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ENERGY OPTIMIZED MACHINE TOOLS AND PROCESSES WITH ADVANCED MEASURING TECHNOLOGY AND EVALUATION

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ABSTRACT

Today, end users as well as manufacturers are interested in both efficient, high-quality products and highly efficient production processes. Therefore, energy-optimized machine tools and processes are examined. To reduce the level of energy consumption it is necessary to know the energy costs per machine hour and the ratio of energy expense related to the machined part. One approach is to measure and analyze the power variation of machine tools used in production processes. Further, there is a need for an accurate and quick method to interpret such measurements and to provide recommendations regarding retrofitting components. This paper is based on a state-of-the-art method to determine the retrofit factor and discusses problems arising from it. With a new calculation method the retrofit factor is much more significant. This contribution compares the new evaluation with the existing method. Based on time-dependent measurements of machine tools, specific knowledge concerning the energy consumption of machining has to be utilized for evaluation.

Keywords: Retrofit factor, energy optimization, machine tools

1. STATE OF THE ART

To save energy, resources and costs in manufacturing, it is necessary to identify energy-saving potentials in machine tools. Energy laws, like the eco design law in the EU [1], lead to analyses of machine tools to understand in more detail their energy consumption.

The ISO-14955 standard, which is under review, focuses on environmental evaluation of machine tools [2]. The content of this standard is to evaluate machine tools with an energetic comparison, in order to determine which machine is more energy efficient for use in manufacturing. Processing strategies and tools, also play an essential role in saving energy.

The Institute of Machine Tools and Manufacturing (IWF) in Zurich has defined a classification factor - the retrofit factor [3].

For the energetic comparability of metal-cutting machine tools and their components, the retrofit factor is an optimization technique used to find inefficient components and modules in machine tools. It indicates which components have a large energy-saving potential.

A research paper from the Institute of Production Engineering (IFT) in Graz describes the modification of a weighting factor to calculate the retrofit factor [4].

The focus of this paper is the power measurement result of a CNC lathe with the new calculation method of the retrofit factor.

Process design strategies and power measurements of a test piece will be explained.

2. RETROFIT DEFINITION WITH MODIFICATION OF THE LOAD SPECTRUM NUMBER

The retrofit factor $I_{R,i}$[-] is a multiplication of two weighting factors (Formula 1).

$$I_{R,i} = A_{E,i} \cdot A_{0,i} \qquad \text{... (1)}$$

The most important steps for the calculation of the retrofit factor are explained in the following. The first weighting factor $A_{E,i}$[-] describes the energy ratio of the considered component to the total energy of the machine tool (Formula 2).

$$A_{E,i} = \frac{E_i}{E_{Total}} \qquad \text{... (2)}$$

The load spectrum number $A_{0,i}$[-] is defined as follows: First, the power performance curve of a component is normed. Second, the normalized values are rearranged in a cumulative frequency distribution. Finally, the area $A_{c,i}$[-] of the normalized power performance curve is calculated. Figure 1a) shows an example of an energy distribution of a machine tool, and Figure 1b) shows the area $A_{c,i}$[-] of a component with its power distribution.

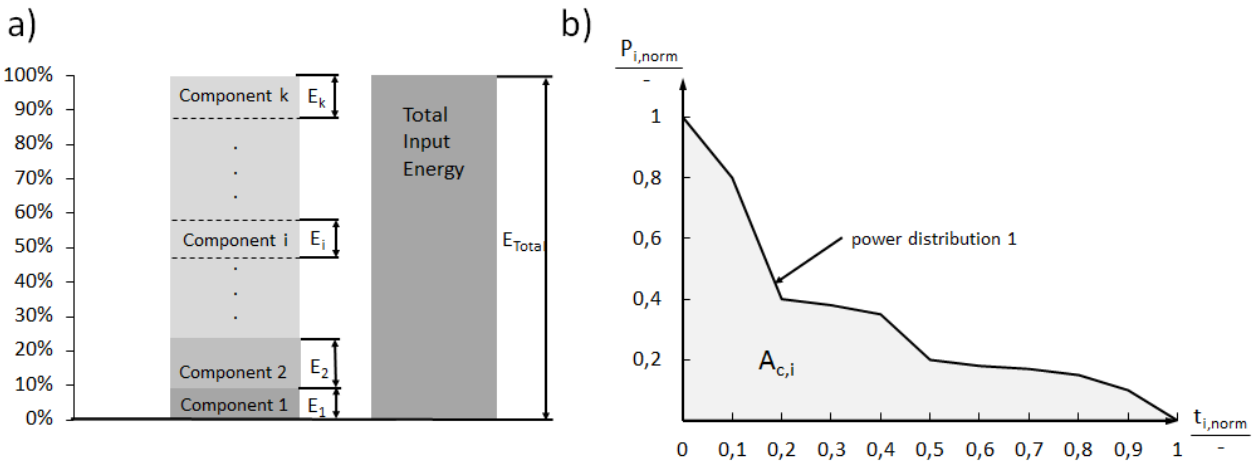

Figure 1: Example of an energy distribution of a machine tool.

The second weighting number $A_{0,i}$[-] describes the load spectrum of the component. It is calculated in the following way: An ideal working component has a constant power consumption and a constant power distribution. The area $A_{c,i}$[-] of an ideal power distribution is one. The weighting number $A_{0,i}$[-] is the difference of the ideal area and the area $A_{c,i}$[-] (Formula 3).

$$A_{0,i} = 1 - A_{c,i} \qquad \text{... (3)}$$

The smaller the area $A_{c,i}$[-] is, the larger the weighting number $A_{0,i}$[-] becomes. The higher the load spectrum number, the greater the retrofit factor. A high value of the retrofit factor indicates that the energy-saving potential of a component is high.

3. PRACTICAL IMPLICATIONS

Several power measurements on a CNC lathe are performed to evaluate the new method. It is necessary to define a test piece and process parameters for the evaluation. As a test workpiece a steel shaft is chosen, where different steps are turned down. Components are measured which are needed for the processing of the test workpiece.

Figure 2a) shows the total power consumption of the CNC lathe and the milling spindle capacity when manufacturing a test workpiece. The milling spindle has only a low power requirement. The high performance peak is due to the facing. This peak is required to define the timing interval, so that the amount of energy for the weighting factor A_E[-] can be determined. Figure 2b) shows the distribution of energy in the CNC lathe.

The biggest energy consumers are the main spindle, cooling pumps, hydraulic pump and the cooling unit. These components also have the largest energy-saving potentials. The load spectrum has also been taken into account in an efficiency analysis. The feed axis in x and z direction demand a low amount of energy because they are seldom needed in manufacturing the test workpiece.

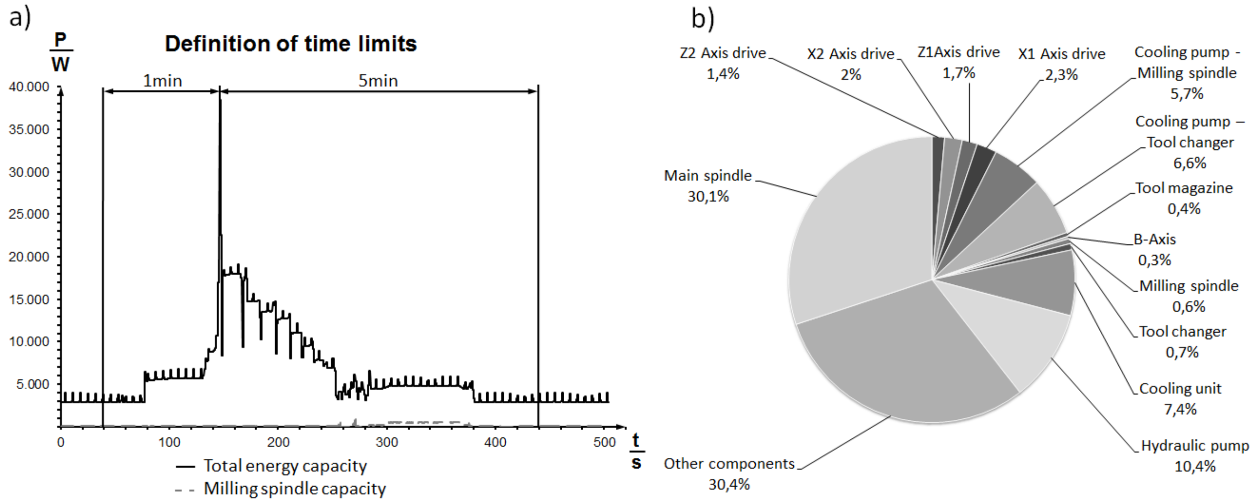

Figure 2: a) Total power consumption of the CNC lathe b) Energy distribution when manufacturing a test workpiece

Table 1 compares both retrofit methods. The total energy consumption of the machine is 702 Wh when processing the test workpiece. In total thirteen components have been measured that are used for the processing. The unmeasured components require a power consumption of 214 Wh. From the determination of the amount of energy the weighting number A_E[-] can be calculated.

Table 1. Comparison of the IWF and IFT evaluation method.

.	E_i [Wh]	$A_{E,i}$ [-]	$A_{0,i}$ [-] - IWF	$A_{0,i}$ [-] - IFT	$I_{R,i}$ [%] - IWF	$I_{R,i}$ [%] - IFT
Milling spindle	4	0.006	0.630	0.849	0.36	0.48
Hydraulic pump	73	0.104	0.359	0.735	3.74	7.65
B-Axis	2	0.003	0.786	0.933	0.22	0.27
Tool magazine	3	0.004	0.334	0.768	0.14	0.33
Cooling pump – Tool changer	46	0.066	0.720	0.896	4.72	5.87
Cooling pump – Milling spindle	40	0.057	0.791	0.930	4.51	5.30
Main spindle	211	0.301	0.810	0.936	24.36	24.12
X2 Axis drive	14	0.020	0.608	0.884	1.21	1.76
Z2 Axis drive	10	0.014	0.808	0.948	1.15	1.35
Cooling unit	52	0.074	0.970	0.006	7.18	0.04
Tool changer	5	0.007	0.937	0.983	0.67	0.70
X1 Axis drive	16	0.023	0.023	0.757	0.05	1.73
Z1 Axis drive	12	0.017	0.788	0.940	1.35	1.61
Other components	214					
Total component E_{Total}	702					

By evaluating the load spectrum of the individual components, the second weighting factor A_0[-] can be determined. The retrofit factor shows that the biggest energy consumers have the biggest energy-saving potential. A significant difference arises in the cooling unit and hydraulic pump. The cooling unit takes on a constant power and the power distribution is nearly constant. The load distribution number $A_{0,i}$[-] of the cooling unit is low, because the area $A_{c,i}$[-] is nearly one and the weighting number $A_{0,i}$[-] approaches zero. In the IWF method a trend line is placed in the determination of the load distribution number $A_{0,i}$[-]. The trend line has a certain angle and is used for to determine the factor $A_{0,i}$[-]. That is the causes of this difference.

The hydraulic pump has a fluctuating power curve when processing the workpiece. The IFT method rates the hydraulic pump better than the IWF method does.

4. PROCESS DESIGN

The process design is a main factor for saving energy, costs and resources during manufacturing. The power consumption can be optimized by selecting the correct tools and process strategy. The power measurements on the CNC lathe shows that the cooling pumps especially require a lot of energy. With an industry partner, power measurements have been made just to see the influence of changing the cutting-edge geometry of a milling tool and changing the process strategies. By optimizing the cutting-edge geometry and process strategy, a non-negligible amount of energy can be saved. Examining different geometry for cutting tools shows that the choice of cutting tool has an important influence on the energy consumption for manufacturing a working piece [5]. Furthermore wet processing and dry processing by milling a reference hole with a diameter of 90mm were analyzed. Due to the low efficiency of the compressor for air cooling during the dry processing, its energy consumption for processing a reference hole is greater than during the wet processing.

Power measurements have shown that different maximum power peaks can arise. The power consumption of a machine tool is obtained by the superposition of the individual power consumptions of individual components. To avoid large peak loads, a strategy could be used, to push load peaks into valleys, where consumption is low, and thus to keep consumption below a certain overall limit. This can be used for load management to analyze the quarter-hour values, which energy companies use to calculate the price of their service provisions.

5. CONCLUSION

The power measurements have shown that the retrofit method is a good way to compare components. However, the results depend greatly on the geometry of the test workpiece and of the cutting parameters. By measuring several machine tools it can be determined which machine tool is better suited for processing. The difference between both IWF and IFT evaluating methods is clearly seen in components that operate at an almost constant level of performance. The disadvantage of the IWF method is that the working components with different load spectrums can have the same trend line angles. With the same angle of the trend lines but different load spectrum characteristics, the weighting number $A_{0,i}$[-] is the same. In the IFT evaluating method the load spectrum is taken into account with the area $A_{c,i}$[-] and provides more practice-oriented results.

The load management plays an essential role in avoiding high energy costs. With an optimized overlay of the component performances, load peaks can be avoided. Further power measurements in different processing strategies can yield a better understanding of improving the efficiency of machine tools.

6. REFERENCES

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