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Artificial intelligence for an energy and resource efficient manufacturing chain design and operation

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Abstract

The energy and resource efficient manufacture of consumption and investment products is becoming a competitive advantage and companies are increasingly interested in optimal manufacturing chain design and process operation. Based on the discrete events modeling approach empirically parameterized process models for heating, hot-rolling, forging and turning are combined to two alternative manufacturing chains for the manufacture of countershafts. The discrete events also consider specific NC codes (e.g. for turning) and allow for time-depended consumption profile calculations. Further defining and structuring all parameters of the manufacturing chains with all their processes in so-called system entity structures provides the basis for a numerical optimization by artificial intelligence tools. A genetic algorithm in combination with a fitness function has been employed to find the manufacturing chain design and process parameter set with the lowest energy and resource consumption for the manufacture of the shafts in an effective way.

1. Introduction

The improvement of the efficiency of machines and manufacturing systems as well as the reduction of manufacturing costs have been important since the beginnings of industrial manufacture. However because of ecological and economic reasons, the energy consumption and more general the utilization of resources in manufacturing are becoming increasingly important. A continuously rising energy demand, coming along with a shortage of energy resources, causes energy costs to rise and to increase the burden on the ecosystem as well, as the main sources for the world energy consumption are still the fossil fuels. Energy and resource efficient manufacture of consumption and investment products is becoming a competitive advantage and companies are increasingly interested to design their manufacturing chains in an optimal way.

There have been various analyses targeting on the reduction of e.g. the energy and resource consumption of machine components [1], the energy consumption and the total life-cycle costs of manufacturing systems or of single processes [2, 3, 4]. Helu et al. [5] discuss the surface quality of machined parts relative to energy, resource and service costs. Teti et al. presented advanced methods for monitoring process states [6]. In order to allow for a flexible or alternative systems analysis regarding energy and resource efficiency as well as for its prediction during the design and planning phase of manufacturing processes as well as chains, capable modeling and simulation approaches are necessary such as described in [7, 8, 9]. Hagendorf has described such a method [10]. He employed the so-called system entity structure approach, which describes and structures the relations between the entities of a system, and modelled the manufacturing process of a workpiece by discrete events of process states that take place during the operation of a tool machine (cf. figure 1). When a part enters the event steering block (here 2-axis turning), parallel or successive machine control events are initiated at a given time according to the NC code of the specific part. All temporary energy and resource consumption are integrated over time and all changing states (e.g. new
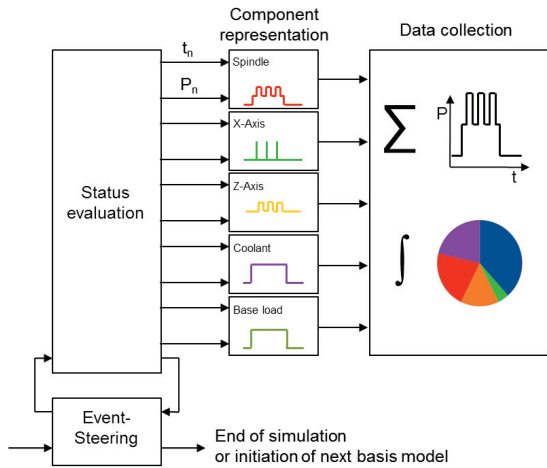
Fig. 1. Modeling the energy and resource consumption of a manufacturing process by discrete events systems [10].

Fig. 2. The manufacturing chain models, one involving hot-metal forming (left) and the other shaping by cutting (right).

shape) are recorded and returned to the entity, respectively the workpiece. Larek et al. [7, 11] have used the system entity structure and discrete event approach by Hagendorf to analyze and predict the energy consumption for a turning operation of a shaft. For this purpose all energy consuming entities and discrete events of a 2-axis turning machine respectively process were described and parameterized on basis of measurements. The comparison of the measured and calculated power consumption profile showed very good agreement.

In this contribution the approach by Hagendorf and Larek [7, 10] is extended to the manufacture of a simplified countershaft considering metal forming processes. To demonstrate its potential for a resource efficient manufacturing chain design two rather classical types of manufacturing chains were compared: a rather short cutting based one (turning) and a hot-metal forming based manufacturing chain. The analysis focused on the consumption of operation resources like materials (material removal, swarf, tool wear), fluids (drag out) and energy (electricity, gas).

2. The manufacturing process chains and process modeling

For the comparison of the two manufacturing process chains, it is necessary to define reasonable boundary conditions. In this analysis we chose to start from a bar stock material (Ø 62 mm) which allowed the direct turning of the shaft shape after cutting off cylindrical sections from the steel bar. Figure 2 shows the bar stock material data in the upper central block from which the two manufacturing chains are starting. They end at the turned sample shaft (center of figure 2).

The manufacturing chain involving hot-metal forming, starts with heating the bar stock material, followed by rolling it down to Ø 42 mm in order to make a better use of the material and to reduce the necessary material removal. Cylindrical sections are then die forged to the final shape,
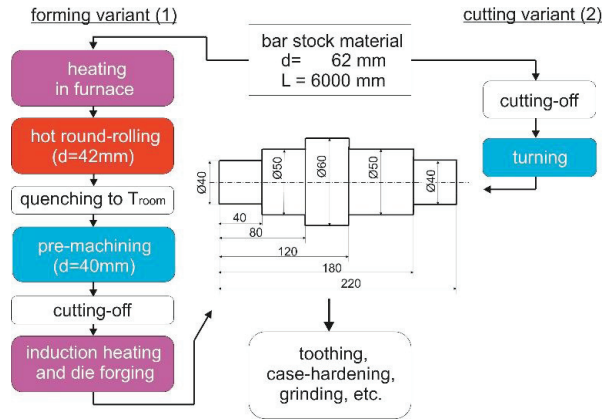
considering 2 mm for material removal. Following the considered shaping operations forming and turning possible toothing, heat treatment and grinding operations would follow for the manufacture of a countershaft. Since these processes would be the same for both manufacturing routes, they would contribute the same amount of resources consumption to both manufacturing chains analyzed here. Therefore they were neglected in this analysis.

In this analysis the so-called basis models for turning and heating developed by Hagendorf [10] and Larek et al. [7] were employed. Hence only the measurements, parameterization and process representation by discrete events for the additionally developed hot-metal forming processes, respectively the rolling will be discussed here. For the discrete event approach it is necessary to distinguish between a constant consumption level of a process, respectively machine, which is ready-to-operate and the load-dependent consumption state while in operation.

Figure 3 shows the power consumption profile of the auxiliary equipment of the analyzed rolling machine, which consists of a two roller stand, a gear box, a speed-regulated direct current motor and a hydraulic oil supply for the roller bearings. This profile is helpful e.g. for analysing and optimizing the energy consumption of auxiliary equipment, but also for describing the shutdown, stand-by and run-up behaviour of a process into the ready-to-operate state.
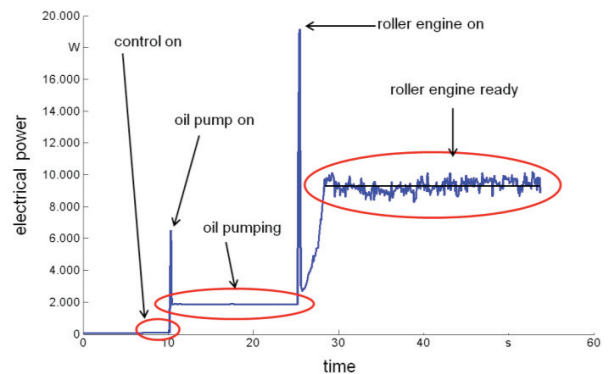

Fig. 3. Power consumption of a rolling machine
- from hibernation to ready-to-operate.