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Dawn of new machining concepts:

Compensated, intelligent, bioinspired

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Abstract

The impact of Industrie 4.0 onto machine tools is significant, despite the fact, that quite some of the novelties discussed within this new paradigm have their roots decades earlier. But especially the concerted action, which strives the development of sensors, controls, data processing together with connectivity, unprecedented data integration and the notion of cyber physical production systems open up new development lines towards manufacturing systems as enablers for the progress in manufacturing. Highly developed compensation concepts are developing into state depending AI-supported strategies. Maintenance becomes predictive, as learning of machines becomes global and model based. Further inspirations taken from biological systems are adopted for machining centres and drive a biological transformation of manufacturing machines. Machine intelligence becomes the basis for executing manufacturing processes, which requires a close integration of process intelligence (CAM-systems) and machine controls.

Keywords: Biologicalization, Industrie 4.0, Cognitive Technical Systems, Machine learning Strategies, Bioinspired, Biointelligent Manufacturing, Adaptive Thermal Compensation, Self-Organization, Self-Healing, Sensors in Abundance

1. Introduction

In the past 10 years it became obvious, that manufacturing provides the basis for a stable society. 20% of GDP as industrial production or 25% as production of tangible goods seems to be the basis of wealth even in a service oriented society. In the end, all thoughts of engineers have one unique dedication, namely to provide products to fulfill requirements of mankind. Therefore, it is not only money, that makes the world go round, but production machinery. The modern world is populated by about a new value of 350 billion $ of CNC driven machine tools, which is approximately 2.5 million CNC machines. As shown in Figure 1 each year a value of 50 to 60 million CNC machines is added, still increasing the population of CNC machines, because some of them replace non-counted non-CNC machines. Approximately 2/3 of them are cutting machines.

In 1951, the CNC control has already been invented, being one of the most groundbreaking developments in production machines, but the transition is still on its way. According to [47] from 2018 to 2025 the population of CNC machines in Europe will increase from 700'000 to 800'000, while non CNC-machines will strongly decrease in number. Since then the overall increase in productivity, which according to [58] is approximately 2 to 3% per year is basically supported by an incredible amount of ameliorations and better exploitation of the technology. Just as an example: a tool segment for the tire industry produced on one of the old punchtape based machines would require 1000 kg of punchtape, which moves this production clearly in the vicinity of technical overkill at that times. Figure 2 shows for a gear grinding machine the overall increase in productivity over the years, driven by enhanced process technology, enhanced tools, machine tool development being capable to withstand higher forces and vibration excitation, faster controls, more powerful drives, sensory, and better automation. Naturally also set point generation has largely enabled higher cutting speeds and it can be estimated that in case of more reliable cutting

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materials and better tool benign tool paths a reduction of production time in the two-digit percent range can be achieved. Within CIM in the 80s and 90s an attempt was made to automatize the strategy planning, an intelligence or experience requiring act within the process chain of cutting. This was not successful due to limited computational power and economic interests. In the meantime, additive manufacturing still in the stage of rapid prototyping showed the possibility to start manufacturing only a few minutes after the workpiece geometry has been provided, which takes hours in case of cutting. To face the truth, produced parts in rapid prototyping lack several industrial requirements indispensable in the mature cutting technology. But the discussion on the notion of a “five-minute-machine”, requiring machine intelligence has been implanted.

Compensation, as kinematic, thermal gravitational or dynamic compensation is one of the achievements in recent times towards accuracy, reliability and robustness. The physical modelling behind are highly complicated, if they take into account all the essential influential effects within a machine tool. Models in use and scientific discussion spread from physical to phenomenological approaches, and in this range from complex and nearly unmasterable to simple while vice versa the parameter identification effort ranges from simple to awfully huge. Self-learning approaches based on some model seem to be the suitable work around for dilemmas like this.

Obviously, the human ability to take up pieces of information, store and combine them and take decisions on the basis of information from different times and environments is valuable in those cases of complicated and even complex behavior. Also other capabilities of biological systems besides cognition, learning capabilities and intelligence are highly desirable for machine tools and deserve research, such as machine autonomy, abundance of sensors, sensor fusion and redundancy, swarm intelligence and fleet learning, strong reliance optical image recognition, self-healing or wear and failure compensation and also teaching competence. Bio inspired structures are topics already introduced at least on the scientific level into machine tools as demonstrated in [41], which is insofar a fairly weak approach, as the condition of manufacturability needs to be taken into consideration, which today is only done by intuition of some designer. But for sufficient development of additive manufacturing for large structures a really topology optimized lightweight structure can be realized. Bio inspired functional surfaces for machine tools suffer from the fact, that these structures are extremely vulnerable and their lifetime is strongly limited. Biological systems always come up with self-healing capabilities, restoring the fine surface structures. Therefore, the capability for self-healing opens new potentials in very different aspects from tool sharpening to play filling, but is still in its infancy.

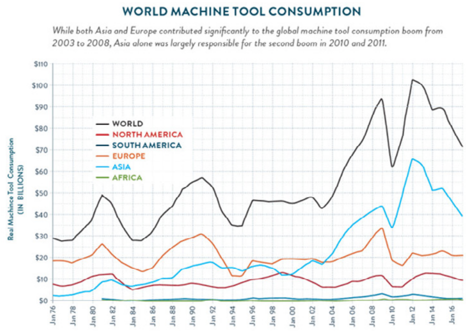

Figure 1: Increase of the machine tool population over time [60]

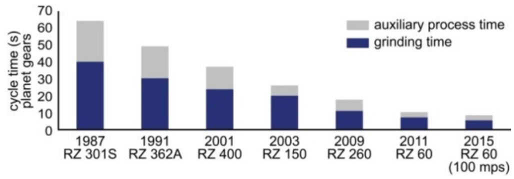

Figure 2: Reduction of manufacturing times (Courtesy Reishauer) [56]

2. Compensation

2.1. General remarks

Driven by accuracy requirements of machine tool applications the expenses for the mechanical improvements of machines by mechanical means are becoming more and more expensive. This requires a paradigm change which was attempted in several waves starting decades ago, namely to charge the control system with compensating for erroneous movements of the machine. These are always due to the fact, that positioning and position measurement of machine tool axes takes place far away from the TCP which shall be controlled and between those two the machine mechanics with its physically given insufficiency reigns. Several aspects today justify independent of earlier failures a reconsideration of this topic:

1.) A consequent design for compensation declaring repeatability as the highest principle has not yet been attempted [57].
2.) IT-technology of today offers drastically increased computational performance, especially if intensive number crunching required by the modelling approach is performed on the GPU (Graphical Processor Unit). Thus real time delivery of new compensation values becomes achievable.