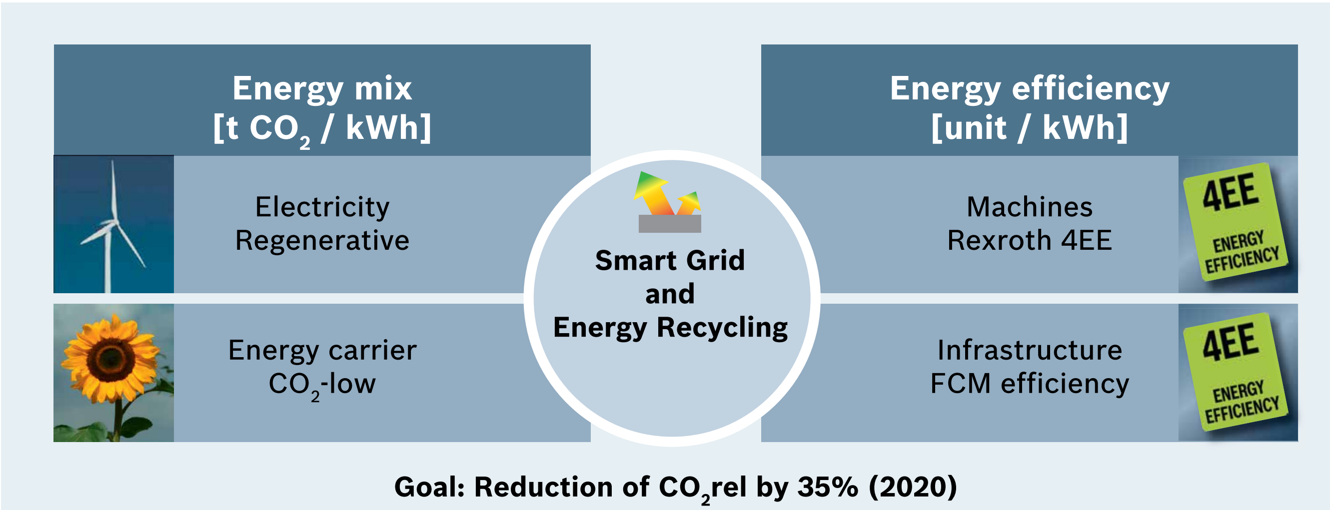


Fig. 6: Leverage for reducing CO_2 emissions

The aim of the Bosch Group is to reduce CO_2 emissions by 35%. The two types of leverage to achieve this are the energy mix and energy efficiency.
You can reduce CO_2 by choosing the right energy mix, which is brought into the company by the energy carrier, for example by replacing heating oil with gas or converting from electricity to gas. A CO_2 factor of 202 g/kWh is assumed for gas. The factor for electricity in Germany is nearly twice as much at 404 g/kWh! Choosing the energy carrier can therefore have a big impact on the amount of CO_2 emissions. These options are absolutely available in practice, for example by operating the hardening shop of a plant with electricity or gas.
From a commercial point of view, the gas version today is often even more economical than operating with electricity.

The second major type of leverage lies in the energy efficiency of machines, systems and the infrastructure. How much energy is needed to produce a part? How much energy is required to heat a square meter of hall area? The energy efficiency of a production facility is expressed with such variables and can be applied to the direct production (kWh/part) as well as to the associated infrastructure.
Rexroth 4EE is primarily focused on manufacturing. This objective is clearly expressed with the maxim "Less energy with greater productivity." More economical machines with simultaneously increased productivity is the Rexroth's domain.

What is the result of a holistic plant analysis?
The result of a holistic plant analysis can be represented with a so-called "bridge" (see "Example of a Holistic Plant Analysis" on page 22)

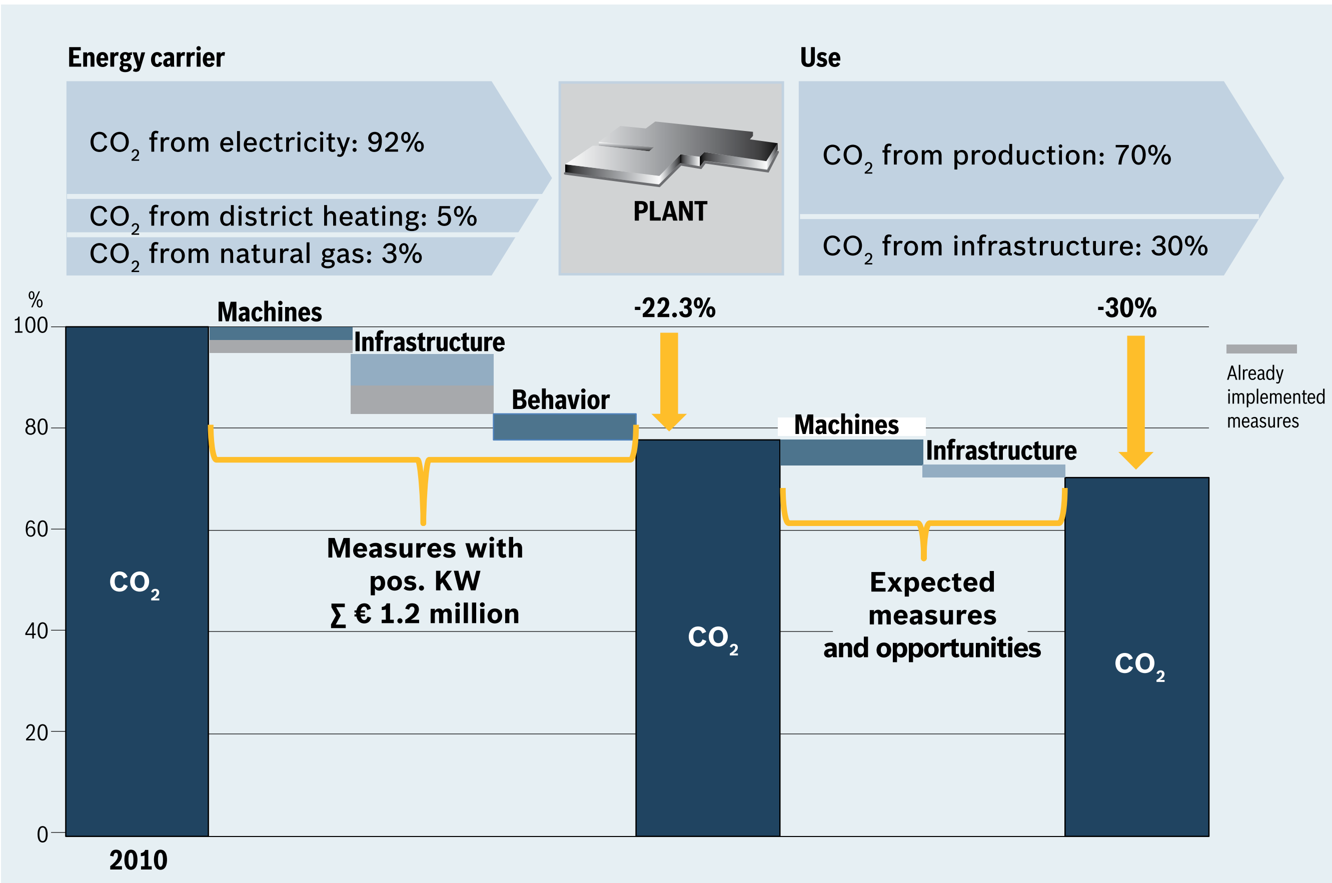


Fig. 7: *Example of a Holistic Plant Analysis*

At a glance, the plant manager receives the information regarding by how many percentage points CO_2 emissions can be reduced with economical measures (middle bar) and what means are required for this purpose. These measures are shown in the diagram as the three areas of machines, infrastructure and (employee) behavior. The plant manager also sees opportunities that may result from additional ideas, but whose feasibility and economic viability could not yet be sufficiently examined. "Hidden" behind the bar are specific measures that will be explained in more detail in the next chapter.
Once the economic potential of a plant is known, this knowledge can be used to create a plan to tap into that potential step by step in the following years. This makes it possible to plan the improvement and the necessary material expense.

From a group perspective, this thus results in the advantage that goals are not equally distributed for everyone from the "watering can," but rather all plants receive the same "degree of strain," i.e. all plants must put forth the same effort to achieve their goals.
The first step, namely the planning of a typical PDCA cycle (Plan – Do – Check – Act), is started with the analysis, evaluation and determination of which measures are to be implemented. The next step is the implementation of the measures (Do).

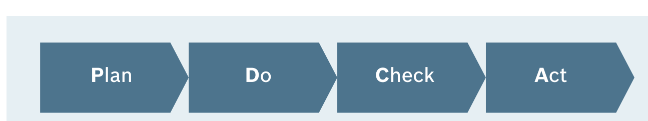


Fig. 8: *Elements of the PDCA Cycle*

6.5 Fully-Integrated Hydraulics – Energy Efficiency at the Drive Level

There are currently some fundamental technology trends that play a central role in particular for the electrification and electronization of the hydraulics for Bosch Rexroth. Rexroth 4EE components with fully integrated hydraulics therefore continue to gain importance.

Traditional fluid technology regulated flow and pressure and branched performance with a throttle control via valve technology. A fixed displacement pump always generated the maximum pressure and flow rate. Everything not required by the process was deflected via the valves and converted into unproductive heat. This system design is absolutely energy-efficient for applications where the process always demands maximum power. However, there are phases with partial load or even zero load in many applications. In these cases, traditional hydraulics are less energy-efficient. This changes fundamentally with the success of the rpm-variable pump drive Sytronix. Sytronix stands for "Smart interplay of Hydraulics and Electronics", i.e. the smart interplay of hydraulics and electronics. In conventional hydraulic systems with a constant drive, the hydraulic pump with a high speed continuously generates the maximum flow rate. If the process does not demand this output, the energy is "destroyed" via throttle valves and converted into heat. The Sytronix pump drives developed and patented by Rexroth, on the other hand, are rpm-variable and generate the volume flow for hydraulic actuators as needed. They electrically control the pressure and flow rate and adjust it to the current demand. In the case of a partial load, they reduce the speed and thus the energy consumption. This improves the energy efficiency up to 80 percent depending on the cycle characteristic. However, the power split still occurs hydraulically via valves.

Fully integrated solutions from Rexroth are now being used more and more where both the power control as well as the power split occur purely electrically. The basic idea: Smart electro-hydraulic individual drives with an energy-efficient displacement control system takes the place of a central unit that supplies all hydraulic consumers via a throttle control. From the speed of the motor and the pivoting angle of the pump, they regulate the pressure and flow rate largely without valves. This creates a variably adjustable hydraulic transmission. Press manufacturers already use this for upper forcer drives.

Table "Electrification of Hydraulics" on page 78 compares the solutions described above.

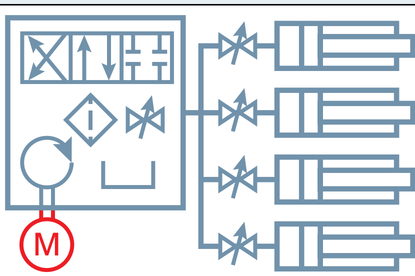
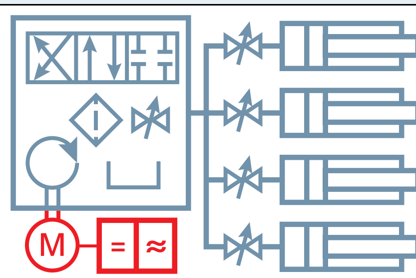
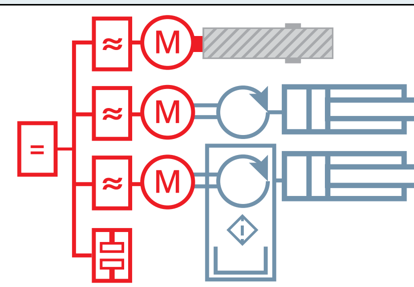
Traditional	**Electro-hydraulics – Level 1**	**Fully integrated solution**
 Hydraulics Electrical system	 Hydraulics Electrical system	 Hydraulics Electrical system Mechanics
▶ Hydraulic control of flow and pressure ▶ Electric constant drive (with supply frequency) ▶ Hydraulic power split	▶ Electric control of flow and pressure ▶ Demand-oriented power generation ▶ Hydraulic power split	▶ Electric control of flow, pressure and position ▶ Demand-oriented power generation ▶ Electric power split ▶ DC intermediate circuit
▶ Low energy efficiency ▶ High energy consumption	▶ Average energy efficiency ▶ Reduced energy consumption	▶ High energy efficiency ▶ Optimized energy consumption

Table 8: Electrification of Hydraulics

Bosch Rexroth has developed a modular system of autonomous axes for linear movements. Identical servo drives drive both electromechanical and hydraulic axes. These servo-hydraulic axes have a separate local fluid circuit and they do not need a central hydraulic unit. For example, machine manufacturers can thus freely choose between the drive technologies within a machine family depending on the power level - with nearly identical mechanical design, software and energy efficiency.

The conversion from a central unit to several electro-hydraulic individual axes results in additional savings: The required amount of hydraulic oil drops from previously more than ten thousand liters to a few hundred liters and an energy-intensive cooling unit can be done away with completely. This is an important contribution to more resource efficiency and low overall operating costs (total cost of ownership).

6.6 Differences Between Traditional Hydraulics and Sytronix Solutions

Traditional hydraulics

In traditional hydraulics, the power or pressure and volume flow are mechanically or electro-hydraulically controlled in the pump. “Principle of Traditional Hydraulics” on page 79 shows this concept in a simplified schematic diagram.

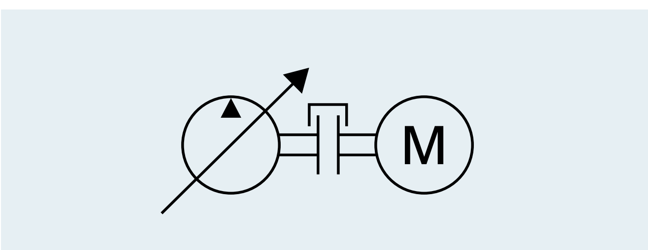


Fig. 50: Principle of Traditional Hydraulics

Hydraulic pumps can be equipped with different controllers, such as pressure controllers or pressure-flow rate controllers. “Combination of the Variable Displacement Pump NG 100 with Different Controllers” on page 80 shows how a variable displacement pump can be equipped with different controllers.

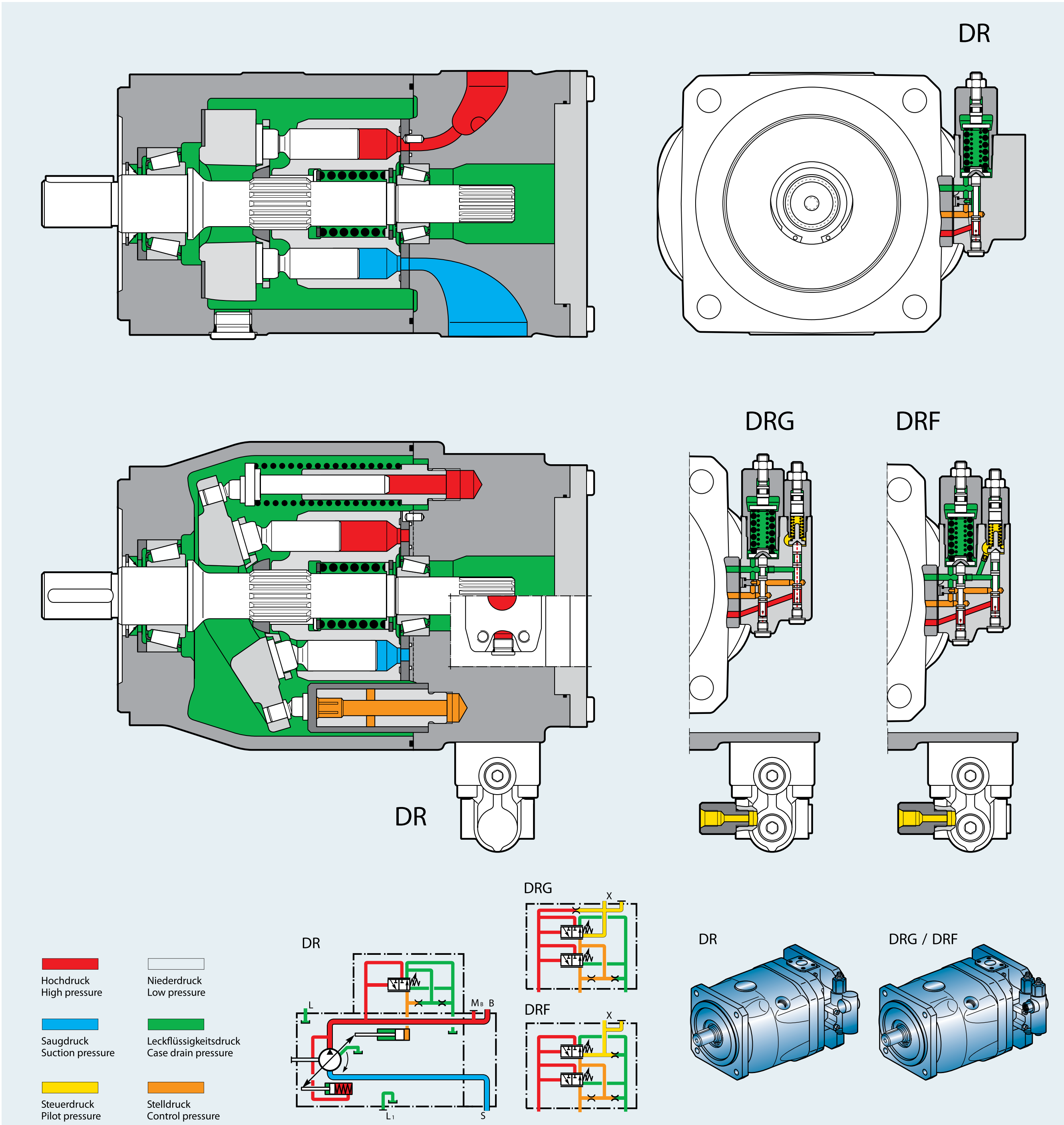


Fig. 51: Combination of the Variable Displacement Pump NG 100 with Different Controllers

- Pressure controller (DR)
  The pressure controller limits the maximum pressure at the pump outlet within the control range of the variable displacement pump. The variable displacement pump only requests as much hydraulic fluid as is needed by the consumers. If the operating pressure exceeds the desired pressure set at the pressure valve, the pump regulates in the direction of smaller displacement volume and the control deviation is reduced.
- Pressure controller (DRG)
  The pressure controller (DRG) is a remote-controlled pressure controller. The remote-controlled pressure controller can be used to set the desired pressure via a separately arranged pressure relief valve.

- Pressure-flow rate controller (DRF/DRS)
  In addition to the function of the pressure controller, an adjustable shutter (e.g. directional valve) is used to reduce the differential pressure before and after the shutter, which regulates the flow rate of the pump. The pump requests the amount of hydraulic fluid actually needed by the consumer. The pressure controller is superimposed.

Let's continue to consider the standard motor that is operated at its power frequency-dependent nominal speed of 1,500 rpm.
The hydraulic partial load share greatly dominates many applications. In this operating range, a standard motor with a low torque output only has a very low degree of efficiency, since the motors were designed for nominal capacity at a nominal working point. Adjusting the pivoting angle of the variable displacement pump regulates the volume flow in the system The torque output at the electric motor varies with the adjustment of the pivoting angle of the pump and the corresponding delivered pressure level. In many applications, the electric motor and the variable displacement pump runs in zero stroke or partial load operation for a very long time. Chipping machine tools can be listed here as an example, such as turning machines. The function of the hydraulics with a turning machine can frequently be reduced to “only keeping the pressure in the system” and “compensating for internal leakage.” The hydraulic variable displacement pump is operated in zero stroke mode and the electric motor is also operated in partial load operation. “Degree of Efficiency Characteristic Curve of a 18.5 kW Standard Motor” on page 81 shows the degree of efficiency of a 18.5 kW standard motor.

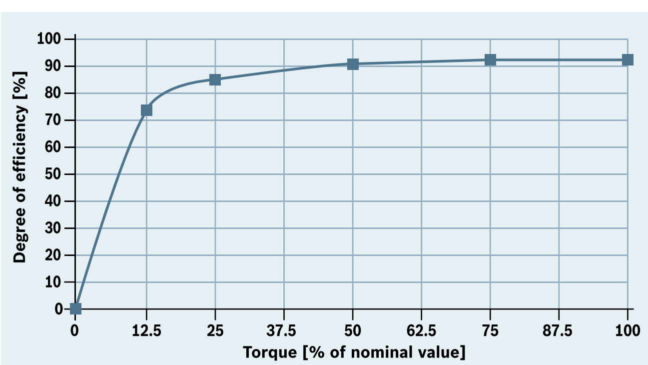


Fig. 52: Degree of efficiency characteristic curve of a 18.5 kW standard motor

Sytronix Solutions

With Sytronix solutions, however, the control is no longer directly integrated in the pump, but rather is carried out by the electronics in the inverter. The inverter can receive different signals as set values here. The integrated hydraulic firmware, either as a pre-defined list of parameters or freely programmable PLC (programmable logic controller), prepares the set value The current actual value, which is typically measured with a pressure load cell, compares the control system with the set value. The motor speed and thus the volume flow of the pump are varied as a manipulated variable. The position of the cylinder can also be specified as a set value, which then can be directly regulated to the position with the drive.
“Schematic Diagram of a Sytronix Solution with Constant Displacement Device” on page 81 and “Schematic Diagram of a Sytronix Solution with Adjustment Displacement Device” on page 82 shows the schematic diagrams of the possible Sytronix module solutions. The volume flow can be proportionally changed via the speed with hydraulic constant displacement.

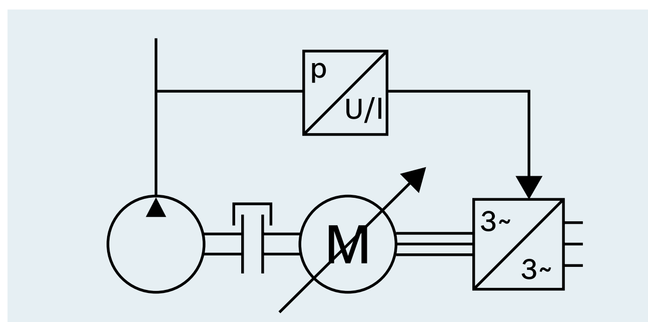


Fig. 53: Schematic Diagram of a Sytronix Solution with Constant Displacement Device

With hydraulic adjustment displacement devices, the volume flow is adjusted independently of the speed. A higher degree of freedom is thus available for a process optimization. This flexibility has a very positive effect on energy efficiency, because integrated loss models of the hydraulic adjustment displacement devices can be resorted to in the inverters.

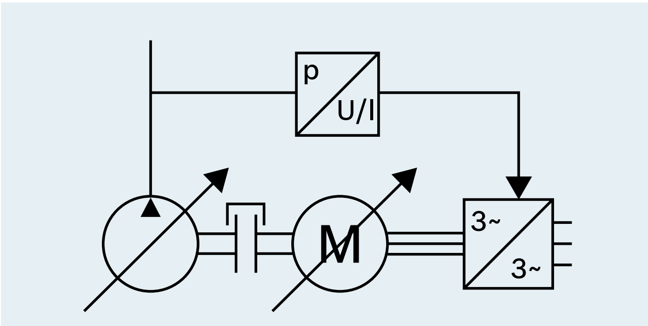


Fig. 54: Schematic Diagram of a Sytronix Solution with Adjustment Displacement Device

The merging of hydraulics and electrical systems has now advanced so far that it is accepted on the market. Bosch Rexroth offers these multi-technological solutions in standard products. These system solutions are divided into three main functional groups (see "Sytronix Standard Products from Bosch Rexroth" on page 82):

- Solutions optimized for constant pressure systems,
- Systems for p/Q controls and
- Solutions for positioning and force control.

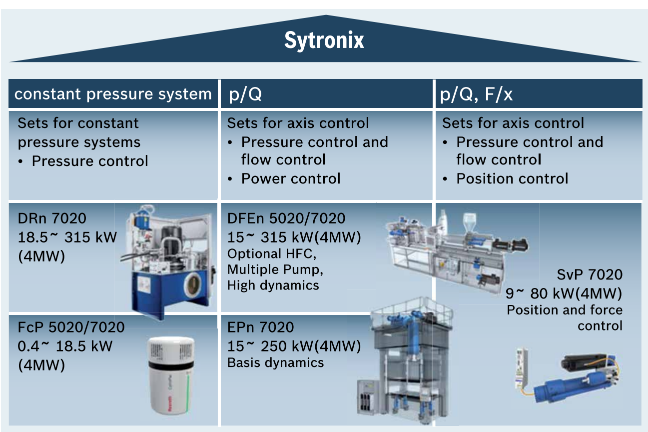


Fig. 55: Sytronix Standard Products from Bosch Rexroth

The standard applications for constant pressure control in the open hydraulic circuit are divided into two product groups: Sytronix DRn and Sytronix FcP. Sytronix FcP systems consist of an asynchronous motor, a frequency inverter and preferably a hydraulic gear pump. These are suitable for solutions in the smaller power range for machine tool applications. The solutions are used as the basis for the small-scale unit CytroPac.
The Sytronix DRn solutions are based on hydraulic adjustment displacement devices with a mechanical pressure controller, rpm-variable asynchronous motor and an inverter. These can be found in the ABPAC unit by default.
Three product groups offer a relieving pressure/volume flow control in the base version. The DFEn and EPn versions are based on hydraulic adjustment displacement devices, an rpm-variable asynchronous motor and an inverter. They are distinguished by the choice of adjustment displacement devices and the control algorithm in the software package, which is implemented in the inverter. The third product group SvP, which is generally characterized by a servo synchronous motor, servo inverter and a hydraulic constant displacement device, can also be functionally used for complex positioning tasks.

6.7 Advantages of Sytronix RPM-Variable Pump Drives

In addition to energy savings, using Sytronix solutions offers a number of other benefits:

- Less energy consumption
  Energy savings of up to 80% lead to a reduction of operating costs and also to a reduction of emissions of climate-harming carbon dioxide.
- Less noise emissions
  By lowering the average noise emissions of the hydraulic unit by up to 20 db (A), legal noise protection requirements can be met more easily and the effort for noise protection measures can be reduced.
- Less effort for installation and commissioning
  Pre-configured Sytronix sets as motor-pump units or as units with coordinated components make it possible to specifically select the entire pump drive system with short installation and commissioning times. Rexroth overall offers more than 100 sets in three different performance classes.
- Less cooling effort
  RPM-variable pump drives reduce the average speed of the hydraulic pumps. This results in much less friction heat and the effort to cool the hydraulic unit is reduced.
- Less space required
  Using Sytronix drives considerably reduces the space required in the machine:
  - Compact design of the Sytronix system
  - Less complex proportional valve technology and control cabinet control electronics
  - Smaller hydraulic units due to the reduction of the required hydraulic fluid volume
  - Smaller devices for cooling and noise insulation due to less heat and noise development
- Higher level of operating safety
  - Optimally coordinated and proven hydraulic and electric standard components
  - Condition monitoring through the diagnostics and status monitoring in controlled drives
- Efficient retrofitting
  Rexroth specialists support machine users throughout the entire retrofitting process, from project planning to the quick assembly and commissioning on site.
- Compliance with legal requirements
  Sytronix rpm-variable pump drives help to comply with legal requirements for noise protection in production halls (e.g. directive 2003/10/EC) and for the efficiency level of electric motors (e.g. ordinance (EC) no. 640/2009).
- Pre-defined functional packages
  The pre-defined system solutions at Sytronix are already equipped with functional packages upon delivery. The functional packages are mainly dependent on the type of inverter. It is possible to expand the functional packages.

The hydraulic units of the ABPAC and CytroPac series from Rexroth already combine these advantages by using Sytronix components. In addition, the hydraulics were designed for an open exchange of data by using inverter technology and bus systems. With localized intelligence and optional sensor packages, the units continuously record all operating states and communicate with higher-level control levels via open interfaces or use authorized smartphones and tablet PCs for this purpose. The system solution is thus capable of Industry 4.0.

6.8 Support with the System Design

The requirements for the system solution must first be available in order to obtain an innovative product as a customer. In order to record these requirements, checklists and software applications can be used to collect and evaluate them. Bosch Rexroth offers a special questionnaire for this purpose for energy-efficient hydraulic units, the "SytronixSize" software and the simulation tool "Simster S," which are used by the sales department for consultation.

"Options for Providing Hydraulic Performance" on page 84 shows four different ways how the hydraulic performance, consisting of pressure and volume flow, can be provided and distributed in a system for throttle control or a control with a variable pump.

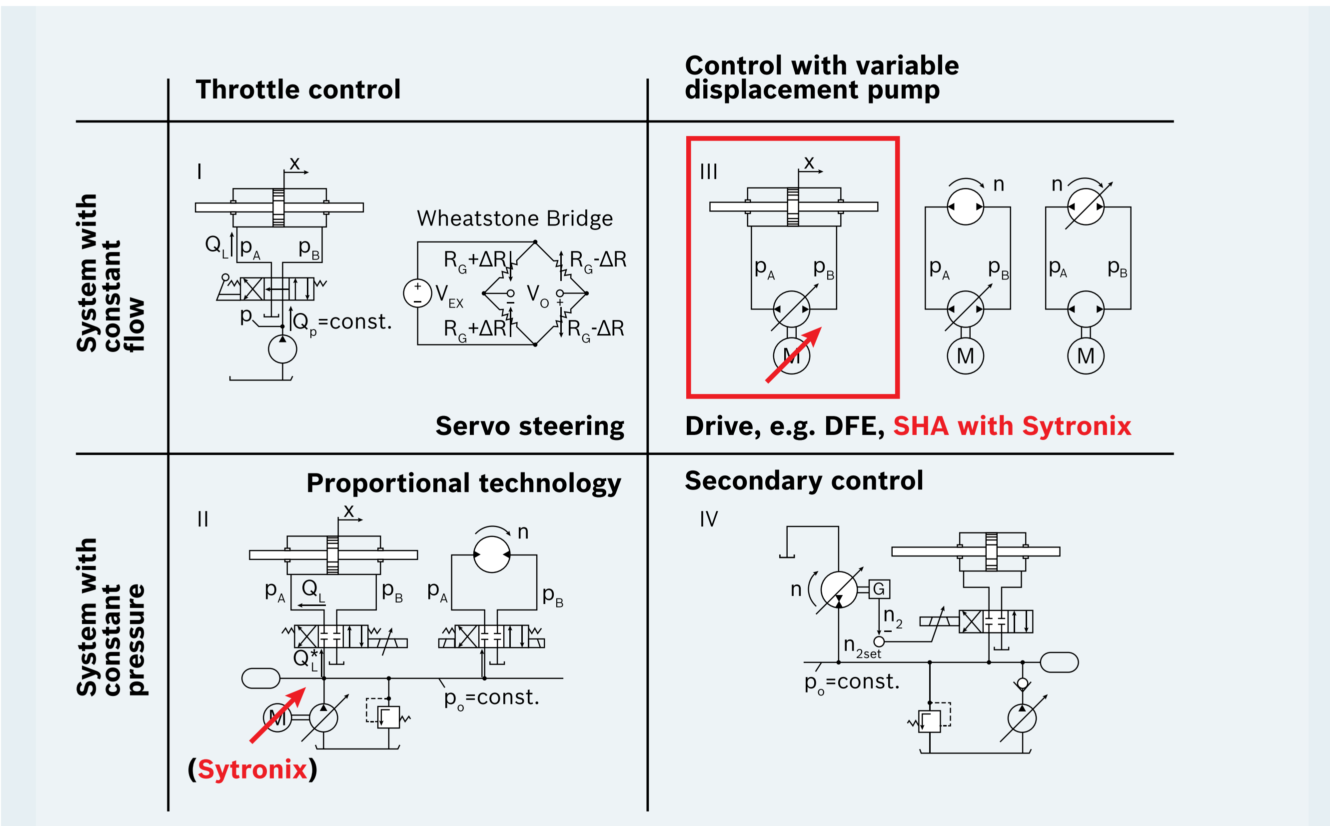


Fig. 56: Options for Providing Hydraulic Performance

Sytronix solutions can be used for two of the four systems shown. This knowledge can now be used to consider the systems weighing four different types of criteria, such as the four types of leverage of Rexroth 4EE.

Questionnaire for energy-efficient hydraulic units or system solutions

In addition to the load profile, this questionnaire records a number of other framework conditions to be able to optimally adapt an rpm-variable drive solution for a retrofit or new application to the customer-s application (see "Framework Conditions for Customer Applications" on page 85). On the hydraulic side, conditions such as the fluid, hydraulic system, cooling requirement or the existence of an accumulator, are important factors that may influence the composition of a Sytronix system. From an electrical standpoint too, parameters such as the power supply voltage and power supply system form, the superordinate control system used, ambient temperatures and the performance required for the overall system, are important bases for a targeted configuration of the Sytronix solution.

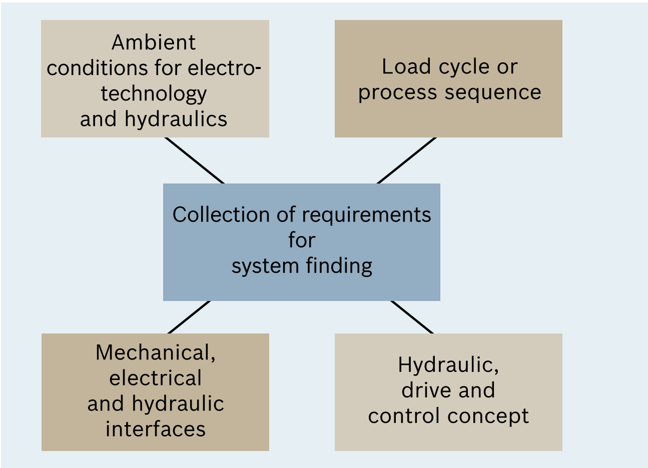


Fig. 57: Framework Conditions for Customer Applications

Tool-guided design through “SytronixSize”

The dimensioning of the components adapted to the energy requirement of the machine is the key to an energy-efficient and cost-efficient rpm-variable drive solution. Bosch Rexroth uses the design tool “SytronixSize” for this purpose. Using the machine cycle data, the corresponding pump is first determined using technical design criteria, then the electric motor and the matching inverter from the Bosch Rexroth portfolio. As a result of the Sytronix system design, the software provides a print preview of a print-out that can be used to make the decision (see “Print Preview or Print-Out from ‘SytronixSize’” on page 85)#

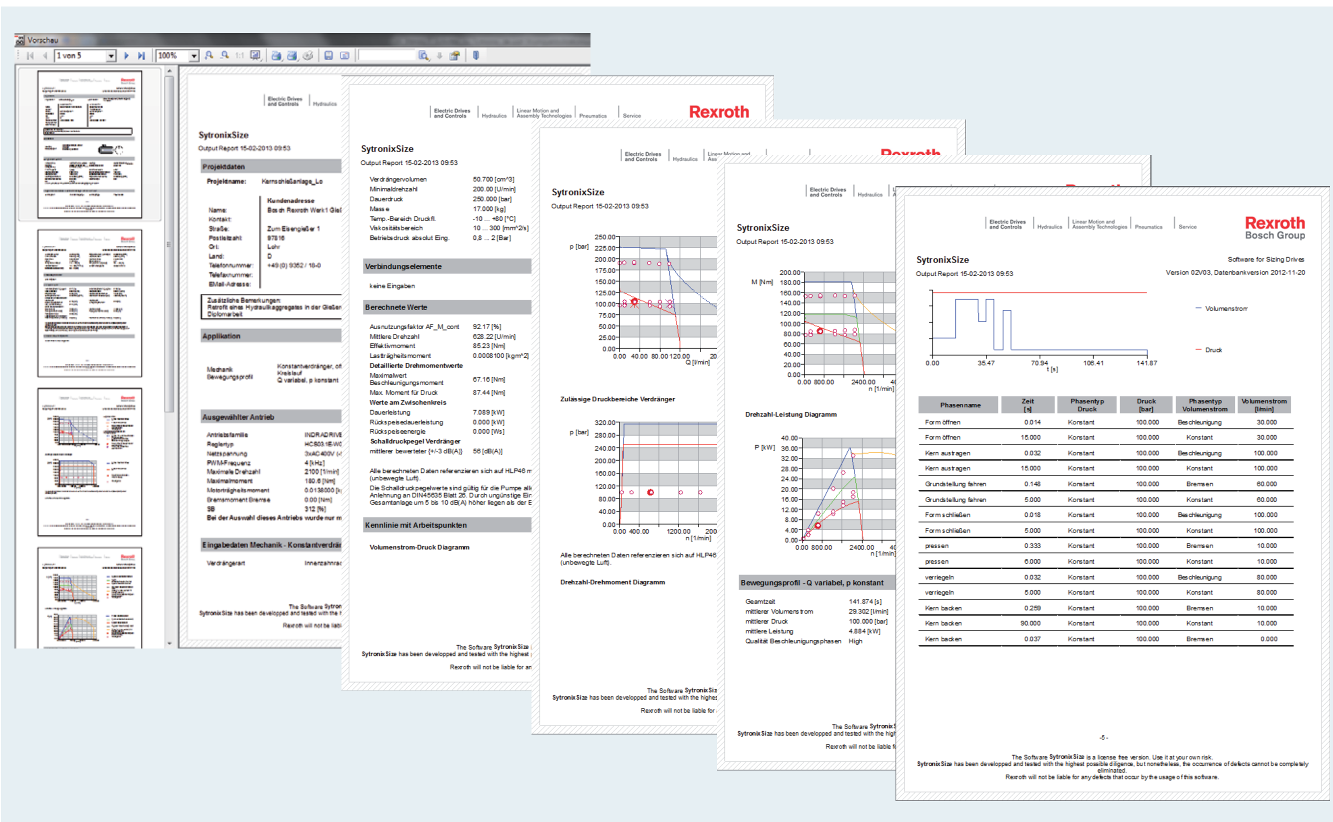


Fig. 58: Print Preview or Print-Out from “SytronixSize”

In addition to the energy balance comparison between traditional solutions with an electric fixed displacement motor and the chosen Sytronix solution with a hydraulic variable displacement pump or fixed displacement pump (see “Energy Balance Calculation in ‘SytronixSize’” on page 86), “SytronixSize” can also show additional calculated noise values based on its own pump models across the entered load cycle. These two types of technical information provide an optimal basis for being able to make a decision for or against a retrofit or new investment. The powerful engineering tool “SytronixSize” simplifies the optimal design of electro-hydraulic drive systems and can be downloaded from the online portal for free.

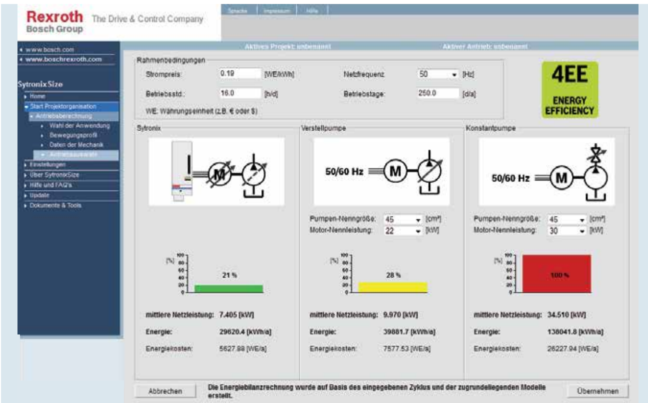


Fig. 59: Energy Balance Calculation in "SytronixSize"

Simulation of the selected components

The system behavior of the chosen components can be simulated with the software "Simster S" from Bosch Rexroth (see "Simulation of the System Behavior in the Software 'Simster S'" on page 86). "Simster S" is a powerful multi-domain simulation platform for modeling and optimizing controlled machine drive systems. Furthermore, generic model libraries of all domains (hydraulics, mechanics, control technology and much more) are also available. Either the Sytronix base models or the system models of the hydraulic pump and electric drive that can be independently created are used to simulate drive solutions with Sytronix. In addition, integrated interfaces allow for a co-simulation, for example in OpenCore, Matlab/Simulink©, TCP/IP, C/C++. The tool is intuitive to use and easy to learn. It can be downloaded for free from our online portal.

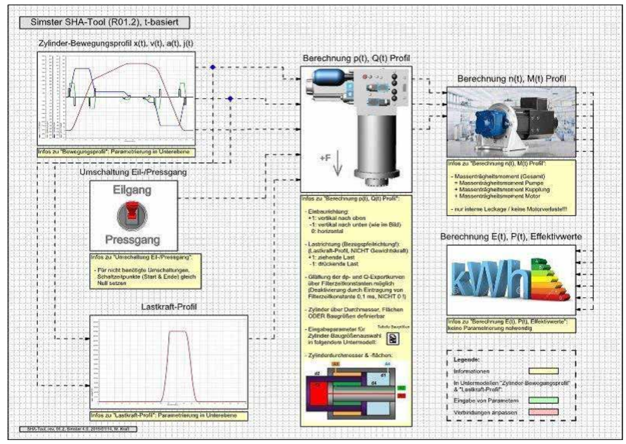


Fig. 60: Simulation of the System Behavior in the Software "Simster S"

The system analysis with the software "Simster S" allows for a graphical representation of the energy consumption of the individual components, which have been configured beforehand in the system with SytronixSize (see "Representation of the Results in the Software 'Simster'" on page 86). Based on the simulation of the entire system, technical limits can be identified and possibly optimized in another design step.

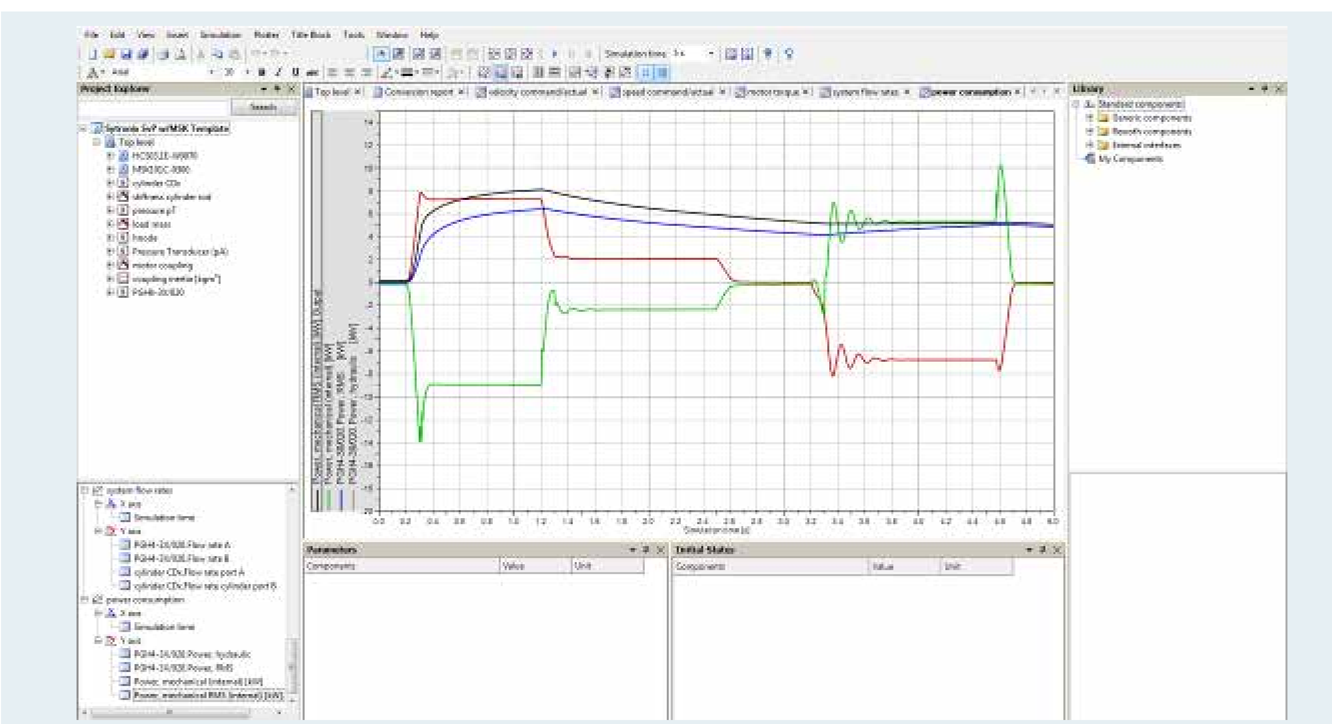


Fig. 61: Representation of the Results in the Software "Simster"

6.9 Innovations in the Sytronix Product Group

The Sytronix product group includes products with innovative functions that have already be implemented in various customer solutions (see "Overview of Already Implemented Sytronix Functions" on page 87). More innovations, such as electronic nameplates, smart service apps and much more, are in the planning phase.

Innovation	**Implementation**	**Advantages**
Innovative motor technology	Servo-synchronous motor with direct pump attachment option	Compact
		Reduced costs
		Dynamic performance
	Asynchronous motor without external fan	Compact design
		Reduced costs
Innovative pump technology	Dual pump (PGH)	Energy-saving
		Smaller engine size
		Reduced costs
	2-point pump (A10/A4)	Energy-saving
		Smaller engine size
		Reduced costs
Energy management and power supply	Optimization of the pump volume flow with a dual pump and hydraulic transmis-sion	Higher dynamics (dQ/dt)
		Energy-saving
		Smaller engine and drive size
		Reduced costs
	Smart power supply with capacitive or ki-netic accumulator	Energy exchange
		Energy storage or recovery
		Reduced power peaks
		$\cos \phi = 1$
Improved control functionalities	Optimized control algorithms	Higher dynamics without overshooting
		Sturdy control system
		Simple configuration
	Active use of hydraulic pump adjustability	Less installed power
		Smaller motor
		Higher dynamics for Sytronix FcP
	Position / force control for cylinders	Higher dynamics
		Reduced costs
		Drive-based solution for the sub-system
	Vibration dampening	Higher dynamics
		Higher accuracy
Monitoring and protection functions	Monitoring the hydraulic unit (HPU)	Several sensors integrated in the HPU
		SYTRONIX as sensor gateway
		Network capability
	Energy monitoring	Optimized power consumption
		Energy control
	Status monitoring	Error detection
		Preventative maintenance
		Simple diagnostics
	Integrated protective functions	Component protection for hydraulics
		Easy to operate

Innovation	Implementation	Advantages
Communication – Machine integration	Open interfaces (SYTRONIX template)	Open source for additional applications
		Ensuring know-how
		Programming according to IEC 61131
	Multi-Ethernet interface	Open for the integration of external applications
		Standard communication hardware
		Software solutions
	Master / slave sub-system	Modular system design
		Plug & Play
		Smart sub-system with SercosIII
	PLC modules for PLC external applications	User-friendly with PLC external applications
		Reduced design effort
Commissioning and maintenance functions	IndraWorks SYTRONIX wizard	User-friendly
		Product database available
	Menu for quick configuration	Shorter commissioning on the PC
		Simple diagnostics
		Low costs
	Embedded web server	No installation required
		Maintenance-friendly (electronic nameplate aligned with the application)
	PLC modules for PLC external applications	User-friendly with PLC external applications
		Reduced design effort

Table 9: Overview of Already Implemented Sytronix Functions

6.10 Availability of Sytronix in System Solutions

Product program Sytronix

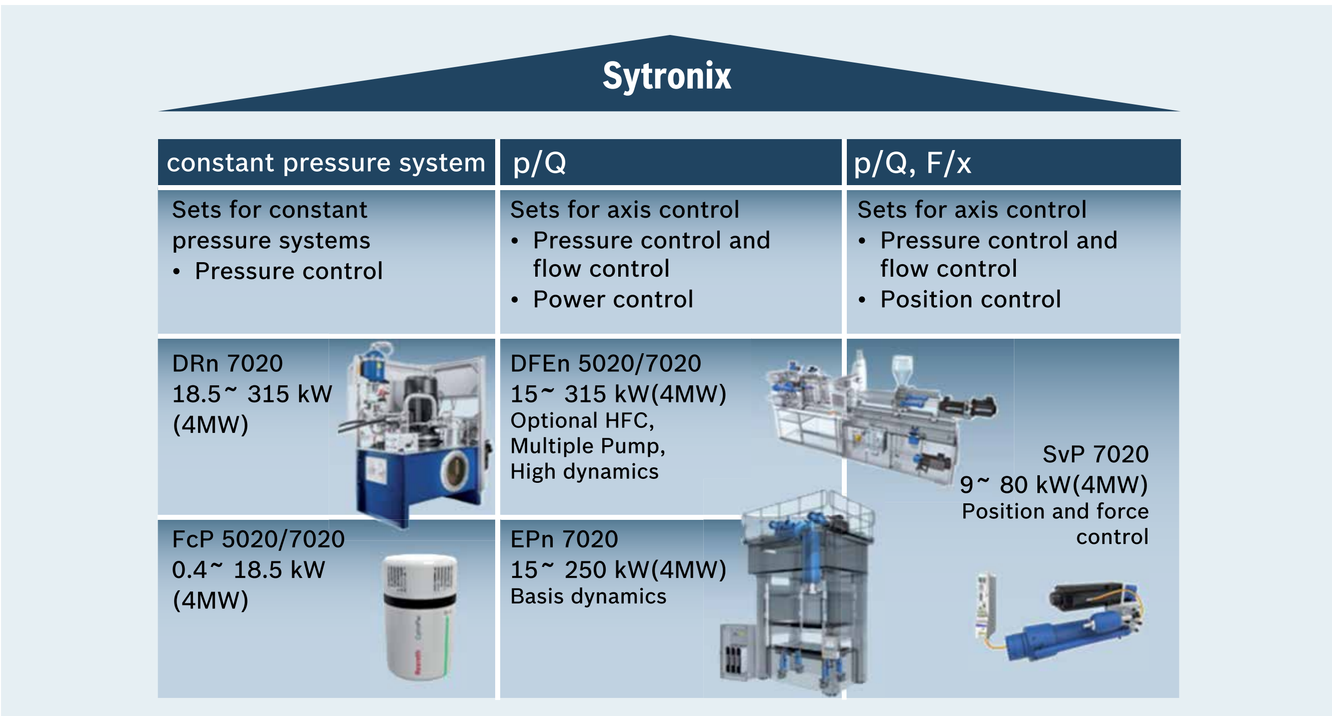


Fig. 62: Sytronix-Portfolio

The Sytronix is finely scaled. Function-oriented, pre-configured and individual sets of inverters, motors and pumps together with accessories serve as the base program. The individual components used are part of the standard product range of Bosch Rexroth. The main application areas of Sytronix can be seen from the perspective of hydraulics by means of different software functionalities. These solutions are focused on constant pressure systems, p/Q controls and axial controls. The hydraulic drive unit in a hydraulic unit either meets the task of providing a constant pressure system or of controlling the volume flow while relieving pressure. This task can be supported with Sytronix solutions. Sytronix drives with the “axial control” software function are used with servo-hydraulic compact axes.

Smart standard unit ABPAC: configurable, network-capable, energy-efficient.

The ABPAC hydraulics units consist of standardized modules as a modular designed series.
The new hydraulic units series ABPAC from Rexroth bears witness to electrification and Industry 4.0. All units of this series are designed for the use of rpm-variable pump drives for constant pressure systems, such as with FcP or DRn solutions. They reduce the speed in partial load operation as needed and reduce the hydraulics energy requirement by up to 80%. In addition, the drives of the Sytronix SvP family can be used where the special requirements of fluid technology are already integrated in the software of the smart drives. The commissioning and diagnostic tools for this are the same that are also used for Rexroth electric drives.

Open interfaces for machine control and in the IT world integrated the APBAC units into horizontally and vertically networked production environments in a future-proof manner. An integrated universally usable sensor package continuously records all relevant system states of the unit:

- Degree of contamination of the filter
- Oil quality
- Sensors for working, suction and storage pressure
- Oil level
- Different temperatures

Fig. 63: New Generation of ABPAC Hydraulic Units – Smart, Networked and Energy-Efficient Hydraulics

The sensor data, system sizes and the derived status messages are made available by the ABPAC units on standardized interfaces. The user either reads these messages via Ethernet bus or via the machine controller or via an integrated web browser wirelessly from a smartphone or tablet PC.
With its new hydraulic unit series ABPAC, Bosch Rexroth offers flexible and energy-efficient pressure supply units that are ideal for stationary machines, such as chipping machine tools, wood processing or presses and plastic machines. In order to shorten design and delivery times, great attention was paid to standardized components and processes.

- Short delivery times, faster to start
- Smart condition monitoring with open core interface
- Mobile access, intuitive control, economical drives
- Custom: the right drive for any application
- Save energy: with rpm-variable Sytronix drives
- Container size: 100 to 1,000 liters
- Special functions in the field of cooling, noise reduction and efficiency

CytroPac hydraulic unit

Bosch Rexroth rethought the new up to 4 kW small unit not only visually, but also technically. CytroPac offers an energy efficiency and noise optimization package in the smallest space by means of a Sytronix drive. Significant costs are eliminated due to the ready-to-connect internal wiring of all sensors, such as pressure, temperature, fill level or contamination. Value was also placed on the aspect of Industry 4.0 capability by means of a multi-Ethernet interface. In addition to the EU directive, CytroPac is ready to support the approach of simply connecting the supply, fluid and data interface. It doesn't get any easier.
The following advantages result from special product features

- Practical – Sensors allow for preventative condition monitoring in real-time; the easier integration and commissioning
- Compact – Space-saving, low-noise design concept is ideal for machine tools, for example
- Highly-efficient – rpm-variable Sytronix drives for demand-driven performance; the latest heat pipe technology allows for water cooling
- Networked – Completely wired and integrated frequency inverter; no additional installation space required in the control cabinet
- Future-proof: Designed for use in Industry 4.0 concepts

Fig. 64: CytroPac with Integrated Pump Drive Sytronix FcP

Servo-hydraulic axes: smart self-supplier for powerful tasks

There is movement in the market for powerful drive tasks: The ready-to-install servo-hydraulic axes essentially consist of electric and hydraulic standard components. Their structure is largely standardized. With a separate closed fluid circuit, they only need a power supply and no connection to a hydraulic unit, just like the electro-mechanical versions. To this end, IndraDrive controllers use their multi-Ethernet interface to support all common Ethernet protocols, such as Sercos, ProfiNet, EtherNet/IP, EtherCAT or Powerlink. The axial control adopts a newly developed and hydraulically optimized technology package Sytronix Position-Force-Control (PFC). Condition monitoring functions of, for example pressure, temperature and degree of efficiency, are available in the software, thus enabling a data exchange in the sense of Industry 4.0. The complete systems are available for large forces of up to 2,500 kN.

Fig. 65: Servo-Hydraulic Axes (SHA)

6.11 Converting a Machining Center to Sytronix

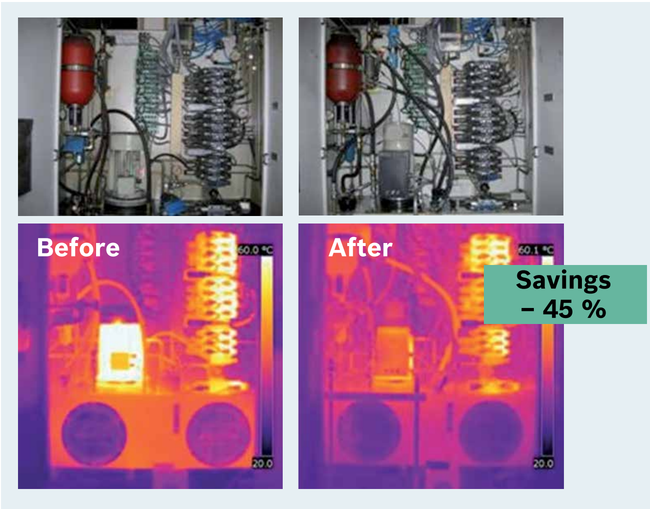


Fig. 66: Thermal Image of the Machining Center at the Homburg Plant

A 2-spindle machining center from the year 2003 was converted at the Bosch Rexroth plant in Homburg so that the energy consumption could be reduced by 45%. The “Energy System Design,” “Efficient Components” and “Energy on Demand” types of leverage of the Rexroth 4EE system were taken into consideration here. The material costs for the conversion amounted to EUR 5,000. The amortization period amounted to about 3 years and 2 months.
The energy savings can be made immediately visible using a thermal image taken before and after the conversion (see “Thermal Image of the Machining Center at the Homburg Plant” on page 92).

	Original drive solution	**Rexroth 4EE automation solution**
Implementation	▶ 5.5 kW engine ▶ Regulating pump 250 bar / 13 l/min ▶ Fixed displacement pump for filter / cooler	▶ 4.0 kW engine ▶ Speed-variable drive ▶ 6 ccm gear pump ▶ Tank line passes through the filter / cooler
Energy consumption	24,600 kWh/a	13,620 kWh/a
Savings	10,980 kWh/a €1,537/a*	
CO_2 avoidance**	6.7 t/a	

* Electricity price 0.14 €/KWh including 3.592 ct/KWh Renewable Energy Law apportionment
** Energy mix, Germany according to GEMIS Version 4.2 in the comparison year 2004: 0.613 kg CO_2/kWh

Table 10: Comparison of Different Solutions for a Machining Center

Due to the high profitability, four additional system have now also been converted. Another eight system are in the planning state at two locations.

11 Machining

Author: Dr. Andreas Emrich

The topic of "machining" will be looked at in this chapter. Aspects will be discussed in the process that primarily, but not exclusively, can be influenced by the machine manufacturer (components, design, etc.), as well as those aspects that are more likely to be influenced by the machine operator (process, technology, etc.).

11.1 Savings Potential of Different Machine Groups and Examples from Practice

In addition to some of the most common and at the same time most energy-intensive machine groups (cleaning systems, painting booths, hydraulic presses, etc.), which are discussed in more detail in separate chapters in this book, additional machines (in particular in the Bosch Group, but frequently also others) can be assigned to groups of machining centers, turning machines and grinding machines. They form the core of cutting machines. Other groups with lower quantities are, for example, honing, planing, slotting and/or sawing machines. Each of these groups can then be subdivided further according to different criteria so that a large number of individual machine types can be named for each production process. So as not to get lost in detail at this point, select examples will be presented below that are used to explain the measures for energy savings in the respective initially mentioned machine groups.
Many of the measures shown are generally transferable, even if they may differ in detail. This also applies in part to the machine groups of the cutting machines not explained in detail here.
In principle, so-called Sankey diagrams are showed hereinafter for the machines under consideration. These illustrate the energy flows within the machine and show what portions of the supplied energy are used for which components and functions. They are therefore a similar type of diagram as the classic pie charts.
For better understanding and easier transferability, the individual measures are assigned to the four different types of leverage of the 4EE system. The three types of leverage "Energy on Demand," "Efficient Components" and "Energy Recovery" in particular are considered in the process. The fourth lever of "Energy System Design" takes into consideration the entirety of a system and primarily is used during its development and design. You can find information about this in chapter "Holistic Approach to Energy Management" on page 17.
An exact assessment and representation of the individual savings and the economic efficiency must generally be foregone, since this would not be useful. As already explained, the individual savings are greatly dependent on boundary conditions, which greatly differ depending on the specific application case. Some main influencing factors are named here as examples:

- Workpiece (material, volume of metal removed by cutting,...),
- Type of machining (e.g. roughing, fine machining or complete machining),
- Technologies used (drilling, deep drilling, milling, threading,...),
- Tools and cutting materials used,
- Technology parameters used,
- Usage time of the machines per year,
- Machine availability,
- Price of electricity,
- Internally or externally realized conversion costs,
- Internal rate of interest,
- etc.

Machining centers (drilling & milling)

Machine tools that in the past were primarily designed for the use of a single production process have now been developed into machining centers where the entire production is made possible through the use of different procedures. The reasons for this development are very diverse. The complete machining of the workpiece in a single clamping thus allows for the implementation of the highest quality standards or reduces the handling and transport requirement in production considerably. The prerequisite for this was, among other things, the availability of powerful computer systems (control systems and programming systems) and tools with long service lives. [see 10]
Different groups of machining centers were examined within the Bosch Top 10 initiative presented above. Distinguishing was done here according to the main criterion of "wet or dry machining" and the number of main processing spindles. Since there was a large number of different manufacturers within the Bosch Group machining centers, exemplary machines of the manufacturer GROB-Werke GmbH & Co. KG, Mindelheim (see "Machining Center G320 of GROB-Werke GmbH & Co. KG, Mindelheim" on page 136) and STAMA Maschinenfabrik GmbH, Schlierbach were chosen as representative for closer examinations.

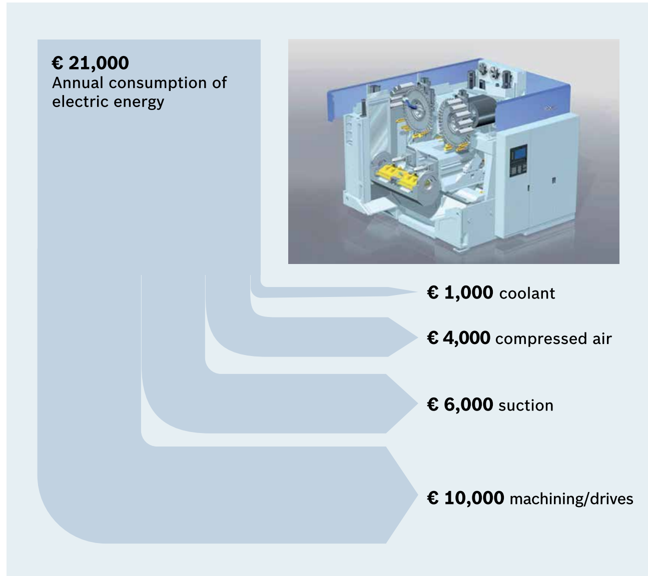


Fig. 96: Machining Center G320 of GROB-Werke GmbH & Co. KG, Mindelheim

With the G320, there is presumably an unusually low proportion that goes to cooling. The representation summarizes all electric drives within the machine in the "machining/drives" section. "Coolant" as well as, for example, "compressed air" refers to energy that also has to be used in external systems (central coolant network in the plant, central compressed air generation) to operate the machine. It is shown here how important a neat and clear definition of system boundaries is for a examination, especially if the results are to be transferred to other application cases.
For reasons of clarity, in the representation the main adjusting leverage types for non-optimized machines and the solutions for these are always shown, usually in list form, and are assigned to the different 4EE types of leverage. The measures are a comprehensive representation from the results of the two considered machining centers of the companies GROB-Werke GmbH & Co. KG, Mindelheim and STAMA Maschinenfabrik GmbH, Schlierbach.

4EE leverage "Energy on Demand"
Actual condition of non-optimized machines:
- The cooling lubricant (KSS) is not provided in a demand-driven manner. The proportion of the energy requirement is very high.
- The hydraulic performance required in the machine is not provided in a demand-driven manner. The proportion of the energy requirement is very high.
- The hydraulics drives run continuously. The proportion of the energy requirement is very high.
- Sub-components, such as monitors or exhaust systems, are not shut down in standby mode.
- The chip conveyor runs the whole time, even if no chips are being created or are to be conveyed

Target state:
- Use of speed-controlled motors, pumps for KSS and hydraulics
- Use or optimization of shutdown and start/stop modes (in addition to the direct energy savings, the energy requirement for cooling is also reduced here, because less loss heat is introduced in the circuits or in the system and has to be cooled back down)

4EE leverage "Efficient components"
Actual condition of non-optimized machines:
- Use of inefficient electric motors
- Use of inefficient clamping systems

Target state:
- It should be possible to release the motors from the control when at a standstill, i.e. they can be shut down. Use of existing (mechanical) clamps.
- Hydraulic clamping systems with low leakage are chosen, which reduces the demand for hydraulic performance (primarily affects the workpiece clamping).

Turning machines

Different groups of turning machines or turning centers were also examined as part of the Bosch Top 10 initiative. Distinguishing was also done here according to the main criterion of "wet or dry machining" and the number of main processing spindles. Machines from EMAG Holding GmbH, Salach (see "Turning Machine VSC250 Duo from EMAG Holding GmbH, Salach" on page 137) and Alfred H. Schütte GmbH & Co. KG, Cologne (see "Turning Machine SC9-26 from Alfred H. Schütte GmbH & Co. KG, Cologne" on page 138) were taken into consideration here, for example.

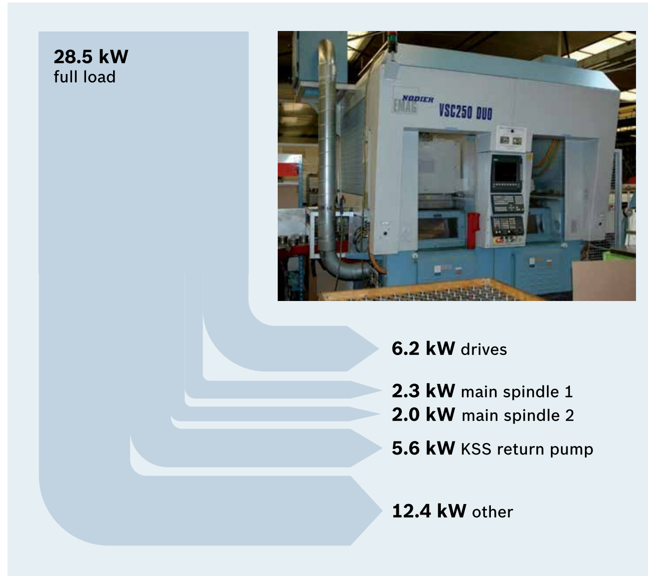


Fig. 97: Turning Machine VSC250 Duo from EMAG Holding GmbH, Salach

The high proportion is allocated to "other" with the EMAG turning machine. It is also shown with this example that a detailed measurement has clear advantages with respect to a real usage-driven allocation. With such a result, it is difficult to identify the consumers with the actual largest potential and to derive measures.
The following Sankey diagram of the Schütte machine is, however, a good example of a detailed measurement with significant meaning. The main drives are grouped under inverters. This is quite permissible and meaningful for reasons of effort, since usually no potential (can be) is found with the drives as the intervention in the machine would be too elaborate and not economic.

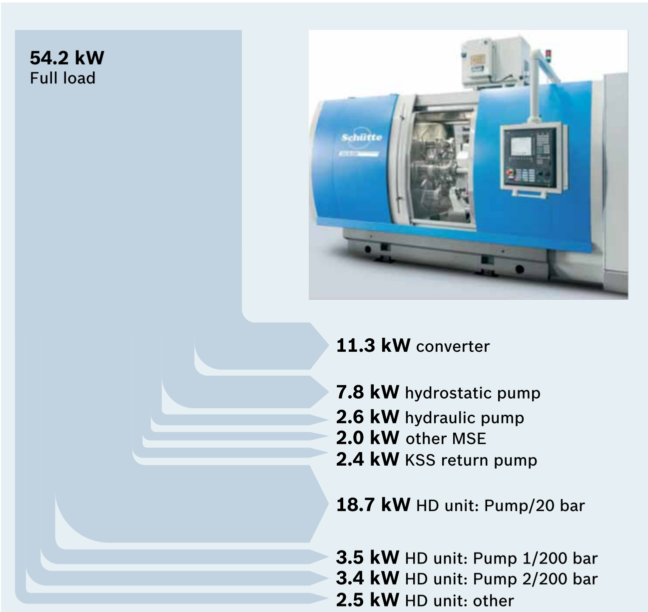


Fig. 98: Turning Machine SC9-26 from Alfred H. Schütte GmbH & Co. KG, Cologne

Traditional multi-spindle turning machines pose a special challenge, in particular with respect to the subsequent improvement of the energy efficiency. The machines are highly productive (very short cycle times within seconds, no tool changer), highly complex and equipped with a number of axes and secondary components (e.g. rod loaders). In addition, they frequently have complex hydraulic systems, since they are often equipped with hydrostatic bearing systems and/or hydraulic axes. This complex setup is a direct result from the application area in large batch or mass production.
Hydraulic systems where a motor drives several pumps for the different circuits via a central shaft can hardly be optimized in practice. An optimization would only be possible if each pump circuit would be made to be controlled separately in that each pump is assigned to a separate motor, which then in turn can be regulated individually. The retrofitting of several motors and the control technology separation frequently fail both due to costs as well as the additional space required that would be needed for such a process, but that is not available or provided by the manufacturer within the system. In addition, the pump controls would have to be highly dynamic and the shutdown or start-up would have to take place in the shortest of times both in control mode as well as in the event of faults. Limits are set by the motor manufacturers here in turn, since the motors are only designed for a certain number of on / off operations per time unit (per hour). Joining up a hydraulic accumulator in circuit to reduce the on/off operation cycles of the motors is generally possible, but this means additional effort and it would have to be very large to be effective, depending on the required hydraulic performance (pressure, volume flow).
Despite these difficult boundary conditions, opportunities for improvement were also identified in this machine group:

4EE leverage "Energy on Demand"
Actual condition of non-optimized machines:
- Use of uncontrolled motors for the pumps (see restrictions above)
- A lack of or insufficient standby shutdown strategy (time, time periods, scope)
- No demand-driven operation of system periphery (KSS, chip conveyor,...) since these cannot be addressed via the NC program
- Standardized, often low, temperature level with a high cooling effort (see "Savings Potential Through Machining Technology and System Utilization" on page 140)

Target state:
- Controlled motors and pump in the periphery systems
- Implementation of an (automatic) standby
- Use-driven utilization of peripheral devices

4EE leverage "Efficient Components"
Actual condition of non-optimized machines:
- Use of inefficient motors
- Use of inefficient blow-off nozzles for cleaning or as a lock seal

Target state:
- Use of efficient motors
- Use of optimized blow-off nozzles

In general, the savings potential of the machines used in wet machining here is percentaged higher than that of the MSE in dry machining due to the cooling lubricant system as the consumption driver in wet machining. The consumption of comparable dry machining machines, however, is absolutely significantly lower.

Grinding machines

“Similar to milling, a circular tool [...] carries out the cutting movement with grinding too.” [5] This is usually a grinding wheel, a grinding belt or a mounted point. Many different characteristics are distinguished within the grinding process, which primarily depend on the tool, the workpiece and the surface to be machined. The most important processes here are the surface, external and internal cylindrical grinding, which were taken into consideration within the Bosch Top 10 initiative. A selection of the machines considered as part of the Bosch Top 10 initiative is shown in the figure “External Cylindrical Grinding Machine Jucam 1000/50 with Two Spindles” on page 139 and figure “Internal Cylindrical Grinding Machine Ultra Twinner with Two Spindles, Hydrostatic, with High-Pressure Pumps” on page 139.

Fig. 99: External Cylindrical Grinding Machine Jucam 1000/50 with Two Spindles

Fig. 100: Internal Cylindrical Grinding Machine Ultra Twinner with Two Spindles, Hydrostatic, with High-Pressure Pumps

In practice, operators primarily often have major reservations about optimizing fine and ultra-fine machining machines, which also include grinding machines. These reservations result from concerns that the optimizations could be relevant to quality. Due to the high quality requirements, especially with fine and ultra-find machining, the tolerances are accordingly small and often too difficult to comply with. This concern must absolutely be taken into consideration in order to have successful optimizations. They were therefore taken into consideration when selecting and defining the following measures:

4EE leverage “Energy on Demand”

Actual condition of non-optimized machines:

- Continuous operation of ancillary units, e.g. the KSS pumps with “control” via bypass

Target state:

- Foregoing the bypass through real control
- Use of shutdown and standby modes

4EE leverage "Efficient Components"
Actual condition of non-optimized machines:
- Use of standardized, non-efficient pumps and motors
- No standardized, energy-efficient control cabinet cooling
- Increased compressed air consumption due to sealing air

Target state:
- Use of more energy-efficient pumps and motors
- Use of more energy-efficient control cabinet coolers
- Sealing air column optimization at spindles and guides, alternatively the use of brush seals

Another large potential, especially with grinding (= fine machining with small tolerances) lies in the temperature level of the system or the cooling lubricant used and in the warm-up strategy used. Chapter "Savings Potential Through Machining Technology and System Utilization" on page 140 goes into these points separately.

11.2 Savings Potential Through Machining Technology and System Utilization

In addition to the machine structure topics, additional considerable potential also lies in the operation of the machines. The simplest and most cost-effective opportunity lies in shutting down the machines that are not needed. This is often confronted with two obstacles in practice:
1. Technical problems during restarting, especially with older machines
2. Warm-up phases before starting machining at the expense of effective production time

The problem mentioned first is often countered by the machine no longer being shut down. This may at first look be a pragmatic solution, but of course in no way corrects the actual cause. Besides the costs for the now continuous energy consumption, this "solution" involves a high risk: If the system is to be completely shut down unexpectedly due to a defect of, for example, the fuse, a power failure or faulty operation, this often will lead to an unscheduled and then often long downtime. It would make much more sense to sustainably solve the problems that inhibit the restart in order to achieve a higher level of safety regarding the system availability and lower energy costs. Particularly critical is the control system of older systems, for which spare parts are often no longer freely available. A middle path here can be that to let the control system be permanently powered on, but to shut down all other units (pumps, conveyors, hydraulics, exhaust, etc.).
Other approaches to increasing efficiency result from the so-called warm-up cycles or phases. Before the production of components begins (also applies, for example, to heating cabinets in assembly, baths in cleaning systems), the systems are to be warmed up in order to maintain a constant temperature in the machine and not to generate heat deviation during production. This process is standard in many machines, but it is particularly pronounced with the fine and ultra-fine machining processes and machines. Experience has shown that these warm-up cycles are often extremely long and can extend over several hours or sometimes even an entire shift. Practical examinations have shown, however, that there is a much greater potential for shortening here, which in addition to gaining production time also means considerable energy savings. These warm-up phases are often also the reason that machines in two-shift operation are not shut off in the third shift, because otherwise the employees in the first shift cannot start immediately, but rather have to allow the machine to warm up first. This problem can be solved in a variety of ways:
- Personnel from other areas who work in 3-shift operations switch the machines on in due time before work starts in the first shift.
- Guard or security personnel who are present during unmanned hours switch the machines on in due time before work starts in the first shift.
- The machines are switched on via (retrofitted) timer switches.
- The machines are switched on via a (retrofitted) online tool.

Different commercial solutions are available today on the market for the last two options named.

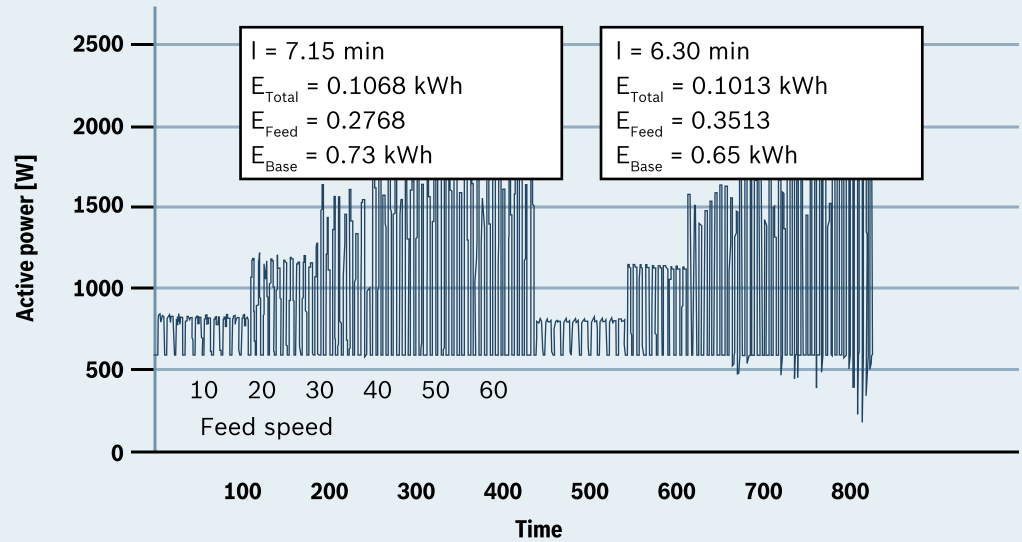
Temperature level in the system

In particular in fine and ultra-fine machining methods, there is also great potential in the temperature level of the system or the cooling lubricant used. Frequently a temperature of 20°C (standard temperature) is set here with a very low tolerance (±1°C), since the specified dimensions of the component relate to this temperature. The temperature-dependent dimensional change of a component depends on its material and is defined by a material constant, the so-called thermal expansion coefficients. For example if you always produce a component at 25°C, correspondingly adjusting the target dimensions (25°C) can create a component whose dimensions at 20°C and a corresponding shrinkage then correspond to the required specified dimensions. This process is called reserving. From a technical point of view, it is thus not absolutely necessary to maintain precisely 20°C, but rather to reach a high temperature constancy and to compensate for the resulting deviation using the method explained above. The advantage is that the process temperature can be adapted to the ambient temperature and, thus considerably reducing the energy requirement for cooling the cooling lubricant.
Example: If you produce “cold” cooling lubricant at 25°C at an ambient temperature of 30°C, you need significantly less energy than if you produced “cold” cooling lubricant at 20°C. This process is successfully used, for example at the Bosch Group in the production of needles for fuel injection systems in mass production. Sub-micrometer tolerances are to be met with these component, which also ensures process reliability.

Energy savings from slower process speeds?

Many processes consume less energy when they occur at a slower speed. This is based on the fact that energy-requiring, almost opposing effects often occur with the second or third power of the speed. A common example here is air resistance when driving a car, which increases in the square of the speed driven. The first logical consequence would be to reduce the process speed of systems in order to achieve a higher level of efficiency and a lower consumption per workpiece. However, this speed reduction is diametrically opposed to the most important optimization criteria in production: economic efficiency. This is because slower process times mean an increase in the piece time and thus a reduction in the output per time unit, per machine or also per hour of employee presence. In light of the principles of modern production systems, overproduction is a kind, possibly even the worst kind, of waste, but it can be avoided by generally creating added value in sync with the customer's requirements and not compensating for available or excess amounts of time by working more slowly, but rather combining these into sufficiently large blocks and then completely stopping work during these blocks of time. Depending on the reliability of the acceptance of products, these free blocks may be hours, shifts or even days long. Thus this is generally practiced as a rule. Returning to the “contradiction” between energy savings and economic efficiency of the overall consideration, investigations were carried out that have revealed a somewhat surprising, but also pleasing result (see “Acceleration Saves Energy” on page 142):

Acceleration Saves Energy



- Energy savings in the axles at low acceleration
- However: Overall same energy consumption due to the base load (only that of the drive train)

Source: PTW, Technical University of Darmstadt

Fig. 101: Acceleration Saves Energy

The total energy consumption at a higher process speed (here through a higher acceleration of the axes) is less than with the process that lasts longer. In this specific example, it is about 5%. The reason for this: The higher energy consumption caused by the higher acceleration is overcompensated for by the saved basic consumption, which results from shortening the process time. The series of tests shown in the figure proves that this is not just a special case. It clearly shows that the basic load (basic consumption) is the dominating element so that the process speed does not necessarily need to be reduced for energy efficiency reasons.

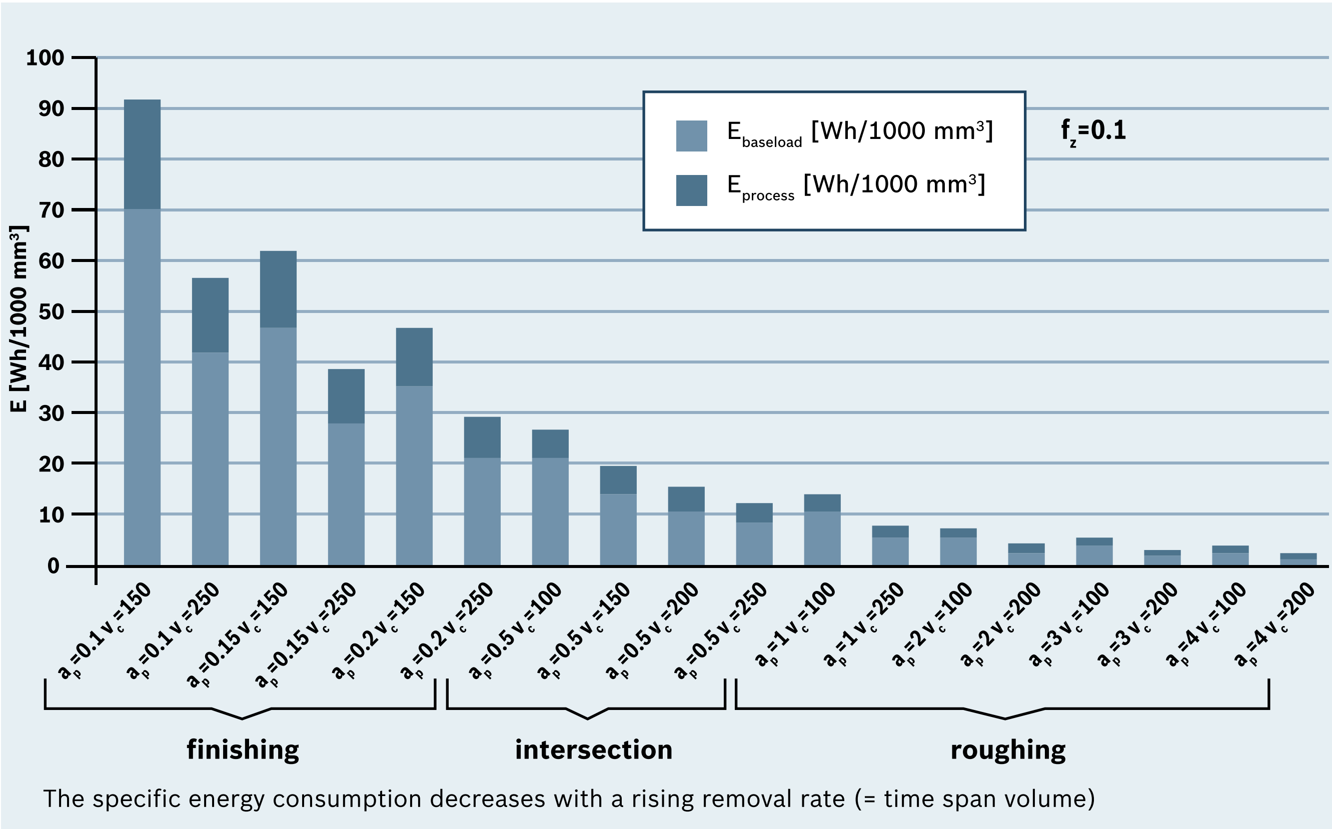


Fig. 102: The Basic Load Dominates the Energy Consumption

Energy savings through efficient programming

The energy consumption of a system is also considerably affected via the CNC programming of the parts programs. Chapter “System Solutions for Energy-Efficient Design” on page 72 in this manual explains in detail what savings potential and tools are available here, which is why it will not be discussed further at this point.

11.3 Summary

In the field of machining, there are a number of measures to increase energy efficiency, both on the part of the machine manufacturer as well as on the part of the machine operator. Measures have been shown and documented for various machine groups. Details of technical implementation, primarily on the component side, can be found in the corresponding technical chapters of this manual. Typical starting points were also pointed out for the operator's part, which can easily also be transferred to other machine groups and usually to other technologies that are not discussed here. Many of the approaches shown here are deliberately kept general. On one hand this is to allow for a high level of transferability and, on the other hand, because the considered scopes of the systems, even within the defined machine groups, would go beyond the framework of such a book when considered in detail and such a specialized book would nevertheless never be able to replace the necessary detailed consideration of existing systems and their use.

20 Examples of Holistic Plant Analyses

Author: Leo Pototzky

A number of holistic plant analyses carried out will be used in this chapter to show what opportunities exist for the reduction of the energy consumption and CO_2 emissions in practice. It will describe how possible measures for energy savings were shown from an economical perspective, prioritized and transferred into a realization plan in the plants. A holistic nature here means that the measures affect both machines and systems as well as the infrastructure area and they influence each other. The analyses were carried out with precisely the tools that are described in the first part of the book.

The first example describes in detail how the analyses and measures at the Glenrothes plant in Scotland were carried out with the representations and prioritization methods explained in this book, while the two other examples are largely limited to the presentation of the results obtained in this way. The goal of -17% named in the “bridges” is derived from the original project goal of improving the energy efficiency by 20%.

20.1 Glenrothes Plant (Scotland)

The Glenrothes plant is about an hour's drive north of Edinburgh in the county of Fife. This area in Scotland is known for its many activities in the field of regenerative energy, such as wind and wave power. The plant has about 400 employees and manufactures radial piston motors, which are used in mobile work machines. These motors are typically used as wheel motors where the motor drives the individual wheel directly.

The plant has already been certified according to environmental standards for many years and has attracted some attention by winning a few environmental awards.

Result of the GoGreen potential analysis: The "bridge"

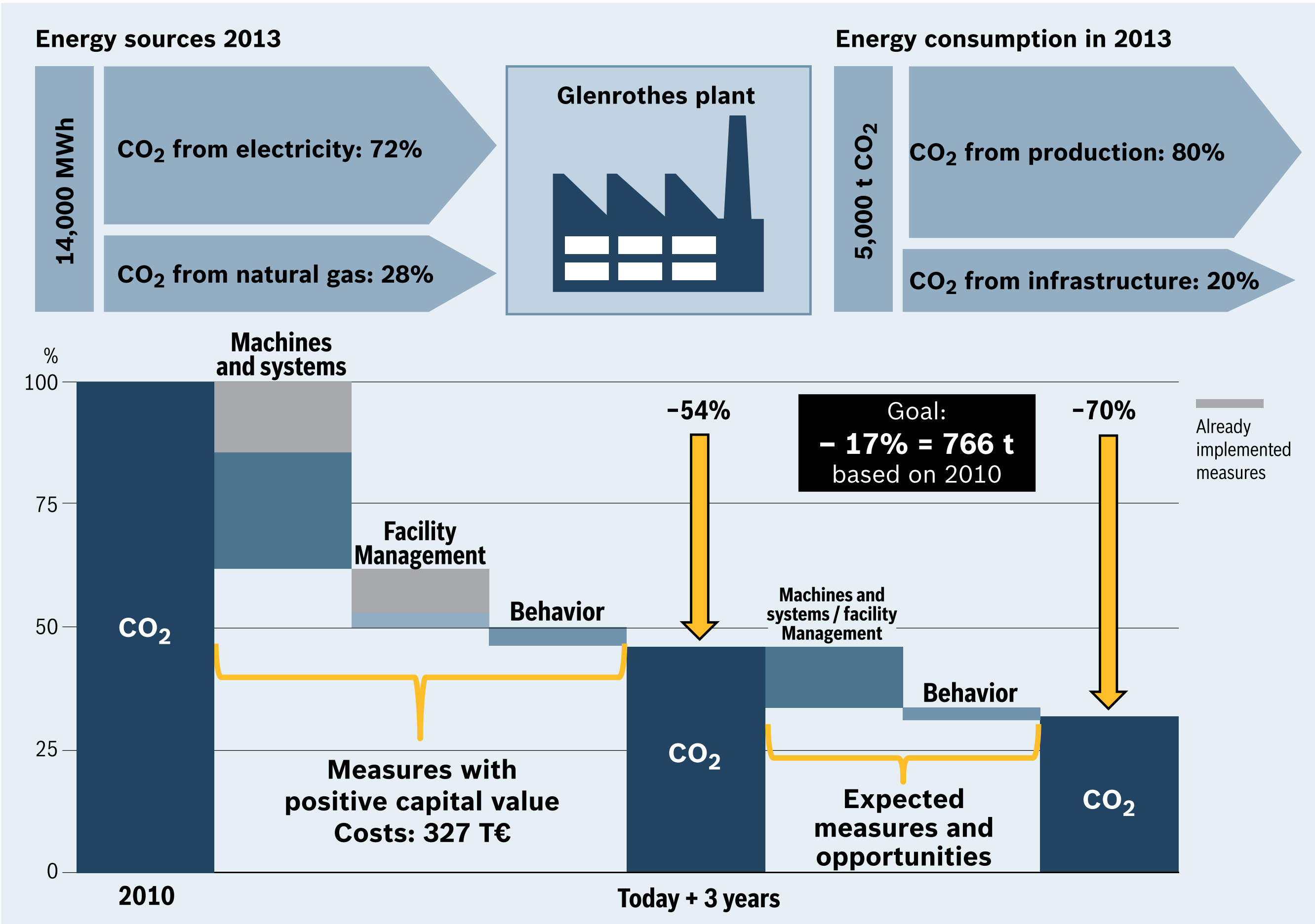


Fig. 150: The "Bridge" (Glenrothes Plant)

The so-called "bridge" shown in "The 'Bridge' (Glenrothes Plant)" on page 218 is the most important form of representation for managing the illustration of the potential for CO_2 reduction. It shows the types of measures for implementing the savings potential as well as the desired future development. In addition, the "bridge" provides a wealth of other basic information, which in this case is the following:

- 72% of the CO_2 emissions come from the consumption of purchased electric energy,
- 28% of the CO_2 emissions come from the consumption of natural gas,
- 80% of the CO_2 emissions are caused by production,
- 20% of the CO_2 emissions are caused by the infrastructure,

The bar graph shows the potential for reducing CO_2 emissions compared to the starting position in 2010. The middle bar "Today + 3 years" shows that 54% of the CO_2 emissions can be reduced with economically efficient opportunities. This potential is a reference value at Bosch Rexroth.

The bar sections marked in gray stand for the measures already implemented by the end of the analysis. It is easy to identify that a large part of the measures was already implemented in the area of infrastructure (FCM). The focus for the future therefore lies in the area of machines and systems (MSE).

The right side of the "bridge" shows other opportunities for reducing emissions with which a reduction of 70% can be achieved. The measures on this side correspond to the status of ideas or their economic efficiency or technical feasibility are not yet ensured.

Prioritization of measures

Chapter "Project Management for Holistic Energy Efficiency Potential Analyses" on page 29 already described what methods can be used to process the results of the studies. The data from the CO_2 calculator can be used to define any premises and evaluate their effect on the measures.
There is a separate table sheet in the CO_2 calculator for each of the measures named that describes the following in detail:

- the respective machine or equipment
- the opportunities for improvement of the machine
- the impact on energy consumption and costs

The following were used as the premises in the Glenrothes example:

- the capital value (NPV – net present value), which describes the economic efficiency of the respective measure,
- the capital payback period (PBP – Pay Back Period), which describes the economic risk,
- the CO_2 savings in tons.

A ranking was created for each premise. Then the average value of the sum of the respective premise results was formed for each measure. The premises were thus weighted equally. Using this value, the measures were distinguished as follows in the last step:

- Highly effective measures (priority A)
- Good measures (priority B)
- Still acceptable measures (priority C)

The described results now result in the table sheet in the CO_2 calculator shown in "Table Sheet CO_2 Calculator" on page 219:

		Ecological Effect		Economical Effect		Priorization	
No.	Measure	MAE / FCM	CO2-Savings [t]	NPV [€]	PBP [a]	Average Ranking [NPV, PBP, CO2 abs.]	Prio
M21	Install new filter to use heat from CHP grid for washing machines	MAE	628	889.336	0,2	16,3	A
M16	Replacement of electrical radiators	FCM	80	81.121	2,4	12,7	A
M18	Implement continuous inspections for compressed air	FCM	44	54.992	1,0	12,7	A
M25	Heller MC 25	MAE	59	62.453	1,9	12,3	A
M27	Daewoo Puma 350 M	MAE	143	122.220	3,2	12,0	A
M1	Installation of motion & daylight sensors	FCM	33	41.890	0,9	12,0	A
M19	Automatic lowering of temperature on w	FCM	38	26.254	1,7	10,7	A
M23	Test Rig	MAE	36	30.921	3,1	9,0	B
M29	Chiron FZ-15KS	MAE	11	12.269	1,3	8,3	B
M24	Nakamura STW 40	MAE	18	15.818	3,1	7,7	B
M26	Knoll Filter System of Heller Maching C	MAE	6	6.847	0,9	7,7	B
M11	Increase room temperature of IT-room	FCM	2	3.423	0,2	7,7	B
M4	Connect direct gas-fired DHW-boilers to CHP (3x)	FCM	15	8.606	2,8	7,0	B
M6	Switching off wall-mounted gas-boilers	FCM	2	1.792	0,1	7,0	B
M28	Daewoo ACE H400P	MAE	29	2.005	9,4	4,3	C
M8	Connect all radiators to CHP-heating system	FCM	8	3.908	4,0	4,3	C
M13	Retrofit installation behind radiators (glazed link)	FCM	1	244	7,2	1,3	C

Fig. 151: Table Sheet in the CO_2 Calculator

In the “Measure” column (as in this example too), frequently only the systems are named where (usually technical) measures for CO_2reduction are implemented(e.g. test rig). These are described in more detail elsewhere in the CO_2 calculator. The division into infrastructure and machine measures can easily be seen in the “MSE/FCM” column. The rest of the columns each name the already explained premises as well as the corresponding priority class of the individual measure. There may still be adjustments, because measures call for them, because they must take place sooner or later or because there is an additional technical risk. Measures can thus be implemented even faster or sometimes even completely done away with.
The “holistic analysis” with this project is especially evident where energy or measures affect both areas, i.e. both the machine and the infrastructure (MSE/FCM).

Example: The improvement of the filter technology at the heat exchangers of cleaning systems (first table row: “Install new filter...:;” MSE measure) makes it possible to better utilize the heat from the combined heat and power unit.
The table “Prioritization of Measures at the Glenrothes Plant” on page 220 shows the potential broken down by priorities. It can be seen that a large part of the measures was assigned to priority A. This is especially due to their very good economic efficiency. Only very few measures belong to the categories B and C. A specific cost of around € 300 per ton of CO_2 reduction results across all measure (calculated for one year). This value exists for only half as many comparable projects and is another positive aspect that supports the implementation of measures.

	CO_2 savings [t/a]	**Cost savings [€/a]**	**Required budget [€]**
Prio A	1,025	220,000	226,000
Prio B	89	18,000	46,000
Prio C	38	8,000	55,000
Total	1,153	246,000	327,000

Table 30: Prioritization of Measures at the Glenrothes Plant

Start-up plan

Based on the prioritizations, the plant defines a schedule for implementing the measures in the coming years. This finally leads to a start-up plan that graphically represents the realization on the time axis (see “Start-up Plan for the Glenrothes Plant” on page 221).

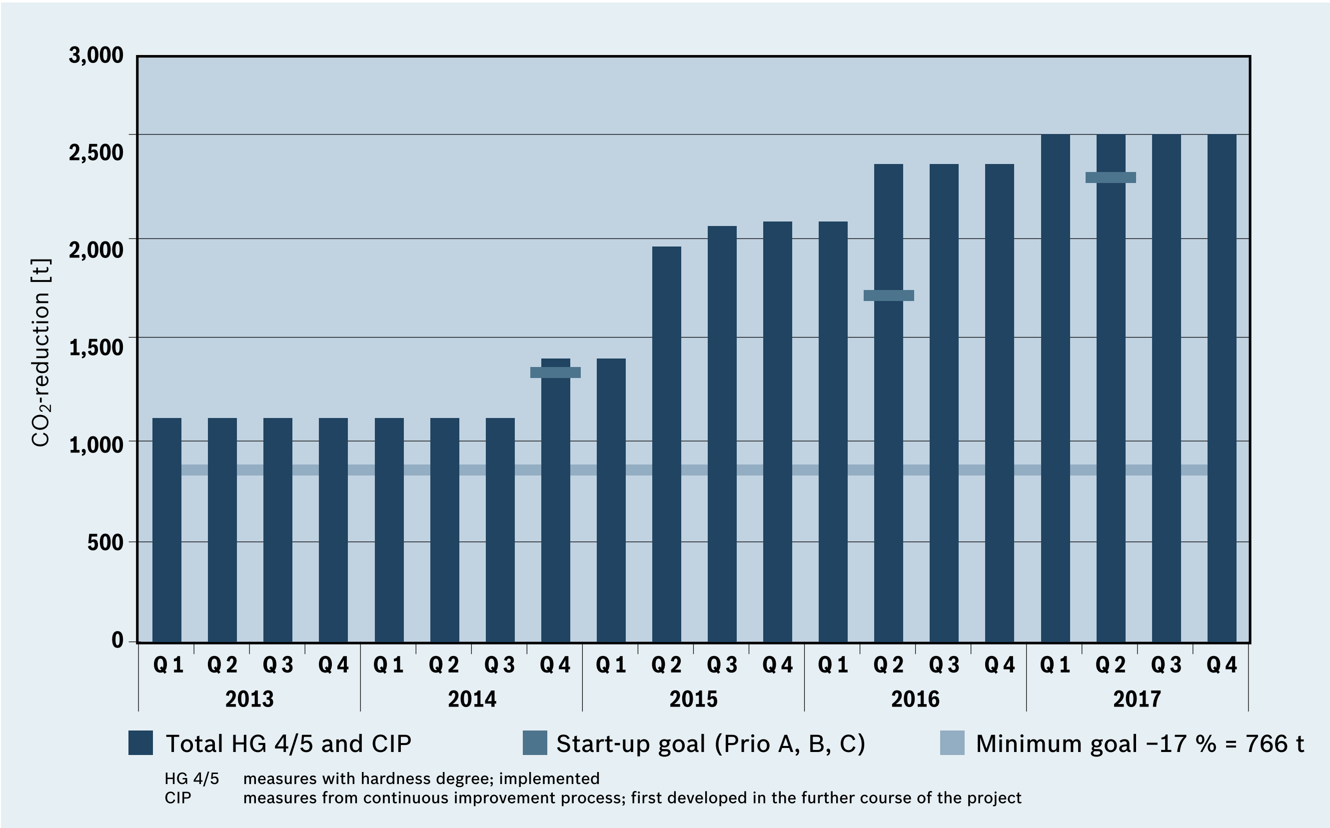


Fig. 152: Start-up Plan for the Glenrothes Plant

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