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Detailed information on energy research

Making machine tools work more efficiently

Researchers are reducing the energy consumption of modern machining centres

BINE Information Service

When machine tools process complex components, often only about 20 % of the energy deployed flows into the actual metal cutting processes. The main loads tend to be peripheral machine components, such as cooling systems or hydraulic drives. In the Maxiem project, scientists from the Technische Universität Darmstadt and industrial partners are showing how this energy requirement can, in ideal cases, be more than halved.

Programme-controlled, fully automated machining centres are true multi-talents. They drill, mill, saw, turn and grind until, after numerous machining steps, the desired component has been created from a blank. The operating cost is minimal. The machines independently handle the necessary tool changes, tool movements and positioning of the workpieces on different rotational axes. However, in the development of such complex machine tools, the energy requirement has until now played a subordinate role. More important selling points have been the precision, speed, reliability and flexibility. As a result, even the machine manufacturers hardly know the actual energy requirements during use.

For some years now, however, there has been growing competitive pressure to reduce the energy consumption. Researchers from TU Darmstadt are investigating where the greatest savings potential lie in conjunction with machine manufacturers, component manufacturers and customers from the automotive industry. The latter have introduced comprehensive energy-saving programmes and, when purchasing new machinery and equipment, are looking to invest in solutions that are as energy-efficient as possible. In a survey conducted ahead of the Maxiem project (Maximising the energy efficiency of machine tools), the researchers determined how high the machine tool manufacturers themselves estimate the potential savings to be. They considered an efficiency increase of 10 to 15 % to be realistic. The results obtained by the researchers allow for far more optimistic forecasts.

This research project is funded by the

Federal Ministry for Economic Affairs and Energy (BMWi)

Fig. 1 *Starting up the machine for making energy measurements*

Fig. 2 *MAG XS-211 4-axis machining centre*

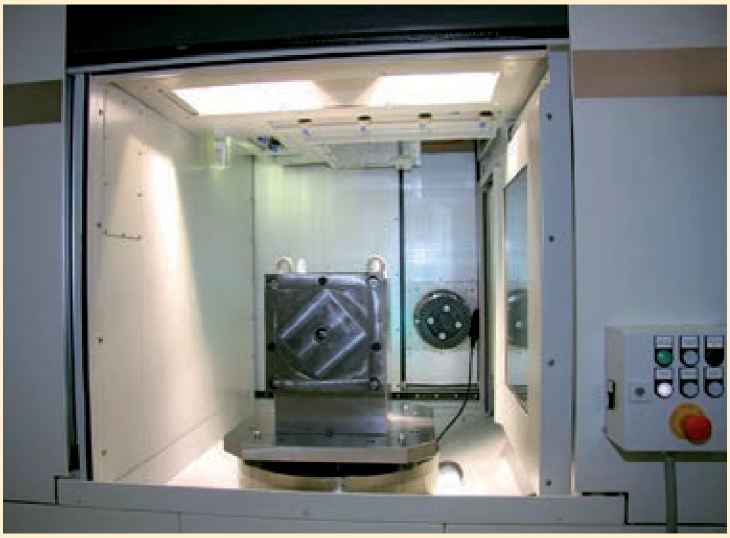

Fig. 3 *View of the workspace with a mounted workpiece on the work table*

By carrying out numerous optimisations to a machining centre, the researchers achieved, for example, savings of over 50 % compared with the initial state. Lower energy costs usually entail higher investment costs. However, even when retrofitting significant savings can still be made when calculated across the entire service life. Individual measures even pay for themselves after just a few months. The scientists provide decision tools and recommendations for action in their research report. The methods developed by them and a newly developed software tool are especially useful when designing new machine tools. It is now easier to predict the energy consumption of components during actual operation.

Analysing the energy consumption

A modern 4-axis machining centre (MAG XS-211), as used in the automotive industry for producing complex drive components, served as a demonstrator. This was specially modified for the research purposes.
At the beginning of the research work, the scientists analysed the energy consumption of individual function modules. It was found that the cooling lubricant systems (CL systems), machine cooling and hydraulics are the most energy-intensive system components. These also form the focus of the potential savings. To exemplify the diverse range of individual findings, some of the suggestions for improvements are presented below.

Cooling lubricants

The researchers found the largest efficiency reserves in the provision of cooling lubricants. Four pumps at various locations add or remove cooling lubricants (CLs). While a high-pressure pump supplies internal cooling lubricant for the main spindle, two low-pressure pumps rinse the machine bed and workspace. A further low-pressure pump delivers surplus cooling lubricant back into the storage tank. Overall, they consume 60 % of the total energy requirement.
As is currently the practice with such machines, the high-pressure pump provides a constantly high pressure of 50 bar against a permanently set pressure valve, regardless of the actual need. The volume of cooling lubricant that flows is also constant and does not accord with the requirements. Energy is applied to pump unused, excess liquid back into the tank. Substantial savings can therefore be made with speed- and pressure-controlled pumps. For this purpose, a variable-speed motor drive and a pressure sensor can be retrofitted. The control system is able to transfer pressure set points from the NC programme. After these optimisations, the power consumption for the high-pressure pump reduces by 75 %. The acquisition of efficient components pays for itself after about seven months.
Various options were calculated for rinsing the machine bed and workspace. Even the simplest solution, in which the unregulated pumps are used as before but are optimally designed to accord with the operating point, realise significant savings. The best possible variant was implemented and experimentally investigated. The researchers replaced both pumps with a joint, speed-controlled pump that uses pressure sensors to adjust itself to the requirements. Compared to the initial state, the energy requirement was reduced by 72 %. In the chosen scenario, such a retrofit would pay for itself in four years.

Regulating the machine cooling with lower losses

With around 15 %, the machine tool cooling consumes a significant propor-

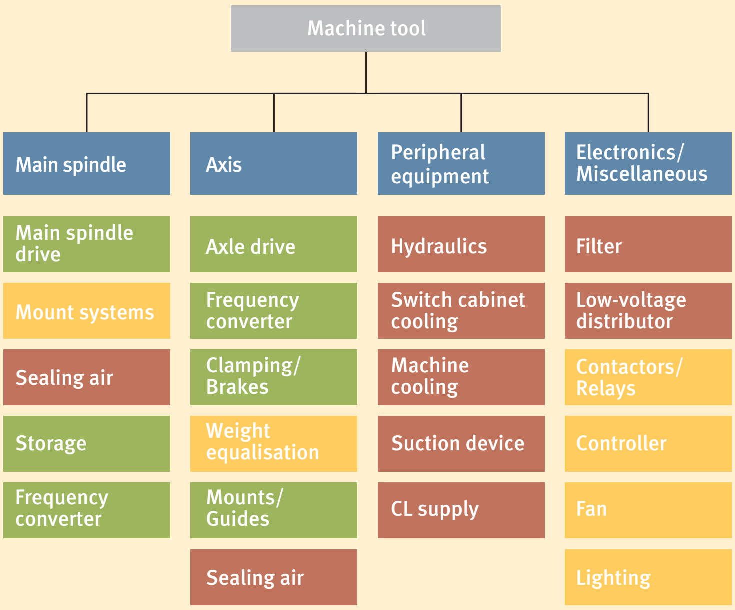

Fig. 4 *Machine structure tree of the components and function modules*

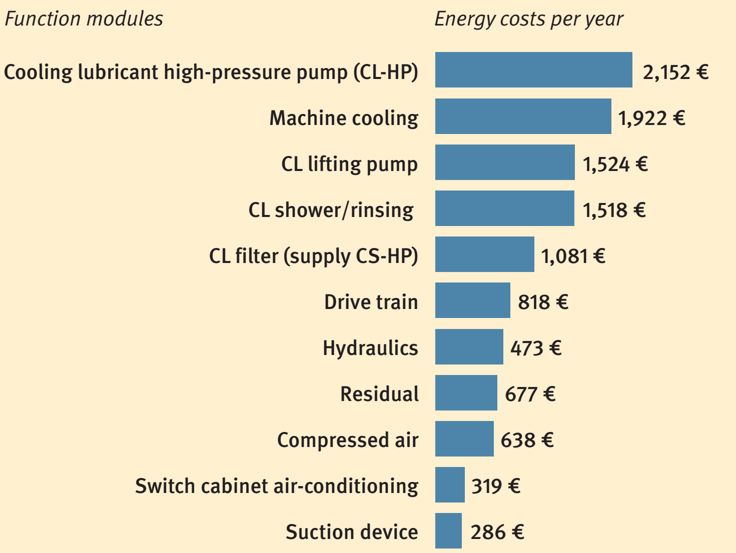

Fig. 5 *The cooling and hydraulics are the main loads for the machining centre*

tion of the total energy used, whereby 3 % is for air-conditioning the switch cabinet and 12 % for the cold water-based machine cooling. It is particularly important to cool the main spindle, since the temperature must be controlled very precisely here. Otherwise, the thermal expansion of the components could cause inaccuracies in the machined workpiece. In standard machining, a hysteresis of 1.5 K can be tolerated. In this case, the compressor for the re-cooling plant is clocked – in accordance with the power requirement. Highly precise finishing, for example with grinding processes, requires in extreme cases a maximum hysteresis of 0.1 K. The clock frequency necessary to achieve this would overly limit the service life of the compressor. Therefore, the temperature accuracy is usually achieved by actively destroying excess cooling capacity. These losses could be avoided by using a digital scroll compressor, which allows a wide-ranging power regulation. This enables savings of 30 % in partial load operation and even greater savings in standby mode. There are similar savings when using inverter-controlled compressors. As another possibility, the researchers also investigated mixing cold water. This provides a good alternative when there is sufficiently large storage.

Reducing hydraulic losses with poppet valves

The hydraulic unit works with a pressure accumulator to provide the accumulator charging operation. It is loaded via an internal gear pump comprising a grid-powered asynchronous motor as the drive. If the pressure in the accumulator drops below 115 bar, the pump uses a valve to switch from the pressure-free circulation into pumping mode until 120 bar is achieved. The valve then closes and the pump works again in the pressure-free circulation. The measurements showed that the pump is switched on every 27 seconds for a short time without hydraulic energy actually being used. This is caused by systemic leakage losses in the spool and/or pressure control valves. The researchers replaced the spool valves with poppet valves, thereby significantly reducing the leakage. The pump now only re-enters the pumping mode after more than 7 minutes.

Software supplies decision basis

For the work in the Maxiem project, the researchers developed a new software tool that compares and evaluates the different machine tool configurations. It is based on a database that stores the characteristic data for individual function modules. The programme already provides an overview of the energy flows and cost structures at an early stage. This makes it possible to estimate the energy consumption and power requirement in accordance with the components installed and the operating method. A cost calculation is also possible which incorporates the energy costs per workpiece and assumed cost increases.

From research into practice

The findings from the Maxiem project have met with considerable interest among the machine tool industry and its customers. By offering energy-efficient machines, the manufacturers can set themselves apart from the international competition and the users will make long-term savings through using such machines. Many machine manufacturers are already implementing the solutions shown. The researchers will continue developing the evaluation methodology together with individual machine tool manufacturers. The aim is to provide an application-ready tool for designing energy-efficient machine tools.

There is still considerable potential in terms of recovering energy, especially with the integral analysis of the entire production, ranging from the machine components to the building envelope. This path is being taken by the researchers from the TU Darmstadt with a new reference project, the eta-Factory.

eta-Factory – Industry 4.0

The joint “eta-Factory” project, which is funded by the German Federal Ministry of Economics, is investigating how the factory of the future might look like. Led by the Technische Universität Darmstadt, scientists are developing a highly energy-efficient model factory for machining metal. They are pursuing an interdisciplinary approach aimed at achieving substantial increases in efficiency by continuously optimising the “factory” as a total system.
The scientists are considering the interaction of buildings, technical building infrastructure and production machines in order to unlock further potential for increasing the energy efficiency. In addition to the possibilities for optimising the individual machines, a previously hardly tapped source of energy efficiency potential lies in utilising the waste heat generated during machine operation. Thermal storage systems and methods for transforming energy make it possible to absorb or provide energy both in spatial and temporal terms.
The eta-Factory will be used for training young scientists and transferring the results to industry. It aims to establish itself as an interdisciplinary training and learning factory at the Technische Universität Darmstadt and, through the interdisciplinary, cross-sectoral approach, strengthen the cooperation between the various disciplines and companies. The fourth industrial revolution is underway. It follows the mechanisation in the 19th century, mass production and digital automation. Communication technology, sensors and actuators are now changing the production technology fundamentally. Logistics and production are networked. Machines recognise current operating conditions, communicate with one another and optimise processes autonomously. However, people are not superfluous in the modern factory. Rather, they receive real-time information as a decision-making basis and depend less on vague experience values or statistical probabilities. The cost advantages of mass production are maintained and, at the same time, products can be increasingly better adapted to individual customer requirements. Rather than just selling products, they are bundled together with high quality services and marketed as a hybrid product. The German federal government has responded to these new opportunities with the “Industry 4.0” high-tech initiative (www.plattform-i40.de).

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