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The Automated Evaluation of the Energy Efficiency for Machining Applications based on the Least Energy Demand

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Abstract

This paper presents the Least Energy Demand as a comprehensive reference value to evaluate energy efficiency. An objective evaluation and calculation of the energy efficiency of production processes represents a substantial challenge with regard to the state of the art. The reason for this is the lack of appropriate reference values. A comprehensive comparison of the energy efficiency is not possible without consistent reference values. First, in order to calculate such a reference value for different production processes, the basics to describe a closed system energetically are defined. Initially, several energy states and the various energy terms are defined to describe a production process as an energetic system. In a second step, the model for the activation energy based on chemical laws is introduced and its basic idea is transferred to the operations of the production processes of DIN 8580. For this purpose, appropriate general conditions have to be defined in order to be able to derive, finally, the existence of a Least Energy Demand for the execution of a production process according to DIN 8580. Based on this information to describe the Least Energy Demand for a specific process, the calculation of this crossbench reference can be automated evenly. By integration of CAD files it is possible to realize a pre-calculation of the Least Energy Demand for a specific product. Even through the interruption between machines controlling data, the crossbench calculation can be realized directly on the tool machine for further evaluation of the energy efficiency during the manufacturing process.

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Keywords: Energy efficiency; Energy Benchmark; Process forward-planning; Sustainable manufacturing;

1. Introduction

In light of the hitherto proposed withdrawal from nuclear energy in Germany and the continuous expansion of electric mobility, the country is facing an ever-growing gap in its energy supply. Renewable energy sources are not yet able to close this gap and to ensure the security of supply. As the current development of energy prices shows, the energy shortage results in the constant increase of electricity prices [2]. Therefore, immediate action is required in order to decrease the energy consumption as a sustainable pillar of the energy transition. [4] Because of its substantial leverage effect the manufacturing industry carries great weight as an important driver of the energy consumption in Germany; its different industries have relative saving potentials of up to over 20%. [1] For the identification of highly efficient production structures a comparison to derive specific saving potentials is possible.

The possibility of a meaningful evaluation and the comparison of energy efficiency hold the potential of furthering a company’s success in terms of increase in turnover, market share, and/or profit. [5][7] In order to gain the maximum use of the available potential, it is important that the energy efficiency can be assessed, compared, and evaluated not only across product categories, but also across industry sectors and enterprises. [6][8] Only by means of this is it possible to identify highly efficient production structures and specific saving potentials that can be a positive example and reference [5]. Because there is no clear description of the state of art in the presented analysis, a definition of energy efficiency has to be made. This approach is considered fundamental and serves

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as a basis for determining a system for evaluation. As a result, the defined relative energy efficiency grants information about the level of target achievement of the absolute energy efficiency and it allows a statement about the theoretically possible potential of energy savings.

2. Definition of the Relative Energy Efficiency (REE)

In order to establish the energy efficiency for the derivation of a formula, the following approach for determining the general efficiency is used. Besides the measured actual value, it also takes the reference value into account [9]: Under the presumption that the output is constant it can be reduced further and the relative energy efficiency is:

$$\text{Relative energy efficiency (REE)} = \frac{\text{minimal required energy}}{\text{actual consumed energy}} \quad (1)$$

Due to the fact that in most cases the consumption of electric energy is measured, the unit kWh is adequate as a consistent measurement parameter. The result of the REE calculation is without a unit and ranges from]0;100%] or]0;1]; a result of 100% is always intended. This outcome is possible if the actual energy use is equal to the minimal energy use, which results in the achievement of the absolute energy efficiency. The considerations illustrate that a statement about the degree of the energy efficiency can be made through the REE calculation and the theoretically possible energy savings potentials can be shown.

3. Definition of the Least System Energy Change Demand

The Least System Energy Change Demand ESM corresponds to the amount of energy that, at the very least, has to be provided to a system in order for it to execute a transformation. The energetic progression of a transformation is shown in Fig. 1. Initial (1) as well as final state (3) are always in a stable or metastable state. Between initial and final state exists an unstable state (2). The amount of energy that is required to reach this unstable state corresponds to the Least System Energy Change Demand ESM.

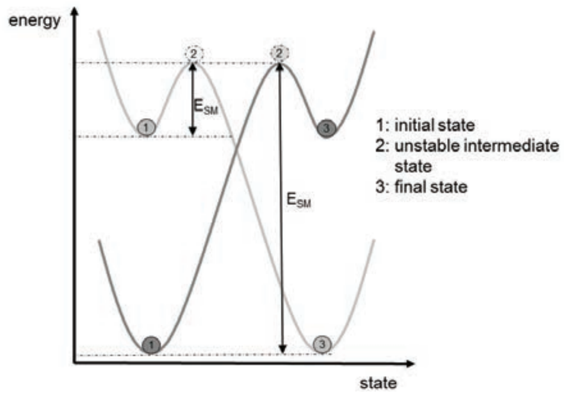

Fig. 1. Least System Energy Change Demand ESM following

4. Transformation of the Least Energy Demand model concept from the microscopic to the macroscopic level

Properties of macroscopic used materials: The transition of the model-like atomic interrelations into a macroscopic view of the materials requires the definition of the following terms: Materials are prepared out of raw materials or substances with particular techniques and production processes. Materials are converted generally into wrought materials, components, assemblies, process materials, and working materials [10]. The term material properties denominates the physical, chemical, and technological properties of a material. Most of these material properties can be specified qualitatively by means of so called material parameters [10]. A material parameter is a measurable material property that characterizes the mechanical, technological, thermic, optical, electrical, magnetic, chemical, and electrochemical behavior of the material [11]. A characteristic material value corresponds to the numeric value of a material parameter, which is determined in a standardized experiment [11].

Using these defined terms, the transition of the ESM from the microscopic level to the macroscopic level is done. This occurs by deriving the material parameters on the basis of the developed model concepts.

5. Derivation of macroscopic material parameters to calculate the Least Energy Demand on the basis of microscopic model concepts

5.1. Derivation of the breaking strength to determine the Least Energy Demand on the basis of the atomic physical model

The determination of the ESM for the atomic physical model is not directly transferable onto the macroscopic level - as it was shown for the chemical and thermodynamic model. In order to transfer the method for determining the Least Energy Demand from the microscopic to the macroscopic level a relation between the microscopic variable, the bond energy, which corresponds to the ESM, and the respective macroscopic variables, that means the characteristic material parameters, has to be created. For this purpose, the elastic modulus is estimated mathematically via the Coulomb potential model. The relation between the elastic modulus E and the atomic specific parameters, namely the bond energy U_0, the inter-atomic distance r_0 as well as the atomic specific constants n and m, is defined as follows [18]:

$$E = \frac{n \cdot m \cdot U_0}{r_0^3} \quad (2)$$

As (2) shows, the elastic modulus can be determined by means of the bond energy and the inter-atomic distance. It is only depending on the type of atoms, but not on its microstructure. Due to this relation the elastic modulus can already be well estimated on the microscopic level in contrast to the material parameters, which describe the strength. This statement on the interdependence of material parameters in the microstructures becomes clear when considering steel materials. The elastic modulus of ferrite, martensite, bainite,