A Framework to Collect, Assess and Reduce Energy Consumption of Manufacturing Equipment

Mehmet Bayram Yildirim[1], Janet Twomey[1], Lawrence Whitman[1], Haitao Liao[1], and Jamal Ahmad[2]

[1]Wichita State University, Wichita, KS, 67260, USA
[2]The Petroleum Institute, PO Box 2533, Abu Dhabi, UAE
jahmad@pi.ac.ae

1. Introduction

Worldwide industry consumes about half of the world's energy [1], and energy costs U.S. manufacturers $100 billion annually. Nowadays, energy use has become a major concern especially considering the depletion of non-renewable resources [2]. In addition to reducing manufacturing cost, energy reduction also positively impacts greenhouse gases as one kilowatt-hour of electricity reduces two pounds of carbon dioxide from being released into the atmosphere [3].

For the reduction of energy consumption many solutions have been proposed, but such reduction is difficult to achieve as it appears that consumption is not managed in a structured way. Gutowski *et al.* [4] notes that in the Toyota Motor Corporation 85.2% of the energy is used in non-machining operations which are not directly related to production of parts. Kordonowy [5] characterizes the power consumption of manufacturing equipment by analyzing the background runtime operations of machining (i.e., spindle, jog, coolant pump, computers and fans, etc.). It is found that over 30% of the energy input into the system during machining is consumed by these background processes. However, these calculations consider the whole system as opposed to a developed model for each process. Dahmus and Gutowski [6] observe that the total energy requirement for the active removal of material can be quite small compared to the background processes needed for operating a machine. In all of the above references, energy consumption calculations point out the magnitude of energy expenditure in non-process related activities and the potential for energy savings.

In order to wisely utilize energy at the sub-cellular operation level and eventually extend the methodology to the enterprise level, it is necessary to look into and quantify the components of energy consumption in each process. This paper reports on a framework for energy collection and operational models at *the machine level*. The framework gives detailed energy profiles of industrial equipment. That detailed profile not only provides an accurate assessment of energy consumed for a given material, machine, and part geometry, but also provides significant information for prescribing energy reduction strategies at the machine level. The intent will be then to integrate those models into energy consumption models at the facility level and ultimately into models at the enterprise level.

2. Key Features

The framework for characterizing the energy consumption of a machine and its subcomponents and determining energy waste consists of the following six steps: 1) Initialization, 2) Configuring the measuring device, 3) Capturing the total system power, 4) Analyzing the total system power, 5) Determining subsystems of primary focus, and 6) Capturing and analyzing subsystem behavior.

A detailed energy consumption profile for a CNC milling machine was obtained using the steps outlined above. It was found that most of the energy consumption is attributed to the machine controller. Additionally, the energy consumed by the spindle makes up 35% of the total energy consumption for that part being machined. However, the energy used to remove the material from the part accounts for only 19% of the total energy. Therefore, to make the milling process more energy-efficient, alternatives should be focused on minimizing the power consumption by the lights, controls and spindle in order to decrease the overall energy consumption.

Using this information in the detailed energy profile, one not only can predict the total energy required/consumed to produce a part but also audit the energy consumption for a machine. The potential applications of automating the energy profile are:

1) Calculating the energy required for machining any part of given geometry and material at any machining center
2) Evaluating the energy efficiency of different machining path optimization algorithms
3) Evaluating the energy efficiency of different part design using machined geometry

4) Evaluating the energy efficiency of different machining centers for machining a part
5) Designing micro-level scheduling algorithms to optimize energy efficiency in machining

A simple strategy for energy conservation is by turning the machine off during idle periods. This however will result in energy saving only when the idle energy consumption is greater than the energy spike caused by turning the machine back on. An application to lower energy consumption at a Wichita, KS aircraft supplier is given here for illustrative purposes. Two types of manufacturing equipment: CNC milling machines and CNC lathes, and two types of materials: aluminum and steel were investigated. It was shown that turning a machine OFF during idle periods could potentially save 13% to 62% per eight hour shift over four machines. In this application energy consumption is shown to vary somewhat according to the type of machine and mostly by production schedules. Energy consumption does vary according to geometry, but was not studied in this application.

3. Conclusions

A framework for energy collection and operational models at the machine level were developed. The framework gives detailed energy profiles of industrial equipment. That detailed profile provides significant information for prescribing energy reduction strategies at the machine level.

Scheduling intervention strategies for turning equipment ON/OFF during idle periods was proposed and its application to lower energy consumption at a Wichita, KS aircraft supplier is given for illustrative purposes.

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Author Biographies

Dr. Mehmet Bayram Yildirim is an Assistant Professor of Industrial Engineering at Wichita State University. His research interests include applied optimization, supply chain management, scheduling, transportation planning, pricing on congestible networks. Email: bayram.yildirim@wichita.edu.

Dr. Janet Twomey is an Associate Professor of Industrial Engineering at Wichita State University. Her research interests include intelligent data processing systems (neural networks, knowledge-based engineering, simulation, information systems, and statistics). Email: janet.twomey@wichita.edu.

Dr. Lawrence Whitman is an Associate Professor of Industrial Engineering at Wichita State University. His research interests include enterprise modeling and analysis, supply chain design, manufacturing systems applications, and production systems. Email: larry.whitman@wichita.edu.

Dr. Haitao Liao is an Assistant Professor of Industrial Engineering at Wichita State University. His research interests include reliability engineering and maintenance engineering (accelerated life testing, degradation testing, system reliability optimization, predictive maintenance). Email: haitao.liao@wichita.edu.

Dr. Jamal Ahmad is an Associate Professor of Mechanical Engineering at The Petroleum Institute in Abu Dhabi, UAE. His research interests include traditional and non-traditional machining of metals and composites, constitutive modeling of materials behavior and material characterization. Email: jahmad@pi.ac.ae.

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