# ANALYSE OF LOAD PROFILE OF A VERTICAL AND HORIZONTAL MACHINING CENTER

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## 1. Introduction

Energy efficiency and sustainability have become important topics in manufacturing industries, because of increasing demands like public pressure to minimize $CO_2$ emissions and rising energy costs. Some optimization approaches like the use of sustainable materials, the reduction of energy consumption and the minimization of manufacturing costs were the basis of many former research projects and are now state of the art in some companies. At the Institute for Production Engineering and Laser Technology several machine tools [1] are analyzed with a focus on their energy consumption and the first results of basic research work have already been conducted [2] [3]. Hence the approaches for saving energy are the reduction of base load, the compensation of current peaks and the use of secondary energy.

## 2. ENERGETIC COMPARISON

For the reduction of the base load, an analysis of the energy consumption during a load process contrary to an idle process is necessary. An idle process is the movement of the spindle without chipping. An analysis of the above mentioned processes was performed and an Energy-Efficiency-Factor $\eta_E$ was developed (1). To compare machine tools of different types the coefficients a (2) and b (3) were added. The coefficient a corresponds to the different base loads and the coefficient b corresponds to the different processing loads of several machine tools (index i). The index min relates to the machine tool with the minimal energy consumption i.e. the reference machine tool. Equation (1) with the coefficients a = 1 and b = 1 can be used to analyze the energy efficiency of a single machine tool. Figure 1 shows the lower part of the course of the function. An example is shown in C..

$$\eta_E(a_e) = \left[1 - \frac{\int_{t_1}^{t_2} f(t)_{idle}^{i} dt}{\int_{t_1}^{t_2} f(t)_{load}^{i} dt}\right] ab \qquad (1)$$

$$a = \frac{\int_{t_1}^{t_2} f(t)_{idle}^{min} dt}{\int_{t_1}^{t_2} f(t)_{idle}^{i} dt} \qquad (2)$$

$$b = \frac{\int_{t_1}^{t_2} f(t)_{load}^{min} dt - \int_{t_1}^{t_2} f(t)_{idle}^{min} dt}{\int_{t_1}^{t_2} f(t)_{load}^{i} dt - \int_{t_1}^{t_2} f(t)_{idle}^{i} dt} \qquad (3)$$

$$[0 \leq f(t) < \infty \ , \ f(t)_{idle} \leq f(t)_{load}]$$

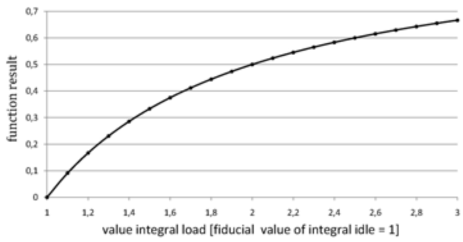


**Fig. 1:** course of function (lower part)

In these paper two machine tools from the company HAAS have been analyzed: An EC 300 and a VF 3SS. For both machines the same workpieces, cutting tools and cutting parameters were used. To measure the electrical current the signals of the alternating current sensors were sampled with a frequency of 10 kHz and a sampling rate of 1 kS [4].

Although the basic machine structures vary, most of the electronic components are similar. The EC 300 has a horizontal spindle and the VF 3SS a vertical spindle. Furthermore the EC 300 has an integrated pallet changer and therefore more electrical drives. This leads to an increased base load compared to the VF 3SS.

Figure 2 shows a peripheral milling process in X-direction for the EC 300 ($a_p$ = 5mm, $v_c$ = 120m=min, $f_z$ = 0,1mm/Z). The same process at idle speed is shown in Figure 3. In Figure 4 the results of the analysis of the two machine tools are shown. Similar results are found for the chipping process in Y-direction.

Fig. 3a compares stress-strain characteristics for pig coronary arteries in circumferential and longitudinal direction.

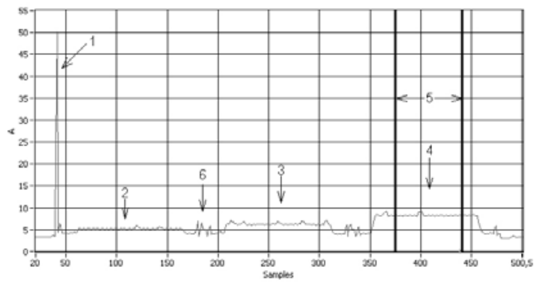


**Fig. 2:** Load process, fast traverse 50%, EC 300

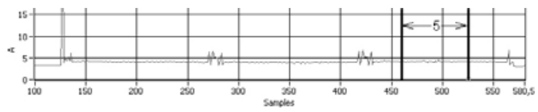


**Fig. 3:** Idle process, fast traverse 50%, EC 300

The meaning of the numbers is as follows: One for ramping-up of spindle, two to four for peripheral milling of ae = 2mm, 4mm and 8mm, five for an example of an integration limit and six for a fast traverse of the axes between the processes.

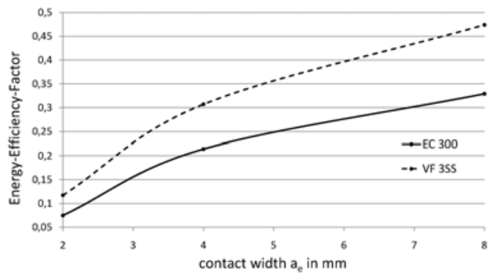


**Fig. 4:** Energy-Efficiency-Factor

Example: Table 1 contains the measurements of the two machine tools with a contact width of 8mm. Equations (4) and (5) show the corresponding calculation of $\eta_E$ for the EC 300. Since the VF 3SS is defined as the reference machine tool, the coefficients a and b corresponding to the VF 3SS would become one for the same calculation.

| Machine | $\int_{t_1}^{t_2} f(t)_{load}^{min} dt$ | $\int_{t_1}^{t_2} f(t)_{idle}^{min} dt$ | $\eta_E$ |
|---|---|---|---|
| VF 3SS | 17,82 | 9,38 | 0,47 |
| | $\int_{t_1}^{t_2} f(t)_{load}^{i} dt$ | $\int_{t_1}^{t_2} f(t)_{idle}^{i} dt$ | |
| EC 300 | 21,39 | 11,25 | 0,33 |

**Tab. 1:** Integral- values and $\eta_E$ at contact width 8mm

$$\eta_E(a_e = 8mm) = \left[1 - \frac{11,25}{21,39}\right] ab = 0,33 \quad (4)$$

$$a = \frac{9,38}{11,25} \qquad b = \frac{17,82 - 9,38}{21,39 - 11,25} \quad (5)$$

## 3. Acknowledgements

The base load in general and the delta between the load and the idle process of the VF 3SS is lower compared to the EC 300. Different idle integrals of the two machine tools cause the divergence of the two curves. All these circumstances lead to the result shown in Figure 4, in which the VF 300 is pointed out as the more efficient machine tool.

As mentioned in 2., this method can be used for machine tools of the same type. For the comparison of completely different machine tools, as for example with four and five- axes, some correction factors have to be developed. Also the measurement of the cutting forces and the calculation of the cutting power are necessary to be able to interpret the whole complexity of the energetic consumption of a machine tool. This research should lead to new knowledge about how to build machine tools with a low energy consumption, and therefore saving energy in general [3].

## 4. References


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