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Energy Efficiency Evaluation for Machining Process in Flexible Manufacturing Systems — A Case Study

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Abstract

In the industry, the cost of electricity, although increasing, is not regarded as a production cost, and thus the energy efficiencies of equipment are usually not considered. To gain knowledge about energy efficiencies in the machining industry, this study proposes a new method of evaluating the machining process and the machines, devices, and equipment involved. To validate the suggested method, a case study in the automotive industry is presented, comparing the machining processes in two flexible manufacturing systems, one in which aluminium is machined and the other in which cast iron is machined.

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Keywords: machining process; energy efficiency; machining; electricity; automotive industry

1. Introduction

In the industry, it is common for the electricity consumption in manufacturing processes not to be considered as a production cost and to be monitored in kWh/month. Moreover, as the consumption is heavily influenced by the production volume, it is impossible to assess the energy efficiencies of different machines and manufacturing systems. Therefore, this study proposes a method, based on efficiency per machine, for evaluating the energy efficiency of a manufacturing system independent of its production. An automated lean manufacturing system composed of different processes is considered in this study. The first step in the proposed method of evaluating efficiency is to determine the electrical losses in the manufacturing line by identifying the less-efficient processes and machines. Many researchers have suggested calculation methods for identifying such inefficiencies [1–3], but all of them analyse only the manufacturing process and do not take into account the consumption of the CNC (computer numerical control) machines. These methods do not permit the comparison of different processes, machines, and manufacturing systems. Renaldi et al. classified the manufacturing process into three categories, namely removal or separation (milling, turning, grinding), addition (sintering, soldering), and mass conservation (forging, bending, laminating), and developed equations for each category [4].

The machining process was chosen in this study to investigate the electrical energy efficiency because, in factories with machining processes, electrical energy accounts for a third of the total cost, and this cost is expected to increase every year, especially with the inclusion of automated machining processes. In order to calculate the energy efficiency of the machining process, it is necessary to understand the energy flow in the machining mechanism. During machining, the material is removed after undergoing elastic and plastic deformations, which cause heat generation. In this energy model, as illustrated in Fig. 1, the chip, heat, and material to be removed are the useful output, internally lost exergy, and consumed input, respectively. Moreover, the reused cutting fluid, lost cutting fluid, and power are the reusable transient exergy, externally lost exergy, and transient input, respectively. During the cutting process, heat energy losses occur in the region of shear. Thus, less energy is used

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when a particular piece is machined with fewer passes than with a larger number of passes.

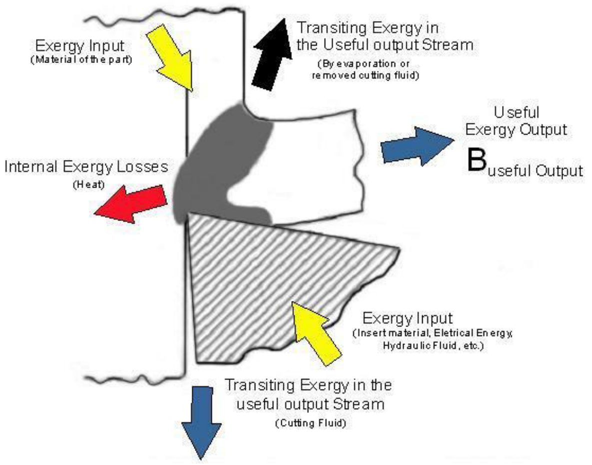

Fig. 1. Energy analysis of machining mechanism

The energy efficiency of the machining process is directly associated with the CNC machine as well as with the entire manufacturing system, because this system works in an integrated manner. For example, the energy efficiency increases when the path of the cutting tool is decreased, because of the lower energy losses from power consumption and the movements of the machine axes, spindle, pumps, and hydraulic system. The energy efficiencies of CNC machines and flexible manufacturing systems should be evaluated by considering the losses in the machining processes as well as in the energy entries such as compressed air, electricity, and oil. Thus, the aim of this study was to propose a method for calculating the energy efficiencies of CNC machines and manufacturing systems, with a focus on electrical energy. This method makes it possible to compare different CNC machines and manufacturing systems by identifying their losses. Such an evaluation is necessary because losses occur in the microscale, such as in chip formation during machining, as well as in the macroscale, such as in the CNC machines used in the manufacturing system.

1.1. Material

In this study, electricity consumption was measuring by an RE6000 portable power analyser (manufactured by Embrasul) installed at the entrance of the CNC machines and equipment, as shown in Fig. 2. The power analyser measures data, such as active power, reactive power, and effective power, at intervals as small as one hundredth of a second and stores the data in a file that can be transferred to a computer via network cable.

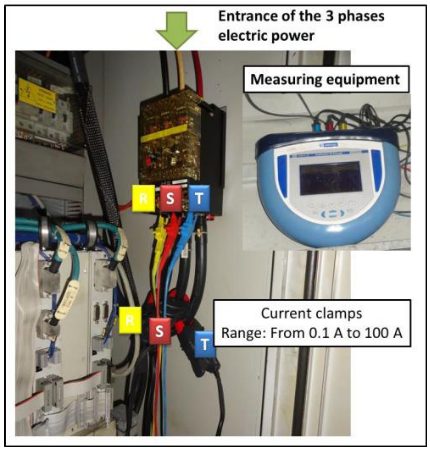

Fig. 2. Measuring equipment inside the machining centre

The data are recorded by a software programme within the measuring equipment and later opened in a spreadsheet, as shown in Fig. 3.

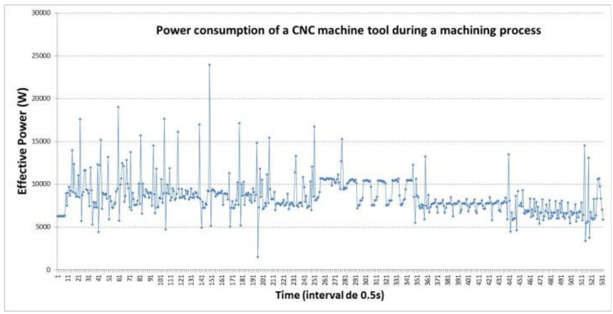

Fig. 3: Electricity consumption of a CNC machine tool during the machining of one part

1.2. Method

The method proposed in this study to evaluate machining processes and manufacturing systems is based on the energy efficiency formulations for the separation process, developed by Branham and Gutowski [5] and Renaldi et al. [4]. These researchers suggested Eq. (1) for calculating the energy efficiency η_r of the machining process.

$$\eta_r = \frac{B_{removed}}{B_{in}} \quad (1)$$

where

- $B_{removed}$ = exergy of the material removed during the machining process
- B_{in} = sum of exergy of the material to be removed and other input exergy