Energy-Using Product Group Analysis - Lot 5

Machine tools and related machinery

Task 5 Report – Technical Analysis BAT and BNAT

Sustainable Industrial Policy - Building on the Ecodesign Directive - Energy-using Product Group Analysis/2

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Executive Summary – Task 5

In this report several Best Available (BAT) and Best Not yet Available (BNAT) Technologies were examined. According to the MEEuP methodology, the only technologies which should be considered are those which are about to enter the market within 2-3 years (BAT definition). However, as technologies which have been recently introduced to the market, or which have not yet been widely introduced, are highly relevant in order to reap the full improvement potential offered by today's technologies, these readily-available solutions are also covered in this task report.

Moreover, the presented solutions do not claim that certain machine tools are the most energy efficient, and therefore represent the best available or best not yet available technology. Instead, there are a large number of energy efficient solutions at the component level for BAT, and potentially as BNAT. Here, the modular system architecture of machine tools has to be taken into account for eco-design measures. Many of the components are manufactured by suppliers, and implemented by the machine tool manufacturers. There are some approaches which address non-energy related improvements, including media consumption, mass reduction, and productivity increase.

As shown, most BAT component solutions are compatible with each other and aid to realise energy efficient machine tools. However, the energy savings which may be realised largely depend on the combination of measures, and the savings potential cannot be just aggregated when more than one option is implemented. The listed examples therefore show existing machine tools and machining centres which are equipped with a selection of energy efficient components, and demonstrate their energy-saving potential. The measures have a strong influence on productivity and partly also the functionality of the machine tools; thus, eco-design solutions have to carefully consider conditions of application, in addition.

The assessment of the various technical eco-design measures is based on a survey among machinery and component manufacturers, and complemented by research on technical options. The assessment reveals that there is a multitude of options, each with a small energy savings potential in the range of 1%, but it can be anticipated that a combination of several options could lead to significant total savings. However, the large spread of answers given for most of the options once again confirms that the feasibility and suitability of any option has to be assessed carefully for the intended application.

The projects presented regarding BNAT which originated from the European area do not only cover solutions at the component level of machine tools. Instead, an overall examination in different areas of energy efficiency of machine tools has been conducted. The amount of technologies presented in both fields, BAT and BNAT, shows the growing importance and awareness to offer and to implement energy-efficient solu-

tions in machine tools, via the research, development and implementation efforts of the metal working machine tools manufacturers.

5 Task 5 – Technical Analysis BAT and BNAT

According to the methodological approach (MEEuP), Best Available Technology (BAT) entails a technical analysis not of the current product on the market but on currently available technology, expected to be introduced at product level within 2-3 years. However, as some technologies are just about to enter the market or are already introduced, but not implemented at large, the BAT chapter covers also these already available technologies as they represent an important improvement potential. The various sub-chapters indicate roughly the status of market availability. Best Not yet Available Technologies (BNAT) summarise the state-of-the-art in research and development for a product, indicating the long-term market possibilities. The environmental performance of BAT and BNAT both provide part of the input for the identification of the improvement potential (task 6).

Although there are some machine tools which are claimed to be environmentally friendly, or eco-efficient, as such it is rather not possible to define a complete machine tool as Best Available Technology (BAT), or Best Not yet Available Technologies (BNAT), as this could only refer to a very specific configuration and application scenario. The BAT / BNAT for machine tools rather is the result of BAT / BNAT at the components level. Therefore individual measures are described below. The advantage is the combarabilty of all machine tools independent of the production process.

As far as Best Not yet Available Technologies are concerned, it should be pointed out that according to CECIMO “there are improvement potentials which we do not know today but which will become available in the future. This goes together with the innovative spirit of the sector and it will have enormous impact on the cutting of energy consumption.” However, a quantification of these potentials is not yet possible.

There are a couple of intitiaves, which foster and promote in particular more environmentally benign approaches at the overall machine level:

The **"Blue Competence®"** initiative of the German Engineering Federation (VDMA) is a joint umbrella scheme for the whole engineering industry of Germany[1]. The German Machine Tool Builders’ Associatioon is a participant in the initative ("Blue Competence® machine tools”). For this intiative, several machine tools manufacturers

[1] http://www.vdma.org/wps/wcm/connect/f0740d80477fca20b08cb76617c93b30/bro_bc_mabau_2011-07.pdf?MOD=AJPERES&CACHEID=f0740d80477fca20b08cb76617c93b30 Access: 01.12.2011

adress - in particular - energy-saving technologies, environmentally sustainable materials and resource-saving processes. Hence, the BATs are partly derived from technologies, which are covered by the “Blue Competence®” initiative. By signing up to the conditions of use, the machine tool builders accept their responsibilities for the natural environment and to climate protection, as well as affirming their readiness to enter into an active dialogue on this with both customers and vendors[2]. Material and mass reduction without loosing stiffness can help to reduce the energy consumption during acceleration processes. Heat and electrical power recovery reduce power loss. Therefore heat exchangers for preheating the components are focused on as a further objective criterion .

In parallel, an initiative by the VDMA and Fraunhofer IPA targets energy efficiency in automation technology: **"Green Automation"** intends to implement an integrated energy efficiency analysis of production in the early conceptual phase of product development. As part of this analysis, the simulation of energy consumption and other energy systems, such as pneumatics and hydraulics, is being undertaken to identify energy-efficient alternatives at an early stage, since these measures have a strong influence on the life cycle energy consumption of a product.[3]

Further initiatives are publicly funded, such as the European public private partnership **“Factories of the Future”**[4] or the Austrian funding programme **“Fabrik der Zukunft”,** and the German cluster **“Effizienzfabrik”**, which research future production technologies, including those relevant for machine tools and related machinery.

A distinctive mark, registered in accordance with the law, the UCIMU Mark is granted to a company, and not to a product, following strict, ongoing tests. The approximately 100 companies which have currently been awarded the UCIMU Mark (out of a total of more than 200 associates), starting from the beginning of 2011, will be able to affix the new symbol expressing the "Blue Philosophy" that governs the Italian production of the sector. [5]

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2 VDW: http://www.vdw.de/web-bin/owa/homepage?p_bereich=leistungsangebot&p_menue_id=1000000019&p_zusatzdaten=dok_zeige_ordner&p_zusatz_id=1989&p_sprache=e

3 Naumann, M.: Energieeffizienzsteigerung in der Automatisierungstechnik. Gießerei 97 (2010) 4, S. 86.

4 Ad-hoc Industrial Advisory Group Factories of the Future PPP: Strategic Multi-annual Roadmap, 20 January 2010

5 http://www.ipfonline.com/IPFCONTENT/news/sector-trends/ucimu-mark-is-now-dyed-in-blue-reflects-eco-compatible-production.php

There are numerous examples where the same manufacturing task could be realised with one technology or another, resulting in greater or fewer environmental impacts. One such example is TIG (tungsten inert gas) welding versus laser beam welding, assessed by Dahmen et al.[6] for a given production task, resulting in lower energy consumption, emissions and material consumption for laser beam welding. However, such optimisation options are a question of proper technology choice, not of the design of a machine as such. Therefore such cases – although they possess the potential for reducing environmental impacts - are explicitly excluded from the analysis provided below, whereas technology improvements, which come with an adapted machine concept, are included, such as machine tools applying minimum quantity lubrication.

Given the high significance of energy consumption in the use phase, as analysed in detail in Task 4, the focus of the BAT and BNAT analysis is on measures to reduce energy consumption in use. However, several BATs listed below have a positive effect not only on energy consumption in use, but also on non-energy use aspects. For example, the major share of BATs referred to in solution 6 also reduce the impact of consumables (dry machining, MQL – minimum quantity lubrication, etc.)

5.1 Definition of BAT

The presented solutions are the result of the survey of this study, market research and stakehoulder information.

As indicated in previous tasks within this study, significant environmental impacts of machine tools are due to the consumption of energy during the use phase. Subsequently, eco-research within the machine tool industry has focused on improvement options to reduce energy losses during operating and stand-by modes; measures to improve other environmental aspects of machine tools are considered as well. In correspondence, another study by the Fraunhofer Gesellschaft assumes that cutting and chip removing machineries in particular provides a broad space for improvement options. This is due to the fact that lower energy and material efficiency is anticipated, compared with forming machine tools. Unlike most forming processes, cutting generates certain amounts of scrap metal and requires consumables such as cooling lubricants and additional energy for suction systems. Consequently a distinction is required when analysing forming and cutting processes, as both feature different

6 Dahmen, M.; Güdükkurt, O.; Kaierle, S.: The Ecological Footprint of Laser Beam Welding, Physics Procedia 5 (2010), p. 19-28

process and environmental characteristics. Despite the lack of systematic investigations into the energy-using profiles of machine tools, several studies revealed great improvement potential for energy saving operating modes, especially during periods of machine idleness.

Current research and development in the field of machine tools primarily deals with methods and technologies to increase the energy efficiency of machine tools. As indicated in task 1.1, it is common knowledge that on one hand, a major share of the total energy consumption is attributed to auxiliary equipment, such as the lubrication system, pneumatic unit, chip conveyor, and the like. On the other hand, significant energy losses can be related to machine tools' idle periods (see Figure 5-1). Depending on the scale of production, the share of total consumption for non-working processes fluctuates between 62 % (large scale) and 85 % (small scale).

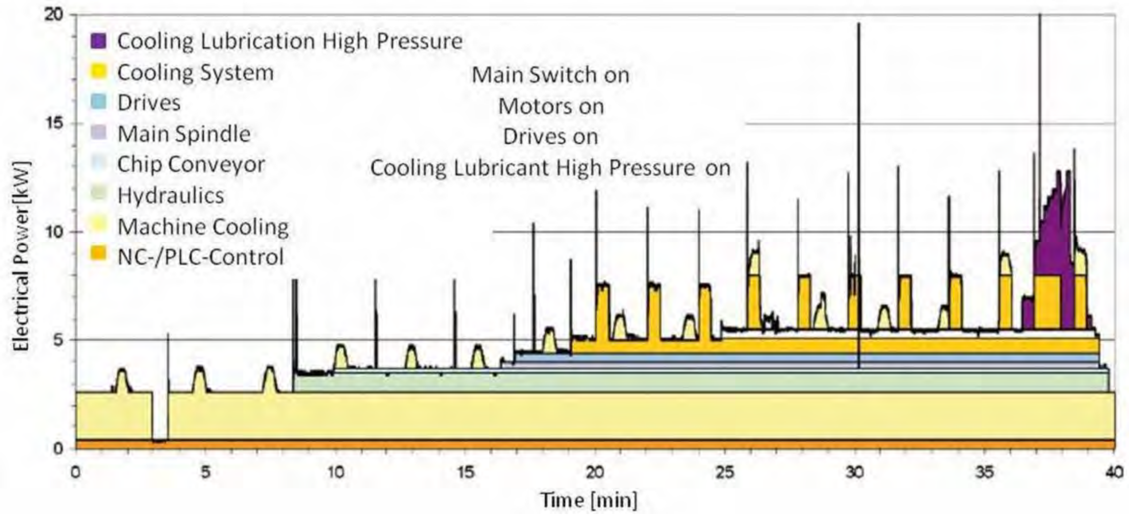

Figure 5-1: Electrical power consumption on component level for a Heller H 2000 milling center[7]

Efficient configurations of process parameters contribute to a decline of energy consumption when high speed cutting is applied. To reduce major shares of energy consumption (especially those deriving from base load, idle periods and periphery maintenance (control, lubrication), peripheral systems (e.g. room lighting, air conditioning)) can be reduced when abridging the processing time. Related to high-performance machining, the specific base load is lowered with increasing feed rates and cutting rates. Moreover, larger rates cause less specific cutting power demand.

7 Brecher, C. et al.: Ressourceneffizienz von Werkzeugmaschine im Fokus der Forschung. In: wt online 100 (2010) 7/8. pp. 559-564

As mentioned before, a major share of the overall energy consumption comes in particular from the base load demand of the machine tool, and also from the dynamic forces. To meet market demands of solid dynamic performances, the machine has to provide - and withstand - immense acceleration and braking processes, which lead to peak loads and increased energy expenditure.[8] Technologically, energy-efficient high speed cutting performance can be realized with the aid of parallel kinematics (PKM), which overcomes previous limits of dynamics and precision compared to serial Cartesian guide systems. Today, there are a few machines equipped with parallel kinematics[9], but this technology – although considered a mega-trend in the 1990s - was never broadly introduced to the market[10]. However, high-performance machining may also lead to higher abrasive wear of deployed tools which should be included into the ecological assessment and evaluation of high speed cutting.[11]

Another approach to cut down the time taken for machining is to shorten the process chain, which can be achieved e.g. by merging processing steps using adequate technologies. For example, rotational turning combines turning and grinding in one machining stage, causing shorter processing times. Machine tools equipped with this manufacturing technology are already placed on the market.[12]

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8 Heisel U. et al.: Einsparpotentiale in der spanenden Fertigung.In: Fertigungstechnisches Kolloquium 2010. Stuttgart, 2010. pp. 201-236.

9 E.g. the Index C100 and C200, http://www.index-werke.de/mediadata/c200-0008e.pdf; Trumpf TruMatic 7000, http://www2.trumpf.com/3.img-cust/TruMatic_7000_en.pdf, accessed January 20, 2011.

10 fertigung: Megatrends der Zerspanungsbranche - Die Topps und Flops der Branche, Branchenreport, 13.09.2011, http://www.fertigung.de/2011/09/die-topps-und-flops-der-branche/

11 Klocke F., Schlosser, R., Tönissen, S., Prozesseffizienz durch Parameterwahl, wt Werkstattstechnik online, Düsseldorf, 2010, p. 346ff.

12 E.g. J.G. Weisser Söhne Werkzeugmaschinenfabrik, http://www.weisser-web.com/index.php?id=10&L=0, accessed January 24, 2011.

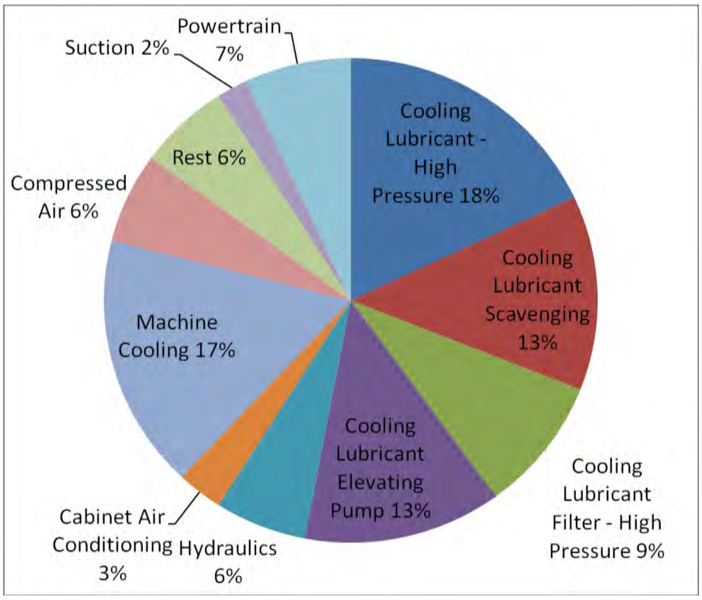

Figure 5-2: Annual energy consumption of components in three-shift operation[13]

Efficient configurations of process parameters contribute to a decline of energy consumption when high speed cutting is applied. To reduce major shares of energy consumption (especially those deriving from base load, idle periods and periphery maintenance (control, lubrication), peripheral systems (e.g. room lighting, air conditioning)) can be lowered when cutting the processing time. Related to high-performance machining, the specific base load is lowered with increasing feed rates and cutting rates. Moreover, larger pitches cause less specific cutting power demand. However, high-performance machining may also lead to higher abrasive wear of deployed tools, designated to be included into the ecological assessment and evaluation of high speed cutting.[14]

A German manufacturer of woodworking machine tools and facilities[15] has estimated that about 20 % of costs are purchasing (investment) costs, and that 80 % of costs occur in the use phase and recycling phase of woodworking machine tools. 90 % of the overall costs are attributed to energy consumption. 10 % of the costs relate to launching, training, spare parts, maintenance, personnel, taxes and assurance, refurbishment and disposal. The enterprise offers energy efficiency measures such as energy efficient

13 Rothenbücher, S.; Kuhrke, B.: Energiebündel auf dem Prüfstand, In: Werkstatt + Betrieb, September 2010, Karl Hanser Verlag, München

14 Klocke et al., *Prozesseffizienz durch Parameterwahl*, 2010

15 Moehringer GmbH, Wiesentheid, Germany

drives and machine control, as well as energy recovery for both new and used woodworking facilities.[16]

Overall, stakeholders offer the following solutions[17]:

- Application of drive axis and spindles by state of the art VAC-Drive Technology
- High efficiency motors (e.g. synchronous motors)
- Stand-by modes

5.1.1 Overview on realised eco-design solutions

BAT measures are displayed in Table 5-5. A detailed description of these follows thereafter.

Table 5-1: Overview of eco-design measures

Solution	Environmental impact	Implications	Impact
1. Mass Reduction of Moving Parts	material reduction, energy savings during acceleration, faster machining speeds and reduced through-put times	shift of material recycling challenges from steel and iron to fibre materials, plastics and lightweight metals	40 % lower mass, 30 % faster spindle acceleration
2. Software-based Energy Management	reduction of energy loss during non-productive times, energy and life time optimised process layout	differentiation between energy monitoring, component switch-off and process optimisation	23 % energy savings in three shift operation
3. Energy Recuperation of Drives and Power Electronics	energy savings while using energy-efficient components and during deceleration, system solutions improves efficiency in comparison to isolated applications	Savings with adapted system design layout	up to 60 % reduced energy input, up to 80 % of regenerated energy during braking
4. Tool Handling and Clamping	energy savings with new physical principles for handling and clamping	use of application oriented components	up to 40 % less energy
5. Hydraulic and Pneumatic Optimized Systems	energy savings with system adapted pumps, motors and auxiliary devices	Savings with adapted system design layout	Up to 66 % of energy savings
6. Energy-	reduction or elimination of cooling lubri-	only metalworking	energy reduc-

16 Source: http://www.moehringer.com/innovation

17 Offered solutions collected from questionnaire

Solution	Environmental impact	Implications	Impact
Efficient Cooling Lubricant Supply	cant within all related devices and processes, e. g. provision, handling equipment, conditioning and recycling/disposal	machine tools, niche application of new media, e. g. nitrogen	tion of between 20 % and 33 %
7. Cooling Systems and Use of Cabinet Heat	reduced electric losses and efficient cooling devices improves energy efficiency	system solution provided by power electronic suppliers	reduction of energy consumption of up to 45 %
8. Energy-efficient Tempering	energy savings with new heating principles, e. g. electric induction instead of furnace heating, fast provision of thermal stable machine tool's state with eliminated non-productive playback cycles and switch-on	process approaches for tempering, system approaches for machine tool improvement	85 % reduced energy input while using electric induction

This list of measures and general tendencies serves for a first orientation only. In partcular the stated impacts are meant to illustrate tendencies, but actual figures are highly dependent on the specific application.

5.1.2 Solution 1: Mass Reduction of Moving Parts[18]

5.1.2.1 Introduction

Finding generally valid energy efficient measures for every production facility is difficult. However, most machines have similar movement generation and allow therefore energy savings through the reduction of moving masses of machine tools. In the same time, longer durability of machine parts can be achieved due to smaller load.

The disadvantages of those lightweight constructions are mostly the flexibility regarding applied forces and the enhanced tendency to oscillate caused by a lack of damping. In order to counteract these negative effects of weight reduction, oscillations have to be actively suppressed, isolated or the excitation of vibrations has to be avoided.

This problem was approached within the project EcoFit which started in 2005, and was funded by the European Union. An international workgroup pursued the objective to drastically reduce moving masses of machine tools while maintaining machine accuracy and productivity. Any noted disadvantages were to be compensated via control engineering measures, using minimal energy expenditure.

18 This solution has an important restriction. Light Weight Design is applicable for light metals only in metal working processes. Nickel based alloys, Tool Steel, ADI, GJV and GJS cannot be cut with Lightweight Design Machine Tools.

5.1.2.2 Measures for mass reduction

Modern machine tools have to meet requirements such as accuracy, productivity and reliability. Due to these continuously increasing demands, extremely stiff mechanical systems are implemented with the capability to absorb arising inertia forces. As a consequence, the masses of the machine structure, such as moving machine components, have to be increased. Here, the majority of the mass serves the dynamic stiffness, whereas a fractional part performs kinematic tasks. The high amount of masses, in turn, require motors with high torque output which are able to increase the forces needed during acceleration and deceleration. Therefore, high energy consumption and costs arise.

In order to reduce machine masses and realize energy savings, two strategies can be pursued in the same time:

- Replacement of currently-used materials with lightweight alternatives.
- Structured optimization of machine components, allowing material reduction.

Both possibilities were examined within the project EcoFit.

5.1.2.3 Replacement of currently implemented materials with lightweight alternatives

An overview of different lightweight materials illustrates that not only the material characteristics but also the specific costs and the technical mastery are of high relevance when choosing a potential material. Therefore, it can be expected that titanium and carbon fibre reinforced carbon (CFRC) materials are only used in special cases. The higher the technological sophistication, the greater will be the use of hybrid structures of aluminium, polymer cement, steel and technical ceramics for lightweight constructions[19].

An example for weight reduction through the implementation of lightweight materials is given in the following:

A clamping device made of carbon fibre instead of steel is up to two-thirds lighter, and is even stronger and more rigid – with identical clamping force values.

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19 P. Sekler,A. Dietmair,A. Dadalau, H. Rüdele,J. Zulaika,J. Smolik,A. Bustillo: Energieeffiziente Maschinen durch Massenreduktion, in Werkstattstechnik online, p. 320-327, Düsseldorf, 2007

Figure 5-3: Weight reduction of clamping device (source: Hainbuch)

Using a lathe, the time for spindle acceleration to maximum speed can be reduced by 30 % (see Figure 5-4). Therefore energy savings of 6 % are possible, assuming a machining time of 60 seconds and 20 % of braking and acceleration time for the machine spindle.[20]

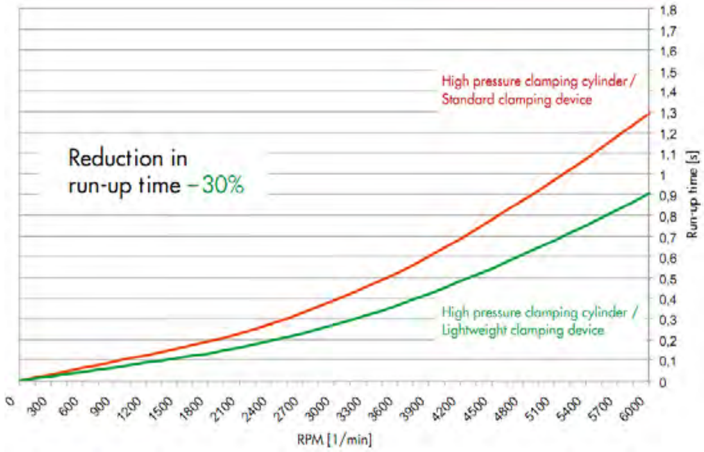

Figure 5-4: Standard and lightweight construction compared

Aluminium foam for moving parts can achieve significant energy savings. An example is the slides of a milling machine, produced since 2004[21]. These machine slides are 28% lighter than conventional slides and features higher speeds and acceleration than a massive slider, therefore also increasing the productivity of the machine tool.

Another example for the mass reduction of machine parts is given by a leading manufacturer of machine tools for sheet metal processing and laser-based production processes[22]. In cooperation with the Fraunhofer IWU, using a carbon fibre reinforced mate-

20 Hainbuch: Lighter and Easier, on the internet: www.hainbuch.com/cms/upload/english/brochures/HAINBUCH_CFK_en.pdf, last access: 22.12.2010

21 Machine tool: MIKRON HPM 1850U

22 Trumpf Sachsen GmbH, Neukirch, Germany

rial a crossbar of a laser cutting machine has been developed. This CFRC material is superior to metallic materials in many ways (e.g. stiffness, stability, damping, fatigue strength, thermal expansion). Through these advantages not only a mass reduction of 50 % has been achieved, but also a doubling of the component stiffness.[23]A further possibility to reduce weight is the use of polymer concrete structures for machine beds. Compared to steel structures, polymer concrete structures offer favourable characteristics in terms of heat conductivity and damping. However, these aspects must be analysed with due care throughout machinery design. Additionally, considerably less energy is required to produce a polymer concrete structure, and prices are less subject to market changes. Table 5-2 compares the properties of a steel structure with a polymer concrete structure and the environmental impact which arise in the manufacturing phase. Polymer concrete is produced with mineral aggregates, which are crushed to meet specific grain size, then washed and dried, before mixing with an epoxy resin at ambient temperature. Resin degassing and vibratory compaction during the moulding process allows for a more homogeneous and compact casting, free of air pockets. There are several recipes for epoxy polymer concrete, each one with different properties and customized for specific applications. [24]

Potential limitations to the use of polymer concrete include:

- Resistance to flame combustion: Direct impact of thermal beams on the structure should be avoided.
- Shrinkage: Might represent a problem in thick structures; high contraction leads to internal cracking appearance.
- Extra thermal processes: Although curing typically takes place at room temperature, some resin systems are heat-treated for added strength and stability.[25]

Table 5-2: Material Properties for Steel Structures and Polymer Concrete Structures[26]

23 Meltke, R.: CFK-Querbalken einer Trumpf-Laserschneidanlage, on the internet: http://publica.fraunhofer.de/eprints/urn:nbn:de:0011-n-1462706.pdf, last access: 7.01.2011

24 Ana Reis (expert appointed by ECOS - the European Environmental Citizen's Organization for Standardisation - to follow the preparatory study)

25 Ana Reis

Criteria	Cast Iron	Welded Base	Mineral Casting
Stiffness	High	Very High	Very Low
Dampening	Medium	Low	High
Thermal Stability	Fast reaction	Fast reaction	Slow reaction
Design Freedom	Less restricted	Restricted	Less restricted
Surface Quality	Low	Medium	High
Re-build	Good	Good	Possible
Lead Time	Very long	Medium	Short
Environmental Aspects	High initial energy consumption to build	High initial energy consumption to build	Low initial energy consumption

There are machinery manufacturers (e.g. from the wood working machine tools segment), which offer a broad range of machine tools with the machine bed made of mineral material, claiming a significantly lower primary energy consumption for the production of the mineral material compared to conventional steel-made machine beds[27]: The mineral material is stated to consume only 28% of the primary energy used for the same amount of steel.

The usage of lightweight materials in principle is possible for all machine tools with moving parts as long as reliability and performance are not hampered. The introduction of new materials, such as reinforced polymer, or carbon fibre materials and light-weight metals necessarily requires a thorough analysis of environmental, technical and cost impacts. For instance, lightweight materials are typically more costly than conventional materials.

In combination with other measures, the savings potential of lightweight materials reduces the energy savings effect of e.g. highly efficient motors and drives and recovery of breaking energy.

[26] Ana Reis; Conrad, K.-J.: Taschenbuch der Werkzeugmaschinen. 2. Aufl. München: Carl Hanser Verlag, 2006

[27] HOMAG Group: ecoPlus – Technology that really pays off, p. 19

Reis points out the following environmental aspects related to polymer concrete (based on a study by INEGI[28]):

- *Embedded Energy: The energy requirements to produce a polymer concrete structure is estimated as about 25% of that needed to produce an equivalent welded steel structure.*
- *Process steps/Production time reduction: Since mineral casted structures can be produced in a single-step, they are substantially faster available than traditional casting or steel welded parts. Normally the curing process can take up to 24 h. The cold casting process has no need for additional heat introduction, thus allowing energy to be saved.*
- *Lifetime/Chemical Resistance: Polymer concrete is chemically inert against aggressive materials such as oils, caustic solutions, acids and liquid-coolants.*
- *Recyclability: Polymer concrete can be deposited and potentially recycled. If crushed it can be re-used as a mineral casting filler.* [Remark by Fraunhofer: It should be acknowledged, that steel machine constructions can be recycled easily as secondary steel, whereas the recyclability and the recycling value of polymer concrete might be limited and, if at all, down-cycling can be anticipated as the most likely end-of-life scenario]

The results of the LCA study carried out (based on Eco-Indicator99), comparing the current steel welded structure and the polymer concrete alternative, are presented in Figure 5-5, and clearly confirm polymer concrete as a far more eco-friendly solution than the current welded-steel solution.

[28] Unpublished source: Figueira J., Local manufacturer internal viability study of polymer concrete for machine-tools, 2010; no further details on machinery type provided

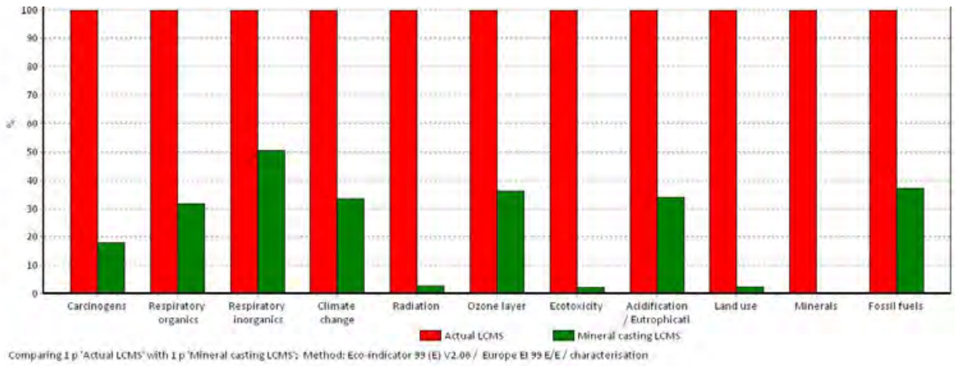

Figure 5-5: LCA results of the comparison between machines with steel welded and polymer concrete (mineral casting) structures

5.1.2.4 Structure optimization of machine components which allow material reduction

Another possibility to reduce the machine tool weight of moving parts, and to minimize energy consumption and costs, is by optimization of the structure. Crucial factors for evaluating structure quality are the following:

- mass
- static stiffness (tool deviation from the predefined path caused by applied forces)
- natural frequencies (definition of the dynamic and behaviour in the closed control loop)
- deflection (result of dead weight during acceleration).

Relating these factors satisfactorily should result in a measure for realizing a mass with the required needed characteristics.

Traditionally, the design engineer carries out these structure optimizations with the help of his/ her practical knowledge. In the past, several methods for automated topology optimization were increasingly developed and applied. Using finite element method (FEM) calculations, iterative adjustments of the initial structure to the reduced amount of materials can be realized. Here, the result of the adjustments does not influence the mechanical characteristics of the materials.[29]

Mass reduction, i.e. mass optimization, is - in principle - possible for all machine tools. Besides the potentially additional design efforts there are no additional costs of implementing this option. On the contrary, material savings are directly related to cost savings.

5.1.3 Solution 2: Software-based Energy Management including Stand-By Mode[30]

5.1.3.1 Introduction

Measurements in the automotive industry have shown that the energy consumption in production during non-productive times still represents 60 % of the demand in normal production times.[31] Through the implementation of intelligent stand-by modes, which allow the user to set default times for shut-down of various machine units, energy savings can be achieved. The extension of these modes with “wake-up and warm-up” functions enables the machine to be set to operational status at a defined point, and to automatically heat up to the operating temperature.[32]

A German manufacturer of drive and control systems[33] offers a Stand-by manager for machine tools which switches automatically to stand-by mode when longer periods of inactivity occur. The possibility to manually configure Stand-by times (e.g. part shortages or end of a shift) by the user is also possible. During test periods with this manager implemented in a machining centre (MAG XS 211), the Institute for Production

29 P. Sekler, A. Dietmair, A. Dadalau, H. Rüdele, J. Zulaika, J. Smolik, A. Bustillo: Energieeffiziente Maschinen durch Massenreduktion, in Werkstattstechnik online, p. 320-327, Düsseldorf, 2007

30 Result of the questionnaire: over 40 % offer this solution

31 Sigma Pool: Sigma REPORT Nr.19, p.5, Vol. 19, 2010

32 Deckel Maho Gildemeister: DMG EnergySave, on the internet: http://www.dmg.com/presse_id,d1204024fd31842ac125772a00480938?opendocument&p=3&kap=$$$$$, last access: 22.12.2010

33 Bosch Rexroth AG, Lohr am Main, Germany

Management (PTW) in Darmstadt realized energy savings of 23 % of total energy consumption during three shift operation.[34]

5.1.3.2 Solution areas

- **Energy monitoring**: Software-based energy monitoring programs enable the user to gain detailed insights into the energy consumption of the production process. Thus, by making energy flows transparent, subsequent economic and ecological measures can be taken. With regard to the ecological relevancy, major areas of energy consumption (at the machine or component level) can be identified. Currently, there is a broad range of energy monitoring software available on the market, some of which additionally include intelligent add-ons, e.g. supporting applications for efficient process management and optimization. To name a few on a holistic level (meaning whole production plants), there are b.data (mainly for economical purposes), SIMATIC powerrate, SIMATIC PCS 7, and SIMATIC WinCC[35]. It should be pointed out that so-called TCO (total cost of ownership) programs also contribute to better energy management, also from an environmental point of view, as major energy consumers are identified and depicted in monetary values.
- **Machine stand-by management:** There are several products for the automated minimization of energy consumption in idle periods, e.g. DMG AUTOshutdown by a leading manufacturer of metal working machine tools[36] or HOLZMA ecoLine by a manufacturer of woodworking machines[37]. Another wood working machinery manufacturer implemented an eco-mode for its edge banding machines, which turns off all drives except the heating of the gluing unit as soon as workpieces cease to be fed into the machine, and, if no workpiece is processed during the following 6 minutes, the heating unit is also switched off, resulting in an almost 100% reduced power consumption compared to the operational mode[38]. In extension to a machine's stand-by mode, a

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34 Rothenbücher, S.; Kuhrke, B.: Energiebündel auf dem Prüfstand, Zeitschrift für spanende Fertigung Werkstatt+Betrieb, S. 130-137, 143. Jahrgang, September 2010

35 Siemens AG, München, Germany products

36 Gildemeister AG, Bielefeld, Germany

37 Holzma Plattenaufteiltechnik GmbH, Calw-Holzbronn, Germany

38 HOLZ-HER: Energieeffizienz von HOLZ-HER-Kantenanleimmaschinen, letter to customers, July 8, 2011

further distinction among operating modes increases the energy efficiency. For example, the operating modes can be divided into stand-by, warm-up, idle, and productive modes. As energy losses due to base load have been identified as a core source of energy wastage, research activities have increased in the field of intelligent stand-by modes (current research projects will be discussed in detail in 5.1.12.5). PROFIenergy by a German manufacturer of drive and automation systems and software solutions[39] goes beyond energy management systems for single machines. It is specifically designed for the overall energy monitoring of the whole plant, including auxiliary consumption, such as lighting and ventilation units. In extension to machine related stand-by management systems, in which unnecessary components during idle periods are switched off, plant-related systems also control logistic systems, whole production islands and transfer lines. To facilitate the integration into an existing production plant, PROFIenergy is a data interface based on the industrial Ethernet standard PROFINET.

- **Energy optimized motion control:** By the aid of control integrated tools, cycle times and energy consumption for each NC set can be analyzed. This way, developers have to define the energy efficient sequence of motions for machining. In this regard, a German manufacturer of drive and control systems[40] offers the following products:
  - *IndraMotion MTX cta*
  - *IndraMotion MTX ega*

Software-based energy management is applicable for all CNC machine tools. Software related costs are relevant, and it might be necessary to equip machinery components with additional sensors to control these modules.

39 Siemens AG, München, Germany

40 Bosch Rexroth AG, Lohr am Main, Germany

5.1.4 Solution 3: Energy Recuperation of Drives and Power Electronics, and Super Premium Efficiency Motors

5.1.4.1 Introduction

After every acceleration process of a drive, a braking process is needed. The energy from the drives' moving masses can largely be reconverted to electrical energy.

There are already existing CNC controls which are designed for regenerative and non-regenerative breaking. Braking resistors transform the kinetic energy arising from the braking process into heat in the non-regenerative supply module. A regenerative supply module instead returns this energy to the power grid. The decision regarding whether to choose one of these modules depends on the expected type of machine operations. An important factor to take into account regarding energy consumption is the expected number of tool exchanges.

The following example explains the differences between these two modules in more detail: A milling operation with 15 kW power consumption is interrupted cyclically by a tool change. Starting the spindle requires a peak power of approx. 60 kW. Whilst the regenerative supply module briefly returns 48 kW to grid power, with the non-regenerative supply module, the kinetic energy is converted to heat. Due to the high power requirement of metal cutting, the more frequently the milling process is interrupted by tool changes, the more that the mean input power requirement is reduced. The regenerative supply module works more efficiently as soon as the time interval between two tool changes is less than 100 s (equals 0.6 tool changes per minute). In processes with many tool changes per minute, a regenerative supply module often proves to be the better choice. During contour milling with infrequent tool changes, the advantages are on the side of the non-regenerative system[41].

[41] HEIDENHAIN: Aspects of Energy Efficiency in Machine Tools, November 2010, on the internet: http://www.heidenhain.it/fileadmin/pdb/media/img/Energieeffizienz_WZM_en.pdf, last access: 22.12.2010

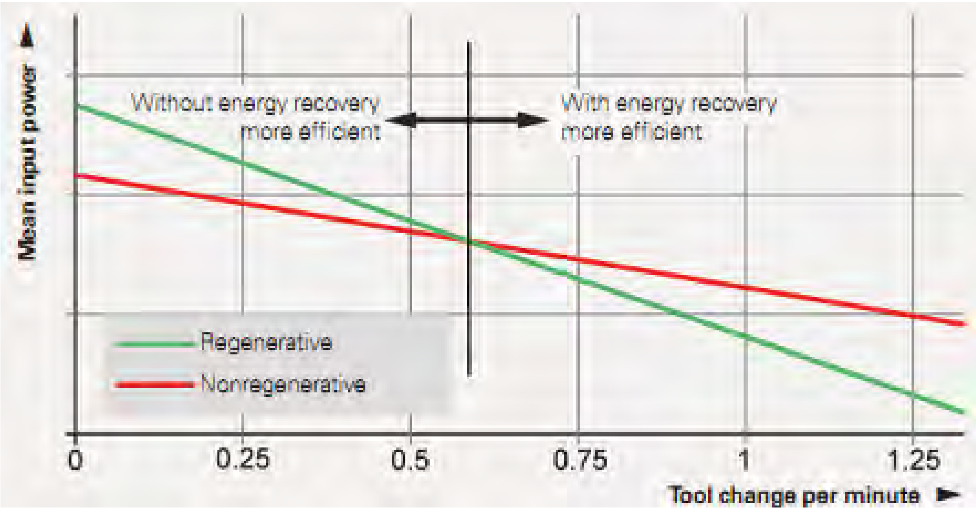

Figure 5-6: Efficiency analysis of a supply module in the version with and without regenerative braking (source: HEIDENHAIN)

5.1.4.2 Main drives/feed drives/drives in other sub-systems and transmission

The following BATs apply for main and feed drives of machine tools, as well as for those of hydraulic and pneumatic systems (e.g. incorporated in pressured air units, lubrication units, disposal units, etc.). Drives and electric motors in particular are of special interest due to the fact that they are the main supplier of mechanical energy for machine tools; thus, they are an important energy consumption source, and determine the energy efficiency of components connected to them, such as pumps, compressors, spindles, and the like. Such circumstances are depicted in Figure 5-7.[42]

[42] Note: The inherent performance improvement of particular electric motors has already been subject to legislation, as described in Task 1.3.

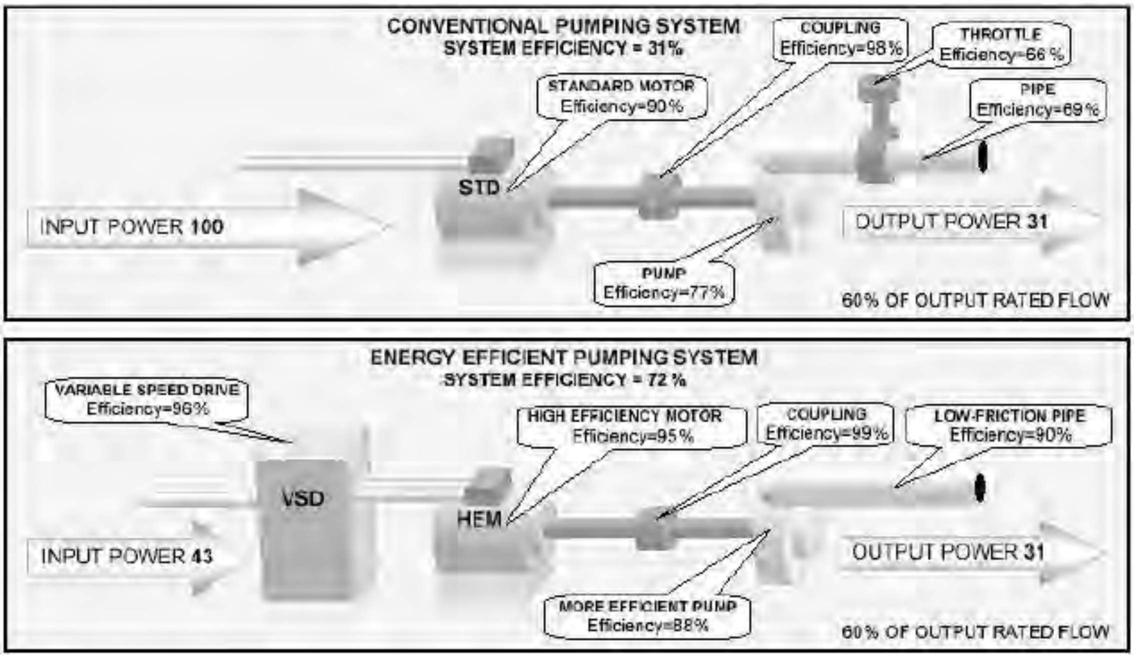

Figure 5-7: Comparison of conventional and energy efficient components[43]

- **Application specific design**: The over dimensioning of drives causes excessive energy consumption. Thus, application specific aspects should be involved during the design phase. Substituting the motor with a larger motor at the same current level results in increased energy efficiency due to reduced ohmic losses. There are several software tools on the market supporting application specific design[44]. However, CLASP states in a stakeholder comment: “From our experience, motor over-sizing is often over-stated, with induction motors having a similar efficiency at 50% to their performance at 100%. Since bigger motors are inherently more efficient, optimum sizing is not that critical except for applications where there will be widely varying loads with greater time at low power levels".

- **Speed control:** The control of engine speed enables the adequate and application specific supply of kinetic energy for various tasks. As far as AC (alternating voltage) motors are applied, this could be done by the use of frequency converters. For example, with regard to subsequent applications, the pressure

[43] Integrated Pollution Prevention and Control, Reference Document on Best Available Techniques for Energy Efficiency, 2008, p. 197.

[44] there are several software tools on the market supporting application specific design, such as *IndraSize* by Bosch Rexroth AG, Lohr am Main, Germany, and Sizer by Siemens AG, München, Germany

range of a pneumatic system can be readjusted by means of a frequency converter to meet specific requirements[45]. “Speed control is only really relevant to auxiliary processes (…) . Many items on a machine tool have to be speed controlled anyway for their functionality, and so there is no further potential.”[46]

- **Direct drive instead of ball screw drives:** Besides higher robustness and less abrasive wear, if high feed forces (e.g. for high speed cutting) are applied, direct drives consume less energy than ball screw drives. This is due to the powertrain of ball screw drives, which heat up during processing.[47]
- **Brake energy feedback:** The infeed unit is capable of feeding back the braking energy to the main power supply. Differentiated by the power range of specific applications, there are several products already available, such as the Sinamics family by a German manufacturer of drive and automation systems and software solutions[48]**.** The power supply modules have to be designed both for regenerative and non-regenerative braking, which is typically the case already for CNC machine tools, to implement this feature. However, the energy savings effect again depends again on the application. Regarding milling operations, regenerative supplies save energy in processes experiencing numerous tool changes per minute[49], whereas in contour milling, where infrequent tool changes are common, non-regenerative systems are said to be probably the better choice[50].
- **Reducing maximal acceleration:** Reducing the maximum acceleration in the setpoint results in a better exploitation of the motor's efficiency. In this case, the overload capability of the motor is not utilized (CECIMO)
- **Reducing transmission losses:** If belt drives are applied for transmitting the mechanical energy away from the electric motor, conventional V-belts should be replaced by other belts whenever possible. Alternatives would be cogged V-

45 Product example: IndraDrive by Bosch Rexroth AG, Lohr am Main, Germany

46 Stakeholder comment by CLASP

47 Röders GmbH, Soltau, Germany

48 Siemens AG, München, Germany

49 Heidenhain identified for one use case a break-even-point at 0,6 tool changes per minute

50 Dr. Johannes Heidenhain GmbH, Heidenhain Corp. Schaumburg, Ill.: Even metal working operations can be optimized for energy efficiency with no adverse impact on productivity, Energy Efficiency & Technology, Sept 1, 2011

belts and synchronous belts. If applicable, direct coupling should be chosen (e.g. direct drives for spindles).[51]

- **Replacing inverter units:** Switching from 200V to 400V inverter units leads to an increase in energy efficiency due to a reduction of ohmic losses. (CECIMO)

Linear motion systems

In the field of linear motion systems for precision machine-tools, which include linear guides and the actuator, three principal kinematic solutions are widely used on the market:

- Linear guide, ballscrew and servomotor
- Linear guide, pinion-rack and servo-reducer + motor
- Linear guide and Direct drive (linear motor)

Field experience shows the favourite areas of application for these 3 technologies:

Stroke<6m low to average dynamic: ball screws

Stroke>6m average to high dynamic: rack and pinion with servo-reducer and motor

High to very high dynamic: linear motors

According to a statement provided by the French manufacturer REDEX “a solution based on rack and pinion with servo-reducer and motor has an optimal power consumption compared to direct drive solution since torque requirements in phases of acceleration and deceleration are lowered.

Another advantage is to provide smaller motors for the same application and, in turn, better power efficiency, smaller cables and drives.

Typical curves of torque vs. speed and automation laws (inertia matching) imply that servo-motor are equipped with reducers. Best eco-design practices imply using a high efficiency gearbox (planetary gearbox with optimized design).”[52],[53]

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[51] BREF Energy Efficiency, p. 203, 2008

[52] Example calculation by REDEX: 5% efficiency improvement on a 10kW motor and 30% use rate over 1 year means more than 1MWh saved per machine axis and per year.

[53] The French manufacturer REDEX SA developed a range of high quality servo-planetary reducers specifically for multi-axis machine tools, which incorporate low friction seals, gear

For milling spindle heads REDEX describes the approach as follows:

“High quality reducers are requested for spindles (milling machines) when the torque has a high value (> 1000 Nm). High-torque motors and drives have poor efficiency and increase machine power consumption.

Due to very high spindle speeds (from 4000rpm up to 15000rpm) the main power loss factor in spindle reducers is oil splash. Efficient reducers should integrate a dry sump lubrication (oil mist spread on gears) to avoid power consumption due to oil bath stirring.

In that case, reducer is included inside the spindle axis. This solution provides dry sump lubrication and avoids thermal loss through splash lubrication. The total mass of the spindle axis is lowered in comparison of a solution with belt and pulleys.”

Bearings

- **Using low friction roller bearings:** Specific roller bearings technologies have a friction coefficient between 0.0004 and 0.001, while conventional slide guides offer a coefficient around 0.1.[54]

Advanced Power electronics

- **Avoidance of transformers:** Instead of using conventional transformers which have power losses of approximately 4 %, voltage-proof converters which are of higher efficiency should be used. (CECIMO)
- **Speed control / variation speed drives:** see Part / tool relative motions → Main drives/feed drives/drives in other sub-systems and transmission → Speed control.
- **Power factor correction:** There are certain products on the market which allow to increase the efficiency of energy transmission systems by automated power factor correction, for example:

  SINAMICS S120[55]

sets quality 5 (ISO 1328), low drag torques. According to the manufacturer, the yield of the reducer is increased by 2% minimum compared with a conventional planetary reducer. Average efficiency at nominal speed is superior to 97%.

54 Bosch Rexroth AG, Lohr am Main, Germany

55 Siemens AG, München, Germany

- **Latest generation IGBTs (Insulated-gate bipolar transistor):** IGBTs are the key semiconductor components for power electronics and determine with their electrical characteristics the efficiency of the power electronics circuitry. A manufacturer of semiconductors and system solutions for automotive and industrial electronics[56] claims to have reduced switching losses and increased efficiency to "best-in-class" for their IGBTs for 600 and 1200 V applications, which are common in e.g. welding equipment[57].

Efficiency of small motors

Larger motors in the range of several kW are those which dominate the energy consumption in machine tools, but for auxiliary systems and smaller machine tools (such as edge bending machines and planing machines) small motors below 750 W are also common. Numerous measures can be considered to improve the efficiency of these motors, but it depends highly on the actual use and application within a machine for which a motor is used, to judge, whether improvements are feasible, and if they may lead to relevant energy savings. Table 5-3 lists technical measures to reduce losses of small motors, although most of these approaches are applicable for larger motors as well.

Type of Loss to Reduce	Technology Option Applied
I_2R Losses[58]	Use copper die-cast rotor cage
	Remove skew on conductor cage
	Increase cross-sectional area of rotor conductor bars
	Increase end ring size
	Changing gauges of copper wire in stator
	Manipulate stator slot size
	Decrease the radial air gap
	Change run-capacitor rating
Core Losses	Improve grades of electrical steel
	Use thinner steel laminations
	Anneal steel laminations
	Add stack height (*i.e.*, length, add electrical steel lami-

56 Infineon Technologies AG, Neubiberg, Germany

57 Technology Media: Infineon Breaks Switching and Efficiency Limits with 3rd Generation High Speed 600 V and 1200 V IGBTs, May 5, 2010, http://www.infineon.com/cms/en/corporate/press/news/releases/2010/INFIMM201005-048.html, accessed January 17, 2011

58 electrical power loss caused by the current flowing through a component

	nations)
	Use high-efficiency lamination materials
	Use plastic bonded iron powder
Friction and Windage Losses	Use better bearings and lubricant
	Install a more efficient cooling system

Table 5-3: Summary of Technology Options for Improving Efficiency of Small Motors[59]

IE4 motors

- **Super premium efficiency motors complying with the IE4 level** as defined in Technical Specification IEC 60034-31 are just entering the market: Whereas ABB as one of the market leaders in motors in 2009 still stated, that IE4 motors are not yet on the market[60], in 2010 they introduced IE4 motors in the range from 75 to 355 kW output[61]. Similarly, WEG announced their range of IE4 motors for industrial applications with outputs of 0,37kW up to 7,5 kW in early 2011[62]. The IE4 level requires efficiency to be roughly 1 % above the IE3 for the higher output range. At the lower end the IE4 level is 4 % higher. The IE4 level is achievable with new motor technologies, such as permanent magnet synchronous motors, for which automation, pumps and CNC machines are fields of application, but which are more costly than conventional motors. Part-load efficiency is also stated as being much higher than with induction motors[63]. Switched reluctance motors are another emerging technology to achieve higher efficiency levels, but their main disadvantages comprise ripple torque, high vibration level and high acoustic noise.

59 U.S. Department of Energy: Small Electric Motors Final Rule Technical Support Document, Chapter 3: Market and Technology Assessment, March 9, 2010, Washington D.C.

60 ABB: Fachwissen IEC 60034-30 Norm zu den Wirkungsgradklassen für Niederspannungsmotoren, 2009

61 Efficiency regulations for low voltage motors, ABB external presentation, July, 2010

62 WEG's new WQuattro Super Premium Efficiency motor exceeds the requirements of impending IE4 classification, January 12, 2011, http://www.weg.net/se/Media-Center/News/Products-Solutions/WEG-s-new-WQuattro-Super-Premium-Efficiency-motor-exceeds-the-requirements-of-impending-IE4-classification

63 De Almeida, A.: Overview of Energy Saving Motor Technologies Emerging on the Market, Motor Summit 2010, October 28, 2010, Zurich, http://www.motorsystems.org/files/otherfiles/0000/0051/EMSA_G_Session1_Almedia_Technologies.pdf

Considering the complete drive system, basic approaches for improving energy efficiency of drives are listed inTable 5-4.

Motors (types, engineering design)
• Energy efficient motors (e.g., Cu rotors, lamination stacks) • Use of permanent magnets • Superconductivity (e.g. superconductive windings, bearings, …) • Selection of suitable motor type
Drive, power converter
• Efficient partial load operation • Starting, acceleration, breaking, stopping (ramping) • Operation control, idling • Power converter component innovations (e.g., IGBT, diodes, SiC,…) • Improvement of circuit topology (e.g., resonant, matrix,…) • Power drive design (e.g., line-frequency rectifier switching) • Regenerative drives
Drive system engineering
• System component selection (selection of motor, gear, box, pipes) • Design, dimensioning (matched power rating) • Adapting to requirements of specific processes
Integration - mechatronics
• Direct drives (replacement of gear boxes by speed control) • Compact drives (motor and power drive integration) • Enhanced functionalities relevant for energy consumption

Table 5-4: Summary of Basic Approaches for Improving Energy Efficiency of Drives[64]

64 ECPE: Power Electronics Potentials and Basic Political Conditions for Improving Energy Efficiency of Electric Devices, 2009

5.1.5 Solution 4: Tool Handling and Clamping

5.1.5.1 Metalworking machine tools

- **Clamping devices:** Clamping tools can be designed e.g. as hydraulic, pneumatic or electro-mechanical clamping devices. Electro-mechanical, pneumatic as well as hydraulic systems can be optimized e.g. by eliminating energy consumption in idle conditions. For hydraulic systems this can be done by storing energy, e.g. in accumulators, or by using load sensing pump systems (see numerous options mentioned in sub-sections 5.1.6.2 Hydraulic Modules/Systems and 5.1.6.3 Pneumatic Modules/Systems). Which technology the machine tool manufacturer may choose depends on several factors, e.g. dimensions and weight of the work piece. Other aspects are the reliability or the durability reached by applying maintenance measures. These are proved for hydraulic systems. Most of the machine tools are equipped with hydraulic clamping devices [S032_MM-005.2012][65]. There are a few companies offering electro-mechanical clamping devices[66,67,68]. Manufacturers of electro-mechanical clamping devices claim as advantages a higher degree of adjustability, and leaner machine design due to the omission of the hydraulic unit[69], and reduced maintenance costs, but these claims were not verified by the study authors nor is there any other published scientific or independent verification to substantiate the claims made by the providers of electrical clamping devices. On the other hand, hydraulic systems can provide high forces within limited spaces, due to their physical characteristics. In conclusion, a comparison of the energy consumption of hydraulic, pneumatic and electro-mechanical clamping systems is not possible, in general. Such an energy comparison has to be done on a case

65 MM-Round-Table-Gespräch: Hydraulik fordert Elektromechanik in der Energieeffizienz heraus, MM MaschinenMarkt 5 2012, p. 32-35

66 E-Quipment, see http://www.roehm-spanntechnik.ch/fileadmin/Downloads/Produkte/Flyer_E-QUIPMENT_de_web.pdf, accessed January 17, 2011.

67 iJaw, see http://www.forkardt.com/news/ijaw/ijaw_flyer_e.pdf, accessed January 17, 2011.

68 electromechanical actuators by Hainbuch, see http://www.hainbuch.com/7/products/clamping-cylinders/electromechanical-actuators436/, accessed January 17, 2011.

69 Which might result in less material consumption for machinery design

by case basis, taking into account the relative advantages of the different technologies, with regard to the whole machine tool.

- **Energy-efficient part fixing:** Other market solutions for energy-efficient part fixing in milling machine tools and machining centres are rotary tables, combining electromechanical and/or hydraulic indexing for high accuracy, absorption of high forces and torques as well as good response behaviour. Self-impeding fixtures, and friction-reduced guidance, are used for decreasing energy consumption.[70],[71],[72] ,[73],[74]

- **Efficient sealing of spindle systems:** To reduce operational costs, particularly for pressurized air in the field of spindle technology, an energy-efficient brush seal system has been developed by a German manufacturer of high precision spindles[75] as an alternative for air-lock systems (which require pressurized air), causing a reduction of pressurized air and subsequently additional energy supply down to zero. Several companies already take advantage of this technology.[76]

- **Using non-pneumatic lubrication systems for spindles:** For the bearing lubrication of spindles, another technology causing a minimal consumption of natural resources has been invented by a German manufacturer of high precision spindles[77]. As an alternative for oil-air-lubrication systems, permanent grease lubrication technologies do not cause additional energy demand. Cur-

70 See http://www.zollern.de/en/drive-technology/direct-drives.html, accessed August 25, 2011

71 See http://www.moriseiki.com/english/mail/user/ue0901a2ss/0901uec01.html, accessed August 25, 2011

72 See http://www.weiss-gmbh.de/New-Products.831.0.html?&L=1, accessed August 25, 2011

73 See http://www.fibro.de/folgeseite.asp?area=hauptmenue&site=pressemitteilungen &cls=02&id=44, accessed August 25, 2011

74 See http://www.rotary-table-1.com/nc-tilting-rotary-table/01.htm, accessed August 25, 2011

75 Weiss Spindeltechnologie GmbH, Schweinfurt, Germany

76 Heuchemer, B.: Energieeffizienz – Energiemanagement bei (Werkzeug-)Maschinen, Symposium „Energieeffiziente Werkzeugmaschinen“, Düsseldorf, February 24, 2010.

77 Weiss Spindeltechnologie GmbH, Schweinfurt, Germany

rently, this technology is partly spread among industry.[78] According to CETOP and VDMA (Fluidtechnik)[79] oil-air lubrication is considered indispensable for high speed cutting applications: The only way to reduce energy [consumption] is to use oil with lower viscosity and to reduce air pressure. The oil contamination of work pieces can be reduced or prevented by optimized seals.

- **Multi spindle systems:** Besides reducing machining intervals and downtimes, multi spindle systems significantly reduce the overall energy consumption of machining centres. As an example, the energy demand of a two spindle system is only 20 % higher than that of a single spindle system, which is basically due to the high energy demand for base load operation and peripheral systems. Examining the energy usage per workpiece, the machining process requires 40 % less energy.[80]

5.1.5.2 Woodworking machine tools

- **Reducing noise emissions:** Vacuum clamping systems are predominately used during the machining of composite boards, leading to vibration and noise disturbances. This can be avoided by applying an active clamping device based on piezo-stack actuators.[81] This option is a variant of the electrical clamping option described for metal working machine tools, as above.

5.1.6 Solution 5: Optimized Hydraulic and Pneumatic Systems

5.1.6.1 Introduction

In the field of hydraulic systems, several products featuring environmental improvements are already placed in the market. Either on-off mode or variable speed drive can be used to reduce the energy consumption of such hydraulic systems. As a case study example, the characteristic power consumption and hydraulic pressure of a conventional hydraulic pump for a typical application scenario is depicted in Figure 5-8.

78 Heuchemer, B., ref 76.

79 Stakeholder comments

80 Heisel U., Stehle, T., ref 8, p. 197ff.

81 Hesselbach et al., Development of an active clamping system for noise and vibration reduction, CIRP Annals - Manufacturing Technology, Volume 59, Issue 1, 2010

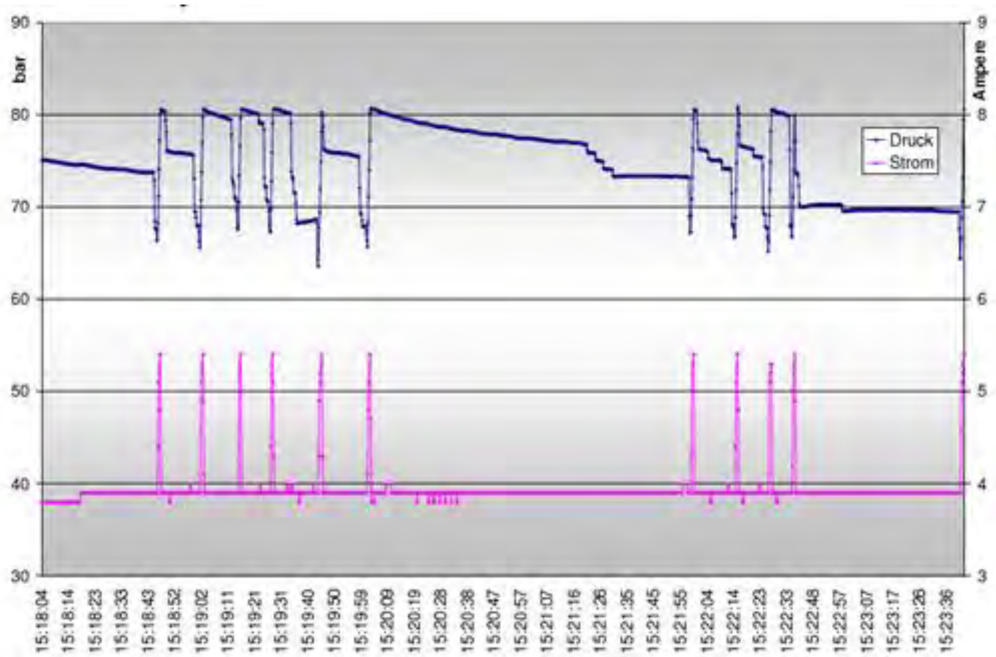

Figure 5-8: Power consumption and hydraulic pressure during conventional pump operation[82]

In Figure 5-9, for the same operation scenario, energy savings are calculated resulting from the incorporation of on/off switching in non-productive times, accounting for 25% of the total energy consumption.

82 Stakeholder Comment HYDAC / VDMA, e-mail M. Scheidt, March 13, 2012

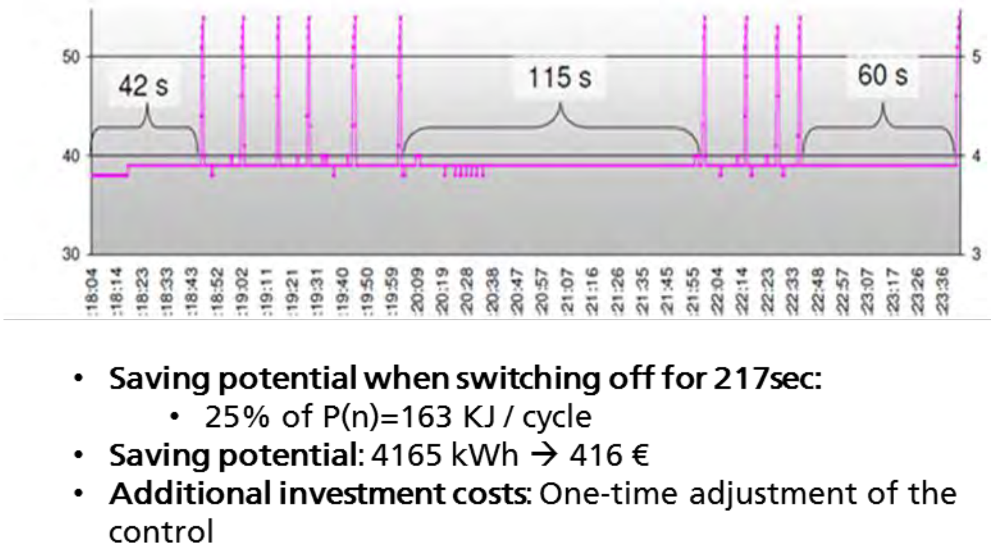

Figure 5-9: Energy savings for a hydraulic pump by switching off in non productive times[83]

Saving resources through the variability of process parameters is furthermore recognized by the hydraulic industry. Anecdotally, besides providing additional flexibility for the user (e.g. by choosing application specific operating points regarding flow rate and pressure), savings between 50 % and 70 % compared to a conventional hydraulic system are claimed by a provider of screw spindle pumps, which are applied in machine tools usually for lubrication systems).[84] These significant differences are primarily attributed to the use of frequency converters, which enable speed adaption. As far as today's hydraulic and pump system industry is concerned, which is partly involved in the machine tool market as suppliers of sub systems, the subject of environmentally-compatible products has already reached the market, not least because of the implementation of ecodesign requirements for electric motors (Commission Regulation (EC) No 640/2009). The advertisement of environmentally-friendly product features is furthermore adapted as part of the marketing strategy, e.g. the Blueflux technology series by a Danish manufacturer of pumps[85]: Motors for pump systems introduced to the

83 Stakeholder Comment HYDAC / VDMA, e-mail M. Scheidt, March 13, 2012

84 Knoll Maschinenbau GmbH, Screw spindle pumps type KTS, Issue 10-2010, http://www.knollmb.de/fileadmin/knoll_mb/pumpen/dokumente/DB_KTS_DE.pdf, accessed January 17, 2011.

85 Grundfos Holding A/S, Bjerringbro, Denmark

market in 2011 are already compliant with the 2017 requirements of the EuP motors implementing measure (namely, that motors from 0.75-375 kW must either meet the IE3 standard, or the IE2 standard equipped with a variable frequency drive [VFD])[86].

Besides the energy aspect of fluid systems, the analysis of hydraulic oil consumption for press brakes / bending machine tools / hydraulic presses (Task 4, Base Case 3[87]) revealed the moderate environmental relevancy of upstream mineral oil production for hydraulics, in some of the impact categories. Some measures may be undertaken to reduce hydraulic oil consumption, and thus also waste oil generation, which comprise: usage of external oil purifiers, or usage of hydraulic oils with better characteristics (e.g., high oxidation resistance, enhanced antiwear and rust protection etc). These measures should result in longer replacement cycles, but should not adversely affect process performance. However, it should be noted that these measures are not related to the machinery design per se, and are thus not implicated in any design options.

5.1.6.2 Hydraulic Modules / Systems

The following list of approaches was provided by VDMA Fluidtechnik, and revised based on feedback and requests for clarifications by other stakeholders.

The energy efficiency of hydraulic and pneumatic modules / systems significantly depends on its specified function. The more detailed the specification (e.g. level of automation, precision, quality, etc.), the more efficient the system can be designed. This comprises the optimal choice of the auxiliary devices (axial pumps, gear pumps, vane pumps, etc.), the pump system (several or one single pump), the pump size, and the motor (both to avoid over-dimensioning, and to reach high efficiency). It depends on the application as to which of the measures listed below can be used, and to what extent improvements can be achieved, via their use.

- **Optimized cooling of the motor:** To improve the cooling capacity, the motor can be integrated into the oil reservoir. Hence, the motor can be run above the nominal point, which makes it possible to use smaller motors. Moving masses as well as the starting current are reduced.

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86 http://energy.grundfos.com/en/high-efficiency-motor-technology/grundfos-blueflux%C2%AE--eup-ready-pumps, accessed January 17, 2011.

87 Note also, that in case of the machining centre (Base Case 1) and other Base Cases, hydraulic oil has a minor environmental impact according to the analysis in Task 4

- **Adaptable levels of pressure:** Pressure adjustment using adjustable pressure valves or zero-pressure circulation.
- **Pressure adjustments for different actuators:** To avoid losses due to pressure reduction, all actuators should be designed for a mutual level of pressure. If not applicable, pressure-controlled drive systems should be integrated to provide the adequate amount of energy for each sub-process. Alternatively, a pressure intensifier can be used.
- **Use of hydraulic accumulators:** Hydraulic accumulators can be used for temporary storage of hydraulic energy, to achieve the best possible match between the pump drive (accumulator charging circuits) and the load cycle, and to compensate for demand peaks (so that drives and pumps with a lower output rating can be used).
- **Adaptable levels of flow rate:** The use of throttle control for a hydraulic system leads to throttle and bypass losses. These losses vanish if the control system is replaced by displacement control. Alternatively, the volume flow can be controlled by means of variable speed drives.
- **Reducing inner leakages:** E.g. by the use of poppet valves in the accumulator charging circuit, leading to fewer reload intervals, and thus less use of the motor or leakage optimised spool valves.
- **Use of optimized valves:** For example, impulse valves (energy demand only during switching procedure), valve connectors with automated reduction of the holding current (reducing energy demand), and valves with 8 Watt magnets (reducing energy demand).
- **Use of hydraulic clamping tools:** Hydraulic clamping tools which consist of cylinder and poppet vales are almost completely closed, meaning that nearly no further energy is needed during clamping.
- **Extending the field of application of hydraulics:** The efficiency can be raised if additional tasks are carried out by the hydraulic system, which may also lead to a reduction in equipment of other modules (e.g. by taking over the generation of high pressure of cooling lubricants).
- **Prevention of nipple collapse:** Flexible hydraulic line systems have a bottleneck at the connection point between the fitting and line owing to their design, which causes considerable shortfalls in efficiency in hydraulic systems. The

pressing in of the hose and connecting fitting additionally aggravates the bottleneck situation as a result of the collapsing nipple. During nipple collapse the cross-section of the orthogonal flow direction is reduced. The flow pressure and velocity deviates from the given optimum. Using self-adjusting press-fit- socket hoses, the bottleneck can be substantially relieved (see Figure 5-10).[88]

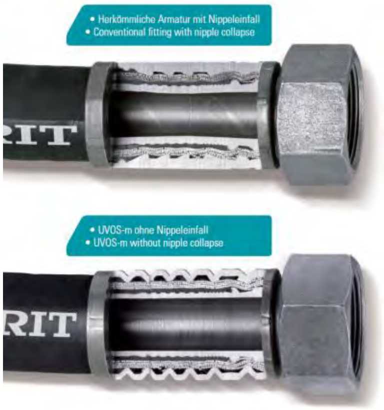

Figure 5-10: Fitting with and without nipple collapse.[89]

Variable speed drives (VSDs) for pumps in hydraulic systems are most relevant where a machine works with varying volume flows. This is typically the case for primary shaping processes, such as injection moulding and die casting, where energy savings potentials of 80% are stated, solely from the introduction of VSD[90,91]. For such types of machinery the payback time is said to be less than one year.

BATs for hydraulic systems are relevant for almost all CNC machine tools.

5.1.6.3 Pneumatic Modules / Systems

The first step in achieving energy saving is to optimize the size of the pneumatic system (after the air compressor) by taking into account the flow characteristics of compo-

88 Voswinkel GmbH, Meinerzhagen, Germany

89 Voswinkel news, on the internet: http://www.voswinkel.net/fileadmin/_elemente/presse/2010-06-16_VOSWINKEL_News_2010.pdf, accessed: 24.10.2011

90 Schmidt, S.: Interview “Amortisation meist schon im ersten Betriebsjahr durch Energieeinsparung”, Industrieanzeiger Nr. 15/KW 25/2010, stated example is a die cast machine, for which installed load could be reduced from 11 kW to 1,7 kW

91 Note that machine tools for primary shaping as such are not in the scope of this study as a “machine tool”, but the hydraulics system is considered a module in “related machinery”

nents, and by using proprietary sizing software. The following improvement suggestions for increased energy efficiency of pneumatic systems are derive from the research project EnEffaH (Energy efficiency in manufacturing in the area of drive and handling technology)[92], and were revised according to additional stakeholder comments received in the course of the study:

- **Application-specific dimensioning**: This means ensuring that pneumatic cylinders are sized to produce the force that is required. Oversizing cylinders leads to increased consumption of compressed air, which is then wasted.
- **Energy-optimized engineering of the machinery:** Drives are frequently overdimensioned, which leads to a higher air demand, and hence energy loss. As a consequence it is important to adjust the pneumatic system to the specific needs. Targeting a pressure reduction to the majority of equipment may allow the installation and use of a pressure booster to smaller air consumers at higher pressure requirements (for example pneumatic clamps). Such equipment suits elements where higher pressure is needed.
- **Application-specific compressed air quality**: To meet the demands of specific applications, the compressed air runs through a drying process and several filter stages. The number of filter stages significantly influences the energy demand of the system. Hence, centralized treatment of compressed air can be a beneficial option. Reducing impurities in the air taken in by the compressor can improve system efficiency, and can increase the life and performance of end-use equipment. Efficiency can be improved by:
    - Treating air to the minimum required standard
    - Correctly installing and maintaining the treatment system, and making sure it is adjusted following any change in demand
    - In all filter bowls the use of an automatic drain function increases filter efficiency, and reduces air loss
    - On compressors, ensure timed solenoid condensate drains are set correctly, or alternatively use more efficient no-loss type electric condensate drains

92 provided by Festo AG & Co. KG, Esslingen, Germany

- Use of differential manometers or element service indicators for filter element status monitoring, in order to reduce pressure losses.

- **Reducing tube length and diameter /dead volume:** If the distance between valve and cylinder increases, longer connecting tubes are needed. For each switching procedure, the pressured air within the tubes is accounted as dead volume and cannot be used for operation. By minimizing the length and diameter of tube lines within the pneumatic system, energy losses due to dead volume will be reduced to a minimum.

- **Minimizing losses due to leakages:** Leakages can lead to a significant overconsumption of energy. Possible measures would be the use of volume flow monitoring systems, which indicatively provide information about the existence of leakages, and the need to remove or close off unneeded compressed air lines. Direct investigation of leaks can be carried out e.g. by the aid of ultrasonic acoustic detectors.

- **Single acting pneumatic cylinder:** If only one drive chamber is needed, springs can be deployed for power absorption during the stroke motion. Thus, the return stroke is realized without the use of further air supply, but it has to be considered, that additional driving force is needed to compensate for the force exerted by the spring.

- **Pressure reduction (system):** Depending on the application, a reduction of the system air pressure level by e.g. 1 bar can reduce air consumption without unwanted performance losses.

- **Pressure reduction (non-productive times)**: In non-productive times, the air can be cut off, due to the fact that, generally, low pressure is sufficient to maintain sealing systems etc. when the machine is turned off or in low power mode.

- **Targeted cut-off from air supply:** If no retention forces are needed, as soon as the drive reaches the end position, the air supply can be cut-off by the valve, to avoid unnecessary pressure build-up within the drive chamber. This option can be integrated into the control of machine tools, and requires application-specific dimensioning of the pneumatic system, and optimised generation of pressure.

- **Use of multiple valves:** Using several different valves for a single pneumatic drive enables working with bridge circuits for more energy-efficient and productive operation. In this way, starting and brake movements can be optimized and performed at short notice. The measure is designed to be integrated into the control of the machine tool. As this option is very specific and increases construction expenditure, its implementation is only useful for a rather small range of machine tools.

- **Pressure reduction:** Where the return stroke requires only minor forces, a pressure regulator consisting of two switching thresholds and some buffer capacity can be applied. It is important to keep certain security aspects in mind, related to the implementation of pressure reduction, and the need to ensure that the functionality of the cylinder prevails.

- **Sectorization of the pneumatic circuit**: The whole pneumatic circuit is not operative while the machine is in production mode. Sectorizing the circuit allows the shutting-off of those pneumatic elements that are not working, and thus reduces/eliminates leaks from those elements.

- **Optimized valve switching:** As the driving of valves requires electrical energy, it should be examined whether an energy-oriented switching strategy may significantly contribute to a decrease in energy consumption. However, it should be mentioned that this option affects only a small amount of machine tools and that it applies more to vacuum technology.

- **Blow Guns:** Blow guns are versatile in their usage, and are commonly used to clean components and surfaces. Having the blow gun fitted with a Venturi-type nozzle delivers the same performance with up to 30 % less air. Using multistage Venturi-type nozzles can result in operating efficiencies of 150 %. However, the VDMA states that the reduced use of air cannot be exactly assessed.[93]

- **Air ejectors:** Air ejectors with a Venturi-type nozzle deliver the same performance with up to 30 % less air. Again the VDMA states that the reduced use of air cannot be assessed exactly.[94]

- **Cascaded levels of pressured air:** For applications which are in need of multistaged levels of pressure (e.g. in processing PET bottles), reusing the exhaust air from high pressure levels as supply air for those at lower levels may be considered. For such use cases (such as PET manufacturing), in which several

[93] VDMA Fluid Power / Power Transmission

[94] VDMA Fluid Power / Power Transmission

pressure levels are required, and play a dominating role, this option is already established to a great extent.

- **Variable speed compressors**: Adaptation of the speed of the compressor to the pneumatic requirements of the process eliminates unnecessary energy consumption and efficiency during part-load operation.
- **Start/Stop system for compressors**: Electronically-controlled start/stop strategies for compressors will disconnect compressors which are not necessary for completing the task, because of low air demand.
- **Choice of materials and light weight**: The component weight should be taken into account when sizing a system, due to the fact that heavier components can have the effect of oversizing the system.
- **Housekeeping and maintenance:** A well-maintained compressed air system needs less energy to deliver the required pressure and flow rate, by adopting best practices. By optimising system design performance, this will achieve better energy efficient results.[95]

In addition, there are some options which are currently technically realizable, but did not yet meet market maturity. In conclusion, the options listed in the following are rather to be considered as potential BATs in the following years.

- **Pneumatic cylinder with optimized drive surface:** For some applications, the maximum driving force is solely needed for one direction, such as for lifting operations. However, the same pressurized air is used for the back stroke. Despite that fact that the piston rod reduces the drive surface for the back stroke, it might be still over-dimensioned, so that pressure losses occur. By means of constructive adjustments, the drive surface for the return stroke can be downsized, which subsequently leads to reduced energy consumption. However, it should be pointed out that such design modifications conflict with industrial design standards for pneumatic cylinders, and therefore this measure does not have a potential for application in the foreseeable future. Hence this measure is to be considered a best not yet available technology (BNAT) - see 5.1.12.5.
- **Pneumatic cylinder with multiple chambers:** Multiple chambers in pneumatic cylinders are useful if multi-purpose processes are at hand. In this regard, the

95 Carbon Trust www.carbontrust.co.uk

adequate chamber is selected according to how much lifting force is required for the operation. Selecting a duplex or triplex actuator where a double or triple piston arrangement offers twice or three times the normal force, from the operating pressure, thus allowing for pressure reduction. At the moment, the implementation of this measure is hampered due to a shortened product life, which must first be solved. Accordingly, this option is to be considered a BNAT.

- **Using exhaust air:** Due to the fact that expansion work from the exhaust air is barely used, the incorporation of further modules for is usage could be considered. One module could be micro turbines[96] for energy recovery, to be placed at the vent connection. With regard to the costs associated with this measure, this approach is solely financially rewarding if large-scale recovery can be achieved. Alternatively, under the implementation of a closed pressured air circuit, the accumulated exhaust air could be returned to the compressor, and again be pressurized. This measure involves additional safety aspects which need to be considered. Also, the quality of the exhaust air and its suitability for further application in a circuit is important. Given the complexity that this approach adds to the machinery design, and the limited energy savings which could be achieved in theory (but no realisation of such a system is as yet known), this option will not be evaluated further.

Deriving from the Reference Document on Best Available Techniques (BREF) for energy efficiency from 2008, a bundling of several single measures were identified to improve the efficiency for compressed air systems (Figure 5-11), which partly covers similar improvement options as stated above. However, it should be noted that only a small number of machine tools have integrated compressed air generation, and thus in-built compressors. Typically, compressed air is generated externally, and most of the measures listed below are not applicable within the system boundaries of typical machine tools.

[96] There are several multi-purpose micro turbines available; however, no specific products can be named in this narrow field of application.

Energy savings measure	% applicability (1)	% gains (2)	% potential contribution (3)	Comments
System installation or renewal				
Improvement of drives (high efficiency motors)	25	2	0.5	Most cost effective in small (<10 kW) systems
Improvement of drives (speed control)	25	15	3.8	Applicable to variable load systems. In multi-machine installations, only one machine should be fitted with a variable speed drive. The estimated gain is for overall improvement of systems, be they mono or multi-machine.
Upgrading of compressor	30	7	2.1	
Use of sophisticated control systems	20	12	2.4	
Recovering waste heat for use in other functions	20	20 – 80	4.0	Note that the gain is in terms of energy, not of electricity consumption, since electricity is converted to useful heat
Improved cooling, drying and filtering	10	5	0.5	This does not include more frequent filter replacement (see below)
Overall system design, including multi-pressure systems	50	9	4.5	
Reducing frictional pressure losses (for example by increasing pipe diameter)	50	3	1.5	
Optimising certain end use devices	5	40	2.0	
System operation and maintenance				
Reducing air leaks	80	20	16.0	Largest potential gain
More frequent filter replacement	40	2	0.8	
		TOTAL	**32.9**	

Table legend:
(1) % of CASs where this measure is applicable and cost effective
(2) % reduction in annual energy consumption
(3) Potential contribution = applicability * reduction

Figure 5-11: Energy saving measures in compressed air systems, adapted from the BREF for energy efficiency (p. 208).

A **sensor-based monitoring of pneumatic systems** does not reduce energy consumption as such, but helps to identify leakages, and optimal operation conditions for the whole system. The pneumatic system has to be complex to a certain extent, so that sensor-based monitoring is justified and useful. Such monitoring might reduce power consumption for pneumatic systems in the range of a few percent.

As pneumatics play a minor overall role for machine tools and as pressurised air or vacuum are typically supplied by an central external system, the potential of improved pneumatic systems is limited for machine tools, but relevant for related machinery.

5.1.7 Solution 6: Resource- and Energy-Efficient Cooling Lubricant Supply

5.1.7.1 Introduction

Coolant supply to machine tools is one of the components with the highest energy consumption during machining. There, the energy demand is between 20 and 33 % depending on the machining method.[97] This aspect is relevant in the metal working industry. 98.5 % of machine tools need lubricant in this branch[98] – from overflow lubrication to minimum quantity lubrication (MMS). For woodworking machine tools it is not relevant. The following technologies show how energy savings can be achieved in this field.

Several pilot projects have been launched in the field of dry machining recently; meaning that by aims of specific technologies, market introduction already took place for efficient cooling lubricant supply. Already in 2001, with funds from the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, a programme was started for lubricant-free aluminium machining at a German manufacturer of aluminium rims[99]. By developing a specially-coated tool, with an internal bore for additional cooling, and the adjustment of process parameters, the usage of lubricants was reduced to zero. The use of lubricants goes hand-in-hand with a significant reduction in overall energy consumption, mainly due to secondary external effects on machinery,

97 Kalhöfer, E.: Ungenutzte Einsparpotenziale in der spanenden Fertigung, In: Economic Engineering, p. 56-59, Vol. 5, 2008

98 Result survey

99 BBS International GmbH, Schiltach, Germany

i.e. no lubricant supply, circulation and emulsion cracking. The results derived from the programme are depicted in Table 5-5.

Table 5-5: Expected resource savings from the implementation of dry machining at BBS Kraftfahrzeugstechnik AG[100]

Environ-mental impact	Wet machining	Dry machining	Savings
Lubricants consumption	71.292 kg/a	0	100 %
Water con-sumption	2.163 m^3/a	32 m^3/a	98,5 %
Energy con-sumption	**643.630 KWh/a**	**278.853 KWh/a**	**56,7 %**

Although the above savings potential regarding lubricants consumption seems substantial, the analysis in Task 4 (Base Case 1, machining centres) unveils a rather minor environmental improvement potential regarding upstream impacts, when reducing the consumption of cooling lubricants.

5.1.7.2 Resource-efficient technologies

Additional technologies for the reduction of cooling lubricant in machining are as follows:

- **Minimum quantity lubrication (MQL):** The advantage of MQL where the lubricant constitutes a lost lubricant is the omission of whole machine components (e.g. purifiers, treatment plants)[101] and therefore less energy consumption.

  Due to the large amounts of generated heat in grinding processes, there is a lack of MQL technologies applicable for grinding machines. A new approach is based on the use of a hybrid MQL-low temperature CO2 system, in which droplets are directly applied onto the abrasive grains, and frozen with CO2 immediately afterwards.[102]

100 http://www.bmu.de/foerderprogramme/doc/2358.php, accessed 10.01.2011.

101 SKF LubriLean: Minimalmengen-Schmiersysteme (MMS), on the internet: http://www.skf.com/portal/skf_lub/home/products?contentId=873205&lang=de, last access: 7.01.2011

102 Sanchez et al., *Machining evaluation of a hybrid MQL-CO2 grinding technology*, 2010

The use and maintenance of lubricant circulation systems consume high amounts of material and energy. Therefore, a German manufacturer of cutting machines[103] and three project members developed an optimized solution for the supply and mixing of a MQL lubricant called Aerosol. This oil-aerosol mixture is directly prepared in the tool holder (requiring a two-canal system) instead of an external MQL-aggregate which normally diminishes the aerosol quality.[104]

- **Coolant lubricant supply through pressure control valves (PQ-Tronic-System):** A German manufacturer of conveying and filter systems for chips and cooling lubricants[105] conducted several tests regarding the coolant supply. Using screw-spindle pumps with controllable pressure control valves they discovered an energy consumption reduction of 11 %. Due to the fact that the used valves can be controlled and the pressure during tool changes can therefore be almost completely reduced to zero, these savings are achieved. If the cooling lubricant processing plant is equipped with pressure control valves with constant speed and controlled variable pressure, then energy savings of 36 % are possible. Nevertheless, the highest energy consumption reductions can be seen with the new PQ-Tronic-System, which allows energy savings of up to 70%. This technology applies frequency-controlled pumps with variable pressure, volume flow and speed adjustments.[106] Similarly, another pump manufacturer states significant savings potentials of 40-60% when coolant pumps in machine tools are equipped with variable speed drives. Design requirements effective for water pumps are basically also suitable for “clean side” pumps for cooling lubricants (whereas for pumps for chip removal, this might not be the case)[107].

- **Optimised pipe dimension for coolant lubricant supply:** The pumping medium is responsible for pressure loss through development of friction on pipe walls. This pressure loss depends on the pipe diameter and has to be compensated for by the pump. Enlarging the pipe diameter, the pressure loss is lower

103 A. Monforts Werkzeugmaschinen GmbH & Co. KG, Mönchengladbach, Germany

104 Deutges, D.: Weniger ist mehr, In: Zeitschrift für spanende Fertigung Werkstatt+Betrieb, p. 138-139, 143. Jahrgang, September 2010

105 Knoll Maschinenbau GmbH, Bad Saulgau, Germany

106 Drehteil + Drehmaschine: Energieeinsparmöglichkeiten im Kühlschmierstoff-Management, p. 32-41, Vol. 5, 2010

107 personal communication with Grundfos, Denmark

and the pump requires less energy (Table 5-2, example 2). The following example provides evidence for this statement:

Table 5-6: Increased pump performance using different pipe diameters

	Pipe Diameter	Emulsion Flow	Distance	Flow velocity	Pressure loss	Increased pump performance
1. example	20mm	200l/min	10m	10,6 m/s	4,42 bar	2,5 kW
2. example	40mm	200l/min	10m	2,7 m/s	0,12 bar	0,1kW

The flow velocity in example 2 is less than in example 1, but sufficient for the coolant lubricant supply.[108]

- **Cryogenic machining**: Especially in the field of machining super alloys (such as nickel-based alloys, titanium-based alloys), extremely high process temperatures are realized. Oil-based cooling fluids are somewhat ineffective, due to the fact that they vaporize close to the cutting edge at high temperature. Hence, they do not access the tool or the chip. Alternatively, cryogenic cutting fluids can be used. The coolant is usually liquefied nitrogen at -196°C, which is a safe fluid with no hazardous causes to the environment. Cryogenic machining contributes to faster performance, higher quality and reduced costs.[109]
- **High pressure jet assisted machining (HPJAM):** In contrast to conventional machining, HPJAM delivers small flow rates of common lubricants under high pressure (up to 300 MPa), in order to penetrate closer to the shear zone at which the highest temperatures occurs. Thus, the consumption of cutting fluids is lowered, and performance is increased.[110]
- **Direct oil drop supply system (DOS):** The cutting fluid is pressurized at 0.4 MPa and supplied to an oil discharge unit. The DOS nozzle is positioned in such a way that the oil drop hits the rake face of the cutting edge along the lead angle of the endmill cutter. The nozzle itself features two separate air supply

108 Drehteil + Drehmaschine: Energieeinsparmöglichkeiten im Kühlschmierstoff-Management, p. 32-41, Vol. 5, 2010

109 Pusavec et al., *Transitioning to sustainable production – Part I: application on machining technologies*, 2010

110 Pusavec et al., *Transitioning to sustainable production – Part I: application on machining technologies*, 2010

pipes, which significantly suppress peak temperatures. In comparison to conventional minimum quantity lubrication, the occurrence of oil mist is abandoned and the consumption of lubricants is reduced. Additionally, potential harm from cleaning processes ceases.[111]

- **Heat exchangers for preheating components:** The heating can supply new starting points for energy optimization by inductive and conductive systems. It allows time- and pinpoint heating and is particularly suitable for the drawing of high-performance steels and magnesium. These techniques can offer advantages regarding the investment costs and on space requirement. In addition, as for example with inductive systems, higher flexibility is offered. The regulation of the coil power enables different temperatures over the length of the component, without design changes to the heating system. Therefore the strength varies in the component, which may be positive for the following processes. The energy consumption of the process on its own is much higher than the typical "cold" deep-drawing. The advantage of the "warm drawing" is the repeatability as well as economic and ecological savings for all subsequent processes (e.g., elimination of additional straightening processes).[112]

- **Vegetable oils as lubricants:** Under the reformulation of additives, chemical and genetic modification, vegetable oils (e.g. canola oil, coconut oil, olive oil, palm oil, soybean oil, etc.) may substantially substitute petroleum-based lubrication fluids in the long run.[113]

- **Cooling lubricants without mineral oil:** Concepts to replace mineral oils in cooling lubricants use biopolymer-solutions, which offer similar properties to those of conventional cooling lubricants. These sustainable materials save up to 90 % of energy use for production compared to oil-based lubricants.[114]

Optimisation of the cooling lubricant system actually is relevant for all larger machine tools processing hard materials, i.e. metal, ceramics, stone and glass. Efficient usage of cooling lubricants actually results in costs savings throughout the lifetime of the machine tool.

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111 Aoyama et al., *Development of a new lean lubrication system for near dry machining process*, 2008

112 Munde, *Bei der Warmumformung die Energiebilanz im Blick*, 2010

113 Shashidhara et al., *Vegetable oils as a potential cutting fluid—An evolution*, 2010

114 Carl Bechem GmbH, Hagen, Germany

- **Increase of life cycle of lubricants:** One way to reduce the consumption of cooling lubricant is closed-loop recovery of used cooling lubricants. Numerous industrial solutions are available[115], which are largely related to peripheral filters and units, or centralising the cooling lubricants supply system.

- **Technical measures for reducing cooling lubricants emissions** comprise housing, filtering and deposition[116] [117]. In more detail, the following problems are observed, which can be addressed with technical measures within machine tools:

  - Suction nozzle placed too close to the working area, which frequently leads to an extraction not only of mist, but also larger spilled droplets, which results in a much higher amount of cooling lubricants liquid entering the abatement system than required

  - Suction air flow set too high

  - Non-optimal design of suction pipes, where metal chips might block the nozzle

  - Extraction system should not only cover the working area, but also other sources of mist emissions, which are outlets for chips, workpiece and tools, storage units for chips and cooling lubricants, and drains.

  An optimized extraction system can improve the abatement process and reduce the exposure significantly[118]. This must be analysed and considered in the machinery design process, and requires – despite some general principles to be observed - an adaptation to be made to the specifics of the machine tool.

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115 E. g. http://www.leiblein.com/coolant-technology.html, http://www.westfalia-separator.com/applications/marine/lube-oil-and-hydraulic-oil-marine.html, http://cleaner-production.de/fileadmin/assets/pdfs/Externe_Projektbeschreibungen/cpg_newsletter-2006-02-01-en.pdf, accessed March 25, 2012.

116 Pfeiffer, W.: Absaugen und Abscheiden von Kühlschmierstoffemissionen an geschlossenen Werkzeugmaschinen – Einführung, BGIA-Report 9/2006, Absaugen und Abscheiden von Kühlschmierstoffemissionen, Zusammenfassung der Vorträge anlässlich einer Fachveranstaltung am 11. Mai 2006 in Bonn

117 BGIA: Dämpfe und Aerosole beim Umgang mit Kühlschmierstoffen, Ausgabe 0045 · 8/2009 617.0-BGIA:638.1

118 Detzer, R.: Lufttechnische Maßnahmen in Maschinenhallen, BGIA-Report 9/2006, Absaugen und Abscheiden von Kühlschmierstoffemissionen, Zusammenfassung der Vorträge anlässlich einer Fachveranstaltung am 11. Mai 2006 in Bonn

5.1.8 Solution 7: Cooling Systems and Use of Cabinet Heat

5.1.8.1 Introduction

Cooling purposes are an important energy relevant part of the energetic system of machine tools. Especially power electronics are a system heat source. Machine tool manufacturers implement energy-efficient devices in their constructed products to decrease friction-related energy losses. To eliminate the need for extra cooling systems on its EDM machining centres, a leading Swiss machine tool manufacturer[119] uses compact, low-heat motors to eliminate the need for cooling machine drive systems. The integrated approach for energy savings is the improved efficiency of power electronics. The friction-induced heat is reduced, with decreased electric losses in the cabinet components.

5.1.8.2 Solution approach

One possibility is therefore the control cooling through machine integrated cabinets. Heat exchangers are employed for process cooling. A German system climate control manufacturer's[120] solutions reduce the energy consumption by 45 % in comparison to other cooling systems. These results are achieved by a combination of innovative ventilators and cooling compressors, with properly arranged heat exchangers and electronic filling quantity control for refrigerants.[121]

5.1.9 Solution 8: Energy-efficient Tempering

5.1.9.1 Electric inductive heating

Primarily in the field of cold metal forming technologies, the adequate and process oriented tempering of workpieces is required for stable operation. Conventionally, workpieces are brought to process temperature in a heat constant dipping bath, causing an immense need for heating energy. Alternatively, electric inductively heating systems are more efficient (up to 85 %).Via electromagnetic induction, eddy currents are generated within the workpieces, leading to a subsequent heating, which is also much faster

119 Agie Charmilles Management AG, Schaffhausen, Germany

120 Rittal GmbH & Co. KG, Herborn, Germany, being the first one to introduce this approach

121 http://www.rittal.de/downloads/PrintMedia/PM1/de/ReferenzbroschuereHMI_IE.pdf. Last access: 18.01.2011

than conventional heating. In this regard, several pilot projects for the implementation of electric inductive heating have been launched.[122]

5.1.9.2 Thermal compensation

Depending on the scaling and complexity of the machine, the warm-up period before machining is time intensive and leads to a fair amount of energy consumption. Alternatively, for numerically controlled machines, this process can be dropped with appropriate programming of the CNC control system and the use of sensors. Thus, thermal influences will be adjusted by means of automated corrections. So far, there are several machine tool manufacturers using this technology.[123]

5.1.9.3 Minimized pre-heated glue volume

For edge banding machines one manufacturer developed a nozzle system to apply glue to the edges, whereas others use glue rollers, and claim a lower electricity consumption of up to 90% while the machine is heating up[124]. Table 5-7 provides an example calculation of this effect, totalling in a savings potential of roughly 500 kW per year.

Table 5-7: Energy consumption calculation for glue application in edge banding machine tools (by HOLZ-HER, adapted)

		Nozzle system	Roller based system	
Power		2.3 kW	Glue rollers	1.6 kW
			Pre-heating unit	4.6 kW
Heating-up times	(two times daily at start of operation and after lunch)	2 x 3.5 min @ 2.3 kW = 16.10 kWmin/d		15 min @ 6.2 kW + 8 min @ 6.2 kW = 142,6 kWmin/d
Cool down		none		2 x 7 min @ 1.6 kW = 22,40 kWmin/d
Total electricity con-		16.10 kWmin/d		165 kWmin/d

122 See http://www.bmu.de/foerderprogramme/pilotprojekte_inland/doc/45575.php, accessed January 10th, 2011.

123 E.g. Stama (http://www.werkzeugmaschinen-liebetrau.de/Prospekte_files/Verkaufsprogramm_Stama.pdf), brother (http://www.w-r-brother.de/documents/Katalog.pdf, accessed January 21, 2011).

124 HOLZ-HER: Energieeffizienz von HOLZ-HER-Kantenanleimmaschinen, letter to customers, July 8, 2011

sumption		
@ 200 working days/a	53.7 kWh/a	550 kWh/a

This manufacturer claims furthermore, that during normal operation up to 63% less energy is consumed with this system, due to the fact that only the amount which is actually applied to the edges is heated (roughly 4 kW savings, resulting from the 2.3 kW vs. the [1.6 kW+ 4.6 kW] stated in the table above).

5.1.10 Solution 9: Energy-efficient Welding

Increasing productivity, i.e. the welding speed and the reduction of re-work requirements, typically also leads to a more efficient welding process in terms of energy and resource consumption per weld, but also weld costs. Vice versa, any measure that hampers weld quality and increases processing time usually results in additional environmental impacts. Having said this, the following measures have to be considered as environmental improvements only if productivity is not adversely affected. However, some of the measures even increase process efficiency.

Optimising the welding process as such is a complex task, and is subject to steady technological progress regarding welding gas composition, welding wire composition, weld geometries, and materials to be welded.

5.1.10.1 Efficiency of welding power sources

Welding power sources have undergone major technical changes from bulky transformers to inverters. The mass of the power sources, material costs and multi-process capabilities and process controllability were major reasons, which drove this development, which is also related to major gains in power conversion efficiency. However, the potential of this technology has already largely been exploited, as this change took place in the last 10 to 15 years. MIG/MAG welding as the dominant process is well advanced in this respect. Among Manual Metal Arc welding equipment, the transition from transformer type to inverter type equipment is already well advanced. Also among equipment for TIG welding, which is the third important process, but not a mass process, a similar change from transformer type to inverter type took place. However, for submerged arc welding this transition has only just begun.[125]

[125] EWA WG EQUIPMENT, meeting of 13 September 2011, Frankfurt

Inverter type power supplies are occasionally also called medium frequency DC (MFDC) power supplies. For a couple of years now there has been a trend towards medium frequency resistance welding, which works at typically 1000Hz: A three-phase 50Hz alternating current is rectified and supplied to an inverter, which converts the current to a medium frequency of 1000Hz and passes this through a transformer/rectifier, which is typically integrated into the welding gun, resulting in a DC welding current. Some of the advantages of this technology are[126]

- Significant energy savings due to shorter weld times
- Improved and consistent power factor (99% achievable)
- Better weld quality, as the effect of electrical line disturbances on the welding process are minimised
- Higher productivity, as intercool states between cycles are eliminated, which shortens weld times

The efficiency gains of inverters over transformers are related to a couple of design features:

- Use of (more efficient) ferrite cores in the (comparatively small) transformers in the inverter
- Lower resistance through smaller secondary side components and overall shorter wiring due to smaller unit sizes
- Use of efficient power electronics components and related circuitry design
- Operating at higher frequencies, usage of capacitors for interim energy storage
- Above efficiency effects result in less cooling requirements and thus less energy consumption for fans

Table 5-8 lists typical efficiency levels of arc welding power sources, based on estimates by EWA WG Equipment[127]. See Task 4, Section 4.1.3.9, for a more distinct weighted energy efficiency of arc welding power sources. Note that there is a 2005

126 Medium frequency welding of metal components, Metal Matters, Issue 15, Autumn 2009

127 These values do not apply for resistance welding equipment as the transformer used is designed by its thermal performance in order to allow very short welding time with very high welding current

standard for measuring welding power source efficiency (Annex M of IEC 60974-1 ed.3).

Table 5-8: Typical Efficiency Levels of Arc Welding Power Sources

	Power source efficiency
Rotating type machine[128]	45%
"Transformer type" single phase	65% to 70%
"Transformer type" three phases	70% to 75%
"Chopper type" three phases	70% to 75%
"Inverter type" single phase	75% to 80%
"Inverter type" three phases	80% to 85%

Further improvements are now related to advanced inverter technology. According to EWA estimates, the maximum achievable efficiency for arc welding power source might be 90%. Natural Resources Canada[129] states that "modern inverter power sources have energy conversion efficiencies near 90 percent, with idling power consumption in the order of 0.1 kW." Similarly, some welding equipment suppliers claim energy efficiencies of up to "88-90% with a 95% minimum power factor (at rated output)"[130], "90%"[131], 88-91% efficiency for a 3-phase power inverter[132]. Such efficiency increase could be partly realized through better electronics circuitries, but much more through more material in coils, mainly copper for the windings. Such a change has an adverse effect on resource consumption (copper, iron), and again adds weight to the unit, which hampers the mobility of the welding equipment. According to EWA, the efficiency increase as stated above will not be achievable for:

- AC arc welding power sources that need a second DC/AC converter (additional loss), for example, TIG, Plasma, some new MIG low energy process, to reduce frequency of the current intrinsically delivered by the inverter power source to a frequency compatible with the welding process;

[128] not sold on EU market anymore, but could be found in operation still in a few workshops

[129] http://oee.nrcan.gc.ca/industrial/equipment/arc-welding/759

[130] Lincoln Electric: http://www.lincolnelectric.com/en-us/equipment/robotic-automation/products-and-systems/Pages/automation-power-sources.aspx; products: Power Wave® 455M & 455M/STT, Power Wave® 655R,

[131] Fronius: http://www.axson.se/res/broschyrer_pdf/fro_bro_time_twin_eng.pdf, product: Time Twin

[132] Thermal Arc: http://www.thermadyne.com/IM_Uploads/DocLib_2140_84-2626.pdf, product: PowerMaster 500P

- resistance welding power sources that are designed in accordance with the thermal requirement of short welding cycles (typically below 1 second) and not for maximum current at 100% duty.

Regarding idle power consumption Hsu (2010) takes stud welding equipment as an example, and cites that where previous generation welding machines consumed 113 W in idle mode and an additional 50 W for welding gun and feeder, latest stud welding equipment now consumes 7.5 W, with no power for feeder and gun, as the equipment switches into a sleep mode when idle[133].

Air-flow cooled welding units can feature a fan, which is switched off, when the equipment is in idle mode and at cold state[134], which allows reduced power consumption in this mode[135].

5.1.10.2 Maximum Energy Transfer

Besides power conversion efficiency (transfer from mains power to arc power), welding processes may be characterized by their ability to transfer the energy from the arc to the workpiece. Typical heat transfer rates are listed below, related to specific technologies, which are each used for specific applications.

Table 5-9: Heat Transfer Rates of Arc Welding Processes

Process	Heat transfer to workpiece
Submerged arc welding (SAW)	1.0
Manual metal arc (MMA) **Shielded metal arc welding (SMAW)**	0.8
Cored wire welding **Flux cored arc welding (FCAW)**	0.8
Metal active gas/Metal inert gas (MAG/MIG) **Gas metal arc welding(GMAW)**	0.8
Tungsten inert gas (TIG) **Gas tungsten arc welding (GTAW)**	0.6
Plasma arc welding	0.6

133 Hsu, C.; Phillips, D.: Stud Welding Technologies for a Greener Future, Welding Journal, October 2010, p.38-42

134 Depending of the temperature of the power source, the fan may be on during idle mode (see definition in Table 7-2) in order to reach cold state before the next welding period. The fan automatically stops at cold state.

135 See for example Fan-on-Demand™ cooling system by Miller Electric Mfg Co., http://www.millerwelds.com/resources/articles/welding-guide-power-efficiency/

Submerged arc welding technology transfers the heat completely to the workpiece, making it the most efficient process. However, these technology specifics can be influenced by equipment design measures only to a very limited extend.

In a research project a test procedure was developed to determine the welding efficiency, i.e. the ratio of heat energy transferred into the material and electric energy supplied to the arc[136]. For MIG/MAG welding processes efficiencies (η) of 0,72 for spray arc, 0,77 for pulsed arc and 0,82 for short arc (average values for a given welding task) were measured with the developed test procedure, which roughly confirms the above stated heat transfer rate of 0,8.

5.1.10.3 Optimised shielding gas supply

Indirect energy consumption is related to gas consumption, in particular for shielded arc welding processes. Optimised gas flow and avoidance of wasted gas could reduce the environmental impact of welding significantly. Where centralized gas supply systems in industrial applications are used, numerous measures could help to reduce gas consumption, such as:[137]

- using adjustable flow devices
- optimising system pressure settings
- properly calibrating flow meters

The main source of gas consumption is the insufficient maintenance of gas circuits, e.g. leakage, damaged hoses, and old hoses. Proper maintenance measures such as periodic tests to detect leakage and periodic change of hoses are advisable.

However, these measures are not related to the welding equipment design. Measures directly related to the welding unit as such are:

- Minimising the volume between flow device and torch tip (at the wire feeder), which decreases the time required for the flow to reach the set flow rate and, in

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136 IFS Chemnitz, Status report March 2010, research project " Bestimmung von Wirkungsgraden moderner Schutzgasschweißverfahren", 2008-2010, AiF-Nr. 15.562 BR, http://www.dvs-ev.de/fv/neu/getfile.cfm?PID=444&file=ZB_15.562B_10-1.pdf

137 Standifer, L.R.: Shielding gas consumption efficiency-- Part I: Spend a penny, save a dollar, thefabricator.com, February 19, 2001

turn, the amount of gas wasted by momentary excess flow or overflow. This is particularly relevant for high cycle rates, such as tack welds, where the welding process is frequently interrupted[138]. The volume could be reduced by placing the flow device closer to the torch tip and/or by reducing the inner diameter of the hose[139]. Welding gas savings of “40 to 50%” are reported, but this depends on the previous status quo, the actual use scenario, and the experience of the welder to adapt the welding conditions to an optimum for his intended purpose.

- using a welding gas regulator that provides a consistent gas flow from arc-on to arc-off, allowing welders to set a lower flow rate. Such optimized regulators are reported to “reduce the time between gas and arc ignition at the beginning of a weld, and between arc-out and gas-off, resulting in less wasted gas”.[140]

Excessive shielding gas consumption could also have an adverse effect on weld quality. A high volume flow of shielding gas can result in a turbulent gas flow and actually induce atmospheric contamination of the weld puddle, i.e. limiting the intended shielding effect. An optimised gas flow thus also has a positive (environmental) effect on productivity (less re-work), product (i.e. weld) quality and lifetime.

5.1.10.4 Reduction of spatter losses

An efficient welding process requires a maximum use of welding wire material. Losses occur through spatter losses. There are systems which facilitate the reduction of spatter losses. This spatter loss, which can be reduced significantly by using an optimized shielding gas (blend), is reflected in the “deposition efficiency” of the welding process. Typical deposition efficiencies of shielded arc-welding processes are listed in Table 5-10[141].

Table 5-10: Typical deposition efficiencies of shielded arc-welding processes (according to PRAXAIR)

	Typical Deposition Efficiencies
Gas Tungsten Arc Welding (GTAW / TIG):	95%-100%

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138 Standifer, L.R.: Shielding gas consumption efficiency-- Part I: Spend a penny, save a dollar, thefabricator.com, February 19, 2001

139 Uttrachi, J.: MIG Shielding Gas Control and Optimization; W A Technology; July 2011, http://www.netwelding.com/Shielding_Gas_Control_Download.pdf

140 Heston, T.: Better shielding gas flow, efficient welding - Automotive supplier reduces gas consumption, optimizes welding; thefabricator.com, October 21, 2010

141 PRAXAIR: Shielding Gases – Selection Manual, 1998

Gas Metal Arc Welding (GMAW / MIG):	88%-98%
Flux Cored Arc Welding (FCAW, gas shield):	85%-90%
Flux Cored Arc Welding (FCAW, self shield):	75%-85%
Plasma arc welding (PAW)	95%-100%
Shielded Metal Arc Welding (SMAW, stick)	50%-65%

The use of argon blends is reported to result in the highest levels of deposition efficiency. A secondary effect of less spatter losses, higher deposition efficiencies and the use of appropriate shielding gases is the lower generation of fumes, which is a critical aspect for the workers' environment.[142]

The choice of the welding gas actually is not related to the design of the welding equipment, but is an aspect for user information.

5.1.10.5 Adapted Stud Welding Current

For specific welding processes an adaptation of the waveform avoids wasting energy. In the case of stud welding, which is extensively used in automotive manufacturing, construction, ship building and the like the process works as follows: The stud is pushed against the workpiece to make contact. While a low pilot current is applied, the stud is lifted to draw a small pilot arc current. For a set time the current is increased to the intended welding current level to melt stud and workpiece. Plunging the stud back into the workpiece extinguishes the arc and completes the weld. Thereafter the welding current is turned off and the welding tool removed. The synchronization of current turn-off and plunge is a critical process, and a technology was introduced to adapt the current waveform generated by an inverter, and controlled by a digital signal processor with the stud motion[143]. The resulting plunge current waveform is depicted in Figure 5-12. Hsu (2010) cites an estimated energy savings potential of up to 9% and 24% respectively for drawn arc stud welding with and without ferrule. The shorter the process cycles, the higher the savings potential.

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[142] Note, that both aspects, fume generation and welding wire consumption are not addressed in the Base Case calculation in Task 4

[143] Hsu, C.; Phillips, D.: Stud Welding Technologies for a Greener Future, Welding Journal, October 2010, p.38-42

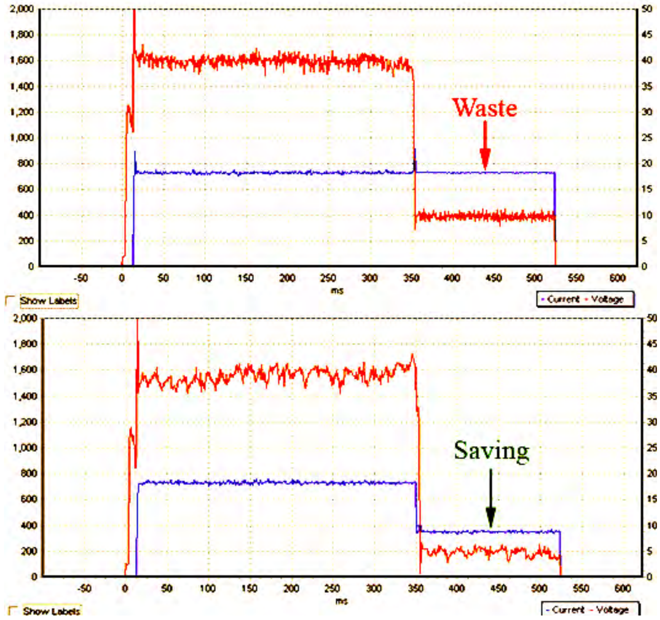


Figure 5-12: Stud Welding: Conventional (above) vs. reduced plunge current waveform (below)

5.1.11 Solution 10: Productivity and processing time

Increasing productivity, i.e. actual throughput, is frequently stated as one major measure to reduce energy consumption per workpiece output. Processing time is key in this regard.

CECIMO provided a detailed analysis as a stakeholder input to verify this aspect exemplarily (data as provided by CECIMO, without further verification by Fraunhofer):

According to research performed by Agie Charmilles SA … faster machining saves up to 30% of energy [analysis refers to electro-discharge wire-cutting machines]*. The measurements were taken on SodickA500 and Robofil310 machines, which are widespread in use; FI440ccs is in full production, but is an older concept than CUT20 … .*

The results show that an older machine under standard conditions (SodickA500 std.), uses 3.86 times the energy of the newer machine with optimized parameters (CUT20 opt.). It means that the optimized machine saves 74% of the energy of the old, non-optimized machine, by performing the same work with the same quality output.

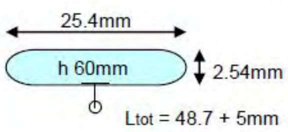
The measurements show that typical savings between standard and optimized (maximized Cutting Rate) are 27% to 45% for all four machines [Ernst R. Bühler & Orio Sargenti, Agie Charmilles SA].

Table 5-11: Energy measurements on metal working machine tools (research data provided by Agie Charmilles)

CR_mm²/min	CP_mm²/kWh	use_kWh	machine	Tech.	CP math_mm²/kWh	use math_kWh
87,2	607	4,813	SodickA500	std.	741	4,11
150,0	1096	2,667	SodickA500	opt.	1275	2,43
98,2	960	3,043	Robofil310	std.	835	3,66
146,1	1320	2,213	Robofil310	opt.	1242	2,50
131,5	912	3,203	FI440ccs	std.	1118	2,76
205,1	1315	2,222	FI440ccs	opt.	1743	1,81
130,0	1557	1,877	CUT20	std.	1105	2,79
229,5	2341	1,248	CUT20	opt.	1951	1,63
5,0					43	70,10
10,0					85	35,10
20,0					170	17,60
40,0					340	8,85
60,0					510	5,93
80,0					680	4,48
100,0					850	3,60
120,0					1020	3,02
140,0					1190	2,60
160,0					1360	2,29
180,0					1530	2,04
200,0					1700	1,85
220,0					1870	1,69
240,0					2040	1,56
245,0					2083	1,53
250,0					2125	1,50

CR_mm²/min:	250
CP_mm²/kWh:	2557
Use_kWh:	1,09
Height_mm:	60
Length_mm:	48,7
a:	8,50
b:	0,10
c:	350

The benchmark workpiece is depicted in Figure 5-13, and is cut from a 60 mm steel plate with a 0,25 mm brass wire.



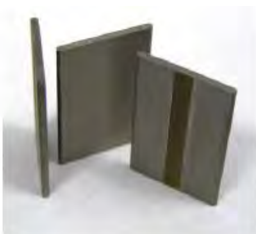


Figure 5-13: EDM benchmark workpiece layout[144]

The energy use in kWh for the various machines matched with the cutting rate is shown in Figure 5-14, according to measurements by Agie Charmilles SA.

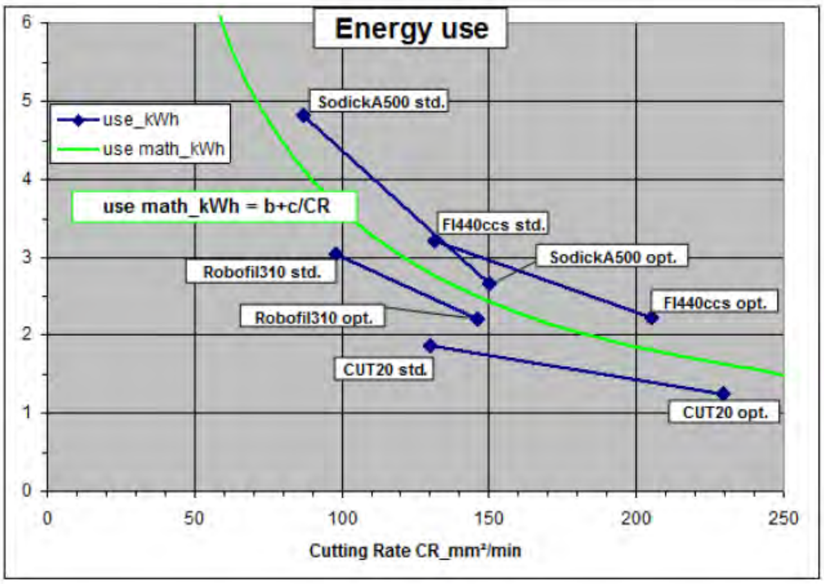


Figure 5-14: Energy use vs. Cutting rate[145]

Figure 5-15 depicts for the various tested machines the cutting power (CP) in mm²/kWh versus the cutting rate (CR) in mm²/min.

144 Ernst R. Bühler & Orio Sargenti, Agie Charmilles SA

145Ernst R. Bühler & Orio Sargenti, Agie Charmilles SA

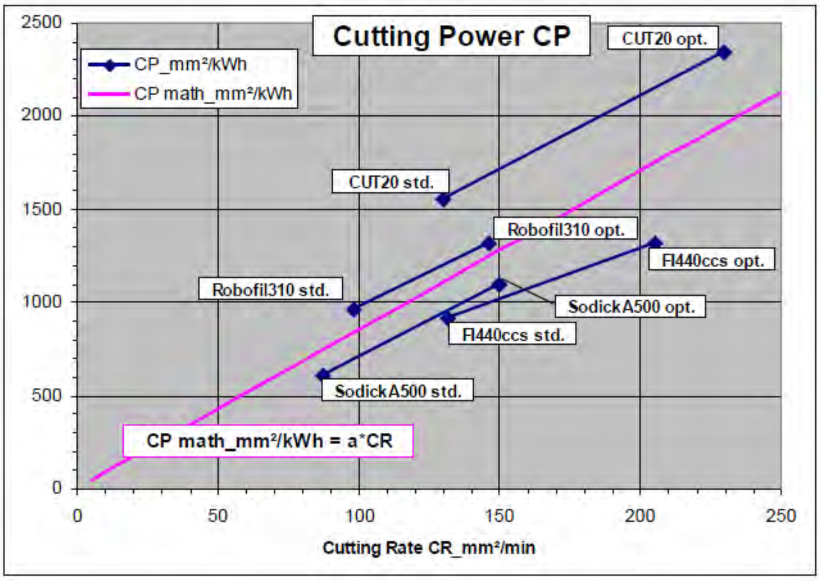


Figure 5-15: Cutting power vs. Cutting rate[146]

Similar findings regarding the energy savings aspect of faster processing were made also by others[147], but again for specific applications, or with slightly outdated data[148].

5.1.12 Examples for the Implementation of BAT

5.1.12.1 System approach for cutting machines

A German manufacturer of machine tools and components for the metal working industry[149] offers a reconfigurable platform based on three variants with the same components and technology modules. The sliding machine table is designed exactly the same way for all machines. Only performance-and quality-determining components, such as the bearings for engines and main spindle, and the guiding principle of the main spindle sleeve, are adapted to the needs of the particular user. The modular system includes, among others, four different spindles. There is a universal standard spindle, a high-

[146] Ernst R. Bühler & Orio Sargenti, Agie Charmilles SA

[147] Diaz, N.; Helu, M.; Jarvis, A.; Tönissen, S.; Dornfeld, D.; Schlosser, R.: Strategies for Minimum Energy Operation for Precision Machining[Strategies for Minimum Energy Operation for Precision Machining; Laboratory for Manufacturing and Sustainability, University of California, Berkeley, and WZL, RWTH Aachen

[148] Rowe, W.B.; Jin, T.: Temperatures in High Efficiency Deep Grinding (HEDG); CIRP Annals - Manufacturing Technology Volume 50, Issue 1, 2001, Pages 205-208

[149] Emag Holding GmbH, Salach, Germany

performance spindle, a precision spindle and a spindle for the multi-use technology with extended C-axis accuracy. The bearings of the Z-axis can either be hydrostatic or conventional roller bearings. Depending on the application, there are several tool revolver positions and numerous automation-options available.

The standard version is designed primarily for job order productions and turned parts manufacturers. The second version is designed as a front-operated production machine, which can be individually adapted to the processing requirements. The third version focuses on multi-technology applications. The modular concept allows quick modifications such as tool module changes. Additionally, energy-efficient motors with integrated energy recovery are used, together with low-watt valves (using 70 % less power than conventional valves), and control panels without active cooling..[150]

Furthermore, the energy saving potential of a vertical pick-up turning machine was defined. Some of these potentials are realized with the newest generation of machine tools, as shown in Figure 5-16.[151]

150 www.emag.com/nc/de/emag-gruppe/presseinformationen/bilderarchiv/presse-detailansicht/news/2/emag-vlc-250-universell-auf-die-produktionsanforderungen-konfiguriert.html. Zugriff: 05.08.2010.

151 Hegener, G.: Energieffizienz beim Betrieb von Werkzeugmaschinen – Einsparpotenziale bei der Auswahl der Fertigugnstechnologie. In: Fertigungstechnisches Kolloquium 2010. Stuttgart, 2010. pp 281-292

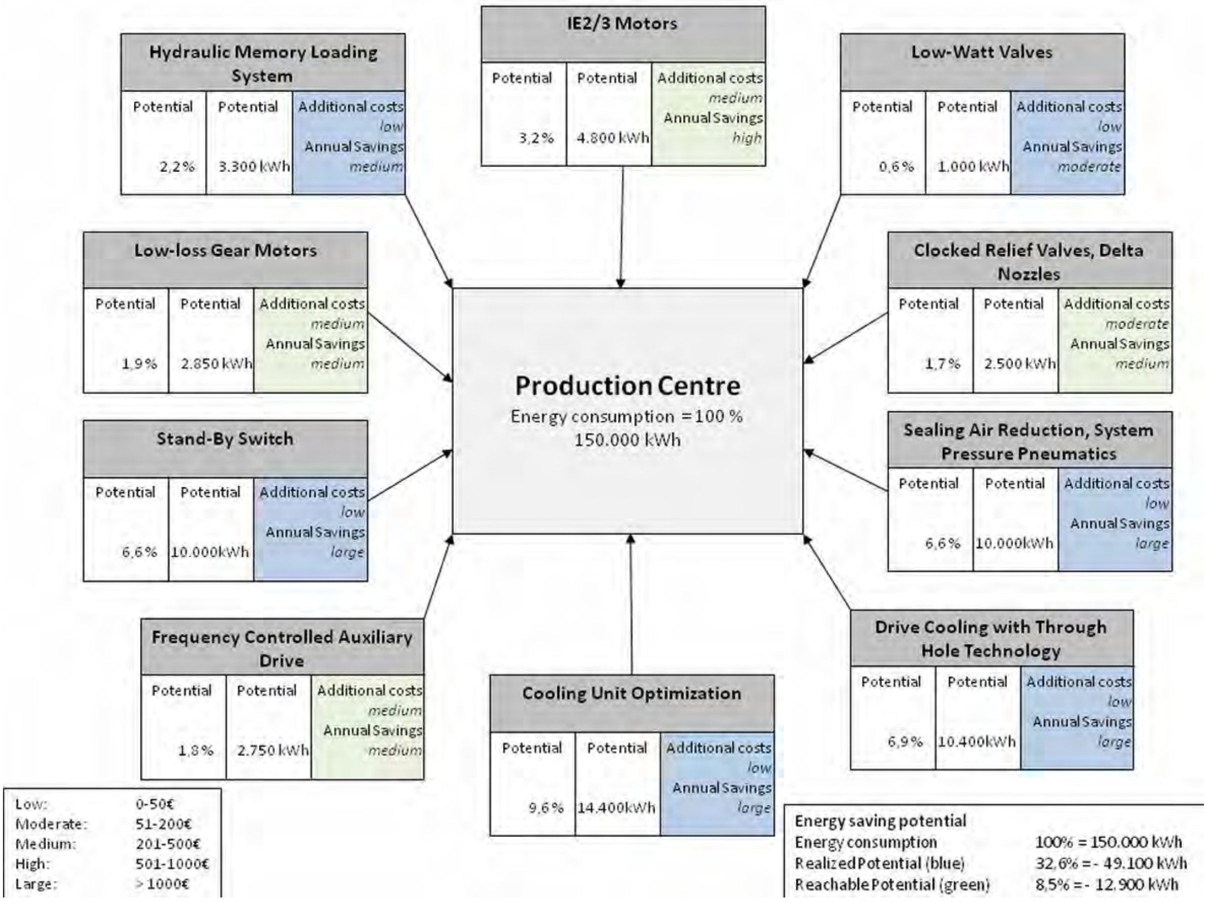


Figure 5-16: Energy Saving Potentials[152]

One of a leading machine tool manufacturer's[153] vertical double-spindle machining centres is designed as a modular system. It is made for parallel 5-axis complete machining in one clamping situation, with up to four work pieces simultaneously. The position of the two spindles relative to one another in the X- and Z-direction can be adjusted, NC-controlled via a torque drive in a range of + / - 0.5 mm. This can compensate for different tool lengths and clamping heights, and can eliminate reverse re-clamping. In addition, energy efficiency options offered include regenerative drives, energy-efficient transformers, power safe functions that switch off auxiliary units in production breaks, aggregate cooling on central circulation and a frequency-controlled high-pressure pump, which requires 60 % less energy. The main goal is to reduce the

152 ibidem

153 Chiron-Werke GmbH & Co. KG, Tuttlingen, Germany

set-up times, for example, with integrated workpiece changing facilities, since an average energy intake of 80 % was identified during these periods.[154]

On typical multi-spindle machines, spindles and their drive motors are both located within the machine's spindle drum, thus creating the need to cool the drum, and necessitating the consumption of more energy. A Czech machine tool manufacturer[155] eliminated having to cool its machine drums through an innovative design. The company's design relocates all spindle drive motors away from the machine's drum. Drive motors reside at the machine end, opposite the end housing the spindle drum. An extra plus is that the design requires motors with a lower power consumption.[156]

A German company offering machine tools[157] focuses on lightweight, energy recovery systems, the processing-dependent regulation of components for standby, and warm-up cycles and reduced air demand. For example, 80 % of their roller guides and spindles are equipped with long-term grease lubrication instead of energy-intensive alternatives. Mineral casting beds are used to preserve resources. Another important aspect of energy and resource efficiency is a detailed analysis of the customer's demand. At the beginning of the design phase, intense customer interviews are made that lead to a performance-based design and dimensioning of the systems.[158]

A further German machine tool manufacturer[159] offers energy recovery of the main spindle, reduced power consumption at auxiliary process time, and standby options, which are adjustable by the customer. There is also an "energy save" software that identifies the down time automatically, on the basis of the current uses, and puts the machine into hibernation. Another measure to increase the energy efficiency of machine tools is seen in the simulation of device and processing with an option of virtual machines.[160]

154 www.chiron.de/index.php?id=981&type=98&L=0&tx_ttnews%5Btt_news%5D=222&tx_ttnews%5BbackPid%5D=962&cHash=74ef879a3f. Zugriff: 08.08.2010.

155 Tajmac-ZPS, a. s., Zlin, Czech Republic

156 N. N.: Power Up. An Energy-Saving Program. In: American Machinist. (2009) 8, pp. 14-17.

157 Maschinenfabrik Berthold Hermle AG, Gosheim, Germany

158 www.pressebox.de/pressemeldungen/maschinenfabrik-berthold-hermle-ag/boxid/330862. Zugriff: 08.08.2010.

159 Gildemeister AG, Bielefeld, Germany

160 www.dmgecoline.com/de-DE/6-news. Zugriff: 10.08.2010.

5.1.12.2 Solutions for particular sub-systems

A leading machine tool and systems manufacturer[161] is planning in the future to exhibit cryogenic machining with liquid nitrogen, utilized via a through-spindle, through-tool cooling system. In milling and boring, liquid nitrogen consumption is about 0.04 litres per minute per cutting edge. It enables higher cutting speeds for increased metal removal and longer tool life. This technology improves lifecycle costs, and is a candidate solution for improved sustainability, since the following are all avoided: mist collection, filtration, wet chips, contaminated workpieces and disposal costs. Moreover, less energy consumption is provided without the pumps, fans and drives needed for handling coolant. The U.S. development will also be introduced in Europe.[162]

To conserve energy, the MAG Specht 500/630 horizontal machining centre eliminates machine warm-up time, sleeps when idle, incorporates regenerative drives and uses half the normal coolant requirements. The machine also offers minimum quantity lubrication (MQL) operation. MQL eliminates the need for chip flushing coolant and the associated energy costs for pumps, filter media and chip drying.[163]

With the help of a system by a renowned German manufacturer of drive and automation systems and software solutions[164] the energy efficiency of machine tools can be improved by dynamic analysis of mechatronic systems and electric drive technology. The control of secondary processes, such as cooling or tool changes, and the demand-driven operation of auxiliary drives for machine-near logistics causes these energy savings.

161 MAG Industrial Automation Systems, Sterling Heights, USA

162 http://www.mag-ias.com/en/mag-news/press-archive/archive/archive2/press-archive/2010/breakthrough-in-cryogenic.html

163 N. N.: Power Up. An Energy-Saving Program. In: American Machinist. (2009) 8, pp. 14-17.

164 Siemens AG, München, Germany

Figure 5-17: Monforts UniCen504[165]

A megatrend in the development of eco-efficient machine tools is the modularization and reconfiguration in order to adapt the machine tool rapidly to the requirements of the dynamic market.[166][167]. Customers' demand for increasingly complex components, with high variety and small lot sizes, in combination with short-term contracts, require various machine tools for manufacturing companies. This leads to higher investment and maintenance costs. The goal of the combined Project KombiMasch (shortening the process chain for manufacturing rotationally symmetrical components, by process combination in modular machine tools) was to develop a combined machine tool which integrates several processing methods. The machine tool combines soft turning, milling and drilling, hardening and coating by laser and the hard turning and milling. Currently available machine tools on the market usually specialize in only one manufacturing process.[168]

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165 Deutges, D: Laserunterstützes Drehen von Keramik. In: Uhlmann, E. (Hrsg.): Berliner Runde 2008 – Neue Konzepte für Werkzeugmaschinen. Berlin, 2008. pp. 77-85

166 Nyhuis, P.; Reinhart, G.; Abele, E.: Wandlungsfähige Produktionssysteme: Heute die Industrie von morgen gestalten. Hannover: PZH Produktionstechnisches Zentrum, 2008

167 Nyhuis, P.; Fronia, P.; Pacho, J.; Wulf. S.: Wandlungsfähige Produktionssysteme. Ergebnisse der BMBF-Vorstudie "Wandlungsfähige Produktionssysteme". In: wt Werkstattstechnik online 99 (2009) 4, pp. 205-210

168 Deutges, D.: Verkürzung der Prozesskette zur Fertigung rotationssymmetrischer Bauteile durch Verfahrenskombination in modular aufgebauten Werkzeugmaschinen.

5.1.12.3 Lightweight solutions

In the FP6 funded project "ECOfit Eco-efficient machine-tools by means of radical mass and energy needs reduction", new approaches to energy saving in the operation of machine tools by reducing the moving masses were investigated. The project aimed at increasing machine tool energy efficiency via the use of elastic structural components with controlled flexibility, through using mechatronic elements.[169] The ECOfit project reported significant improvements in terms of both life cycle impacts of materials production for machinery construction, and power consumption in the use phase due to reduced moved masses. Zulaika et al. state as an outcome:

- Average reduction of 35 % in the energy consumed by the prototype during positioning motions with respect to a conventional machine (see Figure 5-18)
- Average reduction of 18 % in the energy consumed by the machine feed-drive while machining
- Additional 7 % reduction in the energy consumed by the rotating spindle

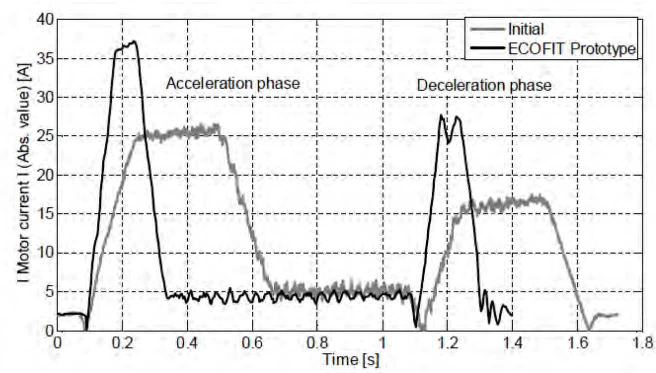

Figure 5-18: Motor current of prototype with lightweight construction compared to a conventionally designed machine[170]

The ECOfit project also provided an LCA, conforming to ISO 14040, of its prototype developments, showing the total life cycle benefits of the approach, although at a

www.produktionsforschung.de/PFT/verbundprojekte/vp/index.htm?VP_ID=1338. Access: 10.08.2010.

169 Sekler, P.; Dietmair, A.; Dadalau, A.; Rüdele, H.; Zulaika, J.; Smolik, J.; Bustillo, A.: Energieeffiziente Maschinen durch Massenreduktion. In: wt Werkstattstechnik online 97 (2007) 5, pp. 320-327.

170 Zulaika, J.J.; Dietmair, A.; Campa, F.J.; López de Lacalle, L.N., Verbeeten, W.: Eco-efficient and Highly Productive Production Machines by Means of a Holistic Eco-Design Approach, E/E 3rd Conference on Eco-Efficiency, June 9-11, 2010, Egmond an Zee, The Netherlands

higher initial investment due to more sensors, more active devices and more control systems than with a conventional machine.

5.1.12.4 Hydraulic-free machining centres

A German company offering machine tools[171] exhibited the first machining centre[172] in the world with no hydraulics in September 2010. Whether this can be considered Best Available Technology or not is heavily debated among technologists, as machine tools without hydraulics can claim some important advantages on the one hand, but on the other hand the inherent potential of optimised hydraulic systems should not be ignored.

On this machining centre, workpieces can be clamped electromechanically, and all tools released electromechanically. The replacement of a hydraulic system by an electromechanical system logically eliminates the consumption and disposal of hydraulic oil. This eliminates also the risk of leakages. From a technical perspective maintenance requirements are reduced, and all the test cycles for the hydraulic pressure accumulator with all its safety valves are avoided. In addition, hoses and seals do not need to be replaced, which leads to an improved technical capacity of machining centres.[173,174]

In one specific case, the shift from a hydraulic system to all-electromechanical resulted in energy savings of 4 % for the machining centre investigated, and the technical adaptation does not result in any additional costs.[175] It is argued that machinery internal electromechanical clamping systems might be limited by work space constraints compared to hydraulic systems, which can be placed externally to the machine tool, thus avoiding limiting the work space. This might be a decisive criterion in certain applications. It should also be noted that optimised hydraulic systems with e.g. two-way pilot valves, which permanently maintain the required pressure, are said to result as well in power savings, if coupled with appropriate power management measures. Thus,

171 Grob-Werke GmbH & Co. KG, Mindelheim, Germany

172 based on a GROB G350 standard machine with Siemens 840 sl MDynamics controls and a GROB 18,000 rpm HSK-63 motor spindle

173 GROB: The first machining center with no hydraulics, September 27, 2010, http://www.grobgroup.com/en/2010/09/27/september-the-first-machining-center-with-no-hydraulics/

174 Fertigung – das Fachmagazin für die Metallbearbeitung: Blick in die Zukunft – Branchenreport, November 3, 2011, http://www.fertigung.de/2010/11/blick-in-die-zukunft-2/

175 Fertigung – das Fachmagazin für die Metallbearbeitung: Blick in die Zukunft – Branchenreport, November 3, 2011, http://www.fertigung.de/2010/11/blick-in-die-zukunft-2/

measures to reduce power consumption in idle times of hydraulic systems and components is key to achieving significant energy savings also with hydraulic systems, which leads to the conclusion, that hydraulic-free machine tools cannot be considered as Best Available Technology per se, but that the specific application scenario and required performance has to be considered with due care. In particular, for applications where the higher achievable body force of hydraulic systems is essential, hydraulic-free machine tools are not an option at all[176], and safety requirements of ISO 13849 partly cannot be met by electrical clamping devices and other electrical components.

5.1.12.5 Summary

All these solutions show different possibilities to integrate energy saving modules into machine tools.[177] The immediately greener image, and long-time cost savings, are the benefit of the implementation of such solutions. However, it is important to reach the demanded productivity and quality required, as well as the energy efficiency. The examples presented combine economical and ecological advantages. It is a profound misunderstanding to talk of a trade-off between the economic and environmental dimensions. Instead it is relevant to draw up a common target tracking to reach the aims.

5.1.13 Evaluation of options

The evaluation of the various improvement options stated and listed above required an approach which allowed a broad coverage of the whole machine tools market, but does not address individual machine tools. For this latter purpose, an assessment matrix was developed and presented at the 2nd Stakeholder Meeting of this study, and stakeholders were invited to provide evidence and estimates regarding the potential of these measures. Annex Assessment Matrix Survey provides documentation of the questionnaire published on the project website.

5.1.13.1 Metal working machine tools

CECIMO cordially supported the survey and assessment regarding improvement options, but adapted the initial assessment matrix to the systematics of ISO 14955 (draft), i.e. deviated from the structure of improvement options outlined above.

176 Kuttkat, Bernhard: Spannsysteme - Röhm forciert die Elektrifizierung, MaschinenMarkt, November 11, 2010

177 Only some examples. Much more are available.

CECIMO coordinated the inquiry among machinery manufacturers from the metal working machine tools market and finally received replies from 18 companies from the three different metal working branches cutting machine tools, servo presses and mechanical presses, and hydraulic presses. The main group are cutting tool manufacturers.

The evaluation of the energy efficiency of functional units by CECIMO takes regard of six functional modules:

M1: Machining (machine process, motion and control)

M2: Process conditioning and cooling

M3: Workpiece handling

M4: Tool handling / die change

M5: Recyclables and waste handling

M6: Machine cooling / heating.

Energy efficiency measures examine the relation of impact on the number of functions between 0 % (no impact), between 0 % and 100 % (total added amount of impact in different functions) and 100 % (total impact on a single function).

The share of each of the functional modules in the total machinery energy consumption, classified into the metal working machine tool technology, is displayed in Figure 5-19**:** In all the three types of machine tool classes the main share of energy consumption concerns the machining process itself (i.e. module M1). The physical necessity of providing energy to shape the workpieces into parts is the core task of machine tools, and therefore dominates the share of energy consumption against the functional modules. It figures out the state of energy efficiency measures where process, motion and control features require the most energy. Machine tool cooling and heating (M6) shows the second largest amount of consumed energy. Workpiece handling (M3) has the second largest share of energy consumption in the category "servo and mechanical presses". The third largest share in the category of "cutting machine tools" is process conditioning and cooling (M2), dependent mainly on the amount of cooling lubrication and installations for transport and storage. This corresponds with energy consumption for recyclables and waste handling (M5) of cutting machine tools. Here, the lubrication means used for cooling has to be mainly purified and disposed.

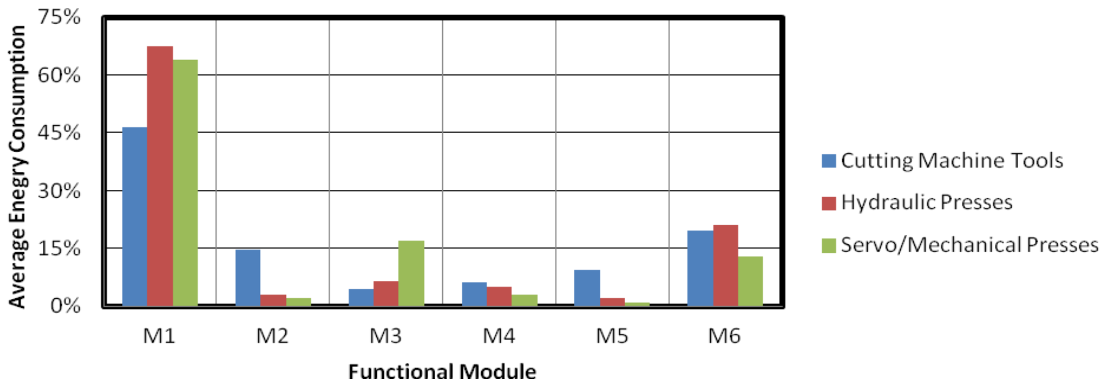

Figure 5-19: Energy consumption allocation per functional module and type of machine tool [CECIMO]

The functional modules are correlated in CECIMO's survey to 10 machine tool components:

1: Overall machine

2: Drive units

3: Hydraulic system

4: Cooling and lubrication system (manufacturing process related)

5: Cooling system / Die cooling/ Lubrication system (components related)

6: Power electronics / Electric system

7: Machine concept (cutting machine tools) Pneumatic system (presses)

8: Peripheral devices

9: Simulation

10: Control

According to the survey, for cutting machine tools, the main energy efficiency potentials are to be seen in component groups 2 (drive units) and 3 (hydraulic system), followed by the groups 4 (lubrication system), 5 (die cooling/lubrication system) and 7 (machine concept). Hydraulic, servo and mechanical presses show energy efficiency potentials in component groups 3 (hydraulic system) and 2 (drive units), followed by groups 7 (pneumatic system) and 9 (simulation).

The following summary of replies is subdivided into the 3 machine tools types: cutting machine tools, servo presses and mechanical presses, and hydraulic presses.

It must be noted that the respondents typically gave deviating estimates regarding savings potential, cost effects and market penetration of certain options, but there is mostly a consensus on tendencies. The following sections therefore present, via graphical illustrations, the number of respondents per category regarding estimated improvement potential and related investment cost impacts. In the tables, the variances are condensed to “tendencies” (percentages are understood as orientation values, i.e. if a majority of respondents replied with an estimated savings potential of 0.5 – 1.5% a value of 1% is taken as tendency). These figures will be subsequently used as approximations for calculations in Task 6. In these tables, a conservative figure is typically stated for cost effects (higher weighting of estimates indicating a larger cost increase) and for energy efficiency potentials (rather a lower percentage is stated, if this is the estimate of several respondents).

The numbering of the options follows ISO 14955 (draft).

5.1.13.1.1 Cutting

Regarding the **overall machine** from the replies given, some tendencies are evident: The energy savings potential by most respondents is estimated to be in the range between 0 and 1,5% of the total machinery energy consumption (Figure 5-20). Individual respondents also state a larger savings potential of even above 5% for 3 of the 4 options. Only the option “reduction of friction” (1.2) has a very minor potential, if at all.

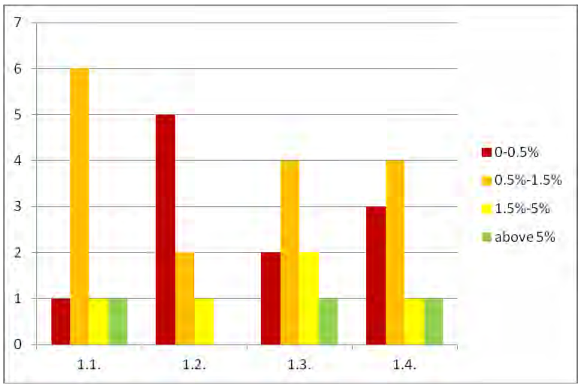

Figure 5-20: Total machinery energy savings potential – Overall Machine

Regarding the overall machine concept, the respondents state a large variation of additional machinery costs with the implementation of options. For each of the options, the full spectrum of answers is covered. At least 2 of the respondents state for each option a cost of more than 3% of the total machinery costs, but there are always two respondents, which replied that there was no cost difference at all (Figure 5-21).

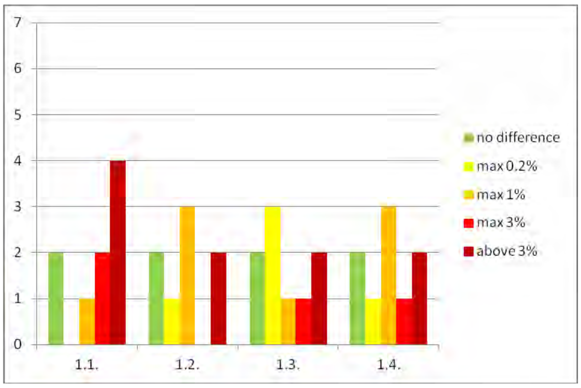

Figure 5-21: Cost effects (machinery invest) – Overall machine

Figure 5-22 depicts the market penetration of individual improvement options regarding the overall machine concept, according to the replies stated by the respondents (averaged values). It has to be noted, that the respondents had in mind their specific market segment, which leads to a broader variation in the stated market penetration. The replies depict the trend that options are increasingly applied in new machines, but that the level of implementation (not considering the aspect of feasibility) rarely exceeds 50%.

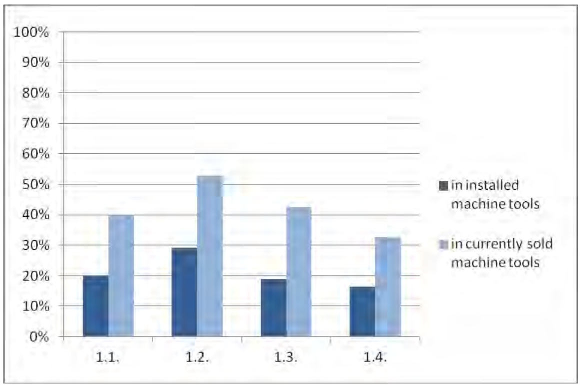

Figure 5-22: Market penetration – Overall machine

Measure	Cost effects (investment) Increase in total machinery invest (tendency)	Total machinery savings potential (tendency)	Market share	
			in installed machine tools	in currently sold machine tools
1.1 minimisation of moved masses	5%	1%	20%	40%
1.2 reduction of friction	1%	0,5%	29%	53%
1.3 optimization of the electrical design	1%	1%	19%	43%
1.4 design for instant machining without warm up	1%	1%	17%	33%

Table 5-1: Assessment of Measures - Overall Machine

The table above lists the values for the overall machine concept, which are used as approximations for calculations in Task 6.

Regarding the **drive units**, the survey unveils a rather small stated energy efficiency potential for most of the options: For almost all options most estimates are in the range 0%–0,5% of total energy savings, but also in this case frequently at least one respondent states a large potential above 5% energy savings for individual measures (Figure 5-23). The most promising options may be concluded as “inverter controlled motors for auxiliary units” (2.7) and “Use of torque motors” (2.3).

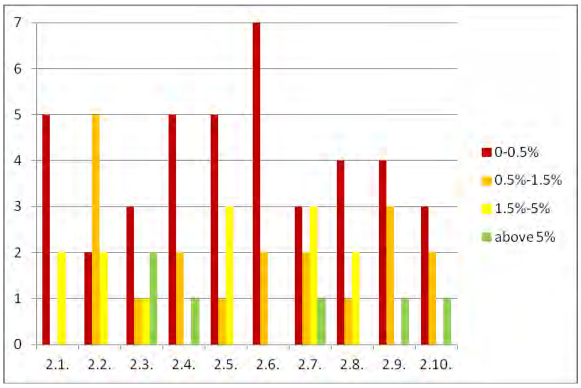

Figure 5-23: Total machinery energy savings potential – Drive units

Replies regarding the cost effects of optimised drive units again cover a broader range of estimates. However, several options are assessed with a rather low machinery cost increase, such as “regenerative feedback of Inverter system (servo motor/spindle)” (2.1). On the other hand, options with a larger energy savings potential are those which are assumed to be costly (such as 2.3 and 2.7), although this opinion is not shared by all respondents (Figure 5-24).

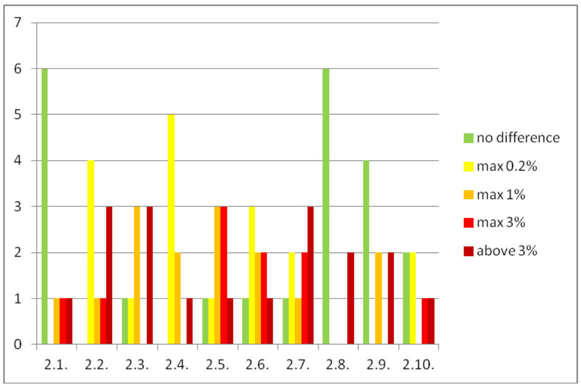

Figure 5-24: Cost effects (machinery investment) – Drive units

Figure 5-25 depicts the market penetration of individual improvement options regarding drive units, according to the replies stated by the respondents (averaged values). The replies depict the trend that the options are increasingly applied within new machines, and for some options the level of implementation (not considering the aspect of feasibility) exceeds 70%, whereas for other options a rather low market penetration is observed – in particular those with a moderate savings potential (2.3, 2.7).

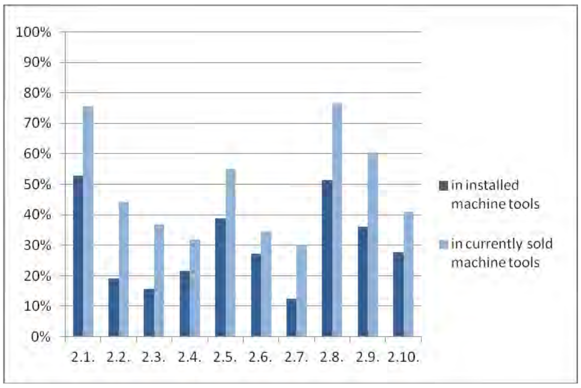

Figure 5-25: Market penetration – Drive units

The table below lists the values for the drive units which will be used as approximations for subsequent calculations in Task 6. For some of the options the range of replies is too broad to state a tendency – in this case “n.a.” (not applicable) is stated.

Measure	Cost effects (investment) Increase in total machinery invest (tendency)	Total machinery savings potential (tendency)	Market share	
			in installed machine tools	in currently sold machine tools
2.1 Regenerative feedback of Inverter system (servo motor/spindle)	0%	0,5%	53%	76%
2.2 Use of energy efficient motors for auxiliary units	3%	1%	19%	44%
2.3 Use of torque motors	1%	1%	16%	37%
2.4 High efficient gear unit	0,2%	0,5%	22%	32%
2.5 Mass free compensation of load for vertical axes	3%	1%	39%	55%
2.6 Use of break to control movement of axes	3%	0,5%	27%	34%
2.7 Inverter controlled motors for auxiliary units	5%	1%	12%	30%
2.8 400V inverter systems to substitute 200V systems	0%	1%	51%	76%
2.9 Spindle-design without belt and pulleys	n.a.	1%	36%	61%
2.10 Intelligent magnetic flux control	n.a.	0,5%	28%	41%

2.1 Regenerative feedback of Inverter system (servo motor/spindle)	0%	0,5%	53%	76%
2.2 Use of energy efficient motors for auxiliary units	3%	1%	19%	44%
2.3 Use of torque motors	1%	1%	16%	37%
2.4 High efficient gear unit	0,2%	0,5%	22%	32%
2.5 Mass free compensation of load for vertical axes	3%	1%	39%	55%
2.6 Use of break to control movement of axes	3%	0,5%	27%	34%
2.7 Inverter controlled motors for auxiliary units	5%	1%	12%	30%
2.8 400V inverter systems to substitute 200V systems	0%	1%	51%	76%
2.9 Spindle-design without belt and pulleys	n.a.	1%	36%	61%
2.10 Intelligent magnetic flux control	n.a.	0,5%	28%	41%

Table 5-2: Assessment of Measures - Drive units

Regarding the **hydraulic system** from the replies given, only “Speed controlled pumps” (3.2) and “Discontinuous operating pumps” (3.1) are likely to have a remarkable savings potential in the range of 1% of total machinery energy consumption (Figure 5-26). For several options there seem to be no relevant energy savings potential at all, namely “Fixed orifice blades to control the system pressure” (3.5), “Leakage monitoring” (3.6), and “Use of hydraulic system with optimized components” (3.7).

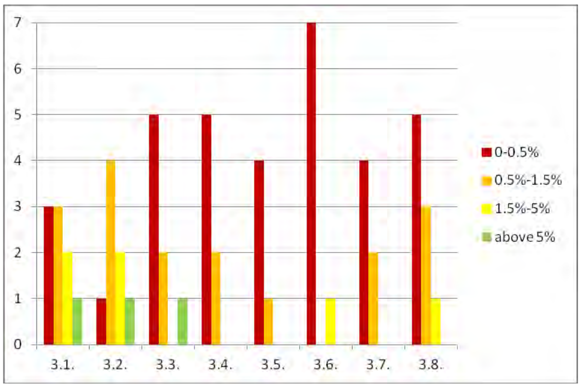

Figure 5-26: Total machinery energy savings potential – Hydraulic system

The options with significant energy savings potential (3.1, 3.2) are related to a cost increase below 1% by most respondents, although a full range of replies (including “above 3%”) is given, overall.

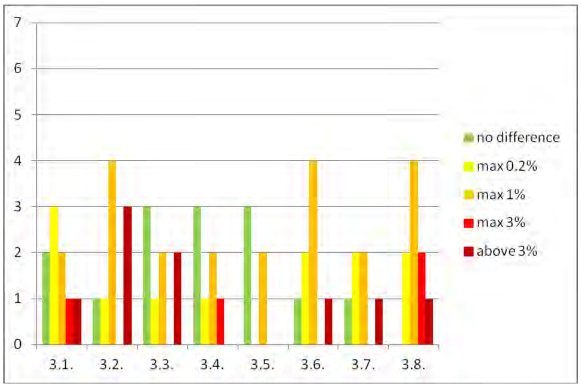

Figure 5-27: Cost effects (machinery invest) – Hydraulic system

Figure 5-28 depicts the market penetration of individual improvement options regarding hydraulic systems, according to the replies stated by the respondents (averaged values). The replies depict the trend that the options are increasingly applied in new machines, but that the level of implementation (not considering the aspect of feasibility) in all cases is below 40%.

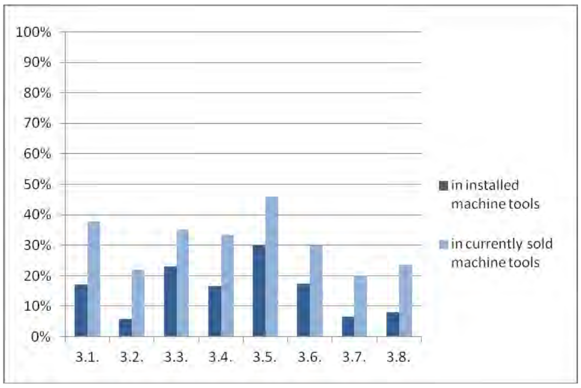

Figure 5-28: Market penetration – Hydraulic system

The table below lists the values for hydraulic systems which will be used as approximations for the subsequent calculations in Task 6. For some of the options the range of replies is too broad to state a tendency – in this case “n.a.” (not applicable) is stated.

Measure	**Cost effects (investment) Increase in total machinery invest (tendency)**	**Total machinery savings potential (tendency)**	**Market share**	
			in installed machine tools	in currently sold machine tools
3.1 Discontinouous operating pumps	1%	1%	17%	38%
3.2 Speed controlled pumps	1%	1%	6%	22%
3.3 Optimize hydraulic system design	n.a.	0,5%	23%	35%

3.4 Optimized piping	1%	0,5%	17%	33%
3.5 Fixed orifice blades to control the system pressure	1%	0,5%	30%	46%
3.6 Leakage monitoring	1%	0,5%	18%	30%
3.7 Use of hydraulic system with optimized components	n.a.	0,5%	7%	20%
3.8 Inverter controlled motors for auxiliary units	3%	0,5%	8%	23%

Table 5-3: Assessment of Measures - Hydraulic system

Regarding the **cooling lubrication system** the survey unveils a rather small energy efficiency potential stated for most of the options (Figure 5-29). The most relevant option is “Apply minimal quantity lubrication (MQL) when feasible “ (4.2), for which several respondents stated an energy savings potential above 5%. For all other options there were at least two statements per option stating that the energy savings potential was at maximum 0,5%, if at all, but also one to two statements per option, stating that the potential was in the range 1,5% – 5%.

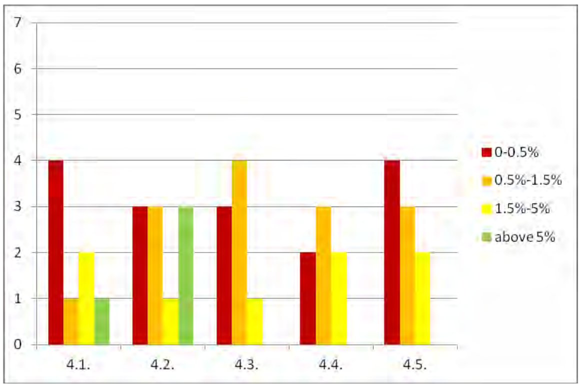

Figure 5-29: Total machinery energy savings potential – Cooling lubrication system

Replies regarding the cost effects of optimised cooling lubrication systems show that the one option with the highest savings potential is also the one which could have the highest potential effect on machinery costs (4.2). However, there were also some statements noting that MQL does not make a cost difference (Figure 5-30). For all other options, the replies cover the range between “no cost difference” and “maximum 3% cost increase”, unveiling again the fact that cost effects are also highly dependent on the application.

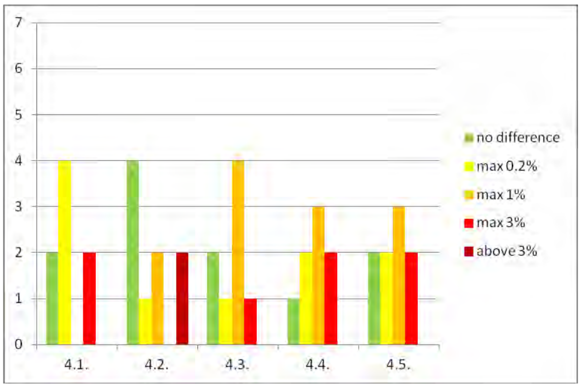

Figure 5-30: Cost effects (machinery investment) – Cooling lubrication system

Figure 5-31 depicts the market penetration of individual improvement options regarding cooling lubrication systems, according to the replies stated by the respondents (averaged values). The replies depict the trend that the options are increasingly applied in new machines, but that the level of implementation (not considering the aspect of feasibility) is below 50% for all options.

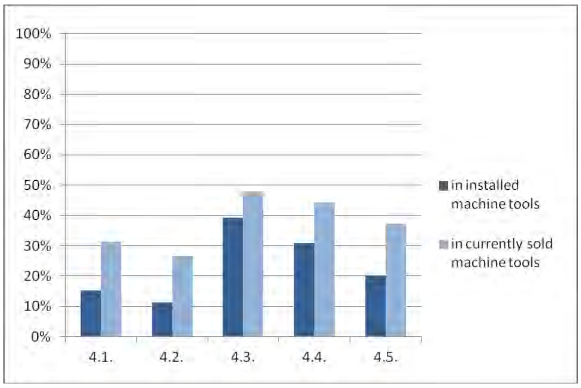

Figure 5-31: Market penetration – Cooling lubrication system

The table below lists the values for the drive units which will be used as approximations for calculations which follow on in Task 6. For some of the options the range of replies is too broad to state a tendency – in this case "n.a." (not applicable) is stated.

Measure	**Cost effects (investment) Increase in total machinery invest (tendency)**	**Total machinery savings potential (tendency)**	**Market share**	
			in installed machine tools	in currently sold machine tools
4.1 Discontinuous operating pumps	0,2 %	0,5%	15%	31%
4.2 Apply minimal quantity lubrication (MQL) when feasible	n.a.	0,5%	11%	27%
4.3 Adjustable pressure for cooling	1%	0,5%	39%	48%

lubrication				
4.4 Controlled flow rate	1%	1%	31%	44%
4.5 Inverter controlled motors for lubrication system	1%	0,5%	20%	37%

Table 5-4: Assessment of Measures - Cooling lubrication system

Regarding the **cooling system,** the survey indicates a relevant level of savings potential for “Thermal management regarding machine tool or its modules” (5.2), but estimates equally cover the full range of possible replies from 0%-0,5%, to above 5% (Figure 5-32). For the other options some estimates indicate savings potentials above 0,5%, although there are always a larger number of respondents being rather critical about achievable savings.

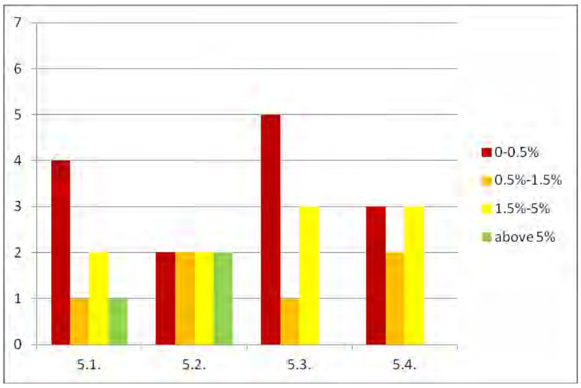

Figure 5-32: Total machinery energy savings potential – Cooling system

Replies regarding the cost effects of optimised cooling systems again cover a broader range of estimates. All options are shown with the possible cost effects in Figure 5-34.

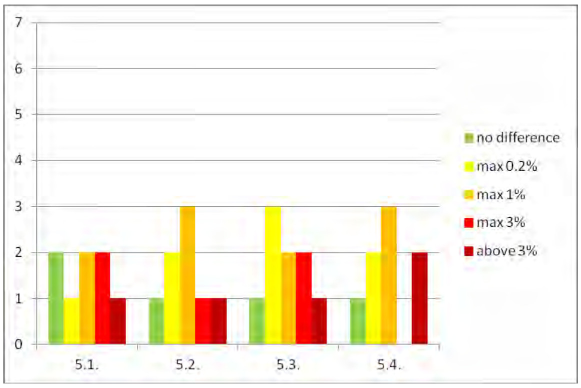

Figure 5-33: Cost effects (machinery investment) – Cooling system

Figure 5-34 depicts the market penetration of individual improvement options regarding the cooling system, according to the replies stated by the respondents (averaged values). The replies depict the trend that the options are increasingly applied in new machines, but that in all cases current market penetration is at maximum 30%.

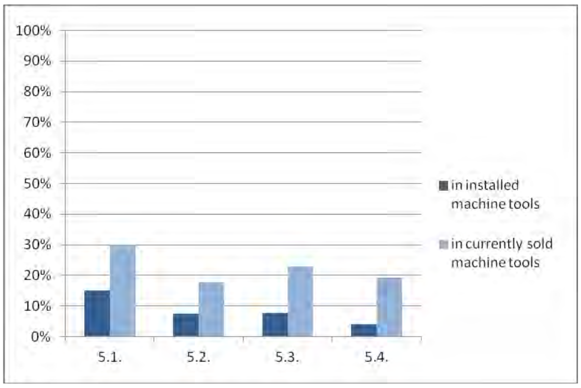

Figure 5-34: Market penetration – Cooling system

Table 5-5 lists the values for cooling systems which were meant to be used as approximations for calculations in Task 6. However, as the stated cost range was too broad to allow for a qualified assessment, no such calculations pertaining to cooling systems will be made in Task 6.

Measure	Cost effects (investment) Increase in total machinery invest (range)	Total machinery savings potential	Market share	
			in installed machine tools	in currently sold machine tools
5.1 Thermal management of all cooling devices	n.a.	0,5%	15%	30%
5.2 Thermal management regarding machine tool or its modules	n.a.	n.a.	7%	18%
5.3 Apply direct cooling of components depending on process	n.a.	0,5%	8%	23%
5.4 Apply efficient cooling system	n.a.	1%	4%	19%

Table 5-5: Assessment of Measures - Cooling system

Regarding **power electronics** from the replies given, it is evident that the energy savings potential by almost all respondents is estimated to be negligible (Figure 5-35).

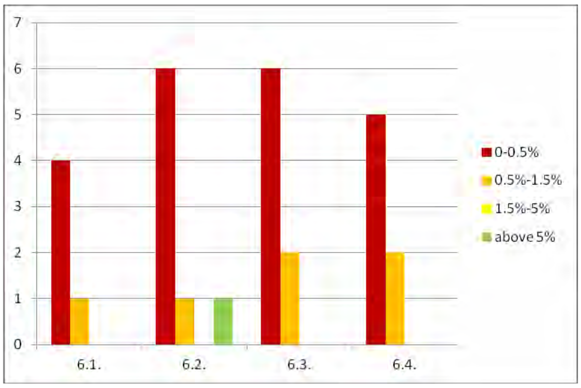

Figure 5-35: Total machinery energy savings potential – Power electronics

Minor savings potential, but at least no major cost difference is the conclusion which may be drawn from the statements given, with respect to the cost effects of improvement options, related to power electronics (Figure 5-36).

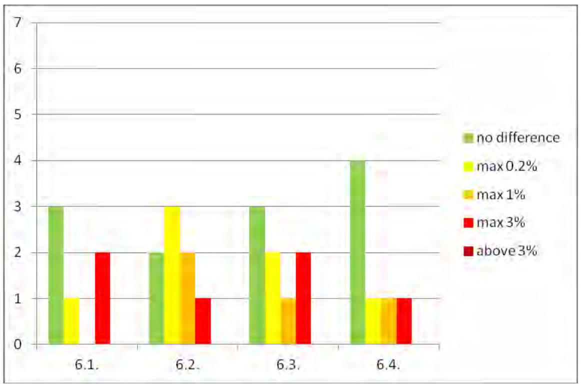

Figure 5-36: Cost effects (machinery invest) – Power electronics

Figure 5-37 depicts the market penetration of individual improvement options regarding power electronics according to the replies stated by the respondents (averaged values).

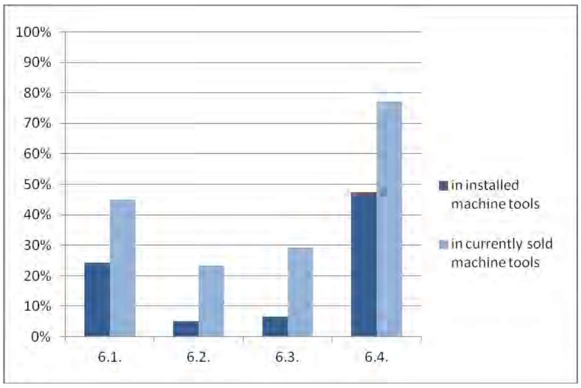

Figure 5-37: Market penetration – Power electronics

The table below lists the values for power electronics which will be used as approximations for calculations in Task 6.

Measure	Cost effects (investment) Increase in total machinery invest (tendency)	Total machinery savings potential (tendency)	Market share	
			in installed machine tools	in currently sold machine tools
6.1 Avoidance of transformers by use of voltage-proof converter	3%	0,5%	24%	45%
6.2 High efficiency transformer	1%	0,5%	5%	23%
6.3 Converter with power factor correction	1%	0,5%	6%	29%
6.4 Controlled switching power supply for auxiliary power 24V	0,2%	0,5%	48%	77%

Table 5-6: Assessment of Measures - Power electronics

Regarding the **machine concept,** from the replies given some tendencies are evident (Figure 5-38): Despite the fact that there was always at least one respondent stating an energy efficiency potential below 0,5% for some of the options, other respondents state a larger savings potential, namely for “Multi spindle-/ multi workpieces machining” (7.5), “Complete machining all sides” (7.6), and “Combination of various technologies (turning + milling + laser + grinding etc.)” (7.7). It should be noted that presumably the respondents, when stating the energy savings potential for these options, did not have in mind the absolute energy consumption, but were rather considering the savings per workpiece, i.e. related to output. For some other options there is also a stated significant savings potential (several estimates in the ranges above 0,5% savings potential): “Optimised compressed air system with minimal losses” (7.9), “Single master switch-off” (7.10), “Individual switched-off capability for specific modules” (7.11), “Intelligent shutdown procedures” (7.12), “Leak indicator, on demand monitoring” (7.13).

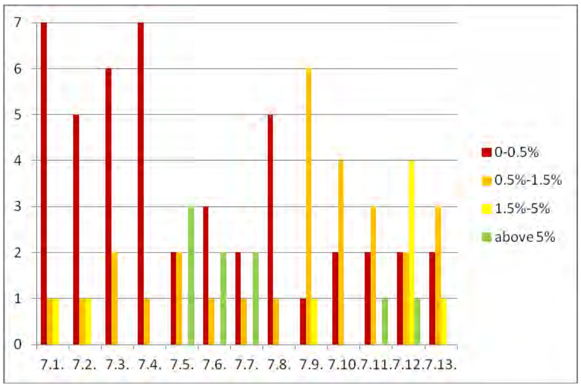

Figure 5-38: Total machinery energy savings potential – Machine concept

The options with the highest stated savings potentials are also those with the highest additional costs, which is logical, as the named concepts (7.5, 7.6, 7.7) require a radical change of the machine tool. In fact, these options actually result in a basically different machine (Figure 5-39). For the remaining options with a significant potential, a broad range of cost estimates is given: For options 7.9, 7.10, 7.12 each, at least two statements indicate no cost difference, as well as a maximum 3% cost difference; this again reveals that the implications of measures have to be judged individually for different machine tools (types).

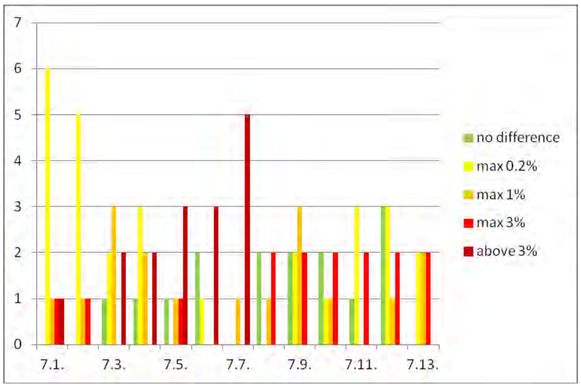

Figure 5-39: Cost effects (machinery investment) – Machine concept

Figure 5-40 depicts the market penetration of individual improvement options relating to the machine concept, according to the replies stated by the respondents (averaged values). The replies display a trend that the options are increasingly applied in new machines, and explicitly the trend towards even more complex machine tools is obvious (7.5, 7.6, 7.7). The level of implementation (not considering the aspect of feasibility) rarely exceeds 50%.

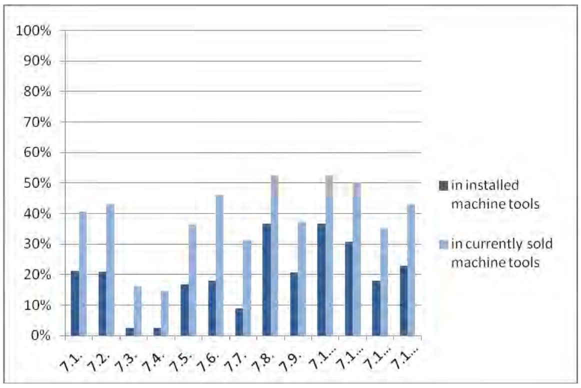

Figure 5-40: Market penetration – Machine concept

The table below lists the values for the overall machine concept, which will be used as approximations for calculations in Task 6. For some of the options, the range of replies is too broad to state a tendency – in this case “n.a.” (not applicable) is stated. For options 7.5, 7.6 and 7.7, a figure of >3% is stated and no fixed value; this is because these options actually signify a change of the whole machine technology.

Measure	Cost effects (investment) Increase in total machinery invest (tendency)	Total machinery savings potential (tendency)	Market share	
			in installed machine tools	in currently sold machine tools
7.1 Thermal management regarding control cabinet	1%	0,5%	21%	41%
7.2 Switching valves with low Watt technology / alternative control via use pulse width modulation (PWM)	1%	0,5%	21%	43%
7.3 Alternative work piece clamping	n.a.	0,5%	3%	16%
7.4 Alternative tool clamping	n.a.	0,5%	2%	14%
7.5 Multi spindle-/ multi workpieces machining	>3%	5%	17%	36%
7.6 Complete machining all sides	>3%	1%	18%	46%
7.7 Combination of various technologies (turning + milling + laser + grinding etc.)	>3%	5%	9%	31%
7.8 Dismantling ability of machine / reuse of materials	3%	0,5%	37%	53%
7.9 Optimised compressed air system with minimal losses	3%	1%	21%	38%
7.10 Single master switch-off	1%	1%	37%	53%
7.11 Individual switched-off capability for specific modules	3%	1%	31%	50%
7.12 Intelligent shut-down procedures	3%	3%	18%	35%
7.13 Leak indicator, on demand monitoring	3%	1%	23%	43%

Table 5-7: Assessment of Measures - Machine concept

Regarding **peripheral devices,** there is only one option stated in ISO 14955 (Figure 5-41), which is a very generic one: “Controlled peripheral devices like mist extraction, chip conveyer, etc” (8.1)

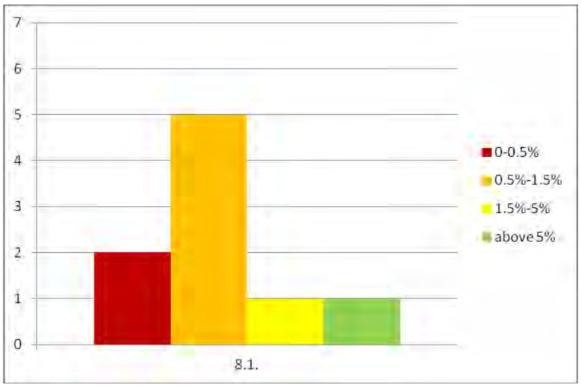

Figure 5-41: Total machinery energy savings potential – Peripheral device

For this option, a relevant energy savings potential is stated, and a rather low cost effect, although also in this case it should be noted that there are deviating replies (Figure 5-42).

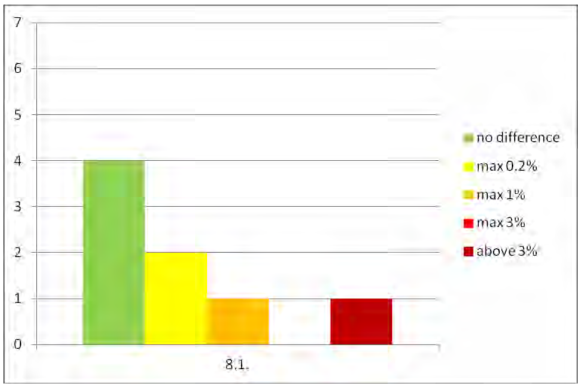

Figure 5-42: Cost effects (machinery investment) – Peripheral device

Figure 5-41 depicts the market penetration for this option according to the replies stated by the respondents (averaged values). Market penetration is on a rather low level.

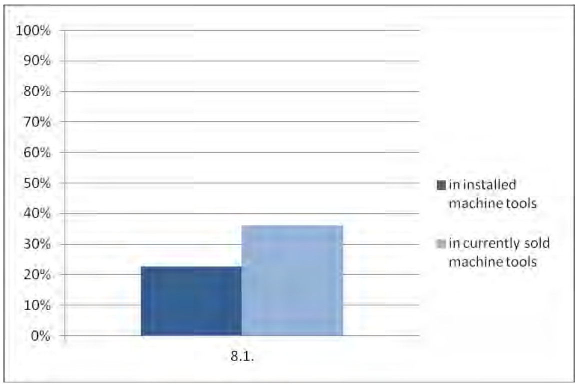

Figure 5-43: Market penetration – Peripheral device

The table below lists the values for peripheral devices, which will be used as approximations for calculations in Task 6.

Measure	**Cost effects (investment) Increase in total machinery invest (tendency)**	**Total machinery savings potential (tendency)**	**Market share**	
			in installed machine tools	in currently sold machine tools
8.1 Controlled peripheral devices like mist	0,2%	1%	23%	36%

extraction, chip conveyer, etc

Table 5-8: Assessment of Measures - Peripheral device

Simulation is a distinct option in ISO 14955. Assessment of this option by the respondents is depicted below regarding energy savings potential (Figure 5-44), cost effects (Figure 5-45), and market penetration (Figure 5-46).

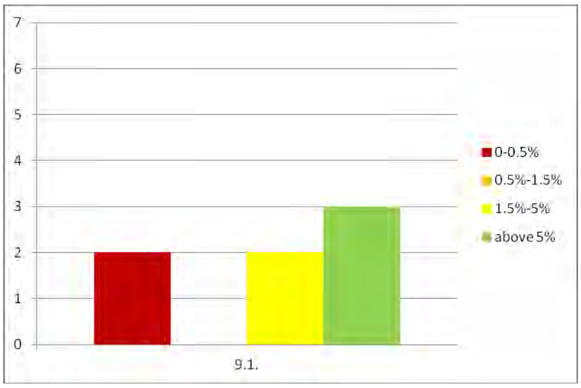

Figure 5-44: Total machinery energy savings potential – Simulation

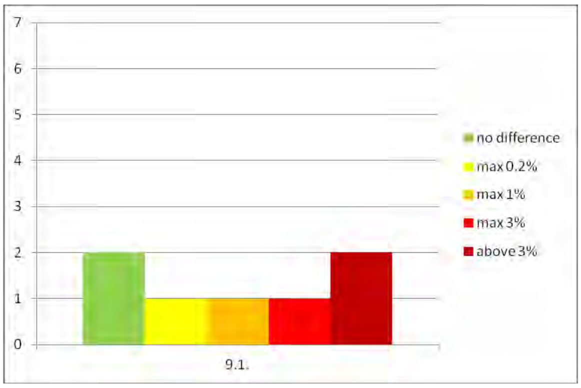

Figure 5-45: Cost effects (machinery invest) – Simulation

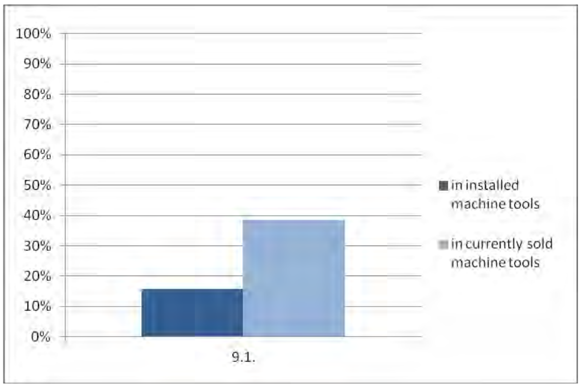

Figure 5-46: Market penetration – Simulation

Measure	Cost effects (investment) Increase in total machinery invest (tendency)	Total machinery savings potential (tendency)	Market share	
			in installed machine tools	in currently sold machine tools
9.1 Optimisation of work piece processing by simulation off-machine ; avoidance of inefficient operating time	n.a	5%	16%	39%

Table 5-9: Assessment of Measures - Simulation

Regarding the **control unit,** the survey (Figure 5-47) reveals a rather small energy efficiency potential stated for “Screen saver for operating terminal and work space lighting to be switched-off, when not in use” (10.2), a moderate savings potential for “Default setting for operating condition (costumer specific unit switch-off)” (10.1), as stated by several of the respondents, and a very significant potential for “Minimise non-productive time” (10.3).

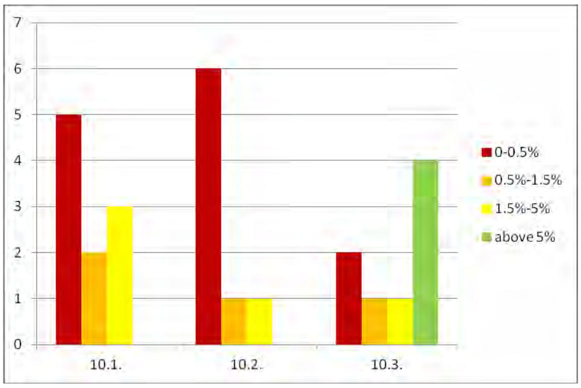

Figure 5-47: Total machinery energy savings potential – Control

The latter (10.3) is assumed by the respondents to be realised with no cost change. This is presumably based on the assumption that this measure could be realised through organisational improvements, rather than by dedicated technical means. Also for the other two options a majority of the respondents anticipates no cost difference (Figure 5-48).

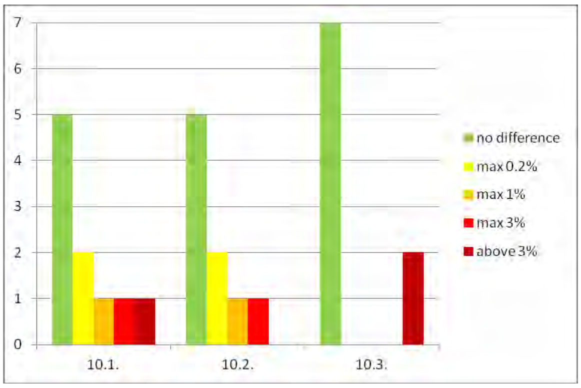

Figure 5-48: Cost effects (machinery investment) – Control

Figure 5-49 depicts the market penetration of individual improvement options regarding control, according to the replies stated by the respondents (averaged values). The replies depict the trend that the options are increasingly applied in new machines, but that uptake does not exceed 50% until now. However, it should be noted that for a very generic option, such as “minimise non-productive time”, a sound market penetration rate is difficult to define.

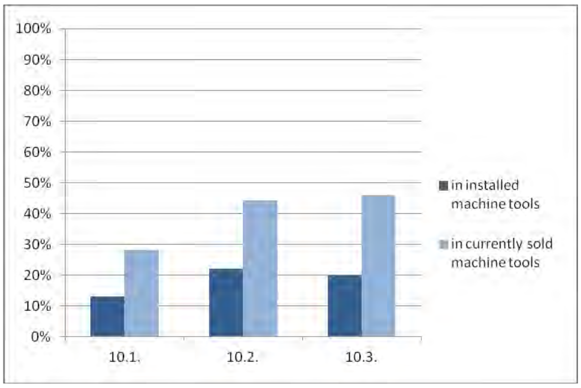

Figure 5-49: Market penetration – Control

The table below lists the values for control which will be used as approximations for calculations in task 6.

Measure	**Cost effects (investment) Increase in total machinery invest (tendency)**	**Total machinery savings potential (tendency)**	**Market share**	
			in installed machine tools	in currently sold machine tools
10.1 Default setting for operating condition	0%	1%	13%	28%

(costumer specific unit switch-off)				
10.2 Screen saver for operating terminal and work space lighting to be switched-off, when not in use	0,2%	0,5%	22%	44%
10.3 Minimise non-productive time	0%	5%	20%	46%

Table 5-10: Assessment of Measures - Control

5.1.13.1.2 Cutting - 2012 Update

The above evaluation is based on feedback received from CECIMO in mid-2011. In April 2012 CECIMO provided an update for cutting machine tools, based on data received from another 12 respondents in this segment. The updated data on total machinery energy saving potentials (Figure 5-50) and potential change in machinery investment (Figure 5-51) are depicted below. Compared to the initial 2011 replies, the updated figures show, for many measures, a more pessimistic assessment regarding potential savings, although overall trends remain the same. Therefore the later analysis in Task 6 is still based on the initial 2011 data.

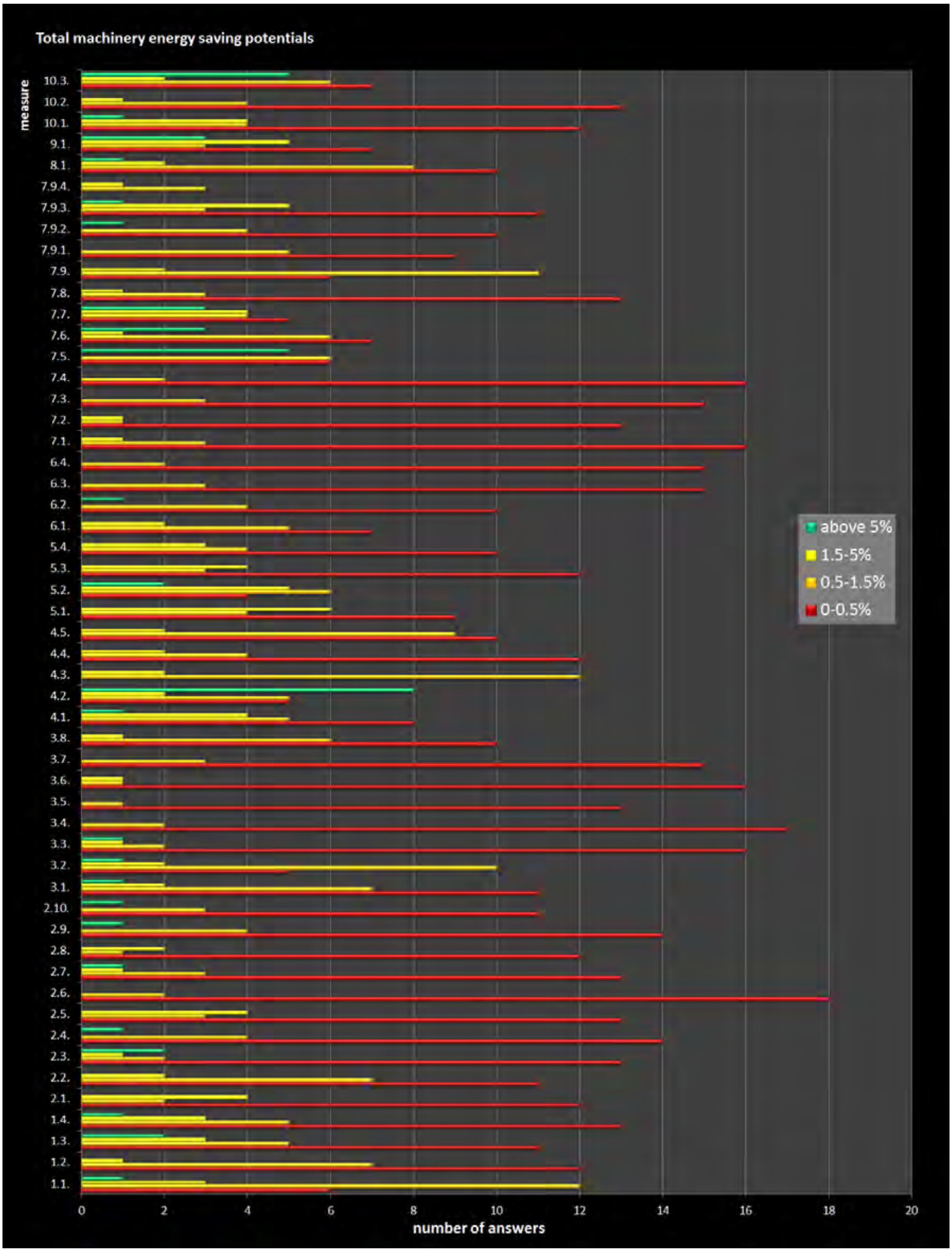

Figure 5-50: Total machinery energy saving potentials – 2012 Update

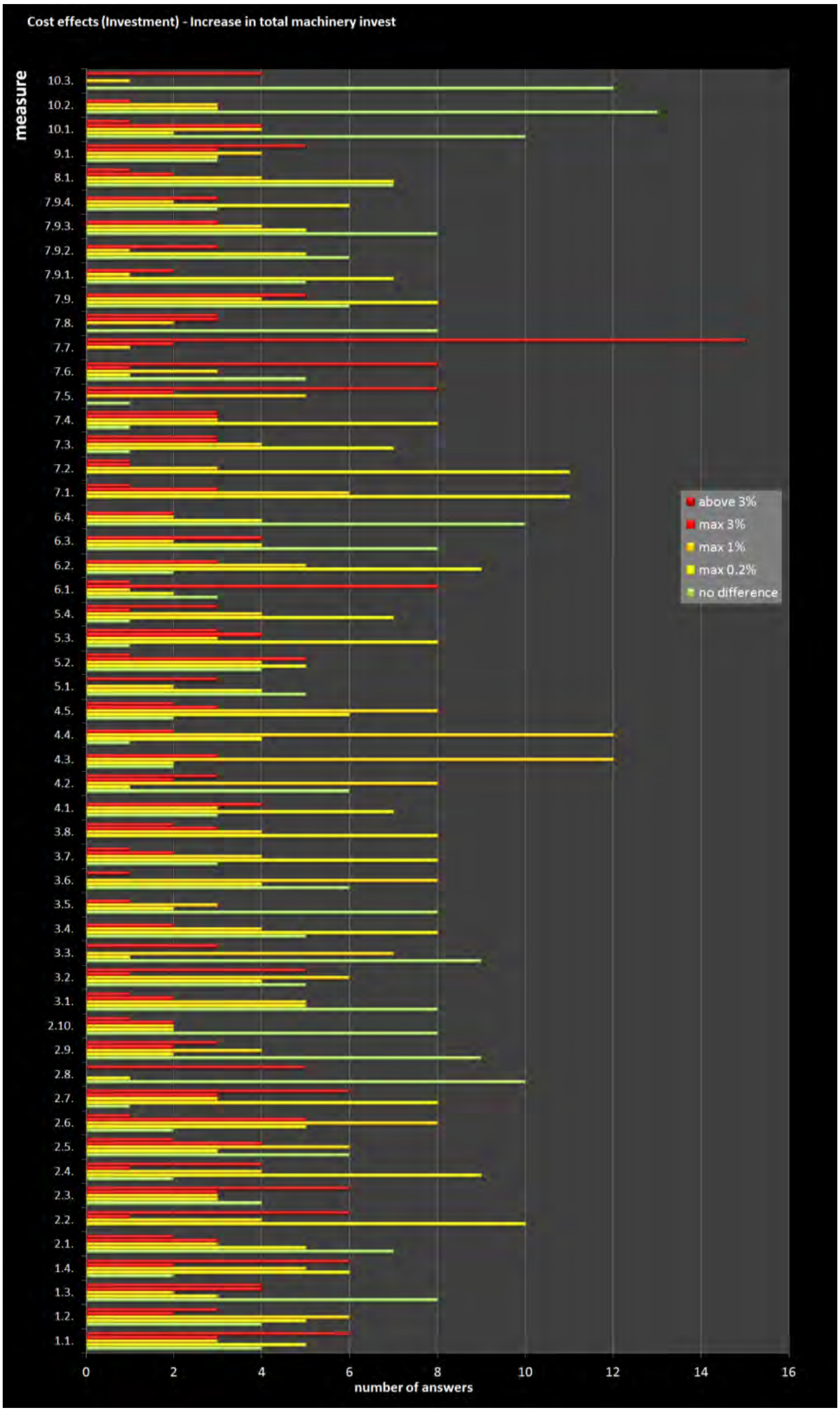

Figure 5-51: Increase in total machinery invest – 2012 Update

5.1.13.1.3 Hydraulic & servo presses

For metal working presses CECIMO received 3 replies to the survey from machinery manufacturers, one for servo presses/ mechanical presses, and two for hydraulic presses.

The tables below list the measures for these types of machine tools according to ISO 14955 (draft, tables B1, B2) and state the estimates given regarding cost effects, total machinery energy savings and market share. Figures stated for servo presses / mechanical presses are those from the one respondent[178]; figures stated for hydraulic presses are meant to be tendencies based on the two respondents.

The minimization of moved masses (1.1) for both hydraulic and servo presses, but more relevant for the latter, unveils a high improvement potential, which comes - according to the respondents - at no additional cost. For servo presses, the market penetration of this approach is stated to be in the range of 50%, for servo presses currently sold. A high savings potential is also stated for highly efficiency cushions (1.5), but at significant additional costs (Table 5-12).

ISO 14955 table B1	ISO 14955 table B2	Measure	Cost effects (investment) Increase in total machinery invest (tendency)		Total machinery savings potential (tendency)		Market share hydraulic presses		Market share servo presses	
			Estimate hydraulic	Estimate servo	Estimate hydraulic	Estimate servo	in installed machine tools	in currently sold machine tools	in installed machine tools	in currently sold machine tools
1.1	1.1	Minimisation of moved masses	0%	0%	1%	5%	80%	95%	20%	50%
1.2	1.2	Reduction of friction	0,2%	0,2%	0,5%	1%	95%	95%	95%	95%
1.3	1.3	Optimization of the overall machine design	0%	0%	0,5%	3%	70%	90%	50%	90%
1.4	1.4	Counterbalance system for vertical axes	5%	1%	3%	1%	40%	60%	95%	90%
1.5	1.5	High efficiency cushions	5%	1%	3%	5%	<1 %	0%	0%	100 %

[178] Note, that the questionnaire defined ranges for costs and energy savings, which are now approximated in the tables with distinct values

1.6		High efficient decompression	3%		0,5%		0%	0%		
1.7		Use regenerative circuit for differential cylinders	1%		0,5%		20%	50%		
1.8	1.6	Die clamping	1%	1%	0,5%	0,5%	50%	90%	50%	90%

Table 5-12: Assessment of Measures - Overall machine

Among the measures addressing the drive units (Table 5-13) there are several options with a stated high efficiency potential, such as the use of multi-pressure accumulator systems for the main axis (2.6), or a directly-coupled energy storing drive system for the main axis (2.7) in hydraulic presses, both still with a very low market penetration , but with a major impact on machinery costs. Similarly, for servo presses, the use of direct drive systems (2.7) is stated to have a high energy saving potential, but again at higher costs. The optimization of the dynamic parameters (2.2) of servo presses involves a high energy savings potential without any (major) cost difference. Inverter controlled motors for auxiliary units (2.9) in servo presses are stated to be of high energy saving potential and minor additional costs. Some other options also come with promising energy savings potential at low to moderate additional costs, which is particularly relevant as the drive unit, as such, in presses is the most energy consuming module.

ISO 14955 table B1	**ISO 14955 table B2**	**Measure**	**Cost effects (investment) Increase in total machinery invest (tendency)**		**Total machinery savings potential (tendency)**		**Market share hydraulic presses**		**Market share servo presses**	
			Estimate hydraulic	Estimate servo	Estimate hydraulic	Estimate servo	in installed machine tools	in currently sold machine tools	in installed machine tools	in currently sold machine tools
2.1	2.1	Regenerative feedback of inverter system (e.g. servo motor, AFE-technology)	3%	1%	0,5%	5%	0%	0%	40%	100 %
2.2	2.2	Optimisation of the dynamic parameters	1%	0%	0,5%	5%			0%	0%
	2.3	Minimisation of spare capacity/customer specific layout of motors		0%		1%			40%	100 %
	2.4	Minimisation of spare capacity/customer specific layout of inverter system		0%		1%			90%	100 %

2.5		Provide most efficient drive system	3%		3%		50%	85%		
	2.5	Optimized axis servo motors		0%		1%				
2.6		Use of multi-pressure accumulator system for main axis	5%		5%		5%	3%		
	2.6	Use of energy efficient motors for auxiliary units		0,2%		1%			50%	90%
	2.7	Use of direct drive systems		5%		5%			1%	50%
2.8		Direct coupled energy storing drive systems for main drives	5%		5%		0%	8%		
	2.8	High efficient gear unit								
	2.9	Inverter controlled motors for auxil-iary units		0,2%		3%			0%	20%
2.9	2.10	Indirect coupled energy storing drive systems for main drives	5%	0,2%	5%	0,5%	0%	0%	5%	90%
2.3	2.11	Optimisation of installed motor power	1%	0%	0,5%	3%	43%	55%	50%	90%
2.4	2.12	Use of energy efficient motors	0,2%	1%	1%	3%	25%	55%	0%	100 %
	2.13	Use of energy efficient pumps		0,2%		1%			5%	50%
2.10	2.14	Intelligent drive management	3%		3%	5%	0%	5%	0%	30%
2.7	2.15	Use of energy efficient pump-motor units	1%	0,2%	0,5%	1%	55%	90%	0%	0%

Table 5-13: Assessment of Measures - Drive units

For the hydraulic system, the ISO 14955 (draft) lists numerous improvement options. The assessment by the machinery manufacturers indicates a small improvement potential for many of the options (Table 5-14). All options assessed with a higher energy savings potential (3 or 5%) are related to significant cost increases. Some measures according to the respondent can be implemented without additional costs on hydraulic presses. These measures comprise:

- Choice of pump systems which match the requirement profile (3.1.1)
- Selecting the correct size pump to avoid over-dimensioning, and operation of the pump in the optimal efficiency range (3.1.3)
- On/Off or stand-by mode, giving due consideration to safety criteria (3.2.5)
- Avoidance of internal leakage (3.3.2)
- Use of energy-efficient pulse valves (3.4.1)

Several options are related to minor cost increases, of up to 0.2 % of the total machinery investment.

ISO 14955 table B1/B2	Measure	Cost effects (investment) Increase in total machinery invest (tendency)		Total machinery savings potential		Market share hydraulic presses		Market share servo presses	
		Estimate hydraulic	Estimate servo	Estimate hydraulic	Estimate servo	in installed ma-	in currently sold	in installed ma-	in currently sold
3.1	Selection of the optimal drive subsystem (motor-pimp system)	5%	0,2%	5%	0,5%	40%	45%	20%	90%
3.1.1	Choice of the pump systems which match the requirement profile	0%	0,2%	1%	1%	95%	95%	20%	80%
3.1.2	Power on demand	5%	0,2%	3%	1%	10%	30%	20%	80%
3.1.3	Selecting the correct size pump to avoid over-dimensioning, and operate the pump in the optimal efficiency range	0%	0%	1%	1%	95%	95%	50%	100 %
3.1.4	Temporary storage of hydraulic energy	1%	0%	1%	0,5%	100 %	100 %	50%	100 %
3.2	Match the pressure level to the load cycle and to the different actuators on the machine	0,2%	0%	1%	0,5%	60%	80%	80%	100 %
3.2.1	Pressure adjustment using adjustable pressure relief valves or zero-pressure circulation	0,2%	0,2%	0,5%	1%	100 %	100 %	50%	100 %
3.2.2	Usage of actuators which are designed to operate at the same pressure level (no pressure reduction losses)	3%	0%	0,5%	0,5%	70%	70%	80%	100 %
3.2.3	Pressure adjustment using pressure-controlled drive systems	5%		5%		38%	53%		
3.2.4	Use of pressure intensifiers for individual actuators which require higher pressure	0,2%	0,2%	0,5%	0,5%	20%	20%	20%	100 %
3.2.5	On/Off or stand-by mode, giving due consideration to safety criteria	0%		0,5%		100 %	100 %		
3.3	Reduce hydraulic losses	3%	0%	1%	0,5%	40%	60%	80%	100 %
3.3.1	Displacement control systems	3%	0,2%	3%	0,5%	45%	65%	30%	80%
3.3.2	Avoid internal leakage	0%	0%	0,5%	0,5%	70%	70%	40%	80%
3.3.3	Optimize the design of the hydraulic lines and reduce hydraulic resistance	1%	0,2%	0,5%	0,5%	70%	90%	80%	100 %
3.3.4	Distributed supply strategies		0,2%		0,5%			80%	100 %
3.4	Reduce power consumption on solenoid operated valves	0,2%	0%	0,5%	0,5%	0%	10%	90%	100 %
3.4.1	Energy efficient pulse valves	0%	0%	0,5%	0,5%	0%	10%	0%	0%

3.4.2	Energy efficient valve connectors	0,2%	0,2%	0,5%	0,5%	0%	0%	0%	0%
3.4.3	Use of low Watt solenoids	0,2%	0%	0,5%	0,5%	0%	0%	80%	100 %
3.5	Leakage monitoring	1%	0,2%	1%	0,5%	0%	10%	0%	0%
3.6	Low flow resistance	3%	0,2%	0,5%	0,5%	80%	100 %	90%	90%
3.7	High-efficiency auxiliary pressure generation	1%	0,2%	1%	0,5%	100 %	100 %	20%	80%
3.8	Warm-up cycle	1%	0,2%	0,5%	0,5%	35%	60%	40%	80%
3.9	Oil temperature	0,2%	0,2%	0,5%	0,5%	98%	100 %	100 %	100 %
3.10	Oil cooling	0,2%	0%	0,5%	0,5%	95%	100 %	50%	90%
3.11	ISO 4413 shall be applied		0%		0,5%			100 %	100 %

Table 5-14: Assessment of Measures - Hydraulic Systems

Only few options are stated for the lubrication system – and savings potentials are minor (Table 5-15).

ISO 14955 table	**Measure**	**Cost effects (investment) Increase in total machinery invest (tendency)**		**Total machinery savings potential (tendency)**		**Market share hydraulic presses**		**Market share servo presses**	
		Estimate hydraulic	Estimate servo	Estimate hydraulic	Estimate servo	in installed machine tools	in currently sold machine tools	in installed machine tools	in currently sold machine tools
4.1	Lubrication flow depending on demand	0,2%	0,2%	0,5%	0,5%	10%	60%	30%	50%
4.2	Low flow rate for lubrication pump	0%	0%	0,5%	0,5%	90%	90%	50%	70%

Table 5-15: Assessment of Measures - Lubrication system

The survey unveils a moderate total energy savings potential for die cooling, and the lubrication system in servo presses, in particular: All options listed in ISO 14955 are attributed with a small energy savings potential, but also with no or minor cost increases. For hydraulic presses, fewer options are stated and these tend to be more costly (Table 5-16).

ISO 14955 table B1/B2	Measure	Cost effects (investment) Increase in total machinery invest (tendency)		Total machinery savings potential (tendency)		Market share hydraulic presses		Market share servo presses	
		Estimate hydraulic	Estimate servo	Estimate hydraulic	Estimate servo	in installed machine tools	in currently sold machine tools	in installed machine tools	in currently sold machine tools
5.1	Thermal management of all cooling devices including cooling device for machine tool and/or its modules	1%	0,2%	0,5%	0,5%	100 %	100 %	30%	80%
5.1.1	Avoid losses								
5.1.2	Losses to be dissipated by air or water cooling	1%	0,2%	0,5%	0,5%	80%	80%	50%	80%
5.1.3	Optimized ventilation		0,2%		0,5%			0%	0%
5.2	Apply direct cooling of components depending on process	0%	0%		0,5%	100 %	100 %	0%	0%
5.3	Apply demand depending cooling	0,2%	0%	1%	0,5%	100 %	100 %	0%	0%

Table 5-16: Assessment of Measures - Die cooling/lubrication system

Power electronics show a moderate total energy savings potential, but as a very high market penetration is already stated for these approaches, there is a very limited potential for further improvements, according to the respondents (Table 5-17).

ISO 14955 table B1/B2	Measure	Cost effects (investment) Increase in total machinery invest (tendency)		Total machinery savings potential (tendency)		Market share hydraulic presses		Market share servo presses	
		Estimate hydraulic	Estimate servo	Estimate hydraulic	Estimate servo	in installed machine tools	in currently sold machine tools	in installed machine tools	in currently sold machine tools
6.1	Avoidance energy losses of power supplies	0,2%	0,2%	0,5%	0,5%	45%	100 %	40%	95%
6.2	High efficiency transformer	0,2%	0,2%	0,5%	0,5%	60%	100 %	60%	95%
6.3	Apply the simultaneity factor when designing the power system	0%	0%	0,5%	0,5%	60%	90%	60%	95%
6.4	Converter/inverter with power factor correction	3%		0,5%		10%	100 %		
6.5	Thermal management regarding control cabinet	3%	3%	0,5%	0,5%	0%	0%	20%	70%

Table 5-17: Assessment of Measures - Power electronics

The pneumatic system is related with significant energy savings potential in both hydraulic and servo presses, but again, it is rather the multitude of individual options, rather than any single option which has an outstanding potential (Table 5-18).

ISO 14955 table B1/B2	Measure	Cost effects (investment) Increase in total machinery invest (tendency)		Total machinery savings potential (tendency)		Market share hydraulic presses		Market share servo presses	
		Estimate hydraulic	Estimate servo	Estimate hydraulic	Estimate servo	in installed ma-	in currently sold	in installed ma-	in currently sold
7.1	Switching valves with low Watt technology, pulse width modulation (PWM), valves with detent (where permissible)	0,2%	0,2%	0,5%	0,5%	0%	20%	40%	80%
7.2	Optimised compressed air system with minimal losses								
7.2.1	Reduction of dead volume (Vcut)	0,2%	0,2%	0,5%	0,5%	40%	80%	40%	80%
7.2.2	Directed switch off of not needed branches	0%	0%	0,5%	0,5%	90%	90%	0%	0%
7.2.3	Dimensioning of tubes and pipes	1%	1%	0,5%	0,5%	90%	90%	90%	90%
7.2.4	Correct layout of pneumatic drives	0,2%	0,2%	0,5%	0,5%	80%	80%	80%	80%
7.2.5	Reduction of pressure	0,2%	0,2%	0,5%	0,5%	70%	70%	70%	70%
7.2.6	Influence of leakage	1%	1%	1%	1%	0%	0%	0%	0%
7.2.7	Optimise cylinder force for the required function	0,2%	0,2%	1%	1%	90%	90%	90%	90%
7.2.8	ISO 4414 shall be applied		0%		0,5%			100 %	100 %

Table 5-18: Assessment of Measures - Pneumatic system

For peripheral devices the energy savings potential is stated to be minor (Table 5-18).

ISO 14955 table B1/B2	Measure	Cost effects (investment) Increase in total machinery invest (range)		Total machinery savings potential		Market share hydraulic presses		Market share servo presses	
		Estimate hydraulic	Estimate servo	Estimate hydraulic	Estimate servo	in installed machine tools	in currently sold machine tools	in installed machine tools	in currently sold machine tools
8.1	Controlled peripheral devices like mist extraction, scrap conveyer, etc	0%	0%	0,5%	0,5%	90%	90%	90%	90%

Table 5-11: Assessment of Measures - Peripheral device

Measures listed under simulation in ISO 14955 (draft), which actually involve aspects of general process information, are related to significant energy saving potentials, according to the respondents: The provision of customer information to reduce consumption of resources (9.3) is linked to an effect on energy consumption. Most options, according to the respondents, are already implemented in currently-sold machine tools (Table 5-18).

ISO 14955 table B1/B2	Measure	Cost effects (investment) Increase in total machinery invest (tendency)		Total machinery savings potential (tendency)		Market share hydraulic presses		Market share servo presses	
		Estimate hydraulic	Estimate servo	Estimate hydraulic	Estimate servo	in installed machine tools	in currently sold machine tools	in installed machine tools	in currently sold machine tools
9.1	Optimisation of work piece processing by die try-out	0%	0%	0,5%	0,5%	30%	60%	30%	60%
9.2	Provisions to reduce scrap production	1%	0,2%	0,5%	0,5%	20%	80%	30%	90%
9.3	Provide customer information to reduce consumption of resources	0%	0%	1%	1%	20%	20%	20%	50%

9.3.1	Information to user on energy efficient use of the machine e.g. on/off programming of auxiliary devices (user's manual, instruction)	0,2%	0,2%	3%	1%	10%	70%	10%	50%
9.3.2	Information to user on optimized movements of axis		0,2%		1%			0%	0%
9.3.3	Information to user on usable energy		0%		0,5%			10%	80%
9.4	Minimize non-productive time	1%	0,2%	0,5%	0,5%	50%	80%	50%	90%
9.5	Optimize productivity by reducing cycle time per part	1%	0,2%	1%	3%	60%	90%	50%	90%

Table 5-12: Assessment of Measures – Simulation

With regard to machinery control, significant energy savings are stated for the three listed options, although for the energy-optimized default setting for operating condition (10.1), no statement regarding its energy saving potential was made by the respondents.

ISO 14955 table B1/B2	**Measure**	**Cost effects (investment) Increase in total machinery invest (range)**		**Total machinery savings potential**		**Market share hydraulic presses**		**Market share servo presses**	
		Estimate hydraulic	Estimate servo	Estimate hydraulic	Estimate servo	in installed machine tools	in currently sold machine tools	in installed machine tools	in currently sold machine tools
10.1	Energy optimized default setting for operating condition - energy level - (customer specific drive management)	0,2%	0,2%		1%	40%	70%	40%	90%
10.2	Automatic operating state switching	0,2%	0,2%	0,5%	0,5%	0%	<1%	0%	0%
10.3	Recording of current energy consumption together with energy relevant production data	0,2%	0,2%	0,5%	1%	0%	0%	0%	50%

Table 5-13: Assessment of Measures – Control

5.1.13.1.4 Module manufacturer / provider perspective

Whereas the above analysis is based on feedback from machinery manufacturers, providers of sub-systems / modules also provided input to the survey. These respondents are affiliated to:

- Bosch Rexroth AG
- CETOP (Comité Européen des Transmissions Oléohydrauliques et Pneumatiques / European Fluid Power Committee)
- REDEX SA

Assessments given by these stakeholders are summarised in the table below, again transferring the ranges stated to distinct values, understood to be tendencies, not exact savings and costs.

Measure	Cost effects (investment) Increase in total machinery invest (tendency)	Total machinery savings potential (tendency)	Comments by stakeholders
Software-based Energy Management incl. Stand-By Mode			
2.1 Energy monitoring	0%	3%	Software based solutions have no additional cost effect. Optional solutions with additional hardware
2.2 Machine stand-by management	0%	5%	Software based solutions have no additional cost effect
2.3 Energy-optimized motion control	0%	1%	Current solutions are motivated by cycle time optimization. These solutions also have impact on energy efficiency
2.4 other: Plant based energy management	0%	5%	Standardised communication profiles allow energy management over several machines by using the existing production network infrastructure.
Energy Recuperation of Drives, Power Electronics, and Super Premium Efficiency Motors			
3.1 Application specific design of drives	0%	1%	
3.2 Speed control	1%	3%	This topic varies broadly between different types of drives. Servo Drives are 100% speed controlled. Auxiliary devices with speed control are very limited in market penetration
3.3 Direct drive instead of ball screw drives			This depends on the specific case in every different machine

3.4 Brake energy feedback	3%	3%	Typical high end machines made in Europe have nearly 100% market penetration for servo drives. Low and medium range machines from Asia usually have no feedback
3.5 Reducing maximal acceleration	0%	0,5%	Has no energy saving effect, because the cycle time will rise. Therefore more energy will be consumed
3.10 Wattless current compensation	0,2%	0,5%	
3.11 Latest generation IGBTs	0,2%	1%	
3.12 Super premium efficiency motors	1%	1%	
3.13 other: use of high quality gears sets qualtity	1%	1%	(REDEX SA)
5.25 other: use of low friction seals	1%	0,5%	(REDEX SA)
6.8 other: Lubrication optimized	3%	3%	(REDEX SA)
Hydraulic and Pneumatic Optimized Systems			
5.1 Optimized cooling of the motor	0%	0,5%	
5.2 Adaptable levels of pressure	0,2%	3%	
5.3 Pressure adjustments for different actuators	1%	3%	Depending on application
5.4 Use of hydraulic accumulators	0,2%	3%	
5.5 Substitution of technologies	1%	3%	
5.6 Reducing inner leakages losses	0,2%	0,5%	
5.7 Use of optimized valves	0,2%	0,5%	
5.8 Use of hydraulic clamping tools	0%	3%	
5.9 Extending the field of application of hydraulics	0%	5%	e.g. hydraulic boosted cooling lubricant supply
5.10 Prevention of nipple collapse	0,2%	0,5%	
5.11 Application specific compressed air quality	0%	0,5%	The evaluation is related to the proposed change in our comments
5.12 Reducing channels of supply / dead volume	0,2%	0,5%	
5.13 Minimizing losses due to leakages (pneumatics)	0,2%	0,5%	
5.14 Pneumatic Cylinder with optimized drive surface	0,2%	0,5%	
5.15 Pneumatic Cylinder with multiple chambers	0,2%	0,5%	Only applicable for specific applications
5.16 Single acting pneumatic cylinder	0%	0,5%	
5.17 Targeted cut-off from air supply	0%	0,5%	
5.18 Use of multiple valves	0,2%	0,5%	
5.19 Pressure reduction	0%	1%	See comment on Task 5 report, 5.1.6.3: pressure reduction (system)
5.20 Using exhaust air	1%	0,5%	If improvements are possible is not proved today
5.21 Optimized valve switching	0%	0,5%	

5.23 Sensor based monitoring of pneumatic systems	0,2%	0,5%
5.24 other: Energy optimized engineering of machinery	0%	5%
Energy-Efficient Cooling Lubricant Supply		
6.1 Minimum quantity lubrication	3%	1%
6.2 Coolant lubricant supply through pressure control valves	1%	3%
6.3 Optimised pipe dimension for coolant lubricant supply	0%	0,5%

Table 5-14: Assessment according to module manufacturers

According to these assessments the following options are of key interest, as they potentially result in significant energy savings at no or low additional costs:

- Any measure under "Software-based energy management incl. stand-by mode"
- Application-specific design of drives
- Adaptable levels of pressure in hydraulic/ pneumatic systems, and pressure reduction
- Use of hydraulic accumulators.

5.1.13.2 Wood working machine tools

No manufacturer of wood working machine tools replied to the call for assessing the outlined improvement options. Therefore Fraunhofer bilaterally consulted manufacturers, and developed the assessment based on the information sourced at these meetings. The assessment for wood working machinery is summarized in the table below.[179]

There are a couple of relevant options for energy savings, particularly stand-by management, optimization and adequate of vacuum systems, and control of extraction systems (technical measures, which depend on a suitable centralized extraction system).

[179] For clarification, this assessment was made by Fraunhofer based on technology insights, but not by machinery manufacturers. This assessment was shared with one manufacturer before being published in this report to seek their confirmation of the stated tendencies.

Measure	Cost effects (investment) Increase in total machinery invest (tendency)	Total machinery energy savings potential (tendency)	Comment
Mass Reduction of Moving Parts			
1.1 Lightweight materials	3%	0,5%	Aluminium instead of steel for moving parts
1.2 Material reduction	3%	0,5%	
1.3 Less parts to be moved	0,2%	1%	in case of panel saw: only saw blade is raised, not the motor
Software-based Energy Management incl. Stand-By Mode			
2.1 Energy monitoring	1%	1%	
2.2 Machine stand-by management	0,2%	5%	
2.3 Energy-optimized motion control	3%	0,5%	
Energy Recuperation of Drives, Power Electronics, and Super Premium Efficiency Motors			
3.1 Application specific design of drives	0%	1%	
3.2 Speed control	1%	1%	
3.3 Direct drive instead of ball screw drives	1%	0,5%	
3.4 Brake energy feedback	1%	1%	relevant for CNC (short processing cycles, frequent tool changes)
3.5 Reducing maximal acceleration	1%	1%	
3.6 Reducing transmission losses	0,2%	0,5%	
3.7 Replacing inverter units	0,2%	0,5%	400 V instead of 200 V
3.8 Using low friction roller bearings	0,2%	0,5%	
3.9 Avoidance of transformers	0,2%	0,5%	
3.10 Power factor correction	1%	3%	
3.12 Super premium efficiency motors	3%	1%	
3.13 efficient motors also <750 W	1%	1%	
Tool Handling and Clamping			
4.1 Electrical clamping devices	1%	3%	electro-mechanical clamping could replace vacuum for larger (CNC) machines, but reduces flexibility
4.2 Efficient sealing of spindle system		0,5%	typically no air-lock systems used, hence no savings
4.3 Non-pneumatic lubrication for spindles	1%	1%	relevant for CNC
4.4 Multi spindle systems	5%	3%	savings related to increased productivity, not per machine
4.5 Softstarter	1%	1%	for saws (typically larger sawing mills), reducing initial

			power consumption
Hydraulic and Pneumatic Optimized Systems			hydraulics applied in presses and for lubrication systems in CNC machines
5.1 Optimized cooling of the motor	0,2%	0,5%	
5.2 Adaptable levels of pressure		0,5%	
5.3 Pressure adjustments for different actuators		0,5%	
5.4 Use of hydraulic accumulators		0,5%	
5.5 Substitution of technologies		0,5%	
5.6 Reducing inner leakages losses		0,5%	
5.7 Use of optimized valves		0,5%	
5.11 Application specific compressed air quality	1%	1%	relevant for equipment with e.g. air tables
5.12 Reducing channels of supply / dead volume	0,2%	1%	
5.13 Minimizing losses due to leakages (pneumatics)	0,2%	1%	
5.14 Pneumatic Cylinder with optimized drive surface	0,2%	1%	
5.15 Pneumatic Cylinder with multiple chambers		0,5%	
5.16 Single acting pneumatic cylinder	0,2%	1%	
5.17 Targeted cut-off from air supply	0,2%	1%	
5.18 Use of multiple valves	0,2%	0,5%	
5.19 Pressure reduction	0,2%	1%	
5.21 Optimized valve switching		0,5%	
5.23 Sensor based monitoring of pneumatic systems	1%	1%	
5.24 optimised blowing nozzles	0,2%	1%	e.g. for chips and dust re-moval
5.25 load-dependent air table control	1%	1%	relevant for larger equipment with air tables
5.26 speed-controlled vacuum pumps with frequency converters in conjunction with an intelligent closed-loop control (to adjust the volume output to match the current need)	3%	1%	
5.27 vacuum system equipped with multi-pump systems with intelligent activation / deactivation of individual pumps on a needs basis	3%	1%	
5.28 line-controlled blow-off device to adapt air consumption to actual needs	1%	1%	

Table 5-15: Assessment of eco-design options for wood working machine tools

5.2 Definition of BNAT

5.2.1 Introduction

Besides industrial initiatives such as "Blue Competence", by the VDW (German Machine Tool Builders' Association), there is a strong push via domestic policy in Germany to promote sustainable technologies in manufacturing. In the frame of the nationwide platform called "Effizienzfabrik", numerous projects have been launched to advance resource efficiency in manufacturing, some of which directly tackling machine tools. These innovation platforms started in September 2009, and will end in August 2013. To provide insights, a brief description of machine tool-related activities are summarized in Table 5-19, of which some will be discussed later in further detail.

Table 5-19: Scope related R&D activities to promote sustainable technologies in the frame of Effizienzfabrik

Project	Target figures	Consortium	Scope related Field of application
BEAT Overall assessment of the energy efficiency of alternative technology chains	Development of a method to compare the production lines on a process level depending on available data, such as cutting parameters, and to configure single processes by means of energetic aspects. *Means*: ▪ Collecting energy and resource consumption figures of single processes considering auxiliary processes and consumables ▪ Comparison of collected data with physically active principles ▪ Creation of benchmark figures for the assessment of the energy and resource efficiency of processes ▪ Analysis of technological chains ▪ Assessment of alternative technology chains from an energetic point of view ▪ Implementation of models and a benchmark figures system into a software application ▪ Recognition of implementing measures (guideline creation)	Daimler AG, Effizienz-Agentur NRW, PE International Experts in Sustainability, Robert Bosch GmbH, RWTH Aachen	Production plants
e-SimPro Efficient production machinery through simulation dur-	Simulation of the energy consumption of machine tools depending on specific process demands, *Means*: ▪ Experimental examination to iden-	EMAG Salach Maschinenfabrik GmbH, August Steinmeyer GmbH & Co. KG, FESTO AG & Co. KG, HANDTE	Metal working machine tools

Project	Target figures	Consortium	Scope related Field of application
ing development	tify relevant components in the simulation ▪ Development of models to calculate the energy use of single components ▪ Development of a method to determine the load profile of single components during cutting process ▪ Development of software modules ▪ Piloting development and implementation of selective optimization measures ▪ Assessment of the configured machining concepts in regard to the overall economic efficiency	Umwelttechnik GmbH, HYDAC International GmbH, Siemens AG, TU Darmstadt (PTW), Volkswagen AG	
EnergieMSP Energy demand optimised motor spindle and adapted electrical powertrain	Reduce or improve the energy consumption of the overall system main spindle of a machine tool by using loss minimizing spindle components and optimisation through lightweight construction	Franz Kessler, PTW, ARADEX, Schaeffler, OTT-JAKOB Spanntechnik, Mecatronix, KLuB, MAPAL	Spindle systems of metal working machine tools
ENERWELD Efficient thermal joining processes	Assessment and optimisation of thermal joining processes in regard to energy efficiency	Technische Universität Berlin (IWF), Benteler Automobiltechnik GmbH, EWM Hightec Welding GmbH, JENOPTIK Automatisierungstechnik GmbH, JENOPTIK Laser GmbH, Klaas Alu-Kranbau GmbH, PLATOS Planung technisch-organisatorischer Systeme GmbH, RIFTEC GmbH, RWE Power AG (assoziierter Partner), Welding Alloys Deutschland Schweißlegierung GmbH,	Welding, soldering, brazing machines
EnHiPro Energy and	Enabling SME to implement organisational and technological measures to increase efficiency and to assess the impact	TU Braunschweig (IWF), Introbest GmbH & Co, ifu	Production plants of small and

Project	Target figures	Consortium	Scope related Field of application
auxiliary consumables optimised production	on energy and consumables used as well as traditional production figures *Means*: ▪ Measurement of energy and consumables consumption ▪ Data processing and management ▪ Assessment and visualisation ▪ Development of measurements for optimisations	Hamburg GmbH, Intronic GmbH & Co., mts Maschinenbau GmbH, Spinnweberei Uhingen GmbH, SSV Software Systems GmbH, Syslog GmbH	medium sized enterprises
EnoPRO Energy optimized path planning to increase efficiency in machine tools		Gildemeister Turning Machines, EXAPT Systemtechnik, meteocontrol, RWTH Aachen (WZL)	
EWOTeK Increasing efficiency of machine tools through optimisation of technologies for operating components	Fundamental examination of the power demand of machine tools Optimising energy demand of machine tools Raising market acceptance of energy efficient technologies Raising consciousness of users regarding energy efficiency	Gebr. Heller Maschinenfabrik GmbH, BKW Kälte-Wärme-Versorgungstechnik GmbH, Bosch Rexroth AG, INDEX-Werke GmbH & Co. KG Hahn & Tessky, Knoll Maschinenbau GmbH, RWTH Aachen (WZL), Siemens AG	Metal working machine tools
FlexWB Targeted design of component properties to increase energy efficiency within the process chain of warm forming	Development and realization of new process chains for warm forming without using ovens Produce components with specific material properties within certain areas of the component itself	Neue Materialien Bayreuth GmbH, Audi AG, Daimler AG, Fraunhofer IWU, preccon Robotics GmbH, Schuler SMG GmbH & Co. KG, SMS Elotherm GmbH, ThyssenKrupp Steel Europe AG	Machinery for modifying material properties, warm forming machine tools
FunkProMikro Function-oriented controlled micro manufacturing processes	Developing methods and strategies to describe the permissible deviation in shape of the workpiece in regard to its later function; as well as for the manufacturing process control, as well as for the assessment of the expected functional quality.	Werth Messtechnik GmbH, Continental Automotive GmbH, Daimler AG, Friedrich-Alexander-Universität Erlangen-Nürnberg, Heidelber-	Machine tools

Project	Target figures	Consortium	Scope related Field of application
		ger Druckmaschinen AG, Karlsruher Institut für Technologie (KIT), MAG Boehringer Werkzeugmaschinen GmbH	
KAMASS High performance parts through efficient cold forming	Revealing the high potential of cold forming for producing high performance parts appropriate to operational demands, especially for alternating load. Reducing production chains. Replacing more resource intensive manufacturing technologies (comparable production chains, e.g. forging – heat treatment – cutting post treatment)	ZF Sachs AG, SSF-Verbindungsteile GmbH, Universität Erlangen-Nürnberg, Wezel GmbH	(Cold forging) machine tools
LaFueSol Laser Welding of Glass Tubes for Solar Thermal Collectors	Energy-efficient welding of glass tubes Development of an online analysis of the residual stresses generated in glass Development of a unit to record temperature fields using an IR camera for process control Reduced cycle time Construction of a prototype to demonstrate the complete concept/process	Laser Zentrum Hannover e. V., Herbert Arnold GmbH & Co. KG, ilis GmbH, IRCAM GmbH, Kollektorfabrik	Laser welding machines
MAXIEM Maximizing energy efficiency of machine tools	Demonstrating the potential savings by the means of configuring a prototypical machine tool, using the most efficient components and auxiliary units available on the market. *Means*: Precise determination of the energy consumption of cutting machine tools, also on component level. Construction of characteristic usage profiles, models, and calculation in order to identify consumers of energy. Systematic identification and quantification of the most promising regulating variables to reduce energy demand. Implement calculated potential savings by	Alfing Kessler Sondermaschinen GmbH, Audi AG, BMW AG, Bosch Rexroth AG, Daimler AG, Grob-Werke GmbH & Co. KG, Gebr. Heller Maschinenfabrik GmbH, MAG Powertrain, Fachgebiet Produktionsmanagement, Technologie und Werkzeugmaschinen (PTW), Siemens AG, Power Generation, Studer Schaudt GmbH, Volkswagen AG	Metal working machine tools

Project	Target figures	Consortium	Scope related Field of application
	setting up a demonstrative machine. Creation of a guideline and handbook for developers and purchaser of cutting machine tools. Development of methods for the objective assessment of the energy efficiency of cutting machine tools and its components.		
NCplus Process and value driven controlled machine tool	Developing prototypical technologies which facilitate a process and value driven operation of cutting machine tools.	Deckel Maho Pfronten GmbH, CAMAIX GmbH, Franz Kessler GmbH, Hydac International GmbH, KME Germany AG, Mayr GmbH, Perpendo GmbH, Bosch Rexroth AG, Institut für Fertigungstechnik und Werkzeugmaschinen, Leibniz Universität Hannover, Walter AG, Otto Bock Healthcare GmbH	Metal cutting machine tools

5.2.2 Metalworking machine tools - solutions

Regarding metal working machine tools, a need for research has been identified in the field of process stability, where energy losses of up to 80 MJ per kg (cutting), and 50 MJ per kg (forming) arise, due to the occurrence of scrap.[180] Thus, anticipatory process monitoring is required, in conjunction with the use of appropriate tools, such as sensors or optical inspection systems. As far as the latter case is concerned, the research project MobiKAM comprises the development of a mobile energy self-sufficient optical sensor, e.g. for measuring and testing in the working area. In this way, a more reliable and transparent machining is facilitated.[181] [182]

180 Putz, M.: Herausforderungen an Systeme und Prozesse in der energieeffizienten/ressourceneffizienten Produktion, Symposium „Energieeffiziente Werkzeugmaschinen“, Düsseldorf, February 24, 2010.

181 See https://mobikam.ipk.fraunhofer.de/pam/?rq_AppId=31303137&rq_TargetId=31303030 (German description only), accessed January 20, 2011.

182 Project time: 01.01.2008 to 30.06.2011

The research project ECOMATION deals with measures for reducing the energy demand of cutting machine tools by means of control and feedback control systems, on the premise that the manufacturing process itself is not interfered with. This is being achieved by the choice of suitable process steps and parameters, which will be determined by experimental examination. In this way, energy optimisation can be achieved without influencing the actual machining process.[183] [184]

The aim of the Collaborative Research Center project SFB 467 "Transformable Corporate Structures of Multi Variant Serial Production" is the development of models, methods and procedures to increase the versatility in manufacturing companies. This includes the investigation of the versatility of machine tools and assembly systems. The solution approaches are based on modular systems. The research activities involve planning tools for the automatic configuration planning to develop versatile systems. Project Area C "Transformable technical systems", of the SFB 467, examined the technical implementation and support of adaptability in production and information technology tasks.. Convertible processing systems are based on the principle of reconfigurability, whereas the base of this adaptability is formed by self-sufficient, mechatronic modules and a self-regulating control system.[185] [186] [187] [188] [189]

In the context of surface technology, great importance is attached to the cleaning of parts after the process to minimize “external” losses of lubrications.[190] Cleaning is the removal of residual lubricants, including process liquids as well as remaining sub-

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183 Heisel, U., et al., ref 8, p. 221ff.

184 Project time: 2009 to 2015

185 Heisel, U.; Wurst, K.-H.; Kircher, C.: (Re)konfigurierbare Werkzeugmaschinen – notwendige Grundlage für eine flexible Produktion. In: wt Werkstattstechnik online 96 (2006) 5, pp. 257-265.

186 Heisel, U.; Wurst, K.-H.: Konzeption und Entwicklung mechatronischer Module für wandelbare Bearbeitungssysteme und Untersuchung deren Auswirkungen auf die Gestaltung von Fertigungseinrichtungen. www.tfb059.uni-stuttgart.de/teilprojekte/tp3/. Access: 31.08.2010.

187 Kircher, C.; Seyfarth, M.; Wurst, K.-H.: Modellbasiertes Rekonfigurieren von Werkzeugmaschinen. In: wt Werkstattstechnik online 94 (2004) 5, pp. 179-183.

188 Westkämper, E.: Modulare Produkte - Modulare Montage. In: wt Werkstattstechnik 91 (2001) 8, pp. 479-482.

189 Project time: 1997 to 2005

190 König, U.: Oberflächentechnik für Maschinen der Metallbearbeitung – Technologien, Potentiale, Anwendungen. In: FTK 2006, pp. 333 – 344, Ges. f. Fertigungstechnik, Stuttgart, 2006.

stances from preceding processes. The total removal of cooling lubricant residuals and chips is usually performed by an aqueous or organic rinsing medium. A significant amount of energy is required for the transfer of the contaminated elements into this cleaning medium, and for the subsequent lubricant regeneration, as well as for the lubrication process itself, , e.g. for the heating or vacuum generation.[191] The project B 2 "Energy efficient cleaning and dry machining" of the CRC 1026 "Sustainable Manufacturing – Shaping Global Value Creation" will comprise research strategies for in-process-cleaning, using dry ice blasting.

The project ConTemp (Self-Learning Control of Tool Temperature in Cutting Processes) is expected to produce two innovative developments:

- Firstly, a new cutting tool system with an integrated high performance micro-cooling device, that enables the application of a closed coolant circuit. The advantage is the elimination of the contamination of the cooling liquid. Therefore a reduction of cleaning costs and waste disposal is possible.
- Secondly, the development of a self-learning control platform that reacts to changes of the process conditions, thus maintaining a constant temperature at the tool tip, optimising the process results.[192] [193]

The project METEOR (more technology-oriented reconfigurable machine tools) develops the adaptation of machine tools and transfer lines to the dynamics of the market. In this case, these production systems are designed independently from the product itself and current life cycle. For this project, the equipment is built from standardized components with standardized interfaces, and combined in a common work space to bring together different manufacturing processes.[194] [195] [196] [197]

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191 Marktübersicht Reinigungsanlagen. In: Metalloberfläche, Volume 61, Issue 5, 2007.

192 See http://www.contemp.org/index.php?id=28, accessed March 25 , 2012

193 Röder, M.: Smarte Werkzeuge für harte Werkstoffe. In: FUTUR 14 (2012) 1, pp. 10-11.

194 Abele, E.; Wörn, A.: Chamäleon im Werkzeugmaschinenbau. In: ZWF - Zeitschrift für wirtschaftlichen Fabrikbetrieb 99 (2004) 4, pp. 152-156.

195 Abele, E.; Wörn, A.: Economic Production with Reconfigurable Manufacturing Systems (RMS). In: Wissenschaftliche Gesellschaft für Produktionstechnik (WGP). Annals of the German Academic Society for Production Engineering. Braunschweig: Vol. XII/1 (2005), pp. 189-192.

196 Stanik, M.: Der Rekonfigurierbarkeit gehört die Zukunft. In: Werkstatt und Betrieb, 137 Jahrgang, Carl Hanser Verlag, München, Wien, (09) 2004, pp. 24-30.

The aim of the project Loewe (life cycle-oriented machine tool) was to reduce the life-cycle cost of machine tools by adapting the modular designed constructions to new production tasks (Figure 5-52). Furthermore, the issue of modularization extended the life time of the machine tool by using modules with defined interfaces. These types of interfaces are not only a mechanical connection, but they also support the supply of energy and auxiliary materials. The control configuration is realized by using transponders, which are used as object data sources.

Furthermore, the modular, adaptable Loewe tool also provides information on the state of the machine and its components for a life cycle monitoring system. The integration of sensory and intelligent components in the machine tool allows the maximization of performance, ensures availability and permanently monitors actual costs. Additional hard- and software-based systems may be required to recognize, process and store lifetime-relevant and cost-effective properties. In addition to the above, a software system was developed which allows the calculation and projection of relevant life-cycle costs during the development, implementation, use, maintenance and disposal of machine tools.[198]
199 200 201

[197] Projet time 01.10.03 to 31.10.07

[198] Dekena, B.; Möhring, H.-C.; Harms, A.; Vogeler, S.; Noske, H.: Können teure Werkzeugmaschinen auf längere Sicht günstiger sein?. In: wt Werkstattstechnik online 95 (2005) 7/8, pp. 519-523.

[199] Denkena, B.; Jacobsen, J.: Senkung der Lebenszykluskosten von Werkzeugmaschinen durch Komponentenüberwachung. In: Zeitschrift für wirtschaftlichen Fabrikbetrieb ZWF 101 (2006) 7-8, pp. 440-443.

[200] Denkena, B.; Harms, A.; Jacobsen, J.; Möhring, H.-C.; Jungk, A.; Noske, H.: Lebenszyklus-orientierte Werkzeugmaschinenentwicklung. In: wt Werkstattstechnik online 7/8-2006, S. 441-446.

[201] Project time: 01.04.04 to 31.08.07

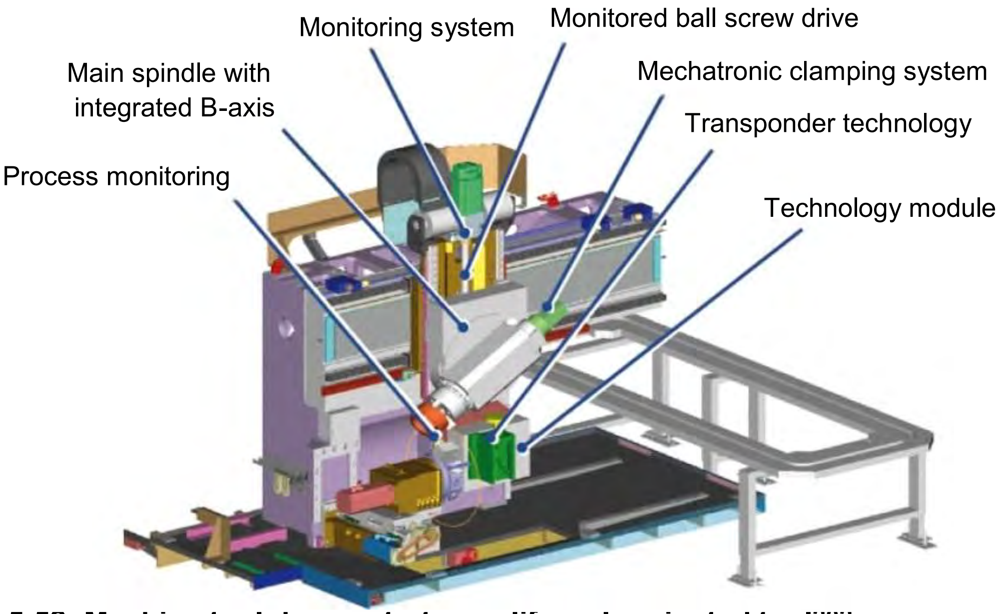


Figure 5-52: Machine tool demonstrator - a lifecycle oriented tool[202]

5.2.3 Modularisation, versatility and optimisation of energy consumption

The mobility of production technology refers to a new level of versatility. Only through the transformation of a company is it possible to operate outside a flexibility corridor. Adaptability is seen as solution-neutral potential that is going beyond flexibility, and can be activated in case of need to make adjustments to changing conditions.[203][204] Critical to ensuring a high pattern of mobility is a highly modular design. Under the joint project ProMotion (design and operation of mobile production systems) the design and operation of mobile production systems were studied.

202 Denkena, B.; Harms, A.; Jacobsen, J.; Möhring, H.-C.; Jungk, A.; Noske, H.: Lebenszyklusorientierte Werkzeugmaschinenentwicklung. In: wt Werkstattstechnik online 7/8-2006, S. 441-446.

203 Wiendahl, H.-P.: Wandlungsfähigkeit - Schlüsselbegriff der zukunftsfähigen Fabrik. In: wt Werkstattstechnik 92 (2002) 4, pp. 122-125.

204 Wiendahl, H.-P.; El Maraghy, H. A.; Nyhuis, P.; Zäh, M. F.; Wiendahl, H.-H.; Duffie, N. A.; Brieke, M.: Changeable manufacturing - classification, design and operation. In: CIRP Annals. Manufacturing Technology 56 (2007) 2, pp.783-809.

The aim of the ProMotion project was to use mobility, both within a site and across sites, as a new degree of freedom, and thus to increase the location and structural variability. Relocation of the equipment at the customer's site is often not provided, or is achievable only with great effort. The possibility to easily move the machine tool has to be considered, and achieved, in the design phase of the machine. Under this project, a special "mobile"[205] machine was designed (Figure 5-53). It is a machining centre with up to a maximum of 5-axle units, and a hanging round machine table. The flexible configuration of the system is realised through the modularization in a product-independent machine platform, and a shift of the entire system, via the solid frame construction. Filling the building columns with polymer concrete, which primarily serves to provide the vibration damping, also reduces the foundation requirements.[206] [207] [208] [209]

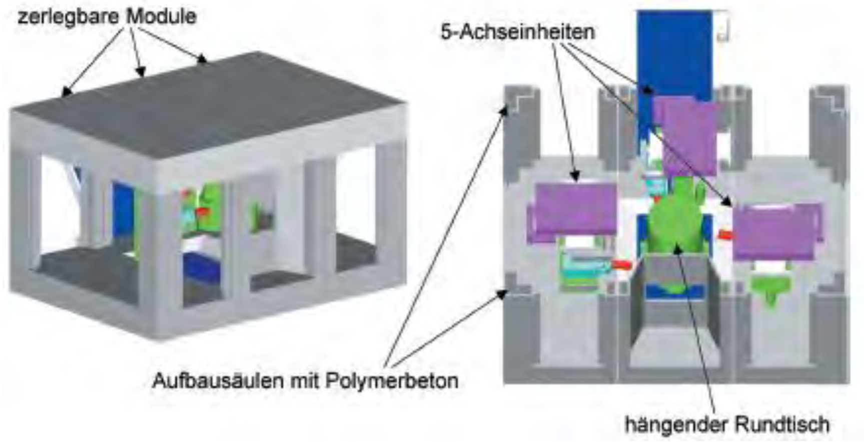


Figure 5-53: Design of a special mobile machine for machining[210]

The joint research project MAXIEM (maximizing the energy efficiency of machine tools) focused on the energy efficiency of cutting machine tools. The aim s to demonstrate

205 But note, that in the terminology defined in task 1, this modular machine tool is considered "stationary" and consequently still is in the scope of the study.

206 Zäh, M. F.; Cisek, R.; Sudhoff, W.; Redelstab, P.: Mit Mobilität zu mehr Strukturvariabilität. In: wt Werkstattstechnik online 93 (2003) 4, pp. 327-331.

207 Zäh, M. F.; Sudhoff, W; Rosenberger, H.: Bewertung mobiler Produktszenarien mit Hilfe des Realoptionsansatzes. In: Zeitschrift für wirtschaftlichen Fabrikbetrieb ZWF 98 (2003) 12, pp. 646-651.

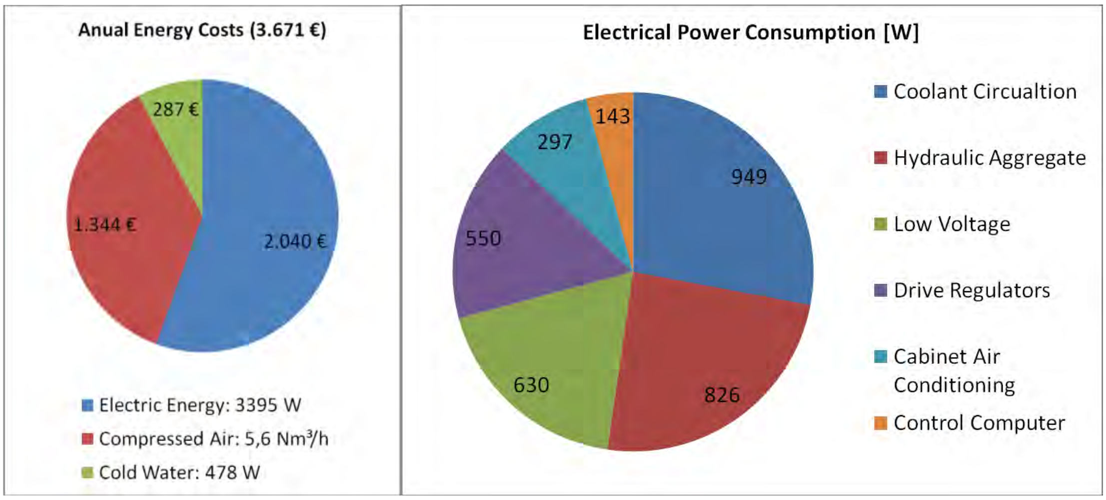
208 Zäh, M. F.; Bayrer, P.: Gestaltung und Betrieb mobiler Produktionssysteme. Abschlussbericht des Forschungsprojektes ProMotion. Utz Verlag, München 2004.

209 Project time: 01.06.2001 to 31.12.2004

210 Zäh, M. F.; Cisek, R.; Sudhoff, W.; Redelstab, P.: Mit Mobilität zu mehr Strukturvariabilität. In: wt Werkstattstechnik online 93 (2003) 4, pp. 327-331.

the savings potentially available through the configuration of a prototype machine tool, by integrating the most efficient components and aggregates available in the market today. The potential of an optimized components control were evaluated. This shows, firstly, the machine-side potential that can be achieved by appropriate design, and secondly, the opportunities that result from an optimized and coordinated operation, identification and implementation.

As a result of ABC analysis, hydraulics, cooling systems for cabinet and drives, coolant system, exhaust, air purge, low voltage power supply, as well as filter components, were identified as modules with the highest potential for reducing energy consumption. Main spindle, fans, contactors and relays, mounting systems, lighting and counterbalance brake own medium, feed drives, axle clamp, bearings, guides, lubrication, and control have the least potential for fuel economy. Criteria were mainly power consumption and service life, with a basic load of the machine of P = 3 kW. Figure 5-54 shows the annual consumption of energy, and the power consumption of components, in working condition for a machining centre.[211][212][213] [214]



211 Abele, E.; Kuhrke, B.; Rothenbücher, S.: Energieeffizienz von Werkzeugmaschinen maximieren. www.maschinenmarkt.vogel.de/themenkanaele/produktion/zerspanungstechnik/articles/251269/. Access: 06.04.2010

212 Abele, E.: Entwicklungstrends zur Erhöhung und Bewertung der Energieeffizienz spanender Werkzeugmaschinen. In: Tagungsband Energieeffiziente Produkt- und Prozessinnovationen in der Produktionstechnik. 25.-26.06.2010, Chemnitz.

213 Kuhrke, B.; Erdle, F.: Energieeffizienz als Investitionskriterium. In: Werkstatt und Betrieb. 143 (2010) 1-2, Hanser Verlag, München, pp. 30-33.

214 Part of „Effienzentfabrik"

Figure 5-54: Annual costs for electric power sources, compressed air and cold water, and power consumption of individual components during working conditions[215]

The research project e-Simpro (energy-efficient machines by Simulation in Product Development) optimized the development of energy-efficient machine tools by simulating the energy needs of the machine tool and its components, as a function of specific process requirements. This included the development and testing of software prototypes that simulated the energy consumption of machine tools, including the power supply modules. In an iterative process, which included modelling, implementation and verification, the models were detailed until an adequate picture of reality was reached. The technology was transferred to the partner configuration tools, for developing energy-efficient machinery. These concepts of energy-optimized machines were evaluated and tested.[216] [217]

Design rules and structure examples of cutting machine tools were installed for the modular structure of machine tools, considering the economic and ecological aspects of design, regarding product recycling.[218] These rules and examples deal primarily with product recycling, and provide a good basis for the module structure and design, as well as proceedings and design rules. Furthermore, a blueprint for the creation of new products with regard to the product recycling is thus developed. Through the results presented, designers are able to extend the life cycle of components and machine tools, and consider the environmental aspects in more detail, in addition.

The energy consumption of electric motors is the cause of over 90 % of the entire life cycle costs. However, on the other hand, the costs of the electrical motors account for only 10 % of the purchase cost of the entire machine tool. Electronic speed controls can reduce the energy consumption of electric drives by up to 25 %. In addition, the process control is easier, and wear and noise emissions are also reduced. Due to the power consumption of the electronic speed control itself, their use is worthwhile only for

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215 Abele, E.; Kuhrke, B.; Rothenbücher, S.: Energieeffizienz von Werkzeugmaschi-nen maximieren. www.maschinenmarkt.vogel.de/themenkanaele/produktion/zerspanungstechnik/articles/251269/. Access: 06.04.2010

216 www.esimpro.de. Access: 14.08.2010.

217 Part of „Effizenzfabrik“

218 Niethammer, R. M.: Modulare Werkzeugmaschinengliederung unter dem Gesichtspunkt wirtschaftlicher und ökologischer Gestaltung zum Produktrecycling. Dissertation TU Bergakademie Freiberg, 1997.

machines that are operated primarily at part load. 48 % of manufacturing companies already use this technology.[219]

The goal of the project EnergieMSP (energy demand optimized spindle motor and electric drive train adapted) was to improve the efficiency of a motor spindle for machining with a defined cutting edge. Three optimization fields were focused on: electric propulsion, power-loss minimized spindle components and lightweight construction. In addition to the efficiency-optimized development of frequency converters and motor drives, spindle-bearings with minimized friction and the use of fibre reinforced plastics are investigated.[220] [221]

The research project EWOTeK (increased efficiency of machine tools by optimizing the technology for components) was to reduce the total energy consumption of machine tools, using – on the one hand – its basis as the measurement of the dynamic performance retrieval of machine tools, and on the other hand, the optimization of selected components. Dimensioning machine tools - and their components - based on transparent energy consumption promises substantial improvements regarding energy efficiency.[222] [223] The project NCplus attempts to uncover the energy use of the clamping-related machinery. Only 20 % to 80 % of the energy consumption is used for the added value. The remaining energy provides related aggregates, most of them running to set machine tools in Stand-By Mode. Similar to EWOTeK, the objective of NCplus was to optimize the dynamic performance of machine components.[224][225] [226]

Track 1 of the EU-funded research consortium project NEXT (Next Generation Production Systems) is the development of machine tools based on eco-efficient criteria for their design and life cycle. These include the use of reusable materials, their full recycling, thus reducing energy consumption as well as achieving production without

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219 Schröter, M.; Weißfloch, U.; Buschak, D.: Energieeffizienz in der Produktion – Wunsch oder Wirklichkeit? Energieeinsparpotenziale und Verbreitungsgrad energieeffizienter Techniken. In: Modernisierung der Produktion. Mitteilungen aus der ISI-Erhebung 51 (2009).

220 www.energiemsp.de/. Access: 16.08.2010.

221 Part of „Effizenzfabrik"

222 www.ewotek.de/de/default.html. Access: 13.09.2010.

223 Part of „Effizenzfabrik, project time 01.07.2009 to 30.06.2012

224 http://www.ncplus.de/ Access: 18.01.2011.

225 http://www.technikwissen.de/libary/news/2010/05/424_54653.pdf, pp 426.

226 Part of "Effizienzfabrik", project time 01.07.2009 to 30.06.2012

waste.[227] The joint research project PROLIMA (Environmental Product Lifecycle Management for building Machine Tools) was also devoted to the life-cycle design of machine tools, and included the development of eco-efficient construction methods, and technical rules.[228]

PROLIMA comprised the methodological design and selection of sustainable use concepts for power systems in machine and plant construction, and was based on the integration of services and the physical product in so-called power systems. Furthermore, this strategy focuses on integrating economic and environmental aspects in a holistic sustainability assessment. To achieve these objectives, all levels of an organization, above all the strategic level, have to be involved.[229]

The EnEffCo-project on energy efficiency controlling uses in the automotive industry and its suppliers is an example of reducing energy consumption by making the main sources of energy consumption transparent, including the temporal pattern of consumption. By recognizing the possibilities of postponement of the energy demand, the so-called functional energy storage, cost savings can be achieved. In addition, the energy consumption efficiency of relevant sectors is calculated and evaluated. Different levels of the value chain in automotive production, in terms of dependencies between consumption patterns and production processes, were investigated. Within simulations of operating modes of system components, relevant energy consumption, cost-and energy-efficient production plans were developed (Figure 5-55). Via these measures, different scenario can be drawn up, and then evaluated for energy-efficient design within the manufacturing process.[230][231] [232]

227 http://www.nextproject.eu/ Access: 10.10.2010

228 www.prolima.net/projects/objetives_html. Access: 01.09.2010.

229 Michalas, N.: Methodik zur Gestaltung von nachhaltigen Nutzungskonzepten im Maschinen- und Anlagenbau. RWTH Aachen, Dissertation, 2002.

230 www.dai-labor.de/act/laufende_projekte/eneffco/. Access: 14.08.2010

231 Schreck, G.: Energieeffizienzcontrolling in der Automobilproduktion. In: Futur 12 (2010) 2, pp. 6-7.

232 Project started in 2009

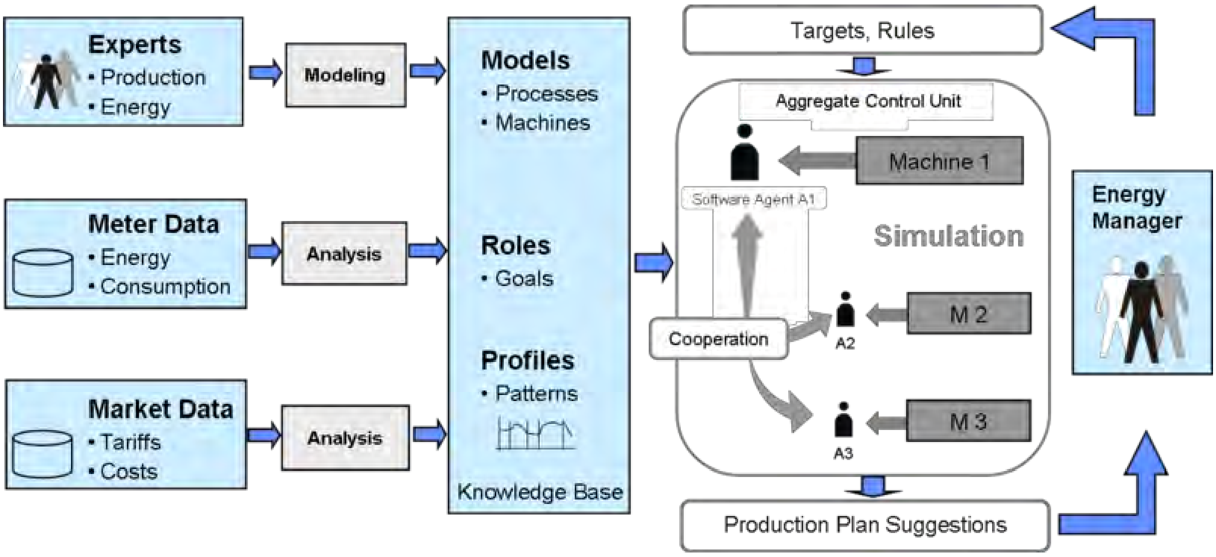

Figure 5-55: Model to identify systems with relevant energy consumption[233]

5.2.4 Wood working machine tools BNATs

No substantial research for particularly eco-designed or energy efficient solutions of wood working machine tools was identified.

5.2.5 Welding equipment BNATs

Welding processes and technologies are subject to intensive research. Frequently specific material types or combinations are in the focus of R&D, to open new fields of applications for welding operations, to increase the performance of processes and to enhance the quality of the welds. Some research projects specifically address technology developments, which are likely to enhance environmental performance as well. Relevant projects on a European level are listed below:

The project SafeFlame (Development of oxy-hydrogen flame for welding, cutting and brazing)[234] intends to overcome some drawbacks of the oxy-acetylene flame, which are becoming more significant with increasing health and safety and environmental concerns. Besides occupational health and safety, the project intends to develop a process to generate oxy-hydrogen flames by the combustion of oxygen and hydrogen produced locally, using an electrochemical cell. According to the project outline, “this

233 www.dai-labor.de/act/laufende_projekte/eneffco/. Access: 14.08.2010

234 SafeFlame - Development of oxy-hydrogen flame for welding, cutting and brazing, FP7, SME-2011-2 Research for SME associations, 2011-2014

approach has the following advantages over oxy-acetylene heating: The cell is highly portable, reducing transportation costs and increasing the flexibility of the process. The fuel is water, which is widely available and low cost. The process requires electricity to generate the gases but is >60% efficient." However, a dedicated LCA comparing on-site generation with the conventional purchase of gas in cylinders is not yet available.

The project SmartDress (Adaptive Tip dress Control for Automated Resistance Spot Welding)[235] is one of the examples where better process control is targeted, resulting possibly in higher productivity and weld quality, and having a positive secondary environmental impact: SmartDress will develop a fully automated adaptive control system that will optimise, monitor and maintain tip quality in high volume automotive production operations, where resistance spot welding is widely used. The project is motivated by the insight that significant losses of output occur as a consequence of frequent production line stoppages, predominantly caused by weld quality issues, which in turn arise from poor maintenance of consumable tips on resistance spot welding guns.

Information technology as an enabler for more efficient welding processes is currently being researched in the project RLW NAVIGATOR (Remote Laser Welding System Navigator for Eco & Resilient Automotive Factories)[236], which "aims to develop an innovative Process Navigator to configure, integrate, test and validate applications of Remote Laser Welding (RLW) in automotive assembly. ... RLW is emerging as a promising joining technology for sheet metal assembly due to benefits on several fronts including reduced processing time (50-75%), and decreased factory floor footprint (50%), reduced environmental impact through energy use reduction (60%), etc. Currently, RLW systems are limited in their applicability due to an acute lack of systematic ICT-based simulation methodologies to navigate their efficient application in automotive manufacturing processes. ... Firstly, the most critical obstacle that currently prevents the successful implementation of RLW is the need for tight dimensional control of part-to-part gaps during joining operations, essential to ensure the quality of the stitch. Secondly, the existing assembly system architecture must be reconfigured to provide the opportunity to evaluate the RLW system in terms of its feasibility to perform all re-

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235 SmartDress - Adaptive Tip dress Control for Automated Resistance Spot Welding, FP7, SME-2011-1 Research for SMEs, 2011-2013

236 RLW NAVIGATOR - Remote Laser Welding System Navigator for Eco & Resilient Automotive Factories, FP7, FoF-ICT-2011.7.4 Digital factories: Manufacturing design and product lifecycle management, 2012-2014

quired assembly tasks. This will provide crucial information about the most advantageous workstation/cell reconfiguration, which will serve as the basis for optimal robot path planning to reduce joining process time and workstation level efficiency assessment." The effectiveness of this approach still has to be proven, and requires a close software-based interaction of the welding equipment with a remote system.

The power electronics components and circuitry of welding power sources are subject to research and continuous improvement at several research institutions[237], but the related publications do not provide an outlook on achievable efficiency improvements.

5.3 Future industrial trends

5.3.1 Energy use monitoring and optimisation

The data collection for various systems such as electrical power, compressed air and steam complicate the uniform collection of energy data. Consistent network structures, such as between management and production, allow an easier system-wide collection of data. Long-term acquisition collects energy-related data in longer intervals of typically 15 minutes by the power company. This results in small amounts of data, but power-peaks cannot be reflected. The short-term data collection in the usual time range of less than 10 ms has the advantage of being able to accurately identify power peaks. Disadvantages are the size of the collected data set, and the associated complex evaluation. To promote energy efficiency as early as possible in the plant- and product-design phase, the following steps need to be accomplished:

- identification and prevention of unproductive consumer of energy by measuring the consumption levels
- linking the energy data collected with job-related information such as produced quantities

237 See e.g.: Navarro-Crespin, A. ; Casanueva, R. ; Azcondo, F.J. ; Performance Improvements in an Arc Welding Power Supply Based on Resonant Inverters, IEEE Industry Applications Society Annual Meeting (IAS), 3-7 Oct. 2010; Klumpner, C. ; Corbridge, M. ; A two-stage power converter for welding applications with increased efficiency and reduced filtering, IEEE International Symposium on Industrial Electronics, ISIE 2008, June 30 - July 2 2008; Sugimura, H. ; Fathy, K. ; Sang-Pil Mun ; Doi, T. ; Mishima, T. ; Nakaoka, M.; Three-Level Phase Shifted soft transition PWM DCDC power converter with high frequency link for arc welders and its extended version, IEEE 6th International Power Electronics and Motion Control Conference, IPEMC '09, 17-20 May 2009

- analysis, and evaluation, of the collected energy data.

Trends noted are to use overall energy data for optimizing the consumption in the use phase, and also for customized design and construction of machines and their connections in the material flow.

5.3.2 Reading system controls or installation of sensors

The information from the control is evaluated for determining the energy consumption. The system can collect relevant data from the actuators and sensors itself, as well as from the communication between them and the superordinate controlling system.

5.3.3 Energy monitoring systems

These energy monitoring systems are used for display and storage of energy data. The report includes the archiving function of energy data in databases, their visualization and analysis. Fundamental functions are the identification of peak loads, the calculation of energy indicators, alerts when exceeding limits, efficiency monitoring and system analysis when parameters have changed. Mobile energy monitoring systems consist of mobile testing units, which allow flexible and rapid system analysis even with non-upgradable machines. The technology opens up new service areas for service providers.

5.3.4 Integration of energy efficiency in the control room

The control console acts as the link between corporate management and controlling, and displays energy data, disorders of energy consumption and limit violations. There is the possibility to pass requirement- and offer-improved control data directly to energy-related components. This also includes the shutdown of components during the non-production time. Furthermore, working time models with staggered pause times and manual shifting operations can be developed. The complete integration of all the systems includes the coordination of cycle times and energy loads within the cycle times of parallel or sequentially related system components.

PROFIenergy represents an energy management system that is currently implemented by the industry. The “Profibus User Organisation e.V.” develops a protocol that defines unified functions and mechanisms for energy control for all relevant machinery components. The system is vendor-independent, and will allow an automatic, time-driven and needs-based connection and disconnection of components during production. The concept includes the definition of various power modes, and the integration of relevant data, such as the starting time to allow full production capabilities at the beginning of production.[238]

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Abele, E., Kuhrke, B.; Rothenbücher, S.: Energieeffizienz von Werkzeugmaschinen maximieren. www.maschinenmarkt.vogel.de/themenkanaele/produktion/zerspanungstechnik/articles/251269/. Access: 06.04.2010

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238 Hiersemann, R.: Integration von Energiemonitoring - Funktionalitäten in Anlagenleitstände Möglichkeiten und Grenzen. In: Fraunhofer IOSB (Hrsg.): Tagungsband Innovationen Produzieren. 09.-10.06.2010, Karlsruhe, pp. 139-152.

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6 Annex Assessment Matrix Survey

The following pages document the Assessment Matrix, which was published to seek input by stakeholders on improvement potentials.

Energy-Using Product Group Analysis

Lot 5: Machine tools and related machinery

Improvement Options: Assessment Matrix

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March 28, 2011

Background

Ecodesign of Energy-related Products (ErP) Directive 2009/125/EC (recast of the former EuP Directive 2005/32/EC) establishes a framework for setting Eco-design requirements (e.g. energy efficiency) for all energy related products and, thus, it is going to affect environmental and/or energy efficiency specifications of such products sold in Europe in the future. For further details on the ErP Directive, please visit the European Commission's websites:

http://ec.europa.eu/enterprise/eco_design/index_en.htm

This Product Group study is the first step in considering whether and which eco-design requirements could be set for machine tools and related machinery falling into the broad scope of this study. The objective of the study is to analyse these products and recommend ways to improve their energy and environmental performance. The study shall provide the necessary information for the next phases (carried out by the European Commission); in particular a consultation forum with the stakeholders, impact assessment, and possible draft implementing measures.

You can follow the progress of the study and also register as a stakeholder on the project website www.ecomachinetools.eu .

Purpose of this Assessment Matrix

This survey is intended to quantify achievable improvement potentials of machine tools. Given the complexity of machine tools and the specifics of the numerous applications it is important to get the order of magnitude right, not to seek detailed quantifications.

Submission of Data

Please, respond to this survey latest by **May 2, 2011**, if possible, to allow for a timely consideration throughout the study. If you need more time to reply, let us know. Feel free to distribute this questionnaire among other stakeholders. Reply to

schischke@ecomachinetools.eu

Guidance to fill in the matrix

The measures are an abridged list of improvement options outlined in the **Task 5 report, chapter 5.1.**:

http://www.ecomachinetools.eu/typo/reports.html?file=tl_files/pdf/EuP_LOT5_Task5_Draft_11-02-28_v10.pdf

Add additional measures you are aware of.

Column: "Cost effects (investment): Increase in total machinery invest (range)"

State the likely **purchase price increase "per (typical) machine"** (*not* per module etc.) when implementing any given approach in the machinery design. This will be taken into account for the life cycle costing and weighted against any savings.

Column: "Module related energy savings potential"

State the energy savings roughly achievable **in the use phase related to the relevant machine module (e.g. hydraulics system, drive systems)**, compared to a machine, which has not implemented this option.

Column: "Total machinery energy savings potential"

State the energy savings roughly achievable **in the use phase of an (average) machine tool**, compared to a machine, which has not implemented this option.

Column: "Other environmental impacts of the approach"

If there are other than energy savings related to an optimization, this should be stated here. Again, referring to the total typical consumption of the whole machine.

Column: "Market penetration"

Most of the optimization options are likely to be already implemented in a certain market share of installed and newly introduced machine tools. Consequently, implementing an option now in all machines where this approach is feasible will result in a lower overall improvement potential, if only a minor market segment still needs to implement this option.
Please make an estimate, which **percentage of the market share** (**in terms of units**, not economics) already implemented this option, making the distinction of **"installed" (i.e. currently operating)** and **"currently sold" (i.e. in 2011)**. Percentage should refer to the market segment, where this option makes sense. Example: For options for reduced cooling lubricants consumption the market penetration should be stated as percentage of all machine tools using cooling lubricants, not as percentage of all machine tools.

Column: "Limitations / remarks"

State for which market segments / under which conditions the individual measures are technically feasible / reasonable, if certain improvements can be achieved only with proprietary solutions, and if other limitations apply to your estimates made in any of the categories.

Contact Details

Organization:

Name:

Telephone:

E-mail:

Replies refer to

- ☐ Metal working machine tools
- ☐ Wood working machine tools

☐ Other machine tools:

Reply only to those measures, for which you can claim a certain expertise ("educated guess"). Skip the others. Feel free to complement your feedback with any additional information or statement.

My / our field of expertise:

Do you agree to be listed in the report as one of the respondents to this survey? (name and affiliation, without stating your individual replies)

☐ yes ☐ no

Measure	Cost effects (invest-ment) Increase in total ma-chinery invest					**Module related** energy savings potential				**Total machinery** energy savings potential				Other environ-mental impacts of the approach				Market penetration		Limitations / remarks
	No difference	Max. + 0.2%	Max. +1%	Max. +3%	Above 3%	0 – 1.5%	1.5 – 5%	5 – 15%	Above 15%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	in **installed** ma-chine tools	In **currently sold** machine tools	
Mass Reduction of Moving Parts														Weight (mate-rial) savings						
1.1 Lightweight materials	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
1.2 Material reduction	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
1.3 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
1.4 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
Software-based Energy Management incl. Stand-By Mode																				
2.1 Energy monitoring	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
2.2 Machine stand-by management	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
2.3 Energy-optimized motion control	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
2.4 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
2.5 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	

Measure	Cost effects (investment) Increase in total machinery invest					**Module related** energy savings potential				**Total machinery** energy savings potential				Other environmental impacts of the approach				Market penetration		Limitations / remarks
	No difference	Max. + 0.2%	Max. +1%	Max. +3%	Above 3%	0 – 1.5%	1.5 – 5%	5 – 15%	Above 15%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	in **installed** machine tools	In **currently sold** machine tools	
Energy Recuperation of Drives, Power Electronics, and Super Premium Efficiency Motors																				
3.1 Application specific design of drives	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.2 Speed control	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.3 Direct drive instead of ball screw drives	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.4 Brake energy feedback	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.5 Reducing maximal acceleration	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.6 Reducing transmission losses	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.7 Replacing inverter units	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.8 Using low friction roller bearings	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.9 Avoidance of transformers	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.10 Wattless current compensation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	

Measure	Cost effects (investment) Increase in total machinery invest					**Module related** energy savings potential				**Total machinery** energy savings potential				Other environmental impacts of the approach				Market penetration		Limitations / remarks
	No difference	Max. + 0.2%	Max. +1%	Max. +3%	Above 3%	0 – 1.5%	1.5 – 5%	5 – 15%	Above 15%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	in **installed** machine tools	In **currently sold** machine tools	
3.11 Latest generation IGBTs	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.12 Super premium efficiency motors	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.13 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
3.14 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
Tool Handling and Clamping																				
4.1 Electrical clamping devices	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
4.2 Efficient sealing of spindle system	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
4.3 Non-pneumatic lubrication for spindles	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
4.4 Multi spindle systems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
4.5 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
4.6 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
Hydraulic and Pneumatic Optimized Systems														Hydraulic oil savings						

Measure	Cost effects (investment) Increase in total machinery invest					**Module related** energy savings potential				**Total machinery** energy savings potential				Other environmental impacts of the approach				Market penetration		Limitations / remarks
	No difference	Max. + 0.2%	Max. +1%	Max. +3%	Above 3%	0 – 1.5%	1.5 – 5%	5 – 15%	Above 15%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	in **installed** machine tools	In **currently sold** machine tools	
5.1 Optimized cooling of the motor	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
5.2 Adaptable levels of pressure	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
5.3 Pressure adjustments for different actuators	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
5.4 Use of hydraulic accumulators	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
5.5 Substitution of technologies	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
5.6 Reducing inner leakages losses	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
5.7 Use of optimized valves	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
5.8 Use of hydraulic clamping tools	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
5.9 Extending the field of application of hydraulics	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
5.10 Prevention of nipple collapse	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
5.11 Application specific compressed air quality	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	

Measure	Cost effects (investment) Increase in total machinery invest					**Module related** energy savings potential				**Total machinery** energy savings potential				Other environmental impacts of the approach				Market penetration		Limitations / remarks
	No difference	Max. + 0.2%	Max. +1%	Max. +3%	Above 3%	0 – 1.5%	1.5 – 5%	5 – 15%	Above 15%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	in **installed** machine tools	In **currently sold** machine tools	
5.12 Reducing channels of supply / dead volume	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.13 Minimizing losses due to leakages (pneumatics)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.14 Pneumatic Cylinder with optimized drive surface	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.15 Pneumatic Cylinder with multiple chambers	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.16 Single acting pneumatic cylinder	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.17 Targeted cut-off from air supply	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.18 Use of multiple valves	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.19 Pressure reduction	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.20 Using exhaust air	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.21 Optimized valve switching	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.22 Cascaded levels of pressured air	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.23 Sensor based monitoring of	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	

Measure	Cost effects (investment) Increase in total machinery invest					**Module related** energy savings potential				**Total machinery** energy savings potential				Other environmental impacts of the approach				Market penetration		Limitations / remarks
	No difference	Max. + 0.2%	Max. +1%	Max. +3%	Above 3%	0 – 1.5%	1.5 – 5%	5 – 15%	Above 15%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	in **installed** machine tools	In **currently sold** machine tools	
pneumatic systems																				
5.24 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
5.25 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
Energy-Efficient Cooling Lubricant Supply														Cooling lubricant savings						
6.1 Minimum quantity lubrication	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
6.2 Coolant lubricant supply through pressure control valves	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
6.3 Optimised pipe dimension for coolant lubricant supply	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
6.4 Cryogenic machining	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
6.5 High pressure jet assisted machining	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
6.6 Direct oil drop supply system	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
6.7 Vegetable oils as lubricants and hydraulic fluids	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	

Measure	Cost effects (investment) Increase in total machinery invest					**Module related** energy savings potential				**Total machinery** energy savings potential				Other environmental impacts of the approach				Market penetration		Limitations / remarks
	No difference	Max. + 0.2%	Max. +1%	Max. +3%	Above 3%	0 – 1.5%	1.5 – 5%	5 – 15%	Above 15%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	0 – 0.5%	0.5 – 1.5%	1.5 – 5%	Above 5%	in **installed** machine tools	In **currently sold** machine tools	
6.8 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
6.9 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
Cooling Systems and Use of Cabinet Heat																				
7.1 Machinery integrated heat exchangers	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
7.2 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
7.3 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	%	%	
Energy-efficient Tempering																				
8.1 Electric inductively heating	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
8.2 Thermal compensation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
8.3 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	
8.4 other:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐					%	%	

Thanks for your input.

We will evaluate the replies for the revision of the Task 5 report and will complement the survey findings with further evidence from the ongoing technology analysis.