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Development and Application of an Eco-design Tool for Machine Tools

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Abstract

Improving the energy efficiency of machine tools is one of the challenges regarding the European energy saving goals. This work presents a new tool, enabling an effective quantification of a machine tool's (MT) energy consumption during all life phases. Scope of the presented tool is the fast and efficient estimation of a MT's cumulated energy demand and the systematic derivation of improvement measures regarding ecological performance. This work will present a framework, as well as the required calculations for this task. Using model and rule-based procedures, only a minimal set of input parameters is required to identify the hot-spots regarding energy consumption and improvement potential. Applications of this tool as well as a systematic approach to derive measures to increase the energy efficiency based on the output of the tool are presented on practice-oriented examples from industry.

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Keywords: machine tools; life-cycle assessment; energy efficiency

1. Introduction

Modern machine tools (MTs) are complex mechatronic systems with high demands on productivity and quality. The substantial number of MTs produced in Europe is reflected by the annual turnover of 22.5 billion € in 2012 generated by the MT industry [1]. These MTs reach from single machines to series products and show heterogeneity in implementation as well as in operation. During their operation MTs generally require substantially more energy and resources then during their construction. Hence, MTs are active products [2, 3] and have to follow the eco-design measures by the directive 2009/125/EC [4]. MT manufacturers are now challenged to establish a continuous energy and resource efficiency improvement in their product developments, as encouraged by the branch organization CECIMO for the purpose of self-regulation [5].

During the development of a new product, the degree of influence on the final product is reduced in each new development stage, while the information available about the final product is increased. The continuous improvement process of a MT is challenged by this opposed developments of information and degree of influence on the final product, as well as by customer-specific engineering. Customer specific engineering increases the diversity and thus limits the applicability of rule-based improvements procedures. Since the time effort for custom specific engineering is limited by cost factors, the question is how to identify and address the relevant ecological improvement potentials in a time efficient way. This work presents a new approach to evaluate the ecological performance of MTs in the design phase, in order to address the issue outlined above. The scope is thereby the required framework layout, implementation and application of the resulting eco-design tool for MTs.

2. State of the Art

Eco-design describes the consideration of the ecological performance during the product development [6], whereas the ecological performance refers to the interference of the products with the environment [7]. To quantify the ecological performance of a MT, two methodologies are required: Firstly, a methodology to acquire the relevant mass and energy flows, and secondly a methodology to aggregate the

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collected data and quantify the ecological performance. Metrological approaches to quantify mass and energy flows on MT are presented by Gontarz et.al. in [8] and Verl et.al. in [9]. ISO 14955 [10] generalizes this procedure into a measurement methodology. ISO 14955 further establishes the system boundary required for energetic MT evaluations as shown in figure 1.

To aggregate the collected data, carrying out a life cycle assessment (LCA) is a well-established method. The general procedure is given by the ISO standard 14040 [11]. The realization of a MT LCA is shown by Narita et.al. in [12]. In general such a LCA provides a detailed insight into the ecological performance of a product at the expense of a significant time-demand required for measurements and other data extraction. Another approach to quantify the product specific ecological performance is given by the cumulative energy demand (CED) as described in the VDI standard 4600 [13]. The CED is the sum of all energy and resource consumptions mapped to the required primary energy demand. The VDI standard 4600 [13], as well as other sources – e.g. Bey [14] – provide the required specific energy equivalents for this procedure. The CED can be calculated for each product life phase separately, leading to the life phase specific primary energy demand (LPED). In [3], the CED is used to quantify the ecological improvement potential of the MT industry.

Data acquisition for mass and energy flows on MTs is state of the art. Regarding the aggregation of this data, LCA and CED, are both established approaches, but a general procedure to apply LCA or CED on a MT in the development phase is lacking – especially in industry. However, the capabilities of a CED regarding the identification and estimation of ecological improvement potential of MT are proven. It is further assumed, that the CED specific effort complies better with the time available during the MT development, than the one of a LCA. This work therefore focuses on a generalized CED procedure for MTs embedded in a framework to support the development of ecological MTs.

3. Empirical basis

This work bases on mass and energy flow measurements on 35 different MTs performed by inspire AG and the institute of machine tools and manufacturing (IWF) within multiple industry projects. Among others, these measurements have contributed to the eco-design potential analysis by the Swiss association of mechanical and electrical engineering industries (Swissmem) [3], the ISO standard 14955-1 [10] and the training program of the Swiss federation [15]. In line with the work of other researchers [16-19] – the measurements have identified the following improvement potentials classification regarding the energy and resource efficiency of a MT:

- Functional fit: For an optimal efficiency, MT components have to be selected with respect to the intended use. I.e. speed control of a pump instead of a valve is required to satisfy a variable demand with optimal efficiency.
- Dimensioning: The efficiency of machine components generally depends on the operational point. Over-dimensioning is thus a common problem in the energy efficient design of MTs.
- Factory integration: MTs tools are substantial heat sources, while showing a significant sensitivity to thermal effects (elongation of structural parts). This implies energy intensive conditioning of the shop floor by the technical building services (TBS) and/or thermal compensation of the positioning errors.
- Operation without use (OWU): MTs have a substantial base load in electric power consumption. Hence non-productive times can have a crucial impact on the total energy demand.

To establish a generalized CED methodology for MT, the data acquisition steps and calculation procedures have to be designed in a generic way, while assisting the user in the typical challenges of a MT CED calculation. Previous applications have identified the following omnipresent challenges:

1. Problem decomposition: A MT is a complex assembly of components. Hence the problem has to be separated into several smaller but easier to examine sub-problems.
2. Heat loss and treatment: MTs produce a substantial amount of heat loss to be treated by the TBS. The information to quantify the TBS efforts is often lacking on the side of the MT manufacturer.
3. Schedule characterization: The MT operational schedule has to be characterized in a way suitable for a CED. In reality, the schedule characterizations are manufacturer specific or even non-existent.
4. Evaluation and presentation of results: Results of the CED must be evaluated and presented, such that improvement measures can be derived systematically. Otherwise expert knowledge is required.

Based on the existing empirical basis and experience, an efficient eco-design tool must be capable to identify improvement potentials according to the four presented classes, while assisting the user during the four challenges discussed above.

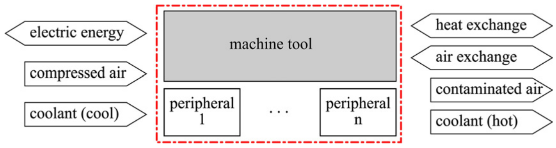

Figure 1: System boundary (red) of a MT according to ISO 14955-1 [10].

4. Approach

This work implements a three step procedure for MT CED calculation: First the machine is decomposed into its components, whereas a CED calculation is performed for each of these components in the second step. The third step includes the presentation and evaluation of the obtained and aggregated results.