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Method for increasing energy efficiency in flexible manufacturing systems: A case study

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Abstract

In manufacturing systems, machines have been operated for years or decades without the concept of electrical energy efficiency, which has resulted in high manufacturing costs. In order to raise competitiveness by reducing energy costs, a method for systematically increasing energy efficiency is needed. This paper presents a new method to increase the energy efficiency of machine tools and equipment with computer numerical control (CNC) or a programmable logic controller (PLC). This new method was validated through application to three flexible manufacturing systems in the automotive machining industry as a case study.

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Keywords: manufacturing system; energy efficiency; electricity; energy; CNC machine tool

1. Introduction

Filippi and Ippolito [1] and Avram and Xirouchakis [2] were some of the first to study energy efficiency in machine tools with numerical control (NC). They compared data from 10 different NC machine tools involved in various operations. They concluded that the installed capacity was never fully utilized because the average power was less than half of the power available; only 60% of the total time was spent on production. Studies on the energy efficiency of flexible manufacturing systems for machining processes are necessary to define the input and output of the system in terms of useful energy. Several studies have attempted to link machining and environmental impacts. The first ones emphasising the importance of this relationship appeared in the early 1990s [3, 4]. Since then, new terms such as ‘green machining’ have gained prominence in the field of computer numerical control (CNC) machine tools and manufacturing processes. Energy efficiency is achieved by streamlining useful energy. A review of recent literature shows efforts being made to increase energy efficiency in the machine tool industry. For example, Weinert et al. [5] investigated reducing the cutting fluid used during the machining process. Rangarajan and Dornfeld [7] proposed a tool path and workpiece preparation method based on energy efficiency. Mori et al. [6] explored the monitoring of energy consumption by machine tools. Diaz et al. [8] investigated the reuse of electrical energy from a spindle. Neugebauer et al. [9] compared different drilling processes with different cutting tools and material removal rates. Suggestions to increase the energy efficiency of machining processes include turning some components of the machine off and on via NC or a programmable logic controller (PLC) [6, 10, 13], redefining the parameters of cutting tools to reduce the machining time [6, 11, 12], redefining the cutting strategy for the trajectory and path of the cutting tool [10], changing devices of low-performance machines for equipment with higher performance [10, 13], and setting machine parameters to reduce consumption (e.g. axis and spindle acceleration) [10].

For all five suggestions, examples include applications to cutting parameters, cutting strategies, and machine parameters which decrease the acceleration along the axes. Li et al. [13] showed the possibility of reducing the fixed energy consumption for different manufacturing processes for

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different machine states.

There are examples of increasing the energy efficiency by switching off and restarting the equipment or equipment parts during productive and non-productive times and how to implement this approach. Turning equipment on and off reduces the electrical energy consumption when the machine is in standby mode or in operation. This is true even when the equipment is responsible for a significant portion of the energy consumption of a manufacturing system. This approach has mainly focused on reducing the energy consumption of machine tools. This paper proposes a systematic method applicable not only to machine tools but also to any equipment in a manufacturing system with a PLC. The goal was to develop and apply the method to a manufacturing system. The proposed method improves on the work by Li et al. [13] to reduce the fixed power of machine tools.

1.1. Material

The electrical energy consumed by a machine is measured using measuring equipment. The measuring equipment is installed at the entrance of CNC machines and equipment. This research used the RE6000 portable power analyser (EMBRASUL) as the measuring equipment; this is shown in Fig. 1.

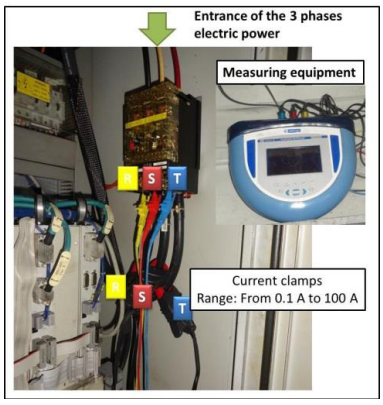

Fig. 1. Measuring equipment inside machining centre.

The power analyser stores data on the active power, reactive power, and effective power measured at intervals of up to hundredths of a second. Energy metering and monitoring is essential to obtaining authentic information from each individual machine, and the sample rate should be less than 0.5 s [13]. Data are stored in a file which can be transferred to a computer via a network cable. Data are obtained by a software program within the measuring equipment and later opened in a spreadsheet, as shown in Fig. 2.

After the power analyser is installed, the electrical energy consumption of each function is measured by programming the PLC. A function is a device which consumes electrical energy and executes an action. Examples include an electrical motor or electrical resistance. With the PLC, it is possible to switch the functionality of sub-components on or off to adjust the energy consumption.

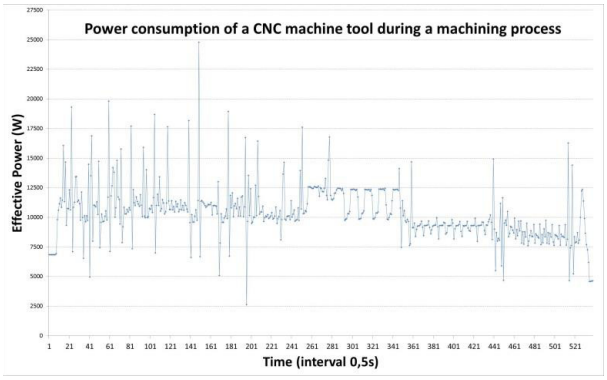

Fig. 2. Electricity consumption of CNC machine tool during machining.

2. Method

For current manufacturing systems, the development of a method to increase energy efficiency is essential to minimizing the impact of the rising costs of electricity. Industries with manufacturing systems which are more than 10 years old are common. Hence, there are machines and equipment that were designed without concern for energy efficiency, which wastes electricity. In order to avoid having to invest in more energy-efficient new machinery, a systematic method was developed in this study to improve energy efficiency in manufacturing systems with new or old machinery, which is presented in Fig. 3.

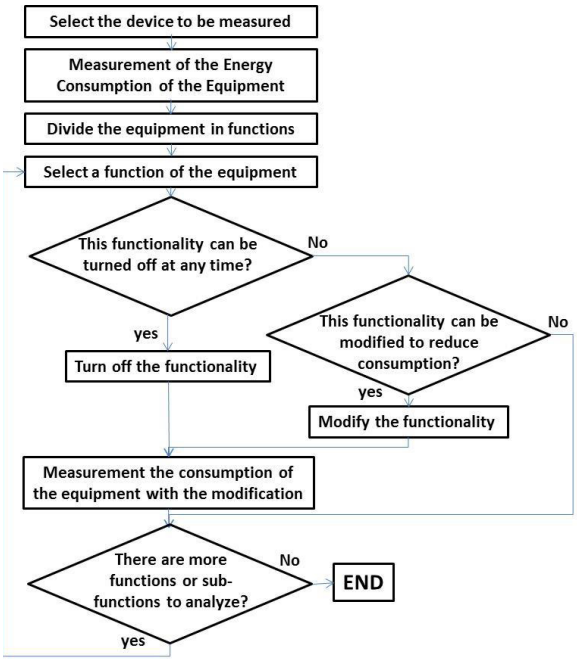

Fig. 3. Method to increase energy efficiency of equipment in manufacturing system.

The first step is to measure the energy consumption of the