CIRP Journal of Manufacturing Science and Technology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

CIRP Journal of Manufacturing Science and Technology

journal homepage: www.elsevier.com/locate/cirpj

Evaluation and modeling of the energy demand during machining

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ARTICLE INFO

Article history:
Available online xxx

Keywords:
Milling
Drilling
Energy efficiency
Modeling
Production planning
Embodied Energy
Cutting tools

ABSTRACT

This paper deals with the creation of a holistic and easy to use model for predicting energy use during machining operations. The created model offers the process planner the possibility to determine the electrical power demand of the machining operation before actual machining occurs. After checking the model results, the process planner is able to change many of the process parameters. With the new NC file, the model can be used again for evaluating the related energy demand.

The first step for setting up such a model is to understand what factors influence the power demand for the machining operation. Step two is the measuring of these factors and setting up a suitable model with each variable that can influence the energy demand. In the end, the electrical energy demand for the machining process of a certain part can be predicted with sufficient accuracy.

Introduction

Energy efficient production technologies present companies a significant competitive advantage and increase their ecological awareness [1,2]. Depending on the manufacturing technology used, the energy costs may have a significant impact to the overall cost of the produced goods [2,3]. Conserving energy is a significant market advantage in reducing production cost while, at the same time, being environmentally friendly in highly automated and energy intensive manufacturing processes.

In a strongly industrialized country like Germany, 45% of the electrical energy demand is required by the industry [4]. Almost one third of the energy is needed for metal production and machining [4]. An energy efficient use of resources is indispensable in mass production manufacturing processes. The need for optimizing the energy demand of these material removal processes can be seen in the increasing research activities across the field [5,6].

Basically, there are different possibilities for reducing the energy demand during chip removal. One possibility is to replace old and inefficient machine tools or to upgrade machine tools with new and energy optimized components [7]. These actions will have high energy saving potential because in the past the focus of machine tool development was in higher productivity and higher precision [8,9] and not in an efficient use of electrical energy.

Not until recent years the development of energy efficient machine tools and components has been focused by the machining industry [10]. However, a large amount of energy is already been lost during manufacturing of current machine tools [11]. Additionally, there are approximately 300,000 machine tools in use in Germany today [12] that cannot be replaced immediately.

Another possible way to save energy can be seen in the process configuration. Process developers can determine the bulk of the energy demand by choosing a certain machine tool, the selection of the cutting tools, and the definition of the cutting parameters. Using this technique can yield a difference in the energy demand up to 70% between two drilling operations on the same machine tool [13].

However reliable numbers and models are currently missing. The process developer has no chance to rate changes in process parameters or choice of machine tools or cutters to save energy. There is a need to understand the energy consumption of cutting manufacturing systems [2]. In this paper detailed energy measurements for tool manufacturing and machining are presented. The energy measurement of the machining is used to set up a model for the investigated milling machine tool. Herewith the process developer gets the possibility to evaluate the energy demand for a certain machining operation prior the real manufacturing.

Main variables of energy demand during cutting

The topic of this paper is the evaluation and predicting of the main energy influences for the energy required during chip removal operations. The forecast will be made for an existing

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http://dx.doi.org/10.1016/j.cirpj.2017.05.003
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machine tool to demonstrate the idea. All variables that could be affected by the process planner should be taken into account. Definitions of the system boundary are shown in Fig. 1.

The machine tool is the core element of the manufacturing process. Any machine tool needs electrical energy, most of them in addition compressed air, and in many cases also constant supply of cooling lubrication for manufacturing, which is usually neglected [14]. The cutting zone is applied with cooling lubrication (cooling lubrication or minimum quantity lubrication (MQL)). Cooling lubrication is not dissipated within the system boundary. The lubrication medium is circulated and filtered. The necessary pumps and filter devices are inside the system boundary, and their energy demands are also taken into account. The considered machine tool needs compressed air for sealing reasons or for the minimum quantity lubrication.

Generally, the compressed air is produced in centrally located compressors. The air is transported via pressure pipes to the machine tool. The required amount of compressed air has to be converted in electrical power to compare the energy demand with the other influencing factors. In Ref. [15] extensive measurements were made to gain representative numbers for the power demand for conditioning and transportation of the compressed air. Therefore, a comparison between the amounts of compressed air to the demand of electrical power can be made.

Dahmus and Gutowski divide the power demand of machine tools into three different modes: idle mode, run-time mode, and production mode [16]. Mativenga and Rajemi indicate the importance of the tool life for the whole energy footprint of a cutting operation [3].

Therefore the energy demand for machining can be subdivided into four different sectors. The 4 sectors are shown in Fig. 2.

Further energy values like the embodied energy of the workpiece are not taken into account, since the process planner is not able to influence this within the system boundaries.

Approach for the forecast model

For setting up a suitable model a detailed understanding of the power demand is necessary. The basic machine load consists of several different consumers; they are summarized for this specific machine tool (Hermle C30) to a constant power level. The process energy consists of two main factors, one is moving the machine (axis drives and main spindle) the other is the chip removal itself. Both power values are calculated and taken into account in the model. Also the amount of the necessary power for the coolant system is determined and used for the model. A routine imports the input data (NC file) and calculates the duration per NC-line. Each power value is multiplied with the duration to gain the energy per step. So a very detailed and easy to interpret result is given after the process planer activates the model.

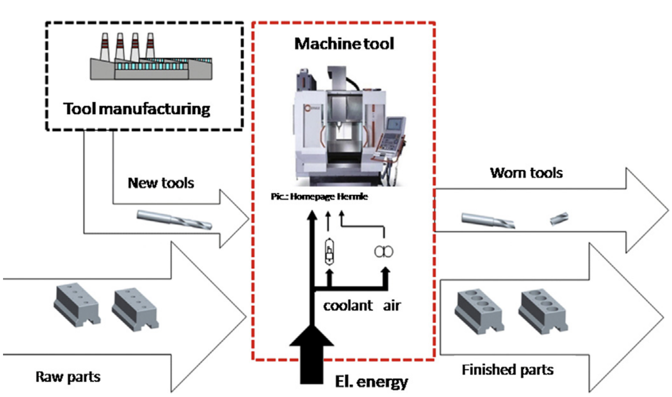

Fig. 1. System boundary for a cutting operation.

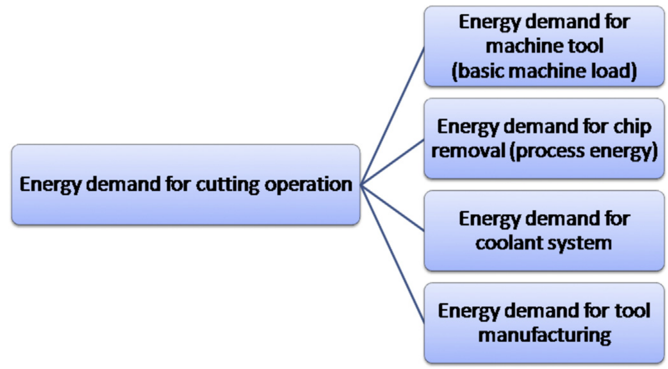

Fig. 2. Main influence factors of the energy demand for chip removal operations.

All these factors can be changed by the process planner — directly or indirectly. The necessary power demand of the **machine tool** can only be changed in an indirect way by the process planer. The power demand of the basic load cannot be changed, but the load cycle is controllable. With a choice of the cutting tools, the **process power** can be directly influenced by the process planer. Also, the power demand for the **coolant system** can be changed by the process planer. Different coolant systems have significantly different power demands. The process planer can take these different power demands into account with the choice of the coolant strategy and the operational time of the coolant system. The cutting tools are subject to wear during chip removal operation. Therefore, in this work also the necessary energy for **tool manufacturing** was taken into account for a holistic investigation. The energy amount for tool manufacturing cannot be changed by the process planer in a direct way, but with the choice of the process parameters the life time of the tools can be influenced. The amount of the energy for tool manufacturing, which has to be attributed to the holistic view, can be changed in an indirect way.

For this reason, there are no general approaches for energy consumption optimization. Main reason is the interaction of the different factors. Therefore, all four influential factors have to be measured and their interactions have to be taken into account for the energy forecasts. Only a holistic approach with all relevant energy consumptions allows an energy optimized operation.

Power for the machine tool

The core part of manufacturing is the machine tool itself. Immediately after the power switch is on, the machine tool requires energy. A detailed analysis of the basic load is necessary. An approach for measuring different machine conditions is introduced in Ref. [17]. Following this approach, a classification is necessary, because there are so many variables and demands of power consumption.

Indispensible consumers

There are many consumers which are activated automatically after using the main power switch. These are the control unit and the demanded compressed air. The spindle in this study (Kessler DMS 100) needs sealing air. Additionally also the hydraulic aggregate (FMB-Blickle Spannaggregat 6L) needs a power supply.

The air flow was measured with air flow measurement device (ifm SD 6000). The total amount of all indispensable consumers yields the absolute minimum demand on (electrical) power for the machine.

Please cite this article in press as: M. Rief, et al., Evaluation and modeling of the energy demand during machining, NULL (2017), http://dx.doi.org/10.1016/j.cirpj.2017.05.003