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Content

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Smart and Networked Manufacturing

Preface

In our late-modern mindset, the industrial society's logic of the general, incorporated in the concepts of high volume production, is more and more replaced by the logic of the particular, the individualized, accompanied by the awareness of the need to taking care of our planet. We value the exceptional – unique products and objects, experiences, places, individuals and communities which are beyond the ordinary and which claim a certain authenticity. This decade will be dominated by society's changes e.g. in the thinking of mobility, which clearly affects the production industry. Among key enabling technologies, future manufacturing will change the way people and machines physically interact taking into account safety and ergonomics. Digitalization, connectivity and interoperability are of central importance for the next generation of manufacturing systems to connect products, machines, people and the environment – aiming for operational excellence, autonomous capabilities and the creation of physical value by using information. Cyber Physical Production Systems (CPPS) ultimately represent a central entity.

The 5th Wiener Produktionstechnik Kongress – WPK 2022 – addresses challenges of smart and highly adaptive manufacturing systems and the appropriate information technology including the application of machine learning algorithms for fast process adaptations. Top-ranked national and international experts from governmental organizations, industry and research institutions give insight into the newest results of technological, functional and implementation issues for industrial applications.

The WPK 2022 strives to connect decision makers, production managers and manufacturing engineers with a network of experts – an opportunity to discuss best practice solutions and to contribute in shaping the future of manufacturing. We are convinced that the topics of the WPK 2022 help to accelerate your progress in future manufacturing.

Univ.Prof. DI Dr. Friedrich Bleicher

Head of the Institute for Production Engineering and
Photonic Technologies,
TU Wien

The European Manufacturing System

K. Beetz[1]

[1]EIT Manufacturing

Keywords:

manufacturing, production, innovation, circular economy, sustainability, augmented workforce

1 Introduction

Key elements of process innovation deployment, including people, processes and technologies, are central to a successful implementation of digital transformation. Like in most industries, the transformation of manufacturing is impacted by the skills, well-being and innovative capacity of the workforce [1]. People, with their experiences and knowledge, are the most valuable assets [2] of the European industry leveraging a human-centred approach to Industry 5.0, as it is proposed by the European Commission [3].

Manufacturing is an integrated socio-technical domain, organising processes and logistics management frameworks through a methodical combination of best practices, while still allowing for continuous innovation and improvements. These manufacturing systems often determine the management philosophy as well as manufacturing operations strategy. The main objectives of existing manufacturing systems are to produce products in a competitive way, while reducing overburden and inconsistency as well as eliminating waste that has significant implications on process value delivery.

2 Manufacturing Systems

Many traditional manufacturing systems primarily focus on the optimisation of the constraints quality, time and cost [4] by designing processes that deliver the required results by reducing inconsistency. Multiple tactical and critical improvements in waste reduction and elimination ensure that processes are as flexible as necessary.

The Toyota Production System [5] (TPS) is one of the best-known production systems worldwide. However, it still has its shortcomings, especially when it comes to High Mix/Low-Volume Manufacturing processes and suitability for software-empowered human-machine interaction.

3 Current challenges and developments

With the emergence of global uncertainty in supply chains and unforeseen events like the COVID-19 crisis or man-made calamities like the war in Ukraine, it has become apparent that supply chain resilience and sustainability have gained tremendous importance in the minds of many individuals and society at large [6]. There has been increasing awareness to look at sustainability and flexibility as key drivers which have the same importance as quality, time and cost. Sustainability, circularity and environmental effects of production like decarbonisation and energy consumption have become determining factors that need to be considered when products are designed, engineered, manufactured and reused, thus adding additional constraints to modern manufacturing processes.

In response to numerous interrelated socio-environmental challenges, circular economy is a means of realising sustainable development. This is a notable shift from the current linear economy to a closed-loop system, which prioritises value retention, regenerative design and re-manufacturing of critical materials. It is imperative to see that the expected impact of sustainability, flexibility and resilience in combination with today's increased manufacturing capabilities through emerging technologies, new manufacturing concepts and value chains, requires a newly designed approach towards manufacturing systems [7].

4 Outlook

Therefore, EIT Manufacturing, in cooperation with its partners and network of contributors, is taking initiative by postulating the "European Manufacturing System" as a strategic objective for the European manufacturing industry, with universal implications. The "European Manufacturing System" is a vision to overcome traditional barriers, especially between enterprises, through an ecosystem approach. It features dual transition with sustainability as a decisive factor, while integrating emerging enablers, deep-tech technologies, e.g., artificial intelligence, quantum computing, smart sensors, VR/AR technologies, autonomous automation, trust-based cybersecurity and collaborative robots. Such deep-tech enablers are characterised by core features, e.g., connectivity, integration, intelligence, adaptation and socialisation. In addition, innovative manufacturing concepts like servitisation of manufacturing will be deployed in European value networks to improve resilience and flexibility. The "European Manufacturing System" provides a roadmap to the vision of autonomous, self-organised production and logistics.

Supported by the European data infrastructure Gaia-X [8], it is a foundation for a future-oriented business philosophy that becomes reality in the traditional manufacturing industry, impacting the workforce and society at large.

The “European Manufacturing System” places the PEOPLE at the centre. E.g., for data analytics systems, process know-how and strong tech skills are essential, but often only inherent in the minds of front-line workers and engineers. Technologies, methods and processes should augment and amplify human capabilities to enable a future of industrial work that is inclusive and accessible. This human-centric approach benefits all, the European industry and economy, the European workforce and the European societies to achieve resilience and sustainability.

Europe needs to overcome the potential weaknesses of its present manufacturing systems. By strongly driving the “European Manufacturing System”, the EIT Manufacturing community actively supports the European Union in its strategic goals to move towards a true twin transition. A renewed, competitive, green and digital European industry can be achieved through skilled people, emerging technologies and strong innovation capabilities – the key instrument of EIT Manufacturing.

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Learning what we already know: On the 50th anniversary of "The Limits to Growth"

C. Alvarez Pereira[1]

[1]Club of Rome

The seminal report to The Club of Rome "The Limits to Growth" was published in 1972 and it had a huge editorial success. Millions of copies were sold, the book influenced public agendas and created a wide debate, still ongoing. But overall, humanity did not find its pathway(s) towards equitable human wellbeing within a healthy biosphere, rather the contrary. We are now at a more critical moment than 50 years ago, with a multiplicity of emergencies converging into a suicidal path. In a new report to The Club of Rome, "Limits and Beyond", we suggest that the deep reconfiguration of societal patterns required for desirable futures can emerge from the present state of emergency. But positive emergence cannot be planned nor is it guaranteed. At the very least, it calls for allowing ourselves to explore a wider space of possibilities. Could we liberate our processes of learning from the incumbent mental frameworks which keep us imagining the "solutions" with the same lenses that created the "problems" in the first place?

We propose to question how research, innovation and technology are currently framed. This is the core intention of The Fifth Element program, recently launched by The Club of Rome. It is an invitation to put upside down the existing model of knowledge creation in order to respond to the challenges humanity faces today, which the disciplinary structures of conventional academia are unable to address. Rather than targeting supposedly universal solutions in a top-down manner, this approach bets on a multiplicity of pathways towards wellbeing in the biosphere, in which cultural and geographic contexts, traditional ecological knowledge, relational wisdom, and the best of modern science are woven together. As the name of the program suggests, the process intends to create patterns of learning inspired in how Life works. This has deep consequences on how we conceive economic processes, including the reinvention of the role of industry for desirable futures.

Gaia-X and the Federalisation of Dataspaces via an Open-Source Architecture Framework.

F. Bonfiglio[1], V. Orfanou[1], K. Lechowski[1], R. Goia[1]

[1]Gaia-X European Association for Data and Cloud AISBL

Abstract

Gaia-X represents the next generation of data infrastructure ecosystem: an open, transparent, and secure digital ecosystem, where data and services can be made available, collated and shared in an environment of trust. The architecture of Gaia-X is based on the principle of decentralisation. Gaia-X is the result of many individual data owners (users) and technology players (providers) – all adopting a common set of policy, technical, and labelling rules and specifications – the Gaia-X framework. Together, we are developing a new concept of data infrastructure ecosystem based on the values of openness, transparency, sovereignty and interoperability to enable trust. What emerges is not a new cloud physical infrastructure, but a software federation system that can connect several cloud service providers and data owners together to ensure data exchange in a trusted environment and boost the creation of new common data spaces to create digital economy. The scope of this paper is to give an overview for the reader of the core concept of the decentralisation principle, which defines the Gaia-X Framework, and its' applicability via its business projects (also known as the lighthouse projects).

Keywords:

Gaia-X, ecosystem, trust framework, data space

1 Introduction

In a digitally globalised and interconnected world, data has become a central tenant of all our daily lives – whether we are aware of it or not. As the key driver for the digital economy, data is a source of economic opportunity. But the collection, processing, use and sharing of data comes with certain risks, especially where consumers do not have control over their own data. Gaia-X wants to give control back to the user by creating a common data ecosystem for users and providers across various public, industry and research domains.

2 Gaia-X

Established as a not-for-profit Association in 2021[1], Gaia-X brings together a broad range of organisations (large companies and SMEs, developers and users of technology, industrial players, and members of academia) around one common goal: to boost the European data economy by enabling the creation of common data spaces, in full alignment with the objectives of the EU's 2022 data strategy [2]. To this end, Gaia-X focuses on building a common standard for an open, transparent, and secure digital ecosystem that will serve as the basis for a new model of data infrastructure guaranteeing safe and trustworthy data exchange. Open to anyone but aligned with the European values of human-centricity, transparency, openness, and sovereignty. Gaia-X aims to deliver a framework for numerous individual data owners (users) and technology actors (providers), which would be in sovereign power to adopt a common set of policy, technical, and labelling guidelines and requirements. As a result, it would reduce the dependency on non-controllable technologies while reflecting Europe's need for data and cloud sovereignty.

3 Current challenges and developments

Gaia-X is an association that strives to be a standard-setting organization while not being configured as a formal standardization body. Gaia-X works on an open-source architecture that would set standards for data exchange, while also providing the required technological components to allow this standard to be validated and enable data owners (users of technology) to design their own data spaces to operate on infrastructure and technology owners (providers) to be compliant.

In turn, the creation of specific sectoral data spaces will enable the development of services based on a larger set of data collected along the whole value chain, providing each participant more insight and control of the value chain, and in the end, gaining a competitive advantage in their market.
To achieve a significant competitive advantage, however, the sectoral data space must be compliant at least with the Level 1 of the Gaia-X Compliance and Labelling framework, which defines:

- Data protection.
- Transparency.
- Security.
- Portability.
- Flexibility.

While the Level 1 Labelling criteria are open to non-European entities, who are only required to fulfil ENISA's European Cybersecurity Scheme – Basic level. Levels 2 and 3 extend the above-mentioned standards and promote European-based service providers. At Level 2 the user must be given an option of a European service location, while for Level 3 it is mandatory. Nonetheless, labelling and verification standards were defined by the Label Owner with the support of the Gaia-X. As it stands, the entity that owns the Gaia-X label exercises its sovereign right to define the label's scope and applicability within the federated dataspace architecture. On April 21, 2022, Gaia-X released labeling criteria [3], followed by Trust Framework on May 20, 2022 [4], and Gaia-X Architecture Document on May 25, 2022 [5]. The trust framework defines the mandatory baseline requirements for joining the Gaia-X Ecosystem, which allows for the identification, authentication, and authorization of trusted participants. The Gaia-X label comes in three levels, each showcasing a different level of conformity to the Gaia-X rules. The trust framework brings transparency, whilst the labels express values to businesses. In this way, users and technology providers will gain a better knowledge of each other, enabling easy and trusted decisions that, without Gaia-X, cannot happen.

4 Conclusion

Gaia-X is creating an open-source architecture for interoperable, federated data ecosystems, which enables the compositions of services across multiple providers. The establishment of interconnectivity solutions between dataspaces, Gaia-X works upon the European Union 2020 data strategy, which defines the criteria of data protection, and competition law. The environment, therefore, will be based on openness, transparency and security and sovereignty of all parties. Gaia-X released labeling criteria on April 21, 2022, followed by the Trust Framework, and Gaia-X Architecture Document.

The Architecture Document is one of the guiding documents of Gaia-X that enables a data infrastructure ecosystem. It has been designed to familiarize users with the fundamental concepts of Gaia-X and their relationship among them. It integrates different groups, like Providers, Consumers, and Services and depending on their role, it establishes a connection between them, and how they can act and deliver services on the basis of the guiding elements of the Architecture document.

The trust framework establishes the necessary baseline conditions for entering the Gaia-X Ecosystem and allows trusted individuals to be recognized, validated, and authorized. The Gaia-X labelling enables an optional three levels of compliance, each representing a different level of adherence to the Gaia-X standards. The trust framework enables openness, while the labels represent business ideas. Users and technology suppliers will gain a better understanding of one another, allowing for simple and trusted decisions.

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Technical, Economical and Ecological Potentials of Electrified Roads

J. Franke[1], M. Weigelt[1], M. Kneidl[1], M. Masuch[1], A. Kühl[1]

[1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Institute for Factory Automation and Production Systems (FAPS)

Abstract

Electromobility is the backbone of modern emission-neutral transportation systems. Contactless energy transfer via induction is the associated complementary technology that significantly improves the user-friendliness of energy supply in various use cases such as static or dynamic contactless power transfer (CPT). The functionality of CPT for electric vehicles is extensively demonstrated, but up to now, no automatable manufacturing processes exist to produce them in large scale.

Therefore, this contribution presents the opportunities of dynamic CPT and describes the manufacturing process chain for producing coil modules of inductive power transfer (IPT) systems for electrified roads.

Keywords:

Inductive Power Transfer (IPT), Wireless Power Transfer (WPT), E|ROAD, production systems

1 Introduction

Oil dependence, air pollution, and climate catastrophe are the long-term environmental motivations for the shift to electric mobility. The majority of oil-supplying countries do not share the values of Western liberal democracies and are linked to ongoing political conflicts. Local air pollution especially in large metropolitan areas are related to deaths according to WHO figures. Only the transport sector has so far failed to achieve CO_2 emission reductions. At 71%, road-based individual transport accounts for a significant share of this [1].

2 Potentials of E-Mobility

Battery electric vehicle (BEV) have the highest possible energy efficiency in a well-to-wheel analysis, which will further increase by technological development on the infrastructure and vehicle side. Internal combustion engine-powered vehicles (ICE), on the other hand, lose a large proportion of the energy contained in the fuel through heat losses from the engine. Also, high-energy expenditures are required to refine and provide the fuels. Electric vehicles with hydrogen fuel cells (FCEV) likewise achieve poor efficiencies due to the energy-intensive conversion processes of hydrogen electrolysis and hydrogen fuel cells [1].

For drive concepts based on electrical energy, energy efficiency determines emissions in the operating phase and infrastructure costs (even with a fully decarbonized operating electricity mix). Electrified roads (E|ROAD) enable IPT-compatible BEVs (IPTEV) to have smaller accumulators with initially additional energy transmission losses, and thus in turn lower driving energy requirements, vehicle acquisition costs and vehicle production emissions [2, 3].

3 IPT Approach

Electrified roads can be technologically implemented using conductive or contactless (e.g., inductive) energy transmission. Inductive power transfer operates by a high-frequency output stage generating an alternating magnetic field on the primary side via coil modules integrated in the infrastructure. This magnetic field induces currents in the coil module on the vehicle side, which are rectified and finally made available to the energy storage system or directly to the drivetrain [4].

The efficiency of the power transmission is determined by the coupling factor and the quality factor. For loose coupling in driving operation, high efficiencies are achievable by high quality factors of the coil modules. This requires an optimal design of the magnetic circuit as well as the use of semi-finished products and production processes that contribute to minimal losses in the coil module [5]. The functionality and scalability of the IPT technology has been demonstrated in a large number of test tracks. For further penetration of the technology, automatable manufacturing processes are required in order to implement the infrastructure equipment at low cost [4, 5]. The following figure shows the main process steps in coil module production:

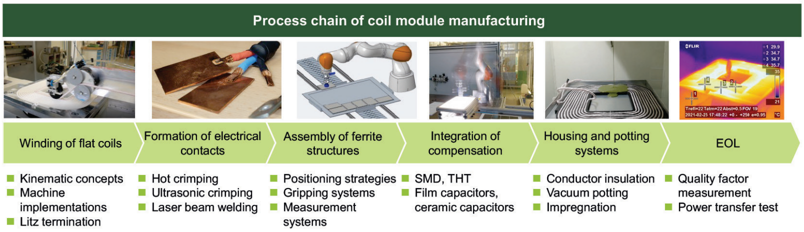

Figure 1: Process chain of coil module manufacturing [5].

The FAPS Institute is addressing this issue in various research projects and, together with an industry consortium including VIA IMC, Risomat and Electreon, will equip an approx. 1 km long section of the federal highway as an E|ROAD by 2025.

4 Summary

This contribution describes the long-term motivators for electrification of the transportation sector. The BEV appears to be the ideal technological solution, but technological, ecological and economic advantages can be developed in conjunction with electrified routes. Inductive power transfer to implement E|ROADs is technologically feasible in this context and scalable using automated manufacturing processes.

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Industrial AI-augmented Data-Centric Metrology for Highly Connected Production Systems

J. Lee[1], P. Kundu[1], P. Gore[1]

[1]Center for Intelligent Maintenance Systems, University of Cincinnati, 45221, USA

Abstract

Modern production equipment and operations are connected together due to rapid growth in the industrial internet of things. Hence, the relationship between different quality operations can be easily evaluated in a multistage manufacturing system. This work presents the concept of Industrial Artificial Intelligence (AI) augmented data-centric metrology for highly connected production systems. The concept is a combination of the Industrial AI Ecosystem, Cyber-Physical Systems and Stream-of-Quality^{TM}. This kind of integrated framework is much important for understanding process-to-process relationships and predicting the quality at each stage of operation.

Keywords:

industrial artificial intelligence, metrology, quality control, cyber-physical systems

1 Introduction

Due to massive growth in industrial internet-enabled technologies, manufacturing assets are now well connected in a multistage manufacturing system, and data from them is easily accessible in real-time. Hence, a data-centric architecture is developed to share and understand the data with a unified description between highly connected production systems. The key components in the data-centric architecture are data label, data quality, data augmentation, feature engineering, etc. Utilizing the data from the kind of data-centric architecture, the potential of Industrial AI can be leveraged to improve the yield and reduce metrology efforts using the concept of virtual and predictive metrology. This Industrial AI-augmented data-centric framework is much helpful in enhancing decision-making and root-cause analysis in highly connected production systems.

2 Methodology

Evaluating complex relationships between different operation stages of a production system is challenging and needs large amounts of data. The application of traditional quality management methods in the context of a multistage manufacturing system leads to a lack of knowledge about the links between individual processes. With the advent of Industry 4.0 transformation, better connections between production operations and equipment can be achieved. Leveraging the capabilities of industrial internet systems along with industrial AI technology, a sophisticated quality management system known as Stream-of-Quality^{TM} (SoQ) can be developed (Figure 1). Industrial AI is a systematic methodology and discipline which combines four technologies, Data Technology, Analytics Technology, Platform Technology and Operations Technology, to provide highly accurate generic solutions to industry problems [1]. The concept of Industrial AI technologies may be better comprehended when it is aligned with Cyber-Physical Systems (CPS). Cyber-Physical Systems (CPS) are interoperable systems consisting of information gathering ability, intelligent analytics, and actuation mechanism that interact with the physical world to support real-time decision-making and guarantee system performance [2,3]. In manufacturing systems, the systematic implementation of four technologies of Industrial AI is very important to establish the connection, conversion, cyber, cognition, configuration, or 5C layers of CPS for fleet-level asset and quality management.

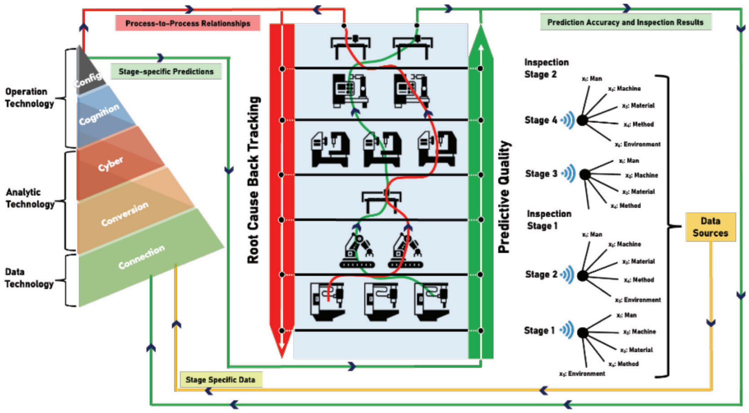

Figure 1: Industrial AI-augmented SoQ methodology for data-centric metrology.

As discussed earlier, in multistage or highly connected production systems, the usage of Industrial AI technology is very important to establish an advanced quality management system, i.e., Stream-of-Quality^{TM} (SoQ) for virtual and predictive metrology. SoQ integrates product quality using a blockchain-based information stream from various stages of manufacturing to increase the accuracy of performance predictions, prevent common failures and increase the traceability of process-to-process relationships [4].

SoQ keeps track of product quality at each stage and uses machine learning algorithms to predict the final product's quality by correlating individual stages' uncertainty with various quality attributes at part, process, and performance levels. To employ mathematical tools for correlating multi-parameter process data with stage-specific product quality, SoQ needs data from the following sources: 1) Man: Critical performance metrics defined by humans interacting with manufacturing machines. 2) Machine: Multisensory data is gathered from different machines' locations during production. 3) Material: Properties of the material used for manufacturing and their safe operating thresholds. 4) Method: Stage-specific operating conditions that are used for the physical transformation of material. 5) Environment: Knowledge about the effect of ambient conditions that are external to the manufacturing process but still influence the final product's quality.

3 Case study

The major battlefield in semiconductor manufacturing will be the advanced process technologies for 7 nm / 5 nm / 3 nm. TSMC and Samsung are the only foundry players that make chips using the 5 nm process node. TSMC is planning high volume production of 3 nm process in the fourth quarter of 2022; Samsung plans to start mass production using 3 nm process node in late 2022. New transistors and materials (FinFET vs GaaFET), new EUV scanner, new atomic layer deposition, smart process virtual metrology and inspection, yield improvement, and packaging will be the key technical challenges for 3nm and beyond. There are several areas using data-centric metrology for machine and recipe calibration that necessitate major breakthroughs. We have developed a digital twin methodology for integrated machine and recipe calibration for 7 nm / 5 nm / 3 nm manufacturing processes (Figure 2). Currently, we have received NIST funding to develop a Roadmap for Intelligent Metrology Systems for high mix semiconductor manufacturing.

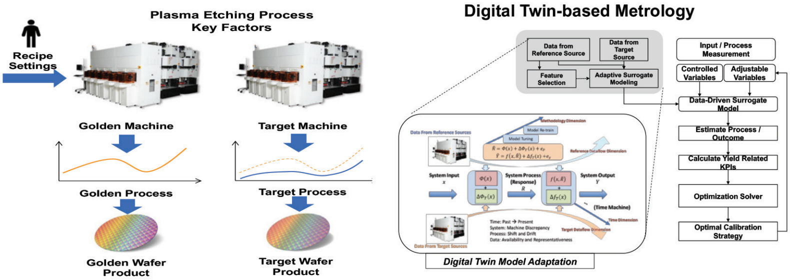

Figure 2: Digital twin methodology for integrated machine and recipe calibration for 7 nm / 5 nm / 3 nm manufacturing.

4 Summary

This article describes the concept of a data-centric metrology framework with the integration of Industrial AI and Cyber-Physical Systems, and SoQ. Real-time data collection, real-time decision making, root cause analysis and process-to-process relationship modelling, and optimization are some of the advantages that can be leveraged by implementing this kind of framework in highly connected production systems. The concept has been briefly explained with its implementation in semiconductor manufacturing.

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Sustainable Aviation: Aircraft Concepts and Production

M. Lange[1]

[1]Premium AEROTEC

Abstract

This article deals with sustainability in aviation industry. Sustainability aspects are explained concerning operation of aircrafts, future aircraft concepts and the machining of integral parts. Here, adapted raw materials, machining strategies, NC-simulation and use of machine tool aggregates lead to improvements in the shop floor footprint and sustainability.

Keywords:

sustainability, aircraft, materials, machining, NC-simulation

Sustainability has become the most challenging strategic goal for the next decades to stop climate change. In aviation sustainability is now an integral part of business strategies and operations – whether through products, industrial sites or people. Specific targets for the main fields of sustainability are clearly defined by timeline and key performance indicators like reduction of CO_2-emission, energy, waste etc. for products and industrial footprint including the supply chain.

Civil air traffic produces roughly 2% of overall CO_2-emission caused by humans [1]. New aircraft concepts, more efficient turbofans and developments based on hydrogen propulsion are massively forced. Airbus has the ambition to develop the world's first zero-emission commercial aircraft by 2035. Earlier CO_2-emission reduction can be achieved by fostering a full value-chain in Europe to produce synthetic sustainable aviation fuel (SAF) at a large enough scale to allow testing in existing logistic infrastructures and in normal flight operations in Europe. The objective for commercial aircraft is to achieve certification of 100% SAF in flight by 2030 [1].

When looking closer to the production of aircrafts, of course, the structures, their materials and manufacturing methods become more important. Bionically inspired lightweight designs lead to optimized aircraft structures and parts, while Aluminum alloys compete with composite based materials for application. Composites might have advantages concerning weight but disadvantages concerning recyclability and cost. Sustainable low-cost lightweight structures might be realized by mainly using Aluminum material with best recyclability. Beside composite and Aluminum, Titanium, Inconel and steel parts will still be used for high temperature and/ or for high stress applications [2].

Due to very high part variety for aircraft integral parts with relatively small batch sizes, machining out of plate material is still widely in use with a high ratio of scrap, up to 98% [2]. Despite sorted recycling of chips and remaining material of clamping connections has been implemented for years, more near net shape raw material like die forgings, extrusions, castings and additive manufactured blanks will alternatively be fostered to minimize material and machining energy resources. Especially two additive manufacturing methods are under development: metal powder bed fusion and wire welding. Premium AEROTEC is already qualified for manufacturing parts made by Titanium powder bed fusion and delivers for example manifolds for the A320-family [3].

For the machining processes several new approaches and developments will lead to more sustainability. However, in the price driven global market for machined parts sustainability just starts to become a unique selling point. High performance machining technologies enables higher material removal rates with higher outputs per machine. According to the Kienzle equation, higher feed rates cause less energy consumption per removed material volume. E.g. for Aluminum machining, doubling the feed rate reduces energy consumption of a milling cutter by more than 15% per part [4].

But it is well known, that most of the energy consumption of machine tools are caused by aggregates. Here, especially coolant supply systems are in focus for energy savings. Frequency-controlled coolant medium pumps improve efficiency [5]. Today, machining operation specific coolant pressures can be chosen in NC-programs. Current developments in technological NC-simulations of milling processes will enable a calculation of current loads of operations with minimized coolant flow rates that are actually needed. Of course, specific energy control systems will more and more adapt energy consumption to different modes.

Hard metal machining leads to high tool wear. For Titanium machining Premium AEROTEC investigated tool wear depending as a function on cutting conditions like cutting speed, feed per tooth and width of cut. The developed tool wear model implemented in the technological NC-simulation enables a prediction of tool wear and simulated tool life times for the different machining operations in seral production [6]. Another research project deals with an automatic tool wear measurement for solid carbide milling cutters to minimize the removed material when regrinding. The overall target for reduction of the resource solid carbide by these activities is -30%.

The technological NC-simulation is another enabler to improve sustainability in machining. For new parts, that have to be produced, already optimized NC-programs reduce the number of iterative evolutions to get a qualified NC-program ready for serial production. By using technological NC-simulation, milling loads can be optimized, chattering can be detected and also tool deflection be can visualized [5]. More efficient milling processes with better part quality, less scrap and shorter machining times per part lead to more sustainability.

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Innovation in Challenging Markets: How Efforts in the Manufacturing Business to Build Ecosystems are about to Change

J. Kruszynski[1]

[1]CTO MAPAL Group

Abstract

This document gives an overview about how current efforts in the tooling industry, in terms of building own ecosystems compared with the market standards need to be reevaluated. This combined with the approach of MAPAL to solve key questions in this aspect and how this translates to the demands of customers in the manufacturing industry.

Keywords:

digitization, ecosystem, tool industry, strategy

1 Introduction

Innovation is one of the value drivers for technology companies – digitalization is one of the key topics that has driven the developments in the past and will be in future as one of the major enablers in the aspect of process efficiency. In a time where change in different aspects, as are insecurity for market trends, demographical challenges, geopolitical powershifts, ecological problems and the influence of connectivity towards our society, finding the right focus is a big challenge.

This document gives a brief overview in which way this challenge can be encountered from the standpoint of a service and solution-oriented company that has its roots in developing customized cutting tool solutions for manufacturing features or designing whole processes for series production in diverse market segments. This with a high claim towards honest partnership that MAPAL gives, when moving things forward together with its partners.

2 Where the industry stands today

To understand where these challenges arise, a neutral perspective can help to understand the trustworthiness, relevance and significance of own efforts measured against the market standards. The markets standards when it comes to innovation in terms of successful business models, driven by a digital approach or by digital core competences are undoubtful defined by the big players in the markets: Google, Amazon, Meta, Apple, and Microsoft. Those companies deliver apparently simple solutions like Alexa serving you when it comes to do daily task, the iOS or Android Appstore's to extend your mobile with new capabilities, or standard operation systems that run 24/7 on billions of computers. To be able to deliver on a standard that enables the world to use those products on a world-class level those companies have spent a combined $126.900.000.000 in R&D efforts only in 2020 [1].

On the example of the amazon ecosystem, which are in some elements quite elementary as developing solutions for the questions "when is AI / Alexa allowed to talk or not", it is clearly visible where we stand today. This translated to the metal cutting industry and the trend, pushed by industry 4.0, where a lot of companies were putting in high efforts to build own ecosystems whilst developing all the elements in a high technological depth is quite contradictory. This also considering the market volume of the metal cutting industry.

Combined with the trends on the side of manufacturing companies, that are pushing towards focusing on own core competences which in most of the relevant cases is not focused on the cutting tool process itself. It is rather following the trends of their customers towards requirements that result out of the customization trends, the lack of resources and societal trends. This unavoidably causes a commoditization of the machining process with rising cost pressure. Out of this the scalable availability of metal cutting core competence in OEM quality is a key issue. Towards this issue and the question on how knowledge and the according provisioning and securing of it can work –the current approach of building own ecosystems is no solution.

3 How that translates into a strategy

To see ways out of the perspective of MAPAL to deliver towards those challenges first focus shall be on existing touchpoints. These touchpoints can be clustered in three main elements aligned to the customer process where MAPAL delivers services:

- Selection and consulting from product catalogue to project setup.
- Logistics, purchasing and operations as elements of tool management.
- Production process performance from optimizations to series production support.

To be more precise the following will only concentrate on the latter two since those are mainly affecting the customers cutting process in terms of efficiency in the use phase of the products.

There MAPAL has a full stack of solutions that are based on an open cloud platform, provided by an independent company within the MAPAL group, the c-Com GmbH. This open platform offers a collaborative approach to link customers with suppliers, supported by three main software-solutions: Tool-Management 4.0, Tool-Lifecycle-Management and Machines Analytics Solutions. Within Tool-Management 4.0 again you find services such as purchasing, logistics, presetting etc., and within those services again products like tool-cabinets including state-of-the-art tool management-software. Or as super summary: the complete technology stack from low-level-hardware up to a complete cloud-infrastructure. That stack is live for more than 8 years now and simply represents the common approach for building ecosystems, that MAPAL consequently implemented as core approach of being a technology leader that is in tune with its partners. Although the platform is open and state-of-the-art in all relevant aspects, as are service-oriented architecture, security, technology – the approach is very holistic from a customer perspective. Because in the end part of key processes (logistics, purchasing, data-management) run on the platform. And from a platform partner perspective, which can be other tool suppliers, coating companies or service companies, trust is always a key topic when acting in a common market. To overcome those challenges in line with the developments in the markets MAPAL has developed a strategy. This is based on knowledge, capabilities, and experience that MAPAL has now and the shift to deliver core competence in a secure, reliable, and qualitative way. The approach is splitting the parts that are already there, into so called manufacturing performance neurons – or better the smallest possible elements of value-add for customer processes in a first step. Whereas in the second step the leverage on key elements together with best practice technology partners are be dramatically increased. How this translates into practice can be seen in an apparently simple element – MAPAL vending machines core competences in sales, software- and hardware-development and after-sales are now enabling other industries and partners to deliver to the specific needs and challenges in their markets without reinventing what is already there. This delivered as an analogue and digital business services. What can be done with the most irrelevant piece – vending – is in development to work for relevant parts that are directly linked to the tool-performance on the machine.

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Optimisation of the Cooling Effect and Defect Identification of Different Machining Processes for the Aerospace Industry

D. Biermann[1], J. Baumann[1], M. Sicking[1], M. Zimon[1], D. Pfirrmann[2]

[1]Technische Universität Dortmund, Institut für Spanende Fertigung (ISF),
Baroper Straße 303, 44227 Dortmund
[2]MTU Aero Engines AG, Dachauer Straße 665, 80995 München

Abstract

An increasing demand for aircrafts causes huge challenges to the manufacturing companies. There are strict quality requirements for such components with simultaneous high demands on productivity and manufacturing efficiency. Therefore, new technologies and methods have to be developed in order to adequately address this conflict of objectives. In this contribution two approaches for an optimisation of the cooling effect and defect identification of different machining processes are presented. Both technological developments address substantial challenges when machining high performance components for the aerospace industry.

Keywords:

flank face modification, cooling, material defect detection

1 Flank face modification for supporting the cooling effect of cutting edges in drilling processes

The concept of a flank face modification for machining high-temperature nickel-based alloys includes a geometric retraction on the primary flank face at a defined distance from the cutting edge. This leads to an improvement of the process productivity and wear behavior of the tools due to the geometrically limited flank wear in combination with the improved cooling lubricant supply [1]. In the further development of the modification, the focus was on the cooling lubricant flow characteristics. The additional flow channels are designed to optimize the cooling lubricant supply to the cutting edge. Figure 1 shows the development of the flank face modification from the standard tool to the second generation.

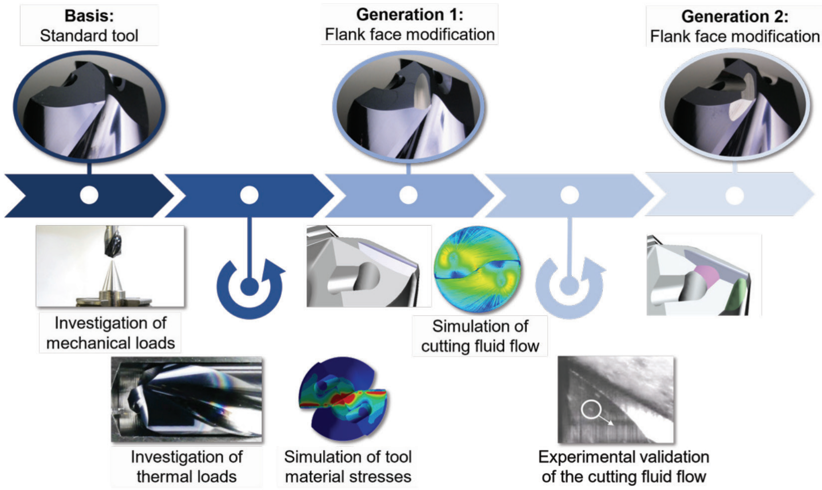


Figure 1: Development of the flank face modification.

The effects of the simulation-assisted optimized flank face modification, which was applied by grinding [1], on the performance of the drills can be seen in Figure 2. For this purpose, the wear process over the drilling path L_f for the cutting speeds v_c = 45 m/min and v_c = 60 m/min are presented. A maximum wear mark width of VB_{max} = 300 µm or a tool failure in the form of chipping at the cutting edge was used as a termination criterion for the tests.

Tool:	varied	**Cutting Speed:**	varied	**Cutting Fluid:**	Emulsion (9 %)
Workpiece Mat.:	Inconel 718	**Feed:**	f = 0,14 mm	**Fluid Pressure:**	p = 55 bar

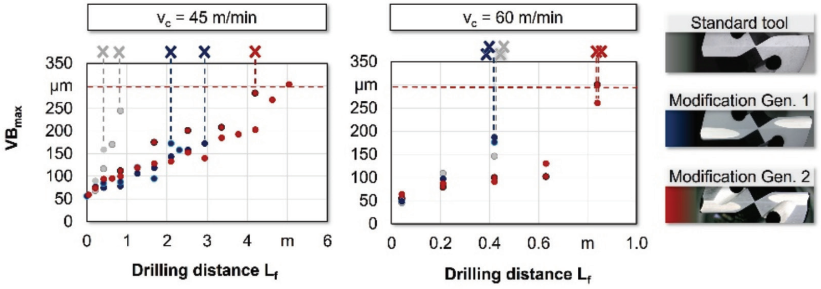
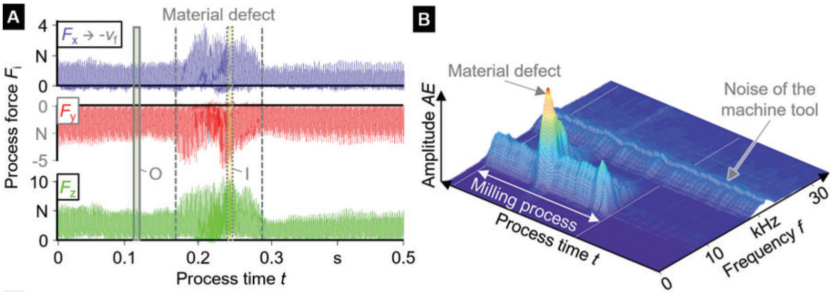


Figure 2: Tool wear progress of the drills at a cutting speed of v_c = 45 m/min and v_c = 60 m/min.

The modifications lead to significantly flatter wear curves at a cutting speed of v_c = 45 m/min. Accordingly, the tools with the first generation modification achieve a tool life increase of ΔL_f = 316% and those of the second generation of ΔL_f = 633% compared to the standard tool, due to an increased coolant supply at the cutting edge. The flank face modification of the second generation enables the tools to be used economically at v_c = 60 m/min.

2 Material defect detection in cutting operations based on in-process measurements

An increasing demand for aircrafts poses huge challenges to the manufacturing companies. There are strict quality requirements for all highly stressed, rotating engine parts, such as compressor components, which are exposed to strong thermal and mechanical alternating loads [2]. Melting defects in the raw part can lead to crack formation over an uncertain period and, in the worst case, to component failure. Due to the high forces, this can lead to a complete engine failure, as happened in an accident in Sioux City 1989. In this case, a nitrogen-stabilized type I hard alpha defect led to an uncontained engine damage [3]. The detection of such material defects is subject of current research [2, 4]. Based on cutting force and acoustic emission (AE) measurements material defects can be detected. As exemplary shown in Figure 3 A, an increase of the cutting force amplitudes could be observed in all force components F_x, F_y and F_z, using a *Kistler* dynamometer (type 91009AA). As depicted in Figure 3 B, the amplitudes of AE signal (QASS sensor) increased significantly if defected material was machined. The amplitudes appeared about three times higher within the process-specific frequency range around 10 kHz [2].



Tool: d = 1 mm; z = 2 **Process**: a_e = 0.2 mm; a_p = 0.02 mm; n = 19,100 min^{-1}; f_z = 0,01 mm

Figure 3: Cutting forces (A) and acoustic emission (B) influenced by the machining of a material defect within a period of 0.5 s [2].

If the presented method is applied for the analysis of milling processes including complex tool paths and varying engagement conditions, the defect related, characteristic cutting-force modulation were expected to be superimposed with the change of the engagement conditions, which will directly result in a variation of the process forces. As an example, a pocked milling process is schematized in Figure 4 A. The progression of the process force component F_x is depicted in Figure 4 B based on experimental measurements and a geometric physically-based process simulation.

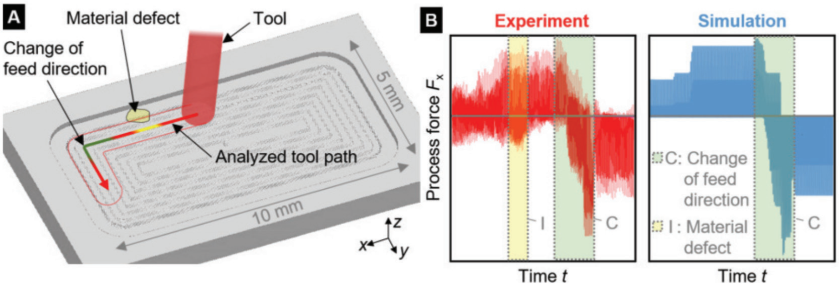


Figure 4: Milling process with varying engagement conditions (A) regarding the experimental and simulated process force Fx (B) [2].

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Digitalisierung – Produktivität – Innovation

K. Brenner[1]

[1]ISCAR Germany GmbH

1 Digitalisierung

Wer Digitalisierung fordert, muss zuerst seine Hausaufgaben machen, denn oft kommen Kunden auf uns zu und fragen „Was können Sie uns dafür bieten?“, sind aber selbst auf das Thema nicht vorbereitet. Es fehlt z.B. an den erforderlichen Netzwerken, um Daten übernehmen und verarbeiten zu können und auch an der Bereitschaft die notwendigen Veränderungen vorzunehmen und Strukturen zu schaffen. Das Ziel muss sein alles mit allem zu vernetzen. Es stellt sich die Frage ist das Unternehmen schon bei Industrie 4.0 oder erst bei 3.5… oder? Einzelne Abteilungen zu vernetzen ist nicht genug. z.B. Konstruktion, Produktion, alle Maschinen, Planung, Steuerung, Lager, Logistik, Einkauf und Vertrieb müssen in einem modernen System vernetzt sein und das nicht nur an einem Standort, sondern von allen Standorten weltweit. Es sollten die Daten in einem Netzwerk gesammelt und ausgewertet werden und für alle zur Verfügung stehen. Weitere Schritte sind die Vernetzung mit Lieferanten und Kunden. Bei ISCAR ist das Thema in zwei Teilen aufgebaut:

1. **Intern durch Automation, Datenaustausch und Fertigungstechnologie aufgeteilt in 6 Bereiche:**

a. Cyber Systeme treffen künftig autonome Entscheidungen.

b. Cyber Prozesse.

c. Cyber Entscheidungen.

d. Cyber Analysen.

e. Cyber Fertigung.

f. Cyber Geschäfte.

Alles ist vernetzt und kommuniziert über das Internet der Dinge und das Internet der Dienste miteinander. Das ermöglicht die Steuerung der Produktion und Geschäftsumgebung. Zur eigenen Standardisierung hat ISCAR seine Fertigungsstätten global vernetzt. Die dabei angewendeten stringenten Verfahren stellen sicher, dass alle Kunden weltweit die gleichen, qualitativen hochwertigen Werkzeuge erhalten. Intelligente Produktionsprozesse mit innovativen, automatisierten Systemen setzen Kapazitäten frei.

2. **Extern durch Softwarelösungen für die Kunden.**

Dazu gehören z.B. Werkzeugverwaltungssysteme deren Software die komplette Logistik übernehmen und Informationen liefert über den Werkzeugverbrauch pro Bauteil. Elektronischer Katalog, der immer auf dem aktuellen Stand ist und die Werkzeugauswahl erleichtert. Der ITA Tooladviser empfiehlt für eine bestimmte Anwendung das richtige Werkzeug inklusive der dazugehörigen Schnittparameter.

2 Produktivität

Im internationalen Wettbewerb kann nur der bestehen, der neben allen Anforderungen und Veränderungen die eigenen Fertigungsprozesse immer wieder hinterfragt und in neueste Technologien investiert. Hier besteht Nachholbedarf und noch sehr viel möglich. Investitionen in modernste Bearbeitungsmaschinen sind nur am Produktivsten, wenn der gesamte Fertigungsprozess hinterfragt wird, die CNC Programme neu erstellt werden und dafür die neuesten Werkzeuge, die auf dem Markt zur Verfügung stehen, eingesetzt werden. Optimale Ergebnisse können nicht erzielt werden, wenn auf neuen Maschinen Werkezuge verwendet werden, die viele Jahre alt und verschlissen sind. Das führt nicht zu den möglichen Produktivitätssteigerungen. Mir wurde schon oft die Frage gestellt, ob die Maschine oder das Werkzeug zu mehr Leistung in der Lage ist. Egal wie die Antwort wäre, sie hilft niemanden, denn es kann nur so schnell gearbeitet werden, wie es das schwächste Glied der Kette zu lässt. Wichtig ist zu erkennen, was bzw. wo das schwächste Glied ist. Letztendlich kommt es darauf an, in kürzester Zeit so viele Späne wie möglich zu produzieren.

3 Innovation

Bedeutet alte Pfade zu verlassen und neue Fertigungstechnologien z.B. 3D Druck in die Entwicklung einzubeziehen. Das ermöglicht Werkzeuge zu entwickeln, die so bisher nicht möglich gewesen wären. Nur neue Schneidstoffe, Geometrien oder Beschichtungen erfüllen nicht die Herausforderungen der Zeit. Innovative Werkzeuge der Zukunft sollten, höhere Produktivität, Prozesssicherheit und höhere Geschwindigkeiten ermöglichen und einen

Beitrag zu Energieeinsparung und Ressourcenschonung leisten. Nachhaltigkeit und CO_2-Fußabdruck sind die aktuellen Schlagworte. Nebenzeiten werden zu immer größeren Kostenfaktoren, wenn die Hauptzeiten immer kürzer werden. Kurze, präzise Werkzeugwechsel, am Besten innerhalb der Maschine, ohne zusätzliche Rüst- und Einstellarbeiten verkürzen die Nebenzeiten deutlich. Das Resultat daraus ist, dass auch bei gleichen Schnittparametern pro Stunde mehr Bauteile produziert werden. Nachhaltigkeit und Ressourcenschonung werden bei der Entwicklung von innovativen Werkzeugen auch berücksichtigt. Es gibt einen einfachen Schlüssel: So wenig wie möglich Hartmetall für eine maximale Anzahl von Schneiden pro Wendeschneidplatte zu verwenden und kleinere auf die Bearbeitung abgestimmte Wendeschneidplatten einzusetzen. Es ist Verschwendung, Schneiden mit einer Länge von 12 mm einzusetzen, wenn die maximale Spantiefe nur 2 mm ist. Bohrer zu entwickeln, die mehr als zwei effektive Schneiden haben, führen zu deutlich höherer Produktivität. Wechselkopf Fräser und Bohrer verbrauchen viel weniger wertvolle Rohstoffe als vergleichbare Vollhartmetallwerkzeuge, bei denen mehr als die Hälfte des Werkzeugs nicht zum Zerspanen benötigt wird. Die Kosten der Werkzeuge machen nur 3% des gesamten Fertigungsprozesses aus, es lohnt sich in modernste Werkzeuge zu investieren.

Modern Lightweight Materials – Challenge and Solution for Cutting Tools

N. Beer[1], C. Gauggel[1]

[1]Gühring KG, research & development, Albstadt, Germany

Abstract

In the field of cutting tools, modern lightweight materials are both a challenge – when they have to be machined – and a solution – as a construction material for high performance machining tools. The paper looks at the requirements that lead to the use of lightweight materials in cutting tools and how these can be met. Furthermore, novel MMCs as well as sandwich materials are considered and solutions for their machining are presented.

Keywords:

cutting tools, lightweight, AM, CFRP, MMC, honeycomb

1 Introduction

In the field of cutting tools, modern lightweight materials such as carbon fibre reinforced plastics (CFRP) are typically seen as a challenge, because they must be machined with special regard to their material characteristics. For many materials, specialized cutting tools have been developed and the increasing usage of these materials for cutting tools gains more focus. Beside the well-known lightweight materials with duroplastic or thermoplastic matrix, new materials with metallic matrix and carbon fibre as reinforcement may be a future challenge and solution for cutting tools. Furthermore, sandwich materials, as used in aeronautics and aerospace, lead to new developments in the field of cutting tools, to achieve a high workpiece quality.

2 Lightweight materials as solution

Increasing popularity of electromobility leads to new challenges in the field of machining. The highly integrated electric motor housings require significantly less machining compared to previous drives, but the stator bore in particular places high demands on the machining result. Diameter tolerances in the IT6 range for diameters greater than 200 mm and high coaxial requirements of less than 40 µm can only be achieved with complex multi-stage reamers. At the same time, these tools must not exceed certain weight limits, as the machine tools used are typically equipped with HSK63 interfaces. These requirements led to the use of lightweight materials for the cutting tools themselves, including hybrid tool concepts.

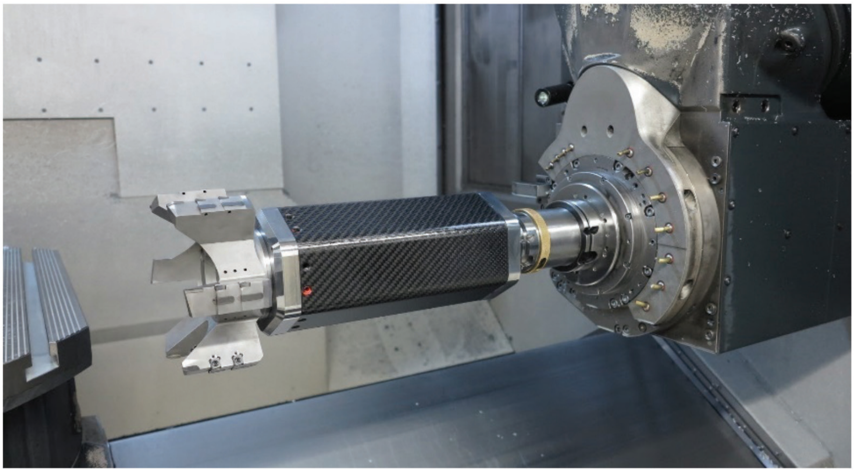

Figure 1: Modular lightweight cutting tool.

Gühring has developed a new modular concept based on a hexagonal CFRP tube, see Figure 1. Due to the choice of tube shape, this concept can transmit torsional forces greater than 1250 Nm without any problems. Also, the bending moment near the spindle can exceed 1000 Nm without damaging the joint between the CFRP and the steel base body. Until now, the cutting-edge supports were located on the face side. The next stage of evolution is the cutting-edge supports applied directly to the CFRP tube. These are additively manufactured for further weight savings. In addition to the connection to the tube itself, special challenges exist here in the thermally decoupled connection for the coolant supply.

3 Lightweight materials challenge

The previously presented concept for hybrid cutting tools relies on CFRP as a lightweight material. In addition, there are a variety of other materials that can be used for lightweight applications and also for cutting tools. These materials lead to new challenges regarding machining.

3.1 Metal Matrix Composites

Even though CFRP is already widely used as a material and has considerable potential for lightweight construction, there are always reservations, especially in the conservative mechanical engineering industry. Examples include ageing of the tools under the influence of UV and cooling lubricants or possible wash-out through chips. Metal Matrix Composites (MMC) can be used to counter these reservations. Such a material with aluminum matrix and CF as reinforcement for cutting tools is being developed in the ZERAL-E joint project. Beside the manufacturing process of the material itself, the development of functionally adapted tools is necessary for machining. Tools optimized for machining aluminum do not achieve a clean cut of the CFRP fibers, see Figure 2. Only by using functionalized chip breakers, a high component quality can be achieved. The chip breakers in these tools have a cutting edge derived from CFRP-specialized tools for fiber catching and shearing and are only used secondarily for chip breaking. With the availability of suitable cutting tools for this new type of MMC, components can be manufactured from it, for example for hybrid cutting tools.

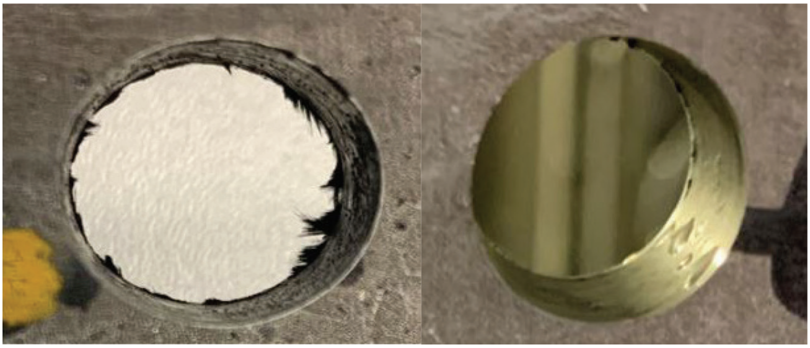

Figure 2: Machining result of circular milling of MMC without (left) and with (right) functionalized chip breakers.

3.2 Sandwich materials

Sandwich materials are another class of structural lightweight materials that are particularly challenging for machining. The cover layers consist of CFRP or GFRP, for example. The core can consist of aluminum honeycomb, paper or aramid honeycomb with or without foam filling or pure foam materials. The core and cover layers place different demands on the cutting tools to achieve a high-quality machining result. The core area must be processed as far as possible without destroying the structures, whereby the wall thicknesses of the honeycombs can be less than 0.2 mm and are correspondingly fragile. The cover layers, on the other hand, are considerably more stable, but sensitive to delamination effects. The typical machining situations, see Figure 3, are also challenging: components with multiple curvatures, mostly unstable clamping and on unstable machines. Compression router tools are used to machine these materials with high productivity and component quality.

The design as a router enables low cutting forces due to the high number of teeth and correspondingly low chip cross-sections. The router teeth also have a compression function to prevent cover layer delamination. The directions of action of the compression cutting edges overlap over large parts of the cutter length to enable more flexible path programming and to spread the wear over the cutting length of the tool. The new compression router can process the entire range of sandwich materials with consistently high component qualities. At the same time, the high number of teeth enables the high cutting speeds known from CFRP machining.

Figure 3: Typical processing situation of a CFRP-aluminium sandwich material.

4 Summary

The article shows what possibilities and potentials modern lightweight materials have for machining. They face machining itself with challenges that can be solved with appropriate tool concepts. At the same time, they enable new types of hybrid cutting tool concepts that can increase machining operations and productivity that could not be achieved with previously used materials and cutting tools.

5 Acknowledgements

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Current Materials and Future Material Developments for EV Application

P. Wagner[1], C. Zenz[1], K. Slanar[1]

[1]ISOVOLTA AG, Technology Department

Abstract

The current private and public mobility is re-shaping towards vehicles whose primary energy storage consists of battery cells (cylindrical, prismatic and pouch cells). While the current battery systems of Electric Vehicles (EV) are well tested and reliable, the industry and lawmakers are still struggling to identify and verify the required certifications, tests, and materials to guarantee passenger safety in case of a battery malfunction causing high exothermic reactions. The company ISOVOLTA with its Mica portfolio is a trusted partner in the electric industry and develops innovative new materials such as CMCs to accomplish the requirements of the emerging vehicle fleet. In this article an insight of new emerging materials is given.

Keywords:

EV, E-VTOL, hybrid-materials, mica, CMC

1 Introduction

The company ISOVOLTA has decades of experience in the field of insulation of low and high voltage applications. In recent years this knowledge has become very useful in the emerging green mobility market. To be able to compete in this market the following requirements according to the Chinese GB Standard must be fulfilled:

- GB 18384-2020 “Safety Requirements for Electric Vehicles”
- GB 38032-2020 “Safety Requirements for Electric Passenger Cars”
- GB 38031-2020 “Safety Requirements for Power Storage Battery for EVs”

The main statement of these safety requirements can be summarized as follows:

A minimum of ***five minutes*** *before fire from a thermal event exits the battery pack or before the battery venting gas enters the cabin the vehicle passengers must be warned.*

While current materials accomplish those requirements, it can be assumed that the regulations will be tightened in the future. The battery pack insulation includes not only the batty cover but also module covers, cell end covers and busbar insulations (Figure 1).

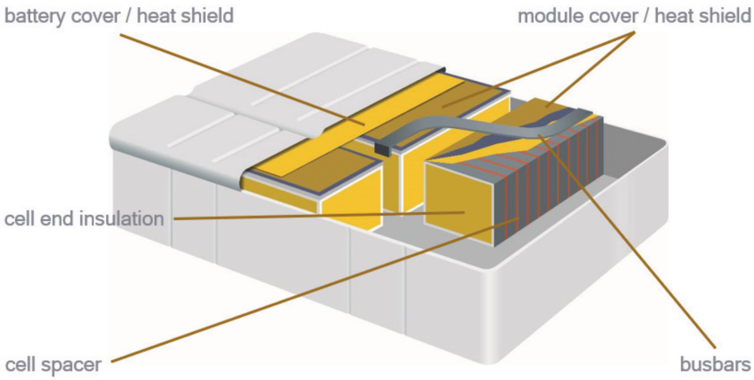

Figure 1: Different insulations according to application.

In this article the focus mainly is on the battery cover and on future material developments.

2 Current materials and future developments

While current materials such as Mica products (Thermiga) fulfill all current requirements, it can be assumed, that with the increase of milage and the change of chemistry inside the batteries towards high-capacity storage the temperatures of thermal events are going to increase from currently 900°C to 1.200°C and therefore will challenge existing systems. For example, the temperature limit of the polymer matrix-based composites (e.g. Cyanatester) is limited to around 350°C operating temperature. And in general, the lightweight performance material market can be divided into three categories:

Organic matrix composites	(-50 to 400°C).
Lightweight metal alloys	(-50 to 1100°C).
Ceramic composites	(>1000°C).

This performance distinction leaves the 400-1000°C-range almost exclusively to metals respectively to metal alloys, with no developments in the last years to push either organic matrices up or ceramic composites down in service temperature, in temperature resistance or to push both down in costs. But due to the special battery requirements of heat and electric insulation, metallic materials are disadvantaged in this case [1,2].

Therefore, two new materials are proposed to fulfill the future requirements of the automotive and aviation industry:

1. Cerapreg – a structural material with very high-performance abilities regarding operating temperature, structural integrity and low to medium production rate.
2. Flexible CMC – an insulation material with no structural requirements but high insulation and ballistic properties and furthermore flexible in nature to be adjusted to any freeform surface. The production rate of the material is high in nature to be suitable for the automotive industry.

2.1 Cerapreg

Cerapreg is a low(er) cost CMC prepreg (Figure 2) with the following key properties [1]

- Service temperature of 900°C max.
- Water-based formulation with a two-stage curing cycle (drying at 110°C, sintering <1000°C).
- Restricted use of expensive Al2O3-ceramic components in both fiber and matrix.
- The product shall be processable in a conventional CFRP-/GFRP-prepreg-production line, with the additional sintering stage.

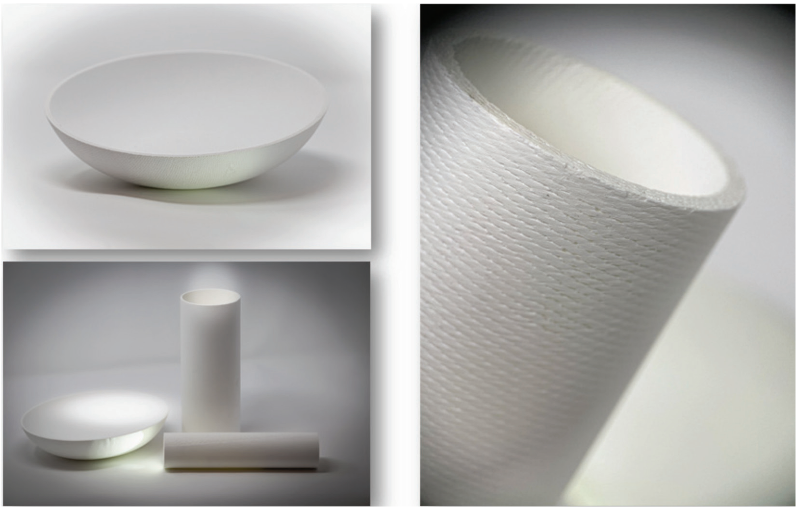

Figure 2: Cerapreg.

Furthermore, a combination of CFRP and Cerapreg is possible in which the CMC provides ballistic and heat protection for the load bearing part of the structure (figure 3). Experiments conducted at temperatures of 1.200°C for 5 minutes confirmed the exceptional insulating properties. The mechanical properties of the hybrid material are promising as well.

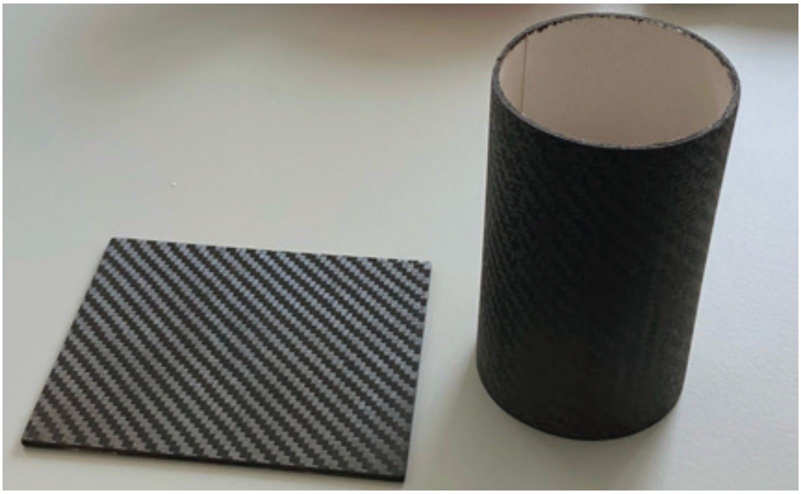

Figure 3: Hybrid Carbon fiber and ceramic material.

2.2 Flexible CMC

While Cerapreg was the first step into the world of CMC for ISOVOLTA, it was also the aim to increase the market potential of CMCs in the fast production rate world of the automotive industry. That's why flexible CMC was developed, a more adaptable CMC with similar insulation and ballistic properties compared to Cerapreg which also keeps its flexibility until a thermal event occurs. The flexibility offers the possibility to be added into any battery compartment in the current production line of the automotive industry without huge additional production steps. This helps to keep the production process as simple as possible while at the same time the safety in case of a thermal event is increased (Figure 4).

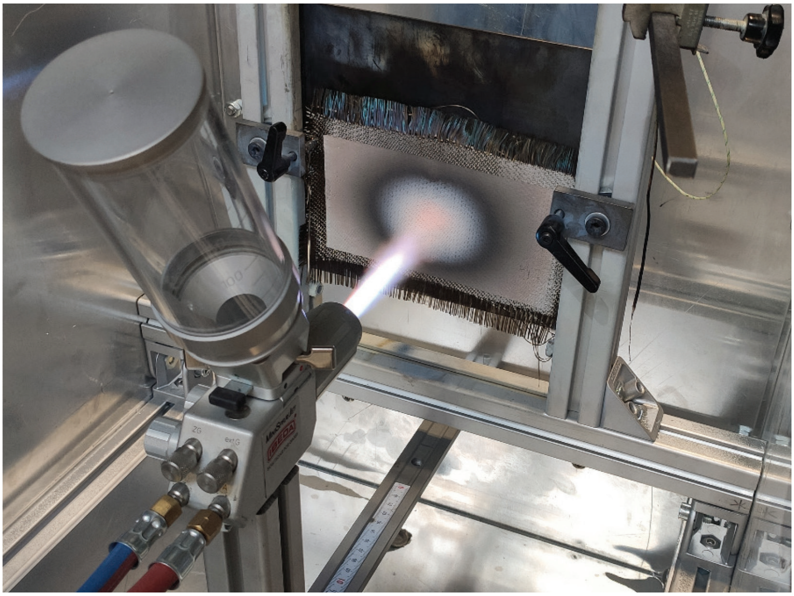

Figure 4: Ballistic and thermal protection test of flexible CMC.

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Environmental Impact of Machining

P.-J. Arrazola[1]

[1]Mondragon Unibertsitatea, Faculty of Engineering, Loramendi 4,
Arrasate-Mondragon 20500, Spain

Abstract

Efforts have been made in the last decades to reduce the consumption of natural resources and environmental impact in manufacturing. In this context, machining is one of the most widely used manufacturing processes in developed countries. Thus, analysis of the impact generated by machining on the environment should be proposed, in order to subsequently plan solutions that fit in with the so-called circular economy.

Keywords:

machining, environmental impact, energy

1 Introduction

It is becoming increasingly evident that society needs to reflect on whether we are going to be able to survive with the available material means and energy we receive on our earth. The processes of manufacturing components to meet human needs, in addition to consuming raw materials and energy, generate various kinds of human waste, which result in a wide range of problems such as the greenhouse effect. The linear concept of extraction-production-consumption-disposal is not sustainable, and a transition to circular economy should be made, in which a large part of the products manufactured and waste generated can be recovered using the concept of circular economy. Machining allows obtaining components of good precision and surface quality, and represent one of the most widely used manufacturing processes representing up to 5% of GDP in developed countries. Therefore, it is advisable to analyze the impact generated by machining on the environment in the first stage, in order to subsequently plan solutions that fit in with the so-called circular economy planning in the future.

2 Aspects to be considered in environmental impact of machining

One of the most detailed analyses to date of the environmental impact of machining is that of Dahmus et Gutowski et al. [1] which presents a very comprehensive analysis of the products entering a machining system and those generated in addition to waste. Figure 1 shows an updated system diagram for metal cutting.

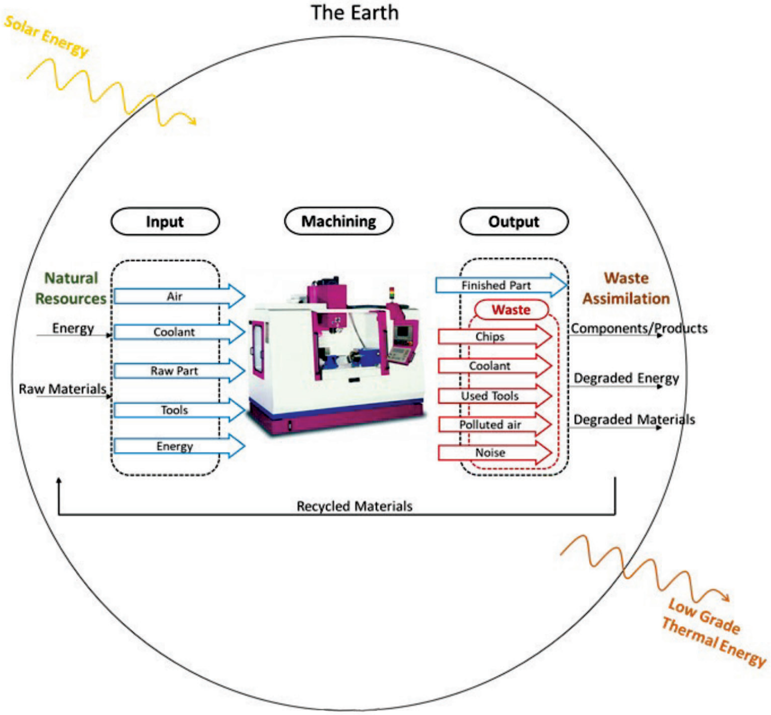


Figure 1: System diagram for metal cutting.

The most common technique for quantifying resource use and environmental impact is Life Cycle Assessment, as its framework and specifications to carry out such analysis are detailed in ISO 14040 and ISO 14044. Different kind of analyses can be carried out depending on the phases of the life of a product or process that are taken into consideration (gate-to-gate, cradle-to-grave, cradle-to-cradle…) but the most relevant for analyzing machining operations would be a cradle-to-gate approach (Figure 2). This analysis takes into consideration the product life (in our case a finished part) from the resource extraction phase until the factory gate (before the finished part is transported to the consumer).

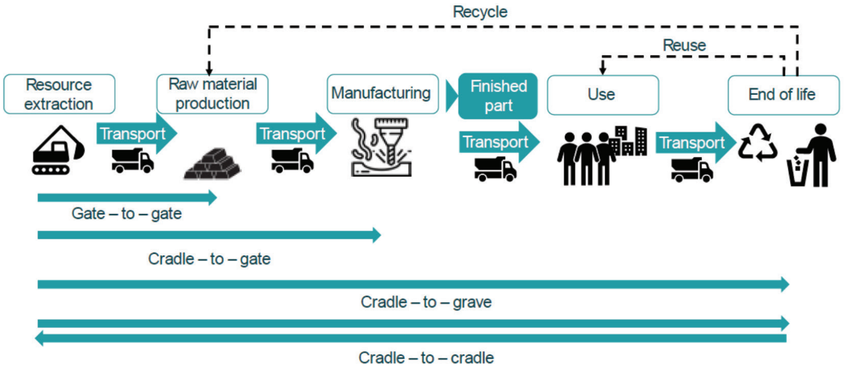
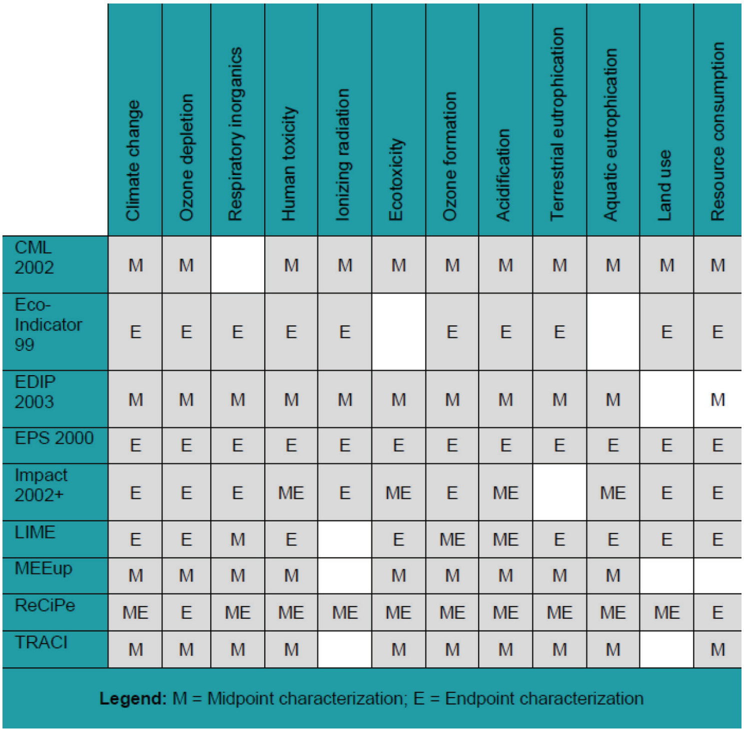


Figure 2: Different types of LCA analysis, adapted from [2].

Once the boundaries of the analysis are defined, the following aspects need to be defined to carry out the LCA:

- Goal and scope definition: i.e. reduction of impact generated by coolant in machining.
- Define functional unit: i.e. one machined part.
- Life Cycle Inventory (LCI): i.e. kg of greenhouse gases per functional unit.
- Life Cycle Impact Assessment (LCIA): Effect identified LCI on impact categories.

There are several impact categories and characterization models in order to assess the effect of the materials and energy flows identified in the LCI to the environmental impact. These are summarized in Table 1. As it can be seen, the characterization models can convert the data from the LCI to midpoint and endpoint indicators. Midpoint indicators focus on a single environmental problem (i.e. climate change or water acidification), while endpoint indicators show the environmental impact on three higher aggregation levels (effect on human health, biodiversity, and resource scarcity). Therefore, the midpoint indicators need to be weighted and converted for an endpoint evaluation. As shown in Table 1 ReCiPe methodology provides the widest range of midpoint and endpoint impact categories from all characterization models.



	Climate change	Ozone depletion	Respiratory inorganics	Human toxicity	Ionizing radiation	Ecotoxicity	Ozone formation	Acidification	Terrestrial eutrophication	Aquatic eutrophication	Land use	Resource consumption
CML 2002	M	M		M	M	M	M	M	M	M	M	M
Eco-Indicator 99	E	E	E	E	E		E	E	E		E	E
EDIP 2003	M	M	M	M	M	M	M	M	M	M		M
EPS 2000	E	E	E	E	E	E	E	E	E	E	E	E
Impact 2002+	E	E	E	ME	E	ME	E	ME		ME	E	E
LIME	E	E	M	E		E	ME	ME	E	E	E	E
MEEup	M	M	M	M		M	M	M	M	M		
ReCiPe	ME	E	ME	ME	ME	ME	ME	ME	ME	ME	ME	E
TRACI	M	M	M	M		M	M	M	M	M		M

Legend: M = Midpoint characterization; E = Endpoint characterization

Table 1: Impact categories considered by different characterization models, adapted from [3].

Employing LCA for evaluating machining operations helps to quantify the environmental hazards derived from the consumption of raw materials, energy and water. However, other aspects, which affect the environment of the workspace, are not taken into account, such as the pollution of the air or the noise at the working area.

These two factors greatly affect the health of workers and the environment at a micro level (the workshop), but unfortunately, they are not considered in LCA as quantifying airborne particles or noise is more difficult than monitoring the materials and energy flows, to complete an LCI.

On the upside, both the measurement of airborne particles and noise are procedures defined by ISO regulations, and indicators could be created to include them in the LCA. Therefore, future efforts should be focused on including Occupational Safety and Health (OSH) aspects into conventional LCA studies.

With regards to machining process, the most relevant aspects to be considered in the environmental impact are the following:

- The energy involved in material removal processes can be quickly estimated using the approximated values shown in Table 2.

Material	Ks (N/mm^2)	Energy (J/mm^3)	Power ($Kw/(cm^3/s)$)
Aluminium	800-1200	0.8-1.2	0.8-1.2
Steel C45, Titanium Ti64	2000-2500	2-2.5	2-2.5
Stainless steel	3000-3200	3-3.2	3-3.2
Nickel based alloy (Inconel 718)	4000-4500	4-4.5	4-4.5

Table 2: Rough estimation of specific energy and energy consumed in machining for several workpiece materials.

- The energy involved in the raw material extraction process in general much more relevant than the energy involved in the material removal process. This result is particularly true if the material being machined is virgin (aluminum, steel, etc.) and has no recycled material. For instance, while aluminum from virgin sources could require around 270 MJ/kg to be produced, aluminum from recycled sources requires only 16 MJ/kg. Similarly, steel from virgin sources requires 31 MJ/kg, while producing steel from recycled sources requires only 9 MJ/kg. The embodied energy of virgin aluminum is around 590 kJ/cm3, that's 40 to 120 times larger than the material removal energies (1 kJ/cm3), while the embodied energy of virgin steel is roughly 4 to 25 times larger than the machining energy (2kJ/cm3). The average greenhouse emission intensity (g CO_2e/kWh) in Europe is around 229 [4].
- Conventional and high pressure cooling represents one of the most relevant auxiliary equipment for energy consumption and thus greenhouse emissions. Alternative methods are proposed to reduce the environmental impact in energy consumption but as well in water: Minimum Quantity of Lubricant (MQL), Sub-zero cooling techniques (CO_2, LN2), Dry Machining.
- The larger effect of machine tools on environmental impact has to do with their energy consumption and efficiency, and especially in modern machine tool efficiency of auxiliary equipment, should be considered.

- The biggest effort in reducing cutting tool environmental impact is using the proper combination of tool material, coating, geometry and working conditions for a given workpiece material and machining operation. The use of proper tool insert can increase the number of tool tips that can be employed and thus reduce the environmental impact.
- The production of carbide tools does require some energy intensive materials and processes: Tungsten, with an embodied energy of approximately 400 MJ/kg, comprises most of the mass of carbide cutters. Moreover, physical vapor deposition (PVD) or chemical vapor deposition (CVD) are quite energy intensive processes (around 1 to 2 MJ per process and cutting insert). Therefore, other currents ways of reducing the environmental impact are the use cutting tool regrinding and cutting tool recycling. These technologies are already employed by some cutting tools manufacturers [5][6].
- Cleaning processes are crucial to the production process, to provide clean and deburred parts. Complex geometric parts require a more sophisticated cleaning procedure than a water-based cleaning solution. Solvent-based cleaners may be required, which raises environmental concerns and may also require strict compliance with regulations.
- Air pollution with metal particles and coolant is quite common in machining processes. Cutting conditions influence significantly the dust generation. The size and the shape of the produced particles, are affected by the cutting conditions and the workpiece materials. The use of coolant has a remarkable influence on metallic particle emissions: using it, we reduce the amount of metallic particles in the air, but on the downside, we increase the emission or airborne coolant droplets The use of coolants can reduce the presence of airborne particles when machining very brittle and porous materials such as cast iron.
- Noise generated in machining has a significant impact on hearing that could cause long-term OSH problems. Apart for potential technological advancements (adding silencing equipment, machine components with passive damping components or active mechanical components) which could be valid for new investments, more effective machining strategies that limit noise emission could be employed [7] in already existing machining facilities.
- OSH aspects are not included in LCA analysis. However, new indicators and libraries can be created in order to extend current LCA databases and consider the impact of machining at the workspace as well as on the environment.

3 Acknowledgements

The author thanks the CRYOMACH (INNO-20182049) and OPTICED (KK-2021/00003) projects, for their financial support to this research work.

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Additive Manufacturing – Desperately Looking for more Smartness and Connection in Production?

F. Feucht[1], O. Elstermeyer[1], M. Slusarek[1], R. Brandis[2]

[1] DMG MORI Additive GmbH
[2] DMG MORI Additive Intelligence

Abstract

The changes we see by using Additive Manufacturing technics are insane. We are all strong believers that this technology is the next big step forward in the future of high-end production. By now, we face obstacles and hurdles trying to integrate this still new production technology into an existing environment. The question is: why? The answer is the complex 3D printing process and the struggle for acceptance. Until now, we need to generate evidence that this production technology reproduces parts reliably in perfect quality. DMG MORI offers an easy-to-use software solution with TULIP, which might fill the gaps and connect loose ends. By collecting all data and generating quality along the production process, we have a chance to destroy doubts and generate trust. This will open doors and give access to new applications!

Keywords:

SLM-technology, process chain, software solution, TULIP, connected production

1 Introduction

The target of the entire Additive Manufacturing community is to generate more applications and use cases for this “new” production technology. Unfortunately, the potential customers do not have enough knowledge, and therefore the potential users of these technologies see more hurdles and obstacles than benefits. By showcasing highly automated and connected visions, potential users are scared and rather try to stick to what they know. In addition, there is NO specific education program for an “Additive Manufacturer”. Taking all this into account, plus the knowledge that a 3D printed part is, in most the cases, only some kind of raw material which needs several additional pre and post-processing steps, might be the primary reason for the still slow growth of this technology. To improve this situation, we need to have more support for the operator by using new technics for smart and connected production sites.

2 Challenges solved in a different way – listen to your customers

DMG MORI Additive faced the same challenges in 2017. By using an easy to use “external” connection via TULIP, we not only generated a new way of connection for the various production steps. We could also extend the information transfer from a one-way street to a bi-directional interaction.

2.1 Fully automated world

We love automation – that’s DMG MORI’s claim in 2022.

The issue is that this could be a tough challenge for SMEs. SMEs are the technology drivers in Europe, and we should be smart and listen to their concerns. To automate all steps in an AM-Process relates to a lot of efforts and the need for a different skill set, which is, in most of cases, not available. Long-term planning is also tough in an economic world which is unpredictable these days. To set up SMART equipment for the use in an AM-process is costly and, in some cases, close to impossible.

2.2 Overcoming hurdles

Having said all this, it seems to be smarter to come up with an “external” connection which smartly supports the operator. TULIP as an easy to use non code platform where everyone who can operate MICROSOFT PowerPoint will also be able to program a TULIP app. This app can be easily connected to different sources (ERP, knowledge database, machines, etc.). With a small terminal and a scanner, you can grab data and give support directly on the shop floor.

3 Internal Success Story

Just to prove the concept DMG MORI ADDITIVE and the consulting team of DMG MORI ADDITIVE INTELLIGENCE developed several apps to support the “production” of test builds and for the turnkey and ramp up support projects.

3.1 Apps

Several apps have been generated by now to support:

- The production planning.
- The order of consumables.
- The tracking of the status of the machines and the maintenance.
- The traceability of consumables and spare parts.
- The entire post processing steps.
- The shipping and the storage of printed parts.

3.2 Benefits

By using this “new approach,” we generated additional benefits

- No loss of know-how between shifts and operators.
- Higher transparency and deadline compliance.
- Better efficiency throughout the entire process chain.
- Faster onboarding of new colleagues.
- Less scrab rate.

4 Summary

It is not a solution to overcome hurdles by setting up even bigger challenges. It might be smarter to connect your production externally and involve the employees and colleagues on the journey to INDUSTRY 4.0. We all need to make sure that the engine of the European Industry – which is still an SME – can keep up and is not scared by a tsunami of buzzwords, new technologies and fancy animations.

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Our Journey from a Lean Factory to a Lean Green Digital Factory

S. Schlauss[1]

[1]Motion Control & Production Site GWE (Siemens AG;
Digital Industries – Motion Control)

Abstract

From a Lean Factory to a Green Lean Digital Factory – A Holistic Approach. The presentation will show the transformation journey "From a lean to a green lean digital factory" focusing on the business impact. After a brief introduction about the Businesses and Services of the Siemens AG, and the production Site Erlangen (GWE), there will be several use cases how we successfully implement digitalization and flexible automation in the whole digital value chain and over the whole product lifecycle. The latter part of the presentation is, how we make these things happen with our people.

Keywords:

digital twin, artificial intelligence, digitalization, logistics, artificial intelligence, edge computing, electronics production, closed-loop manufacturing

1 Businesses and Services of Siemens AG, Digital Industries – Motion Control

The Siemens Business Unit Motion Control (MC) is one of the world's leading suppliers of products, systems, solutions, and service on the motion control market. It has around 20,000 employees and four Business Segments: General Motion Control (GMC), Machine Tool Systems (MTS), Low Voltage Motors (LVM) and Service (CS MC). With our fourteen factories worldwide, we are close to our customers and at home in a huge range of industries. One of our most advanced factories is GWE (Gerätewerk Erlangen) which is located in Erlangen (Germany) and is the Lead Factory of Electronics. The business type for the high-mix, low-volume market, is make to order.

2 Use Cases of digitalization and flexible automation of the whole digital value chain and product lifecycle

In a highly diverse market with continuously growing product variants, GWE has successfully implemented, with its holistic digital approach, a seamless end-to-end digitization over the whole product lifecycle.

2.1 Digital Twin of product, production process and factory

With the digital model of the product and the production process, we accelerate innovation processes and reduce efforts in several fields. In the product design phase, we could reduce manual efforts up to 30%, by implementing a solution, which enables us, to check the design for assembly parameters automatically and in very short cycles. In the factory planning phase, we use 3D brownfield scans, together with 3D process modeling for reachability analysis and offline programming. This allowed us to reduce the efforts for the realization of manufacturing systems, by 50%. With the innovative product design and the realization of a nearly fully automated production line, we could reduce manual efforts, by 80%.

2.2 Smart robotics and AI on the shopfloor

In the realization and optimization phase of manufacturing systems, we are now able to integrate automation within days instead of weeks. With the combination of advanced robotics and artificial intelligence we could reduce the pseudo failure rate by 60% and cut down logistic costs by 50%.

2.3 How we make things happen, with our people

Technologies will change quickly, but it makes a big difference whether an organization can change just as quickly or not. So, the factory culture is for us, one of the most important aspects of the digital transformation. Therefore, we are putting a lot of energy into communication, education and continuously encourage our people to go new ways.

With our holistic approach, we closed the loop in manufacturing, by combining digital twin, robotics, cloud and edge computing. But only with our passionate people, we make all these things happen!

Intelligent Thermal Compensation of Machine Tools

K. Wegener[1], J. Mayr[2], N. Zimmermann[2], P. Kaftan[1]

[1]ETH Zürich, Institute of Machine Tools and Manufacturing (IWF)
[2]inspire AG

Abstract

Thermal compensation strategies are a sustainable and cost-efficient strategy to improve the machining accuracy of manufacturing systems such as 5-axis machine tools or lathes. Especially, self-learning data-driven models including adaptive model inputs allow a precise and robust computation of thermal errors. The learning efficiency of the data-driven models can be further increased by applying fleet learning techniques between different machine tools of the same type. With regards to thermal compensation for lathes, a methodology extension is developed to compensate sudden boundary condition changes due to machine tool door opening.

Keywords:

thermal compensation, phenomenological modelling, fleet learning, lathes, machine tools

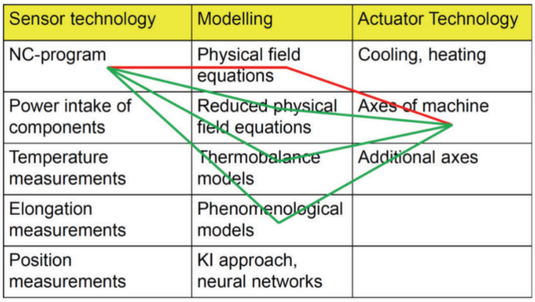
1 Introduction

Increasing precision requirements combined with the need to reduce costs as well as the ecological footprint is the driving force behind compensation technologies. A major part of deviations between the intended and the manufactured geometry of parts is due to thermal movements between tool center point (TCP) and workpiece center point (WCP). High and ultra-precision machines are therefore placed under air conditioning and carefully cooled internally to cope with the influence of external and internal heat sources. Major resource consumptions and expenses are related to these energy-intensive thermal error reduction measures. Commonly, machine tools should avoid excessive energy input, which is a question of suitable design. Keeping the machine cool is no longer required for precision manufacturing with intelligence-based compensation approaches. Compensation is the means to move from a resource-based towards knowledge-based manufacturing.

Today a large number of machine tools already have some attempts of thermal compensation and are capable to achieve some reduction of thermal errors, and are thus valuable. To go beyond that and follow the vision of precision manufacturing under conventional job shop conditions, a sound understanding of the machine tool behavior is indispensable. Thermal compensation attempts that do not consider the thermal history or that are based on one probing point between the tool and workpiece can then be ruled out as insufficient. As the thermal behavior moved in the past decade away from being seen as a mere user problem to become a problem to be solved by the machine tool maker, thermal compensation algorithms have become a highly relevant topic.

2 Model-based thermal compensation

Compensation strategies always follow a mechatronic cycle, starting with some sensors sending signals to predict the thermal errors using models that are integrated within the machine control. Subsequently, actuators initiate the corresponding compensation movements. Figure 1 shows a morphological box for the connection of these three elements. As not only one sensor and one actuator are used, a combination of different elements is also possible and sometimes suitable. For each of the elements, the most cost-efficient solution is to use what is already available on the machine, which especially means that the actuators of choice are the axes of the machine. Physical modelling based on the finite element method (FEM) or similar solvers of field equations as a means of machine tool understanding provides good precision, but needs too much computation time, even if model order reduction algorithms are applied. The lines in Figure 1 demonstrate that the complexity of the physical model is reduced at the expense of increasing experimental effort.



Sensor technology	Modelling	Actuator Technology
NC-program	Physical field equations	Cooling, heating
Power intake of components	Reduced physical field equations	Axes of machine
Temperature measurements	Thermobalance models	Additional axes
Elongation measurements	Phenomenological models	
Position measurements	KI approach, neural networks	

Figure 1: Morphological box of thermal error compensation according to Wegener et al. [1]

Predominantly data-driven models have been integrated in thermal error compensation strategies, as for example presented by Brecher et al. [2], Mareš et al. [3] and Naumann et al. [4]. Mareš et al. [3] apply for example data-driven models, which are based on an ARX (autoregressive with exogenous inputs) structure, to compensate the thermal errors on a working space position of a 5-axis machine tool. The considered thermal load cases encompass single axis movements of the linear axes and a rotary axis as well as the spindle. The following equation

$$\begin{aligned} y[k] + a_1 \cdot y[k-1] + \cdots + a_{n_a} \cdot y[k-n_a] \\ = b_0 \cdot u[k] + b_1 \cdot u[k-1] + \cdots + b_{n_b} \cdot u[k-n_b] \end{aligned} \tag{1}$$

shows an ARX approach that retains the physical history dependence of thermal errors as a function of measurement values. The thermal errors are denoted by y, the thermal loads for instance temperatures or power inputs by u, k means the number of a time step, a and b are coefficient matrices. The order n_a describe the number of past system outputs that influence the current time step and represents the number of time steps of the corresponding input that are considered to calculate the current system output. The optimal numbers of n_a and n_b are estimated by using for example the Akaike information criterion [5] To ensure a long-term stability of the compensation results the thermal adaptive learning control (TALC) combines the data-driven ARX-models with on-machine measurements to realize a closed-loop control for the thermal error compensation of machine tools. Figure 2 shows the full cycle, where all new compensation values are provided to the CNC-axes from the model and from time to time on-machine measurements and model updates take place.

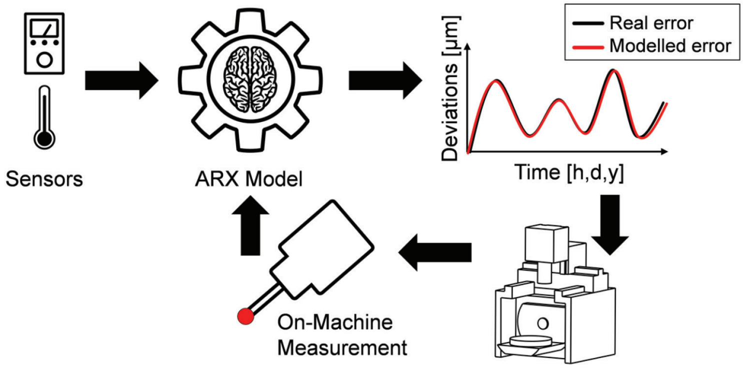


Figure 2: Thermal adaptive learning control (TALC) for compensation of machine tools according to Blaser [3].

The coefficient matrices a and b have to be identified and thus the models are calibrated by probing after random motions of the machine axes and arbitrary environmental conditions, which is shown in Figure 3. Whenever the model precision decreases, which is identified by a probing cycle between TCP and WCP, a recalibration of the coefficient matrices is performed. Probing is done with inbuilt artifacts and a motion cycle that allows the identification of the individual location errors of the axes.

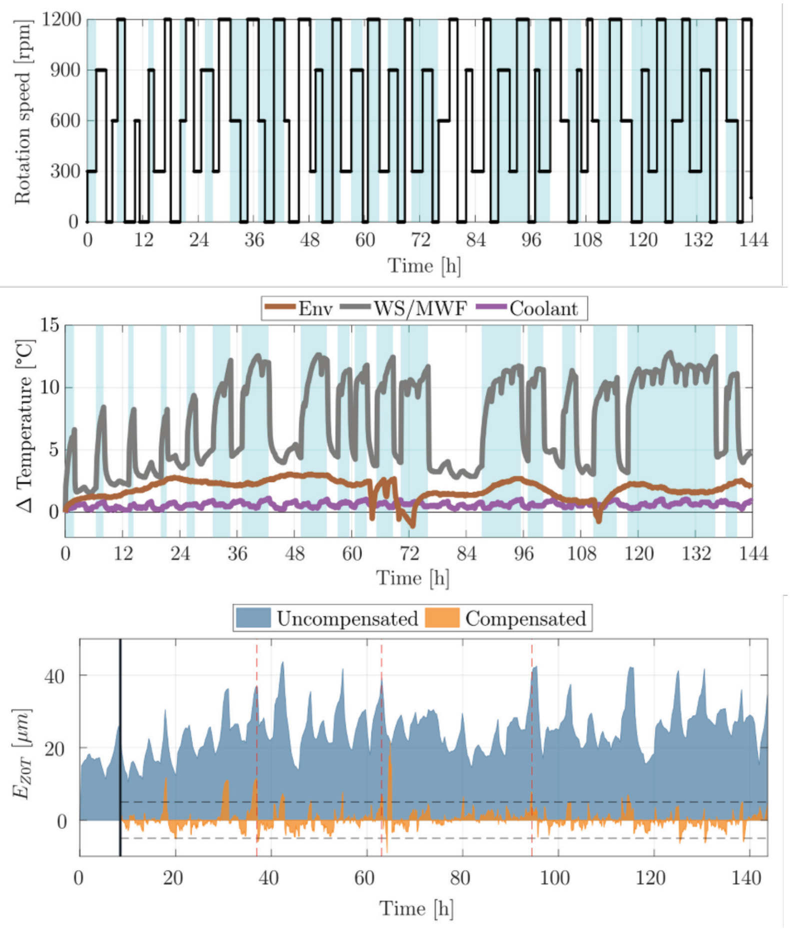


Figure 3: Calibration and validation of the phenomenological ARX model by a randomly chosen speed profile of the C-axis with underlying environmental temperature changes and the application of metal working fluid.
Blue shading are sections with metal working fluid [3].

As this probing uses production time, it is optimal to do it as seldom as possible, either by fixed probing intervals or by identifying so far unknown thermal conditions, which are so far not included in the training data of the data-driven models [4]. This is realized by analyzing the temperature measurements, which do not require a process interruption, to optimize the trade-off between precision and productivity.

3 Input selection

The inputs from the CNC program alone only allow compensating errors that are induced by the drive systems, if the losses in the drives are known, which is usually not the case. Therefore, temperature sensors are included in the system. The question, which sensor shall be selected for the model setup and the model updates, enables an even greater variation of modelling and covering different thermal load cases. This can be realized either by a combination of k-means clustering and the time series clustering kernel [5] or by the Group-LASSO method [6]. Figure 4 shows the difference between the TALC with static and adaptive model inputs.

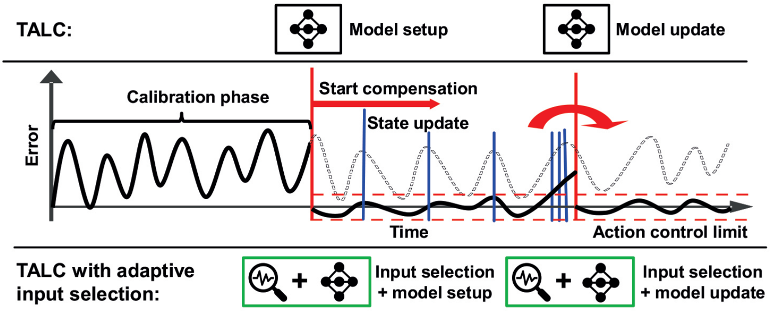


Figure 4: Modified calibration procedure for TALC with input selection according to Zimmermann et al. [5].

The compensation results of the TALC achieved with static and adaptive model inputs are shown in Figure 5. The vertical dotted lines represent the autonomously triggered on-machine measurements to detect a possible exceedance of the error-specific action control limits and the red dashed lines indicate the model updates. The results show that especially the residual of the thermal error E_{X0C} is improved by applying the adaptive input selection. This indicates that the adaptive input selection especially improves the modelling of thermal errors, which are influenced by many different heat sources so that frequently not all relevant thermal load cases have been considered in the initial training data.

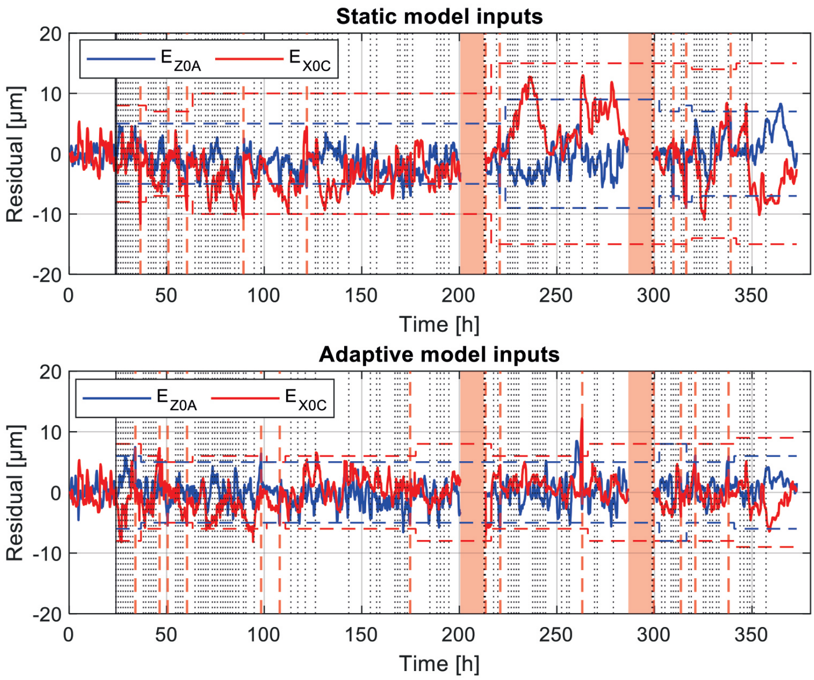


Figure 5: Compensation results for TALC with static and adaptive model inputs using the Group-LASSO method [6]. Red areas indicate an unintended interruption of measurement.

4 Fleet learning for thermal compensation

As the calibration of each machine is time consuming and to provide sufficient learning data, it would be beneficial to re-use as much collected data as possible. Figure 6 shows the cloud-based TALC approach for fleet learning, which was developed in cooperation with IFT from TU Wien. Tests with similar machines at IWF and IFT with different equipment and age show that at least for this case the utilization of model data for the thermal model from the other machine is beneficial.

According to Stoop et al. [9], in general, the TALC consists of the following seven steps:

1. On-machine tool center point (TCP) error measurements and sensor data collection.
2. Computing thermally induced geometrical axis errors of the machine tool.

3. Storing data of past measurement cycles.
4. Building model structure, parametrize model, select input.
5. Computing the axis-related thermal errors.
6. Compute TCP correction values.
7. Compensate TCP position.

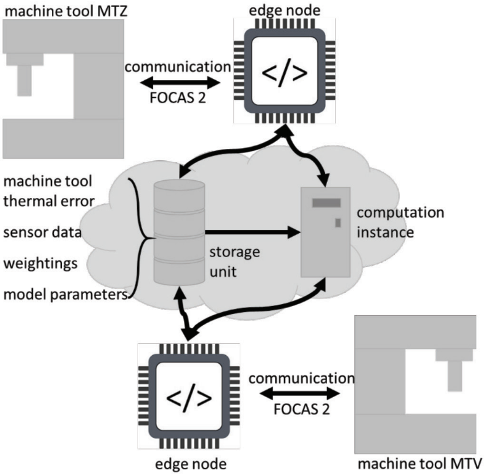


Figure 6: Fleet learning between two different machines [9].

Figure 6 shows the cloud-based TALC approach for fleet learning, which was developed in cooperation with IFT from TU Wien. Tests with similar machines at IWF and IFT with different equipment and age show that at least for this case the utilization of model data from the other machine is beneficial. As step 2 is the inverse function of step 6, these both subroutines run on the edge device, what connects the cloud with the machine tools control. Due to limited access, it is not possible to run these two subroutines on the machine tool's control. As the sensitive manufacturing data are processed in steps 1, 2, 6 and 7, the exchanged data are uncritical and do not include any information about the NC-Program or manufacturing processes performed on the machine tool. For safety reasons, all data are temporarily stored on the machine tool related edge device to prevent failures in the event of losing internet connection.

Figure 7 shows the environmental variation error (EVE) compensation result of machine tool MTV, including the warmup behavior illustrated in Figure 4. A model calibration period predefined of eight hours is too short for this machine tool. In the lower diagram of Figure 7 the simulated compensation results, when using the model of another machine tool MTZ are illustrated. Obviously, when starting the compensation after 8 hours, the model derived on MTZ works better on MTV than its own model.

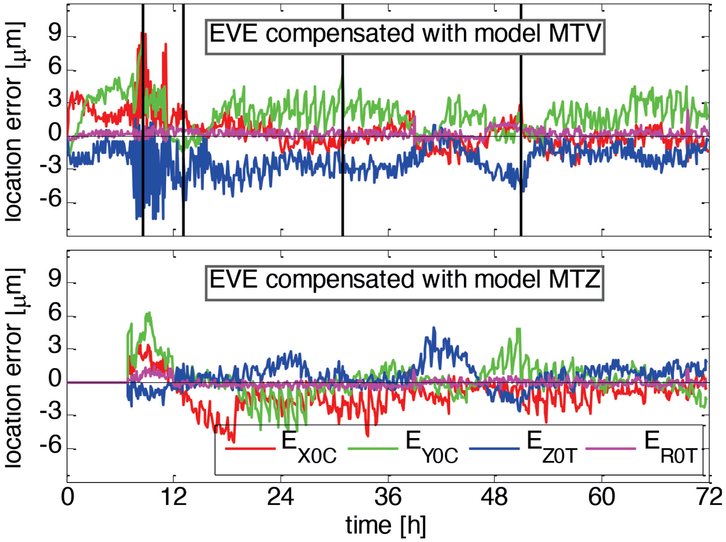


Figure 7 Thermal location errors for EVE test on MTV compensated with model from measurement performed on MTV (top) and with a model derived from MTZ (bottom). Black vertical lines illustrate threshold exceedances and corresponding model updates [9].

5 Thermal compensation for lathes

While milling machines have one clearly identifiable TCP, lathes usually have multiple TCPs due to the presence of various tool holders on linear axes or turrets on rotational axes. On the turning machine shown in Figure 7a, stationary turning tools are positioned above the main spindle. Additionally, the machine is also equipped with a special module for front- and backwork tools, as shown in Figure 7b. Based on the tool that is active, a differently parametrized thermal compensation model runs. Corresponding temperature sensors, placed near the tools (white housings with red points indicated as in Figure 8a) and 8b) are chosen as inputs for the thermal compensation models.

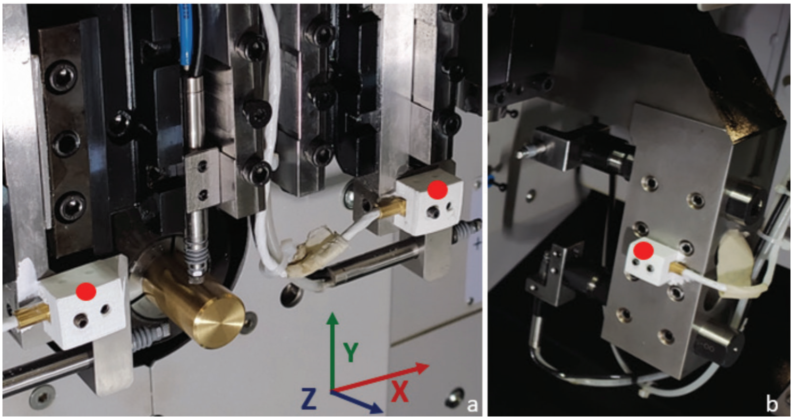


Figure 8: a) lathe tool holder plate for stationary turning tools.
8b) Lathe special module for front- and backwork operations.
Red dots indicate temperature sensors, tools are replaced with probes for thermal error measurement.

Sudden thermal boundary condition changes occur for example in Swiss-type lathe machining, when the operator opens the machine door during a production cycle to change/clean tools or inspect the workpiece [7]. The ARX-Random-Forest model (ARX-RFR) has been developed to compensate thermal error spikes associated with sudden boundary condition changes [8]. The ARX-RFR model uses a smoothed machine door status signal to complement temperature inputs of the ARX model. Fig. 9 shows the compensation results of the ARX-RFR model compared to the ARX model for the thermal error. The peak-to-peak thermal error compensation is increased from 28% with ARX to 77% with ARX-RFR.

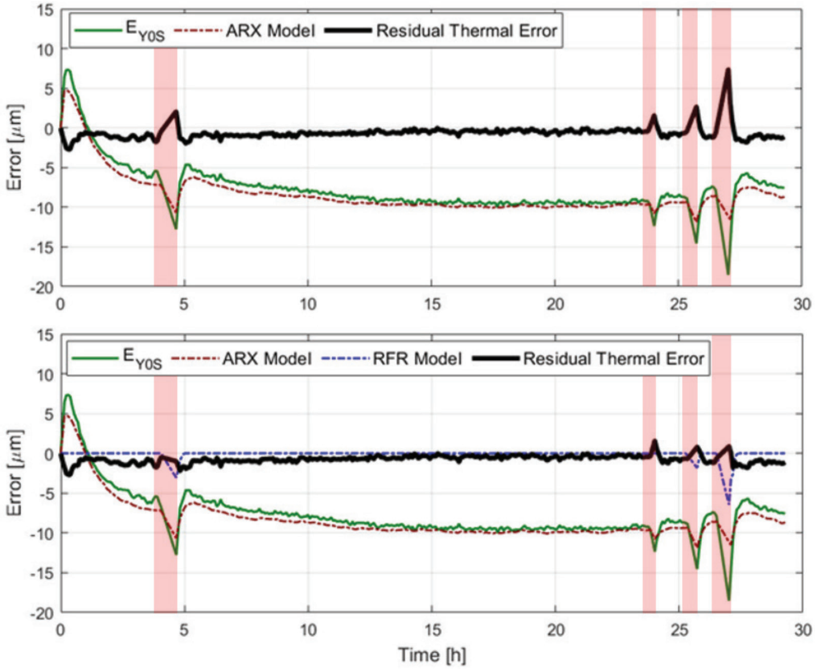


Figure 9: Thermal compensation results of ARX (top) and ARX-RFR (bottom) for a lathe. Red stripes indicate times when the lathe door is opened.

6 Conclusion

In precision production a shift from cooling to intelligent based numerical compensation approaches in both research and industry is necessary. Up to now, understood as a good machine tool design regarding the thermal behavior, is a machine tool that has no thermal error, not considered the energy consumption of the machine tool by tempering. More and more awareness in industry is arising regarding immense costs for internal and external cooling. Machine tool manufacturers are therefore under pressure to provide their customers sustainable precision machine tools, which, beneath other criteria require minimal cooling effort and do not need energy-wasting shop floor air conditioning. Thermal error compensation based on numerical methods, providing efficient and precision results, is the core competence for machine tool manufacturers regarding thermal errors in the next decades. In this paper methods of efficient thermal compensation are presented. Although, as in all disciplines of machine tools, there is still a huge task for research, the methodology and robustness of numerical thermal error compensation approaches reached a high readiness level that is suitable for industrialization.

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Sustainable Self-Optimizing Manufacturing by Intelligent Cyber-Physical Tools

H.-C. Möhring[1]

[1]Universität Stuttgart, Institute for Machine Tools (IfW)

Abstract

This contribution presents innovative technological approaches with respect to their potential regarding the achievement of sustainable self-optimizing manufacturing. Simulation aided process planning, sensory machining tools and knowledge-based application of coolant lubricant, besides others, can essentially contribute to significantly improve the energy and resource efficiency in production. Novel manufacturing hardware solutions are combined with modelling and simulation in order to gain transparency and to enable targeted optimization.

Keywords:

Sustainable manufacturing, process planning, sensory tools, cooling efficiency

1 Introduction

The 17 goals of sustainable development (Figure 1) more and more become the dominating aspect in production engineering research. Resilient supply chains with respect to the goal of “zero hunger”, contributions to the realization of new technologies with respect to “good health”, “clean water”, “clean energy” and “sustainable cities” as well as “climate action” are significant aspects of modern production. The aims of “economic growth”, “industry, innovation and infrastructure” as well as “responsible consumption and production” are core elements of the development of innovative production strategies, processes, machinery, equipment and methods. “Quality education” and “decent work” become increasingly important in production environments, already due to the fact, that the above-mentioned goals can hardly be met without well-educated and motivated workforce.

Figure 1: United Nations Sustainable Development Goals.

In manufacturing, the most efficient use of energy, materials, adjuvants, tools and resources has always been a key issue besides productivity and quality, for economic reasons. Nowadays, new optima must be identified and implemented regarding the setup and operation of manufacturing systems with respect to economic but also ecological targets. Basically, the prevention of defective workpieces and products, the minimization of material usage, the complete exploitation of tool life and performance, and the avoidance of squandering and idle times constitute principle approaches. This includes the achievement of desired workpiece functional properties right from the first produced part by optimally defined and adjusted machining processes considering transient tool wear conditions and applying only the necessarily required amount of adjuvants such as coolant lubricant. Consequently, the entire machining system, including simulation-based process planning, monitored and actively controlled physical process-machine interaction as well as quality assessment of produced parts must be subject to multi-criteria optimization [1]. In this respect, digital twins, comprising appropriate modelling and simulation techniques as well as a real time communication and updating with machine control information and signals of system integrated sensors, establish a fundamental means to tackle the challenges of transparency, faultless interpretation of system states and derivation of optimization measures (see e.g. [2]).

2 Process definition

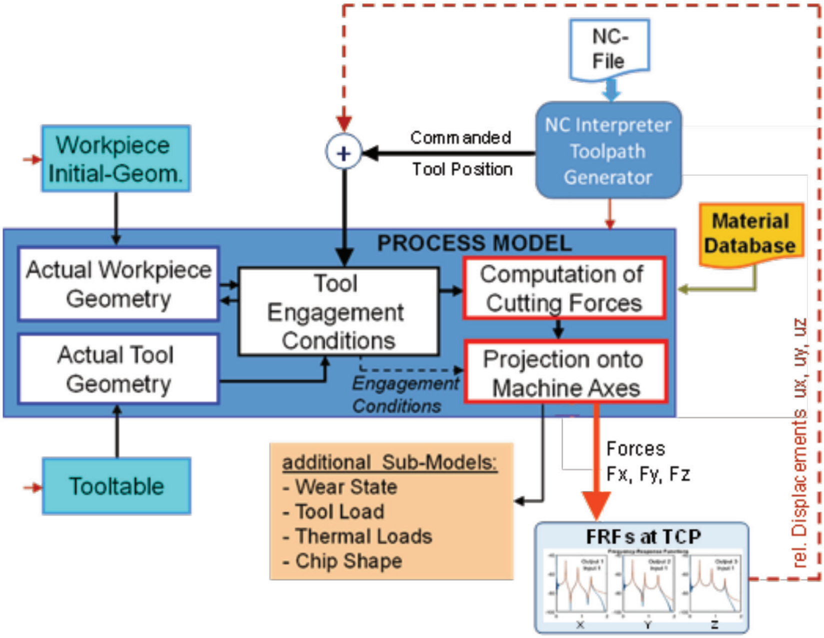

Figure 2: Schematics of a simulation environment for tool path optimization considering process conditions [7].

Extensive research work has been conducted in the past with the aim to predict machining process conditions for consideration during process planning [3]. By means of cutting simulation approaches, e.g. process forces and temperatures acting on the workpiece and tool can be calculated in order to adjust tool paths with respect to reduced dynamic tool loads and interference with material properties of the part (Figure 2) [4,5,6].

Even the unintended excitation of sensitive frequencies of the machine tool can be estimated considering transient cutting conditions in order to avoid instable processes (Figure 3) [7]. In this regard, analytic modelling approaches provide significantly shorter computation times compared to numerical Finite Element simulations.

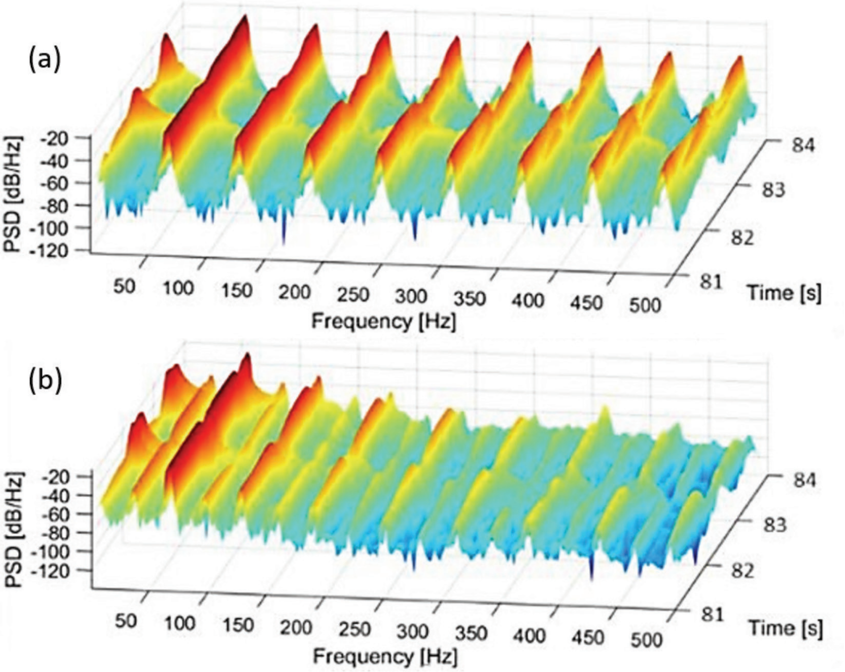

Figure 3: Short Time Fourier Transformation (STFT) of simulated (a) and measured (b) tangential cutting forces [7].

3 Sensor integrated tools

In order to observe the actual process conditions and to enable process control strategies maintaining the desired functional workpiece properties even under transient influences during machining, sensor integrated 'intelligent' tools establish a very promising approach [8,9]. Besides the avoidance of critical process conditions like chatter [10], e.g. the adjustment of desired surface topographies becomes possible (Figure 4) [11,12].

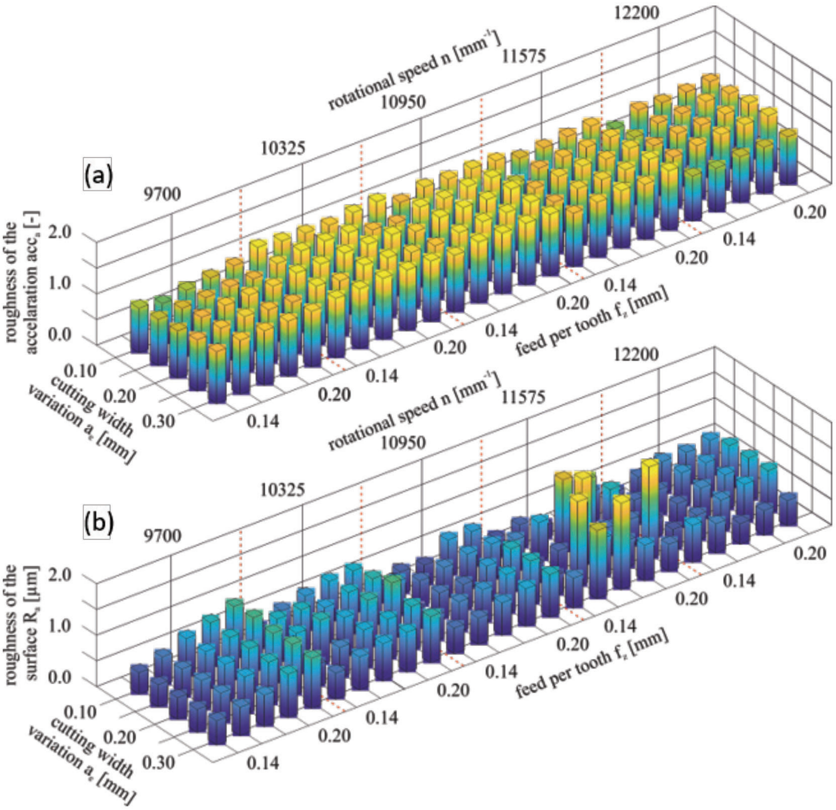

Figure 4: Comparison of surface roughness and acceleration data of a sensor integrated milling tool [11].

In order to derive relevant process information with respect to the complex tool-workpiece interaction from sensor signals and to predict the machining result regarding the distinction of adequate and inacceptable process states, digital twins of various types are incorporated. By way of example, digital models of the tool and tool holder dynamics are necessary in order to take the transmission of forces and excitations between the tool contact point and the sensor location into account in signal processing. Pre-calculated FEM process simulations can be used as a kind of look-up tables in order to conclude the process influences on workpiece properties based on sensor and control information.

Current research even aims in the controlled creation of subsurface properties such as compressive residual stresses in high performance components

[13,14]. By means of temperature, force, torque and acceleration measurements, the thermo-mechanical loads in the cutting zone are observed. Simulation based 'soft-sensors' allow for an estimation of the real values of forces and temperatures at the cutting edge by the computation of the multiple sensor signals. A wireless transmission system communicates the data from the rotating tool (here a single lip deep hole drill [15]) to the signal processing unit which is, on the other hand, directly linked to the machine controller. By adjusting the tool rotation speed and feed velocity, the process conditions in the cutting zone can be controlled and adapted in order to produce compressive stresses in the subsurface of the borehole (Figure 5).

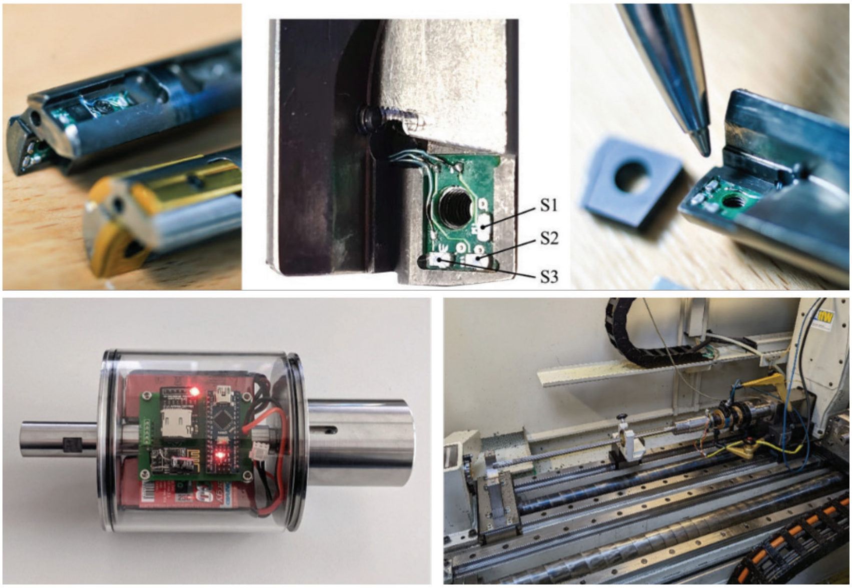

Figure 5: Sensor integrated deep hole drilling tool for the adjustment of subsurface properties.

4 Efficient cooling

Most machining processes require the application of coolant lubricant in order to reduce friction and to lower the temperatures in the cutting zone and, by this, to decelerate tool wear and to avoid material damage of the workpiece. Furthermore, the chip removal is supported by the coolant flow. Regarding the avoidance of squandering, only a minimum amount of the used fluids and just the necessarily required pressure should be applied. However, the adjustment of the use of coolant can only be realized based on a detailed understanding of the fluid-process-interactions. Therefore, present research aims in establishing coupled modelling and simulation of machining processes (e.g. sawing) [16] and the fluid dynamics and thermodynamics in the narrow vicinity of the cutting tools (Figure 6) [17,18]. This will in future enable to adapt the coolant use to actual cutting conditions but also to improve the tool design and to optimize the entire manufacturing systems with respect to resource consumption.

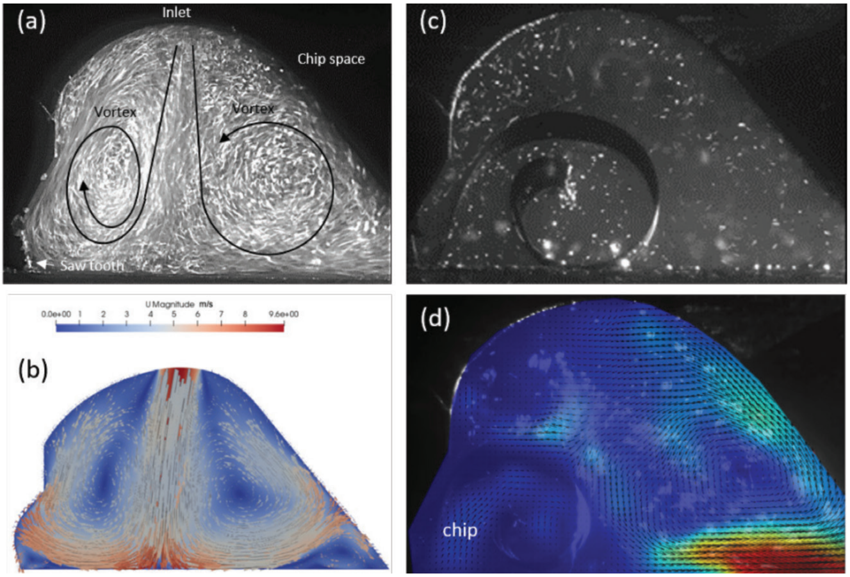

Figure 6: High speed camera analysis of coolant flow (a), simulation of coolant flow (b), interaction with chip formation (c), particle image velocimetry (d).

5 Summary

This paper discusses exemplary contributions of intelligent cyber-physical tools to achieve a sustainable self-optimization in manufacturing. Optimized process planning, monitoring and process control involving digital twins as well as knowledge-based application of resources establish fundamental means in order to meet the goals of sustainable development in production. Besides others, these technologies must be further developed in order to finally reach a CO_2 neutral production of innovative products.

6 Acknowledgements

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Development of an Efficient and Accurate Laser Cladding Control Strategy for Directed Energy Deposition (DED)

G. Li, M. Yang, M. Soshi

Department of Mechanical & Aerospace Engineering, University of California, Davis, CA, 95616, USA

Abstract

Directed energy deposition (DED) is an additive manufacturing (AM) process that can be used to produce customized complicated parts with less cost compared with the conventional subtractive manufacturing method. However, the parts produced by DED can be deformed severely due to excessive heat accumulation. The input energy, typically laser and electron beam, is commonly regulated in many literatures to minimize the deformation based on the temperature information of the existing clad. Although the energy input control method is proved effective in reducing the deformation, the productivity of the DED process is not increased. In this article, a feedback controller based on the fuzzy logic controller is proposed to maintain geometric consistency while increasing the production rate at the same time.

Keywords:

DED, feed rate control, fuzzy logic, simulation

1 Introduction

In DED, laser energy and material are added to the substrate simultaneously along with the inert gas. The melted metal powder and parts of the substrate forms the melt pool together.

Compared with other additive manufacturing methods, DED can be used to repair damaged high value parts and extend their life cycle. Moreover, DED is also capable of printing gradient and multifunctional heterogeneous materials [1]. Despite all the unique features, DED also shares some common disadvantages of the AM, such as relatively expensive material and quality issues.

The cladding quality is generally depending on the major cladding parameters. It has been mentioned in many researches that the major cladding parameters have a significant impact on clad geometry, such as the laser spot diameter, the distance between deposition head and melt pool, and the powder particle size [2]. However, this article is focused on the feed rate, powder flow rate, and laser power, which are also frequently mentioned in many studies.

It has been shown in the research that if the ratio of powder mass flow rate to feed rate is constant, the cross-section area of the clad is also invariant [3]. Therefore, the combination of the cladding parameters is usually used to reveal the relationship between cladding parameters and geometry.

The powder flux (PF) describes the amount of powder added to the clad in unit length and time by assuming the laser energy is sufficient to melt the powder. In the Advanced Research for Manufacturing Systems (ARMS) laboratory at UC Davis, the clad height (h) was found to have a linear relationship with the PF from comprehensive experiments, which is shown in the equation below.

$$h = 1.025 \cdot PF \tag{1}$$

Other than the major cladding parameters, the initial temperature of the substrate is also an important factor. It has been demonstrated that the melt pool width and depth are closely related to substrate surface temperature [4]. The initial surface temperature is room temperature. After each layer is added to the work piece, the new clad surface temperature is different from the previous layer. Therefore, a feedback controller based on fuzzy logic is proposed in this article to adjust the cladding parameters based on the surface temperature of previous layers to maintain geometric accuracy and improve cladding efficiency.

Many researchers have built models both numerically and analytically to better understand the cladding process. An analytical model of laser cladding was developed by Lalas [5] to estimate the clad width, depth, and height by taking into account feed rate, powder flow rate and surface tension. For estimation of the clad characteristic, the approach has a maximum of 13% deviation for the clad width and 30% deviation for the clad height. One of the main sources of inaccuracy is the difference between the assumption of the melt pool geometry and the actual clad shape, which is commonly seen in other literatures.

The theoretical models certainly reveal the connection between cladding parameters and clad geometry, and they can be used as a guide for process monitoring and control of the DED process. A numerical model is built including the effect of temperature-dependent material properties, latent heat, laser distribution, and material addition. Material addition is simulated by using the model change technique.

2 Model development

The cladding process simulation is conducted in ABAQUS first. The silent element technique is adopted to better simulate the dynamic process by which the material is added to the workpiece along with the laser power. Compared with the model change technique, the element is added to the model if only the temperature exceeds the melting point temperature instead of the location and time. The energy balance equation is applied for all the elements and nodes in the model. The substrate is initially active and at room temperature, while the clad part is ready to be activated during the simulation.

3 Feedback control based on fuzzy logic

The fuzzy controller is composed of fuzzification, inference, and de-fuzzification module. The controller takes two inputs, error and error. Error is the temperature difference between objective temperature and current temperature and error is the temperature difference between two consecutive layers. The output is the cladding parameters increment, which is either feed rate or laser power.

3.1 Control schematic

The feedback controller based on fuzzy logic is shown in Figure 1.

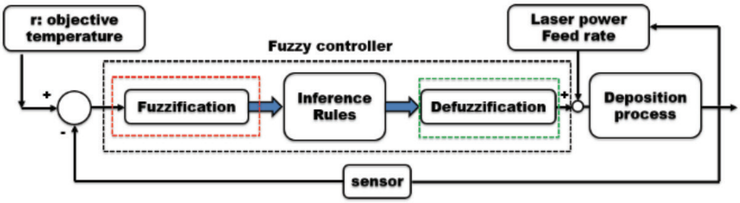

Figure 1: Fuzzy control schematic.

3.2 Simulation result

Series of simulations including thin walls and square blocks are conducted to demonstrate the effectiveness of the fuzzy controller. The partial simulation results are presented in Figure 2.

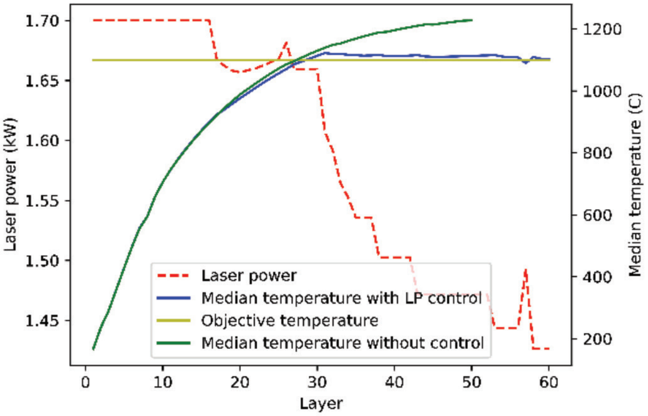

Figure 2: Simulation result of a square block.

4 Experiment

4.1 Experiment set-up

The experiment is conducted on LASERTEC 65 Hybrid. With the help of the dynamic powder splitter system (DPSS), the powder flow rate can be adjusted dynamically during the experiment. The powder splitter is installed on the laser head, showed in Figure 3.

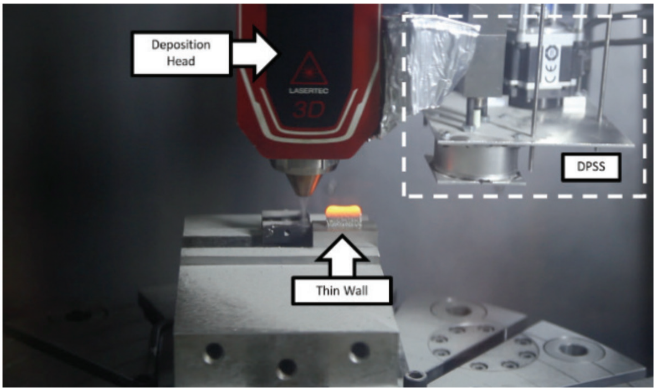

Figure 3: Experiment set-up.

The cladding parameters are generated by the simulation and applied in the experiment for validation. A camera system with a thermal sensor and CDC camera installed will be able to collect the surface information in real time, including surface median temperature and clad size. With the help of the camera system, the cladding parameters, laser power and powder flow rate, can be adjusted dynamically, showed in Figure 4.

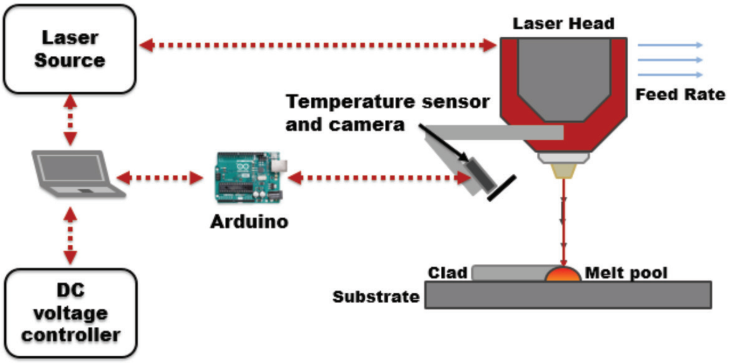

Figure 4: Control schematic of cladding parameters.

4.2 Experiment result

A set of thin wall experiments is conducted to compare the geometry with no control applied to the geometry with laser power control and feed rate control. The initial cladding parameters of the thin walls are the same. The thin wall with the control method applied has much better geometric accuracy than the thin wall without control, figure 5. Furthermore, the fabrication time of the thin wall is reduced by 22% with feed rate control.

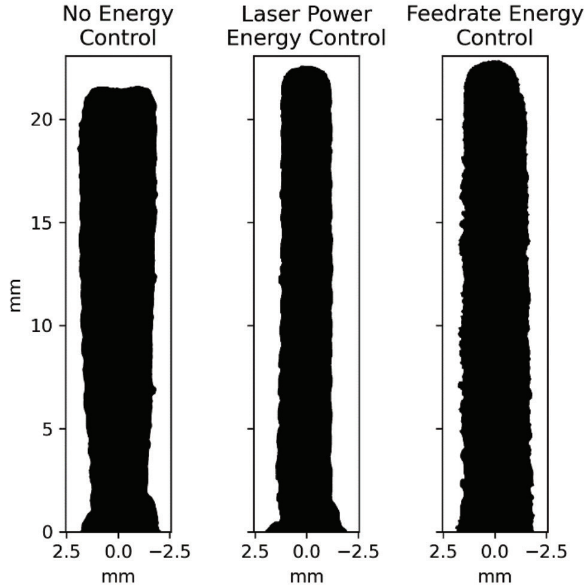

Figure 5: Comparison of thin wall experiments.

5 Conclusion

The clad geometric accuracy can be improved by both feed rate control and laser power control method. Feed rate control can produce geometry closer to the expected value than laser power control with better cladding efficiency. After the camera system is finished, the control system will be able to adjust the cladding parameters based on the clad information dynamically to improve the clad geometric accuracy and building efficiency.

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Digitalisation in Production

M. Stautner[1], D. Plakhotnik[2]

[1]Hochschule Ruhr-West, Institute of Mechanical Engineering, Mülheim, Germany
[2]ModuleWorks GmbH, Aachen, Germany

Keywords:

digitalisation, additive manufacturing, digital twin, sustainability

Digitalisation, particularly in mechanical engineering and there especially in individual areas of production, has been used for some time as an important and decisive building block for solving a wide range of current problems. At first, the optimisation of production despite reduced batch sizes was a goal. The aim here was to minimise manual preparation steps, in particular through greater digitalisation. In recent years, the demand for greater flexibility and resilience in production has been added. Not very surprisingly, the careful use of resources is now also an important objective. It is generally expected that digitalisation will make a significant contribution to this. However, this is also problematic, and there are still a lot of unresolved tasks for software companies and integrators.

In this context, additive manufacturing is becoming increasingly important compared to traditional manufacturing processes. Here, the trends toward smaller batch sizes and resource-saving manufacturing mean that additive manufacturing can be used more effectively than conventional “mass” manufacturing; therefore, the disadvantages of additive manufacturing, such as higher costs per part, a higher technological outlay and the high time required, can be compensated.

Additive manufacturing distinguishes between a wide variety of processes. They range from plastic extrusion (fused deposition modelling, FDM with the materials PLA, ABS or PETG), to binder-based processes, e.g. for, ceramics (binder jetting), to processes for the additive manufacturing of metals. The two most important processes for metals are powder bed-based (Powder Bed Fusion, SLM and EBM) and the direct application and welding of the material as a metal powder or metal wire (Direct Energy Deposition DED).

However, the advantages of these additive processes can only be utilised when these methods are digitised to a high degree, as this is the only way to compensate for the disadvantages mentioned above. However, here in particular, many sub-steps are not or only insufficiently digitized, and there is still a great need for development and training. In particular, current concepts for digitalization, such as IoT and CPS, can only be insufficiently transferred to these production methods. For example, smart sensor technology is difficult or expensive to implement, and some process steps are still carried out manually.

The training of these processes has often not been sufficiently covered in teaching. Graduates who are trained in the application would be ideal employees for SMEs. The possibility of hiring a trained worker would enable many companies to use the positive aspects of digitalisation and additive processes. The aim is to fill these gaps in digitalisation, especially in additive processes, and thus enable effective use and training of the processes to utilize these advantages and the benefits for sustainability.

Figure 1: Process chain in additive manufacturing.

The Human Side of Industry 4.0: Incorporating People's Capability and Personal Satisfaction to System Design

L. Mears[1]

[1]Clemson University–International Center for Automotive Research (CU–ICAR)

Abstract

As the manufacturing industry advances into the "Smart" digital domain, much emphasis is placed on the exchange and use of data by automated systems to provide information to allow user decisions. This black box approach can have a negative effect on the humans of manufacturing, i.e., those involved in carrying out day-to-day operations, because of uncertainty in their control of information and decisions now and in the future. Efforts in explainability of intelligent systems are now being undertaken, but humans in large part remain at the output end of data processes. In this work, integration of the human element within a smart manufacturing system is explored, including methods for extracting human data in real time, aligning it with automated process data, and providing rapid feedback to human-machine processes. Vehicle assembly is used as an exemplar due to the high human capital and agility required in the process.

Keywords:

vehicle assembly, human-machine interface, human data, smart manufacturing

1 Introduction

Modern efforts at deployment of Industry 4.0 technologies focus largely on the exchange of secure data among automated systems and supply chains, generation of information from that data through machine learning approaches, and the output of that information to help guide decision-making in a manufacturing context [1-3]. Such strategies have made clear improvements in the transparency and efficiency of manufacturing operations, but the human element has been left as a customer of the system rather than an essential component. The thesis of this paper is that failure to include the human in the control loop of the new technologies being introduced in digital manufacturing takes away their motivation and ownership of these technologies, which is a barrier to their widespread adoption. This paper explores some human feedback on this situation, and some low-cost technologies which can effectively "plug in" the person to the Industrial Internet of (People and) Things.

2 A Motivating Study

In order to understand human perception of Industry 4,0 technologies and the desire for particular characteristics of new system designs, a series of interviews was undertaken with both company leaders and individual workers. The purpose is to clarify the dichotomy between those that prescribe and those that use smart manufacturing technologies. This study was designed to understand present issues with adoption and future wishes for disruptive improvements, and issued to 25 manufacturing workers.

2.1 Study Results

The worker input is given in the below ranked listing:

1. Proper task allocation between person and technology.
2. Technology should engage the user.
3. Human-technology interface should operate efficiently.
4. Human-technology system should properly handle variation.
5. Information should flow freely between person and system.

Additional preferences include quality and production control, ability for the user to customize the system, and evidence of improvement.

3 Technologies to Address the Gap

In order to better connect the human with digital technologies in the manufacturing workplace and to create and align human data with machine data for generating information, a series of wearable data technologies are explored. Such wearables currently exist both commercially and in research labs, but suffer from high cost and low durability, so they are not feasible for typical production environments. Typical markets for commercial wearables are in product development, healthcare, and high-end athlete training, industries not as cost sensitive as manufacturing. This section will review a sample of these technologies and describe a pair of alternative designs that address cost and durability concerns.

3.1 Brief Background

A summary of recent research-based sensing gloves was undertaken. The main disadvantage of most laboratory implementations is poor durability [4,5]. Commercial offerings improve durability but at higher cost [6,7].

3.2 Wearable Design

The below design is envisioned and prototyped to simultaneously address cost and durability issues through the use of robustly-integrated inexpensive MEMS components. The system connects the user to the digital infrastructure through extra modes of sensing and feedback from operations. The intent is also to classify quality. First, a resistance-based stacked force sensor shown in Figure 1 is developed which measures both normal and shear loading, the latter having a normal component which can be decoupled [8].

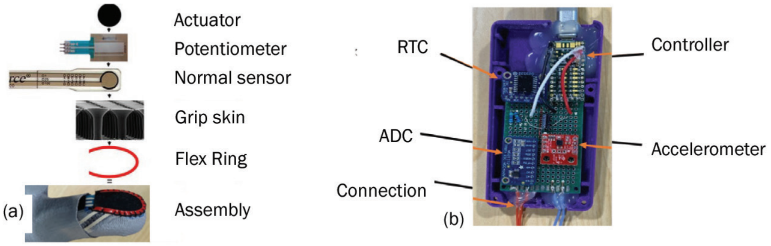

Figure 1: (a) integrated force sensor; (b) supporting electronics.

3.3 Application and Example Data

The force sensing system in Figure 1(a) was employed in a test for electrical connector validation using a subjective “push-pull-push” requirement [9]. Sample data of the test are given in Figure 2.

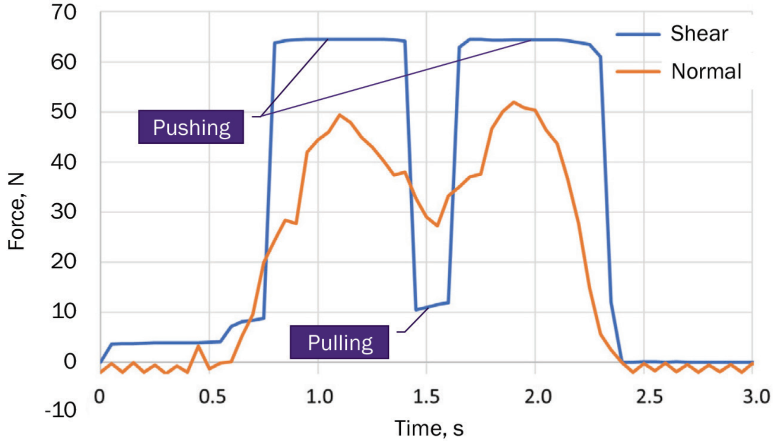

Figure 2: Shear and normal response testing electrical connection.

4 Conclusions and Future Work

This paper has established a perceived need to design more inclusive Industry 4.0 technologies to better connect the worker with the industrial data network. Existing technologies, particularly for human-integrated manufacturing operations, are shown to be largely inadequate (though it is acknowledged that there are numerous research efforts to remedy that). A set of example technologies with validation data were presented, which address the key manufacturing implementation gaps of cost and durability. In future research, these and other technologies will be able to provide the data to more sophisticated and intelligent human state estimation systems, for the purpose of actively adapting process controls. Such a future state will enable more technology ownership, improve quality and productivity in manufacturing operations, but perhaps most importantly reduce future uncertainty and foster human satisfaction in new manufacturing environments.

5 Acknowledgements

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The European Production Giganet – Towards a Green and Digital Manufacturing Ecosystem

M. Weber[1], M. Weigold[1], T. Koch[1]

[1]TU Darmstadt, Institute for Production Management, Technology and Machine Tools (PTW)

Abstract

The European Production Giganet contributes to the twin green and digital transition of the EU strategy to become climate neutral by 2050. The digitalization offers high potential for reducing the greenhouse gas emissions drastically in value creation networks that form data spaces to enable common use of data and services. The Gaia-X initiative for a common data and infrastructure ecosystem based on the EU legal framework offers a unique opportunity to build the future industry's internet where the requirements of self-sovereign data holders and fair business models are met. This creates trust and transparency in the value creation network to collaboratively company-wide reduce the product carbon footprint in the product manufacturing process. In this paper, the methodological approach is presented using plastic injection molding as an example.

Keywords:

product carbon footprint, twin transition, injection molding, Gaia-X

1 Introduction

There is high potential in CO_2-equivalent (CO_2e) emission reduction when using digital technologies that enable a sovereign data economy. Efficiency measures are more and more less effective on a small-scale system level. The climate change is a generational obstacle that can only be solved on a cross-company, cross-sectoral and European wide level. The EU commission highlights in the Green Deal in 2019: "It takes 25 years – a generation – to transform an industrial sector and all the value chains." [1].

2 State of the Art

This chapter explains the EU twin transition and presents demonstrators and standards for CO_2e accounting and reporting.

2.1 The EU strategy of twin transition

The EU commission published the Green Deal with the objective to reduce net greenhouse gas emissions by 55 % by 2030, compared to 1990 levels [1]. The industry domain still has a percentage of 26 % of the final energy consumption in 2020 in the EU [2]. Industrial processes and industrial use of products are responsible for 9 % of the CO_2e-emission in the EU in 2019 [3]. The digitalization in Europe is the second generational transformation taking place in every domain. The EU commission published its data strategy in 2020. The amount of data will be increasing by factor of five from 2020 to 2025 [4]. Additionally, the constitution of the European industry is dominated by small and medium-sized companies by 99 % [5]. There are 24 % of the personal staff of SMEs working in the manufacturing sector [5]. The requirements of those companies are protection of knowledge and human rights as expressed in the GDPR of 2018 [6]. They demand a high trust level in their partnerships and reliability in digital business operations. Due to the current crisis events since 2020 with the COVID-19 pandemic, disrupted supply chains, the Russian attack war against Ukraine, the European industry seeks for safe, secure, resilient, and sustainable production spaces. With the Digital Europe Program, the European Commission fosters the creation of Manufacturing Data Spaces according to their digital strategy. Three major topics are of high importance in the functionality of the Manufacturing Data Spaces. The supply chains in the industry must transform into multilateral agile and resilient networks. The assets of the infrastructure ecosystem must be dynamically manageable using digital twins for predictive and prescriptive maintenance. The companies share data for circularity, recycling, and remanufacturing in a horizontal plane. There will be two funded Manufacturing Data Spaces estimated to start by mid-2023. [7] The European commission formulates the strategy of twin transition meaning that the high potential of CO_2e-emissions reduction and the objective of a climate-neutral Europe by 2050 is only achievable with the digital transformation [8].

2.2 Demonstrators for CO_2e-emission reporting

The Platform Industrie 4.0 and CESMII together with the LNI 4.0 developed a testbed for the calculation of the CO_2e-footprint of a production along the value chain using the standardization of the asset administration shell (AAS) to share CO_2e-reports across companies [9]. The association for electrical and digital industry ZVEI in Germany developed a demonstrator for the creation of a PCF of a control cabinet using the asset administration shell for data exchange [10]. Each assembly of the control cabinet provides its respective PCF via the standardized digital nameplate according to DIN SPEC 91406:2019-12 which defines the automatic identification of physical objects and information on physical objects in IT systems. The kind of use of a digital nameplate providing structured, relevant product information is close to the definition of a digital product pass as proposed in the action plan for circular economy of the EU. This action plan is a major part of the EU Green Deal and aims at creating a sustainable production and products concerning the use and reuse phase in terms of recycling, refurbishing, or remanufacturing along its lifecycle [11].

2.3 Basic standards for CO_2e accounting

The evaluation of the companies related CO_2e-emissions during the production process. Here the basis is set by DIN EN ISO 14064 (2019) defining the so-called Scope 1 and Scope 2 respectively direct and indirect emissions of a company. The Scope 3 indirect emissions are defined for upstream and downstream activities relative to the system boundaries of a company's processes. A carbon report is generated according to the Greenhouse Gas Protocol (GHGP) Corporate Standard from 2015. To obtain the product carbon footprint based on the emission data from Scope 1, Scope 2 to Scope 3 general standards for life cycle assessment DIN EN ISO 14040 (2006) / 14044 (2021) and carbon footprints of products DIN EN ISO 14067 (2019) are adopted.

3 EuProGigant Implements Twin Transition

The presented work in chapter 2 focuses on the product carbon footprint to forward respective information in the supply chain and fulfil the legislative regulations. They do not provide approaches to reuse the PCF information and corresponding aggregated data in new self-sovereign business models of the ecosystem stakeholders to compare and optimize processes and finally reduce the CO_2e-emissions. The EuProGigant use case is called CO_2e-footprint in product engineering and manufacturing. The problem is stated as a lack of information access and digital readiness level of services to study the CO_2e-weighting effect of significant choices made and provoked during the product engineering phase before entering in the manufacturing phase. Core idea of the use case is the prognosis of the PCF through multilateral bidirectional offering and consumption of data and services with Gaia-X.

3.1 Use case for green transition

The methodology is based on the investment and economic efficiency calculation which will express values in CO_2e kg per part produced respecting the cross-company product design phase, mold manufacturing and injection molding machine manufacturing and the production process itself. Additional sources to deliver relevant information are databases for raw material like CAMPUS plastics, databases for energy and life cycle assessment data like ecoinvent. To study and model the information flow between the different stakeholders the MFCA method is transferred [12]. The calculation methodology is validated based on demonstrator components for plastics technology and machining production. Those are a clip for clamping tools in machine tool revolver made from plastics and the production of a gear shaft to verify the methodology in the metal industry. Optimization measures can be derived from applying methods from [13].

3.2 Use case connectivity for digital transition

EuProGigant builds an infrastructure and data ecosystem according to the principles and functionalities of Gaia-X using an open edge to cloud architecture [14]. This allows for enterprises to connect with each other to offer data and digital services respecting the requirements of data sovereignty, personal data protection and IT-security. The industry partner will integrate core functionalities of Gaia-X in their digital products and services to offer edge, on-premises, or cloud-based interoperable usage. The main functions are self-sovereign identity management and APIs to the organizational credential manager to adopt the Gaia-X Federation Services, portal functionality to browse for data and service offerings, data exchange connector to allow self-sovereign restricted access to information and services and Gaia-X Self-Descriptions that may serve as graph-based descriptor for behavioral interoperability of resources to implement resilience mechanisms [15]. Other functionalities can be consumed via trust service providers or the federator of the ecosystem.

4 Summary

This paper presents the transfer of the EU strategy of green and digital twin transition to the European Production Giganet use case of product CO_2e-footprint in the product engineering and manufacturing process using a methodology based on economic efficiency calculation for the prognosis of PCF through evaluation of different manufacturing system set ups in an iterative closed feedback loop. Gaia-X digital technologies are used to enable the use of the respectively needed data and digital services across companies.

5 Acknowledgements

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Resource Optimization in Production – Real-Time Data leads to Closed Loop Processes

Presentation of digitalization in parts production to the smart factory

T. Muecke[1]

[1]Siemens Industry Software GmbH

Abstract

In today's global economy, supply chain and resource reduction are becoming increasingly important for sustainable manufacturing. Thus, flexible production, considering CO-2 reduction, is an essential factor to achieve steady advantages in global competition. To map closed-loop approaches, data continuity from engineering to the machine is an essential factor for a continuous improvement process. The new approaches show the improvements that can be made over conventional processes. Here, the resources used in conjunction with detailed real-time data from the machine play an important role. It is shown how new effects can be achieved in parts production by means of a plannable digitalization roadmap.

Keywords:

smart factory, smart shopfloor, resource management,
Sinumerik Integrate, part manufacturing

1 Introduction

The current situation at end customers influences the digitization strategy, which is defined by a platform concept and a corresponding step model at Siemens. An essential part of this is the connection to the machines, which is described in more detail, especially for customers who have an inhomogeneous machine park (brownfield), which is relatively often the rule. Closed-loop approaches based on CAD features and operations can be mapped by means of the consistency at engineering. Here, the technical and operational processes are mapped to achieve new effects. It is shown which effects can basically be achieved in which stages.

2 Actual situation

Based on current surveys and findings, many companies implemented for parts production the below presented IT-landscape:

- ERP system.
- PDM/PLM system.
- APS/MES system.
- PDA/MDE.
- Connection to machines.

Basically, the following can be observed: the systems are linked, but there is no data continuity. This means-for example, that there is no continuity of the CAD feature via the NC operation to the machine; as a result, detailed feedback is not possible. In this context, one often finds MDA-feedback (machine data acquisition) on basics of a controller or a control terminal, which picks up several signals from the PLC (programmable logic controller) but does not allow detailed evaluation or traceability.

3 Solution from Siemens – general process

The strategies described below create the general procedure for achieving a smart factory via a digitalization roadmap, as described in Chapter 3.3 [1].

3.1 Platform Strategy

Data consistency provides the basis for achieving the effects in the smart factory. This closes the technical and business process on the shop floor. The ERP, PLM and MES platforms (Figure 1) are connected to the production related Sinumerik Integrate 5 platform. In this way, the production-related processes in parts manufacturing are mapped with Integrate.

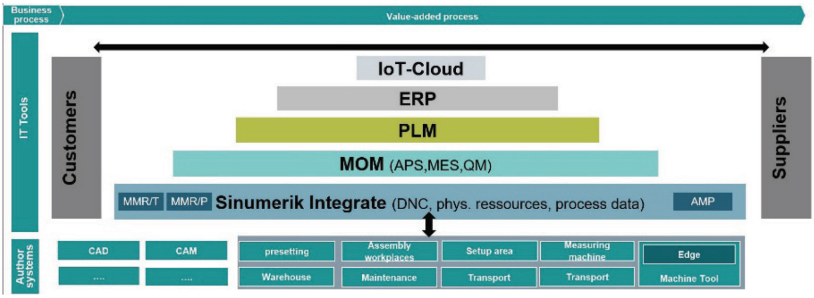

Figure 1: Platform-strategy to support part manufacturing.

3.2 Machine connectivity

An essential aspect is the deep integration into the machine tool. This is usually a challenge for most customers, as they have an existing machine landscape with different production facilities and controls. With a corresponding machine agent (Figure 2), we can represent a deep integration with different connection levels via a connector to the machine. This makes it possible to transfer data to the machine via a connector and to read out detailed NC, process, and tool information up to the order reference. This makes it possible to transfer detailed process, NC- and tool data for each CAD feature, i.e., the NC operation, which forms the basis for a closed-loop approach as well as detailed tracing and tracking data for the product and order up to the operation.

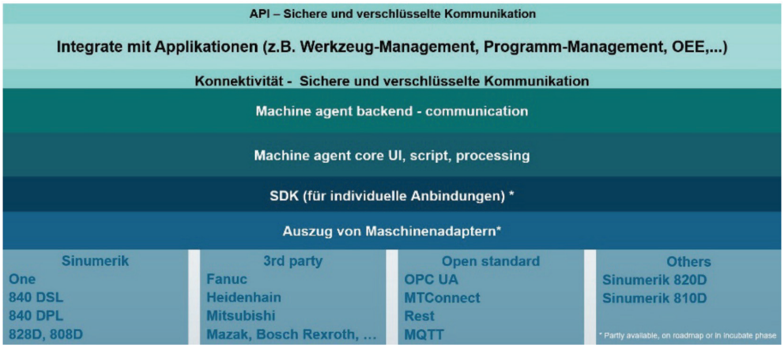

Figure 2: Connectivity via machine agent.

3.3 Stepwise approach

To present a digitization strategy, a corresponding step-by-step concept (Figure 3) exists, so that a customer-adapted strategy can be defined via a plannable budget.

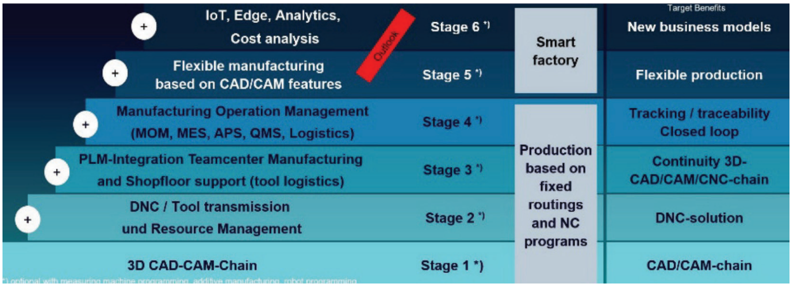

Figure 3: Digitalization step by step concept for part-manufacturing.

4 Resource Management

Sinumerik Integrate with the modules for detailed process data (Analyze my Performance AMP), NC data (mange my resource/programs MMR/P) and tool data (manage my resource/Tools MMR/T) form the basis for mapping closed loop processes. For each feature, detailed information from the machine with a link to the NC block, physical tool information and process data from the NC and PLC control or sensors can be read out. Due to the order reference, the complete provision process of resources (Figure 4) is mapped via the tool cycle [2].

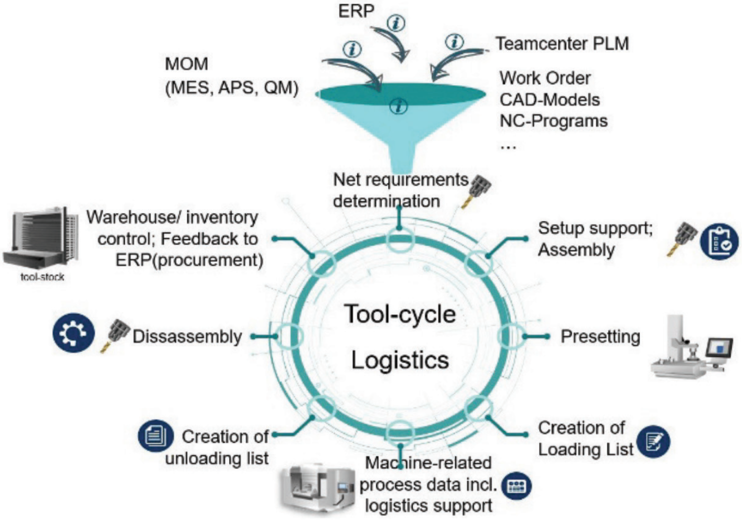

Figure 4: General presentation of the tool-cycle.

5 Way to smart factory

5.1 Basics of flexible manufacturing

To be able to manufacture more flexibly and in a more self-organized way, it’s necessary to take real time data from the machine into account. Thus, the top-down approach from the ERP must be linked with a bottom-up approach from the shop floor (Figure 5) to react flexibly to current utilization, resource utilization, etc. [3].

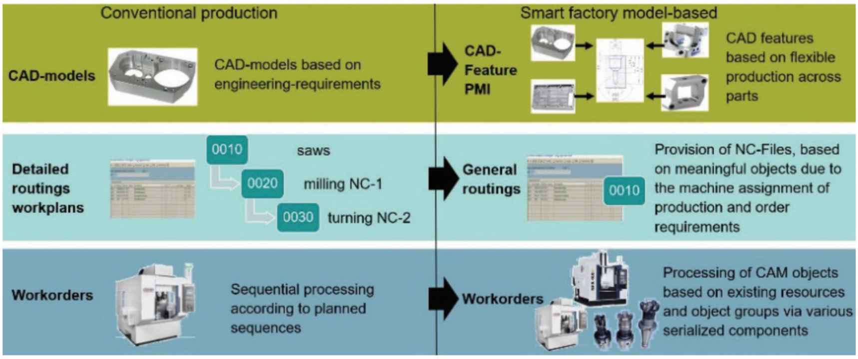

Figure 5: Differentiation: conventional and model-based approach.

5.2 Examples of closed loop installations

An example of optimizing technological data (Figure 6) has been realized at the technical University at Vienna (IFT). Here, vibrations, among other things, are considered based on the sensor technology of the tool holder via high-frequency data and cutting values are automatically adjusted [4].

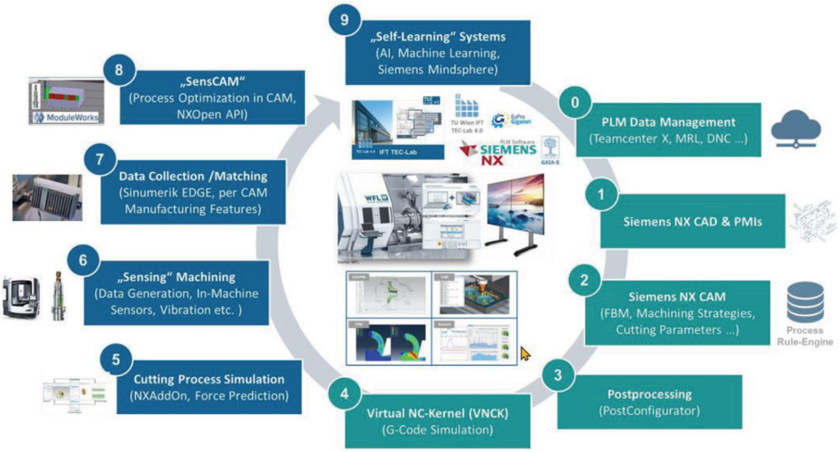

Figure 6: Overview closed-loop approach at TU Wien (IFT).

6 Benefits & Summary

Due to the complete shop floor optimization, considerable effects in productivity at the machine tool as well as in the service areas, such as tool presetting and factory train costs, have been achieved in realized end customer projects. The example (Fig. 7) shows a possible optimization potential with more than 30% cost reduction, based on the stage concept (Fig. 3) with the effects in the corresponding stage for a parts production and the assumptions mentioned below.

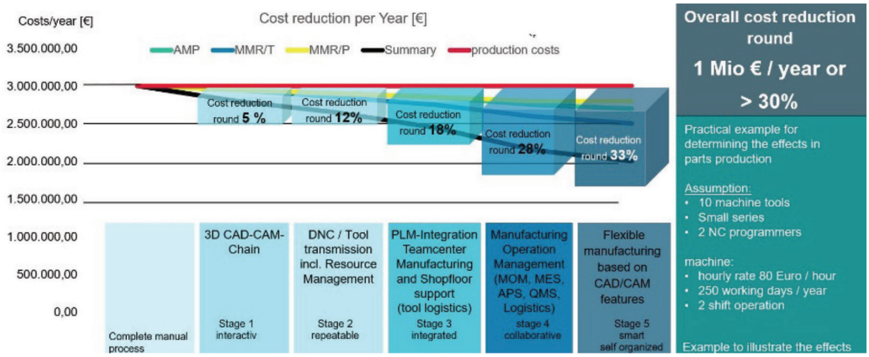

Figure 7: Example of benefits in shopfloor with digitalization.

The possibilities show new potentials. This significantly increases flexibility. Due to the real-time data, the basis is laid for achieving the above-mentioned effects.

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A Review of Multi-Physics Simulations of Additive Manufacturing Technologies

E. Escobar de Obaldia[1], **V. Sharma**[2], **A. Hiricoiu**[3],
A. Anderson[4], **P. Afonso**[5]

[1]Ansys Germany GmbH,
[2]Ansys UK Limited,
[3]Ansys France SAS,
[4]Ansys UK Limited,
[5]Ansys Iberia

1 Introduction

Additive manufacturing (AM) technologies have emerged rapidly in recent years and the application level has shifted from rapid prototyping to end-use functional parts. This holds a huge potential in various industries for improving materials efficiency, reducing life-cycle impacts and enabling greater engineering functionality compared to conventional manufacturing methods. While additive manufacturing evolves, numerical models have also improved to accommodate for multi-physics simulations that can capture different physical phenomena at different lengths scales. Thought to be impossible years ago, Multi-physics and multi-scale simulations are frequently used [1] to estimate defects and impact of process parameters on the quality and structural reliability of printed components.

2 Simulations Strategies

The simulations strategies presented are demonstrated with powder bed fusion processes but could also be applicable to other fabrications technologies (direct energy deposition, binder jetting, etc.). At the lower scale levels, we start with detailed Discrete Element Methods (DEM) that can help address the impact of recoater material and shape on powder distribution. Using DEM simulations can help predict whether powder shortening will be problematic for a given build plate and powder material. By coupling DEM calculations with Computational Fluid Dynamics (CFD), machine parameters could be optimized to reduce defects (e.g. keyholing) and understand complex particle dynamics, such as spatter effects.

As DEM and CFD analysis can be time consuming, meltpool calculations could be adapted under certain considerations and scenarios to Finite Element Models (FEM), which despite not having the same level of description, can still provide value and accuracy. For example, FEM thermal analysis can be used to predict meltpool dimensions, thermal gradients, and lack of fusion porosity.

At the part level, by combining FEM thermal analysis considering machine parameters with structural analysis, users can predict residual stresses and distortions with the highest level of fidelity. In terms of speed, macroscale simulations using inherent strains (IS) have gained popularity in industrial application. The IS method, which was originally developed for welding applications [2], is a simplified method that considers an initial strain value. The IS values are generally obtained through calibration by printing small representative samples and can be used to obtain accurate results. Different IS methods are available in Ansys, including those that consider isotropic or anisotropic strain values, as well as those that consider the strain from a thermal calculation [3,4,5].

3 Summary

In this review, we provide an overview of some of the mesoscale and macroscale modelling strategies that are available for metal AM processes within the Ansys portfolio.

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Improving the Precision of an FDM 3D Printer with Compensation Technique

O. Bodur[1], T. M. Bodur[2], A. Sterca[3],
E. Walcher[1], C. Sulz[1]

[1]TU Wien, Institute for Production Engineering and Photonic Technologies (IFT)
[2]Erciyes University, Wind and Aerodynamic Research Group
[3]TU Cluj Napoca, Department of Manufacturing Engineering

Abstract

Additive Manufacturing is a subdivision of intelligent and networked manufacturing in Industry 4.0 due to its individualized-mass production, reduced time to the market, and momentary viewability by using the Industrial Internet of things. Some detriments of Fused Deposition Modeling Additive manufacturing are undesirable geometrical deviations, low precision, and inaccuracies during the 3D printing process. This paper comes out by exploring and analyzing the volumetric errors of an FDM printer on each coordinate via Laser Interferometry, as well as integrating the compensation technique on a sample geometry to diminish geometrical deviations.

Keywords:

Error compensation, additive manufacturing, precision,
3D printer, accuracy

1 Introduction

Additive manufacturing is a process in which a part is constructed from successive vertical layers by depositing molten plastic with a heated nozzle which performs motions in three-dimensional cartesian space [1]. 3D printers are beneficial for rapid prototyping. Due to developments in recent years and their flexibility, 3D printers can meet specific needs and manufacture custom products for production or scientific fields [2]. Bodur et al. studied dimensional and geometric error compensations using an iterative method in which a part is printed and measured by high-precision metrology and the 3D model is compensated by the empirical data obtained. The process shows an increase in dimensional accuracy of up to 95% after only five iterations [3]. Bhatt et al. conducted a compensation study against the errors that occurred at the end-effector positioning point and determined that the positional accuracy of the end-effector is sensitive to the trajectory as well as to inconsistencies in the load-bearing points. A compensation scheme for the positioning errors has been developed where the input trajectory is sampled. The actual trajectory is measured to generate training data to learn a compensation scheme using an empirical approach [4]. Beltrán et al. have developed statistical methods for the classification, quantization and compensation of errors inherent in the additive manufacturing process with promising results [5]. Becker et al. examined the 3D printer technologies implemented in recent years. They emphasized the lack of position feedback sensors or error detection for other process-critical functions. These issues cannot be ignored in the market if the goal is to increase the quality of additive manufactured products [6]. Charalampous et al. developed a real-time visual monitoring system for additive manufacturing to detect and compensate for errors during the manufacturing process, reducing the amount of wasted material, time and failed parts [7].

2 Theory and Experiment

Figure 1: (a) Renishaw Carto XL 80 Laser interferometer,
(b) Renkforce RF1000 3D printer.

Linear measurements are performed for each of the three motion axes to determine positioning error in volumetric 3D space. The measurements are used to create an error map that can be used to develop a series of compensation models designed to reduce the positional error of the end-effector.

Various compensation models and algorithms are tested to determine the best strategy for reducing the positional error of the machine.

The linear measurements are performed on the three different axes of the 3D printer (Figure 1b) using a Laser Interferometer (Figure 1a). The measurements are performed in 10 mm steps within the limits of each axis in two different directions (forward and backward) for a total of five passes per axis. The limits for the axis are X-axis 10 to 230 mm, Y-axis 10 to 240 mm, and Z-axis 10 to 190 mm.

3 Results and Conclusion

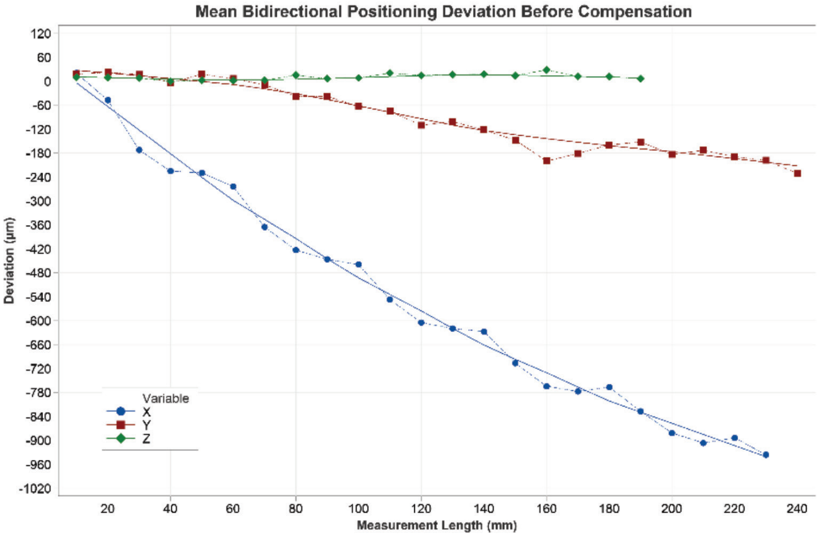

Figure 2: Mean bidirectional positioning deviation before compensation

The measurement results for the uncompensated axis are presented in Figure 2 as the mean errors of five passes for each step. The values obtained are used to compensate for the motion of the axis. The measurement results for each axis after compensation are presented in Figure 3. The measurement results after compensation indicate a drastic improvement in the positional accuracy of the machine.

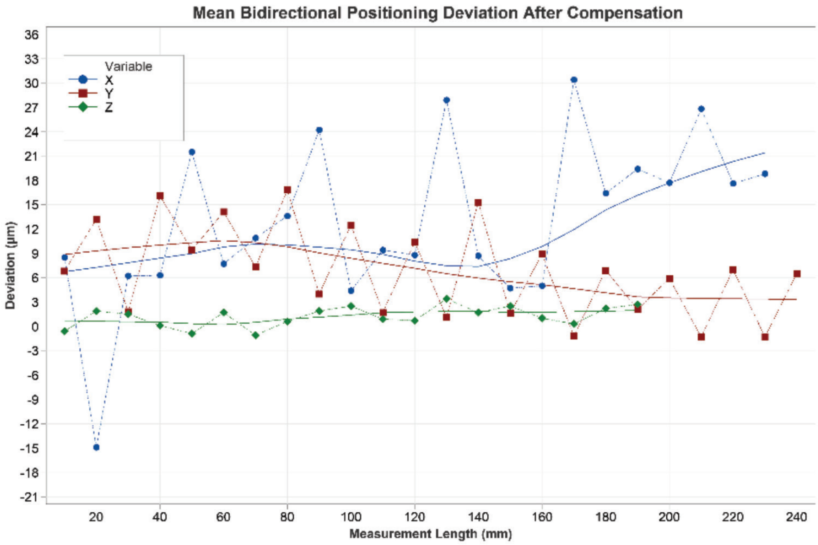

Figure 3: Mean bidirectional positioning deviation after compensation

The compensation table is used to generate a MATLAB program that can interpolate compensated values for complex motions inside a G-code program for a part to be manufactured, increasing the part's dimensional and geometric precision.

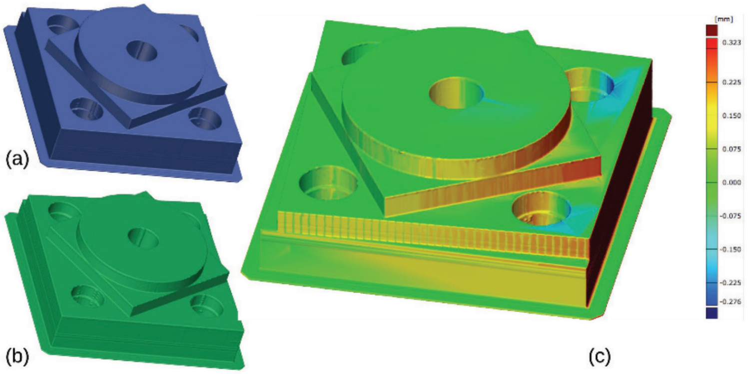

Figure 4: (a) Nominal model (b) Uncompensated model
(c) Form deviation of compensated model versus not compensated model

The G-code of the compensated model is created, and Solid models from both G-codes are visualized by specific software. An example of compensated G-code parameters is seen in Figure 4, which represents the uncompensated G-code (a), compensated G-code (b) and a comparison between the compensated versus non-compensated G-code (c). The precision of printed geometry is increased by the compensation technique. All those integrations propose an innovative solution to improve the machine repeatability and create higher value for the intelligent and networked manufacturing systems in Industry.

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Physics-informed Bayesian Machine Learning

T. Schmitz[1,2], G. Corson[1], J. Karandikar[2]

[1]University of Tennessee, Knoxville, Mechanical, Aerospace, and Biomedical Engineering, Knoxville, TN
[2]Oak Ridge National Laboratory, Oak Ridge, TN

Abstract

This paper provides a physics-informed Bayesian machine learning (PIBML) case study. An integral blade rotor geometry is machined from three materials: 6061-T6 aluminum, 304 stainless steel, and 6Al-4V titanium. Optimal machining conditions are identified using the PIBML approach and compared to recommendations from the manufacturer for the selected endmills.

Keywords:

machine learning, milling, stability, blisk

1 Introduction

Computer-numerically controlled (CNC) machining is projected to be a \$129B industry by 2026 with 5.5% annual growth from 2019 to 2026 [1]. Because significant cost is already embedded in the starting material and the capital resources and hourly rates are high, it is essential that parts are not scrapped and the machine/tooling is not damaged. The production of parts that conform to design drawing specifications requires that the machining parameters, including depths of cut, spindle speed, and feed rate are optimized. This study addresses the industry challenge using a combination of physics-based models, machine learning, and data to provide physics-informed Bayesian machine learning (PIBML) that improves the accuracy of model predictions over traditional machine learning or physics-based methods individually. The application is integral blade rotors (IBRs) or blisks.

2 Modeling

This section describes the modeling strategies used in this study.

2.1 Bayesian machine learning

Bayesian machine learning (BML) defines a probabilistic model of the milling stability map given test results (stable or unstable) over a spindle speed-axial depth of cut domain. Equation 1 shows Bayes' rule for updating the probability of stability at a selected spindle speed-axial depth combination using the stability result from a test point [2].

$$p\left(s_g \middle| r_t\right) = \frac{p\left(r_t \middle| s_g\right) p\left(s_g\right)}{p\left(r_t\right)} \tag{1}$$

In Eq. 1, p denotes probability, s denotes stability, r denotes the test result, subscript g and t denote a selected and test point combination of spindle speed and axial depth. From Bayes' rule, the posterior probability of stability at g given the test result at t is the product of the prior probability of stability at g, and the likelihood probability of the experimental result given g is stable, divided by the marginal probability of the result.

2.2 Finite element force modeling

The finite element software AdvantEdge™ from Third Wave Systems was used to model the cutting force. Orthogonal cutting was simulated for a variable chip thickness. Using the constitutive model for each material (6061-T6 aluminum, 304 stainless steel, and 6Al-4V titanium) and the cutting edge cross-section, the cutting force components were predicted. A linear regression was then performed to identify the slope and intercept values [3]. These values provided the mechanistic force model coefficients.

2.3 Receptance coupling substructure analysis

Receptance coupling substructure analysis (RCSA) was applied to predict the tool tip receptance, or FRF. In RCSA, a simple geometry artifact is first clamped in the spindle and measured by tap testing. Second, the spindle-machine FRF is calculated by decoupling the artifact in simulation (i.e., inverse RCSA). Third, the tool and holder models are coupled to the spindle-machine FRF to predict the tool tip FRF [4].

2.4 Physics-informed Bayesian machine learning (PIBML)

A physics-informed prior was generated by propagating uncertainties in the stability model inputs (force model coefficients and RCSA tool-holder coupling stiffness and damping) to uncertainty in the stability limit using Monte Carlo simulation. In each iteration, a random sample was selected from the input normal distributions. The stability limit was then calculated using these inputs. The spindle speed-axial depth of cut domain was divided into a grid of points. At each grid point, the prior probability of stability was determined by calculating the fraction of the number of stability boundaries where the predicted stable axial depth was greater than the grid point axial depth at the same spindle speed. The prior probability of stability was used in the PIBML approach to calculate the posterior probability of stability after new information was obtained from test results.

3 Results

This section summarizes the testing results.

3.1 6061-T6 aluminum IBR

The IBR geometry was machined using a 12.7 mm diameter, square endmill with three teeth. The prior probability of stability was calculated using Section 2.4. The endmill manufacturer recommended an axial depth of 6.35 mm and a spindle speed range from 6264 rpm to 24828 rpm for slotting. This axial depth was predicted to be unstable for all spindle speeds by the prior. Testing was therefore performed to identify optimal machining parameters. Using the physics-informed prior, six tests cuts were required for the PIBML model to converge to an optimal combination of spindle speed (7360 rpm) and axial depth (2.3 mm).

3.2 304 stainless steel IBR

A 12.7 mm diameter endmill with four teeth and 0.38 mm corner radius was selected for machining the 304 stainless steel IBR. The manufacturer recommended an axial depth of 6.35 mm and spindle speed range of 2215 rpm to 2674 rpm for slotting. Again, the recommended axial depth was predicted to be unstable for all spindle speeds by the prior and testing was performed to identify optimal machining parameters. Using the physics-informed prior, 11 tests cuts were required for the PIBML model to converge to the optimal spindle speed (5000 rpm) and axial depth (1.0 mm).

3.3 6Al-4V titanium IBR

The 12.7 mm diameter endmill with four teeth and 0.38 mm corner radius was also selected for the 6Al-4V titanium IBR. The manufacturer recommended a spindle speed range from 398 rpm to 1314 rpm and axial depth of 2.54 mm for slotting. The maximum material removal condition for this range, 1314 rpm spindle speed and 2.54 mm axial depth, had a 50% probability of stability according to the physics-informed prior. Therefore, no testing was completed and the IBR tool path was programmed using the 1314 rpm-2.54 mm parameters. The cutting conditions were stable.

4 Summary

This paper provided a description of a PIBML approach that implemented two physics-based models: 1) an RCSA prediction for the tool tip FRFs; and 2) finite element prediction of the force model coefficients in a Bayesian machine learning algorithm.

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Solid-State Metal Additive Manufacturing

F.E. Pfefferkorn[1], H. Agiwal[1], S. Krall[2], C. Baumann[2], F. Bleicher[2]

[1]Department of Mechanical Engineering, University of Wisconsin-Madison, Madison, USA
[2]Institute of Production Engineering and Photonic Technologies, TU Wien, Vienna, Austria

Abstract

The objective of this research is to gain insight into the emerging solid-state additive manufacturing processes, examples of which are friction surfacing of 304L stainless steel and aluminum EN AW 6060 - T66.

Keywords:

Solid-state, additive manufacturing; friction surfacing; coating

1 Introduction

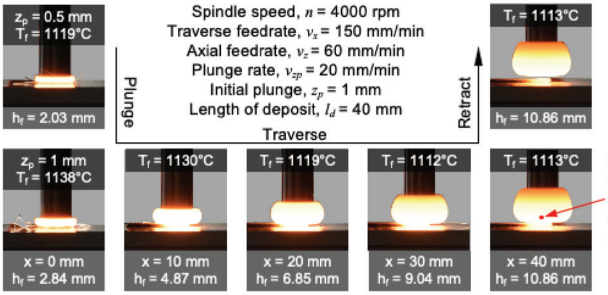
Additive manufacturing (AM), enables the layer-by-layer construction of complex parts from engineering materials without the use of tooling and has the potential to change many manufacturing endeavors [1]. AM processes have been classified into seven categories by the EN ISO/ASTM 52921 (2015) standard. The solid-state additive manufacturing processes are still in the early stages of adoption [2], hence it must still be clarified if they are categorized under extrusion or fall into their own new category due to the prevalence of friction and severe plastic deformation during deposition.

2 Solid-State Metal AM Processes

In a solid-state metal additive manufacturing process, the material does not exceed the melting point. These processes are achieved by hot-working the metal: temperatures are usually around 80%-95% of the solidus temperature. Metal is deformed and bonded to the substrate by utilizing friction, pressure, velocity, and time. The Severe plastic deformation during deposition results in a fine-grained microstructure. The hot working nature of the processes results in large forces and torques (at least locally). The dynamic recrystallization and lower temperatures and temperatures gradients, compared with melting-based processes, results in less formation of intermetallic phases, oxides, and residual stresses. Significant advantages of these processes are their ability to deposit almost any metal alloy, create deposits / bonds between dissimilar materials, and achieve deposition rates at least an order of magnitude greater than powder-based (and fusion-based) metal AM processes.

3 Friction Surfacing

Friction Surfacing (FS) is one of five commonly studied solid-state metal AM process. Friction Surfacing has been receiving a lot of attention recently because of its ability to be easily implemented on a CNC milling machine and produce fine-grained coatings with excellent surface and corrosion properties [3]. A rotating solid rod is pressed against the substrate under an applied axial load and is traversed along a defined tool-path (Fig. 1). Local frictional heating due to the elasto-plastic deformation between the consumable rod and the substrate generates a viscoplastic rubbing interface at the rod tip. The pressure and temperature as a function of time enables the formation of a metallurgical bond.



red dot indicates where the pyrometer was measuring temperature on the flash during the entire experiment

Figure 1: Images of friction surfacing of 304L stainless steel

Friction surfacing experiments were conducted for 304L stainless steel and aluminum EN AW6060 – T66 on a 3-axis CNC milling machine (HAAS, VF2, USA). All experiments were conducted using a position control mode of operation. The length of all deposits (l_d) was 40 mm (center to center). The consumable rods were clamped in a normal collet chuck holder. The relevant process parameter for FS includes the initial plunge (below the point of contact, z_p), a constant plunge rate (v_{zp}), a dwell time (t_{dwell}), a lateral traverse feedrate (v_x), a constant axial (plunge) feedrate (v_z), and the spindle speed (n).

Figures 2 and 3 show a typical cross-sectional view for a single layer deposition and five layers of friction surfacing, respectively. The thickness of the deposition decreases for 304L (~1 mm first layer to 0.5 mm fifth layer) with the number of layers, whereas for aluminum it remains constant (~2 mm). The higher traverse feedrate (vx) applied for aluminum results in a more than 10 times increase in the deposition rate. However, in contrast to 304L, more unbonded areas remain in aluminum, which reduces the joining efficiency. [4, 5]

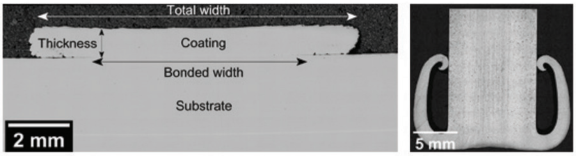


Figure 2: Cross-sectional view of deposit and consumable rod for single layer friction surfacing of 304L stainless steel

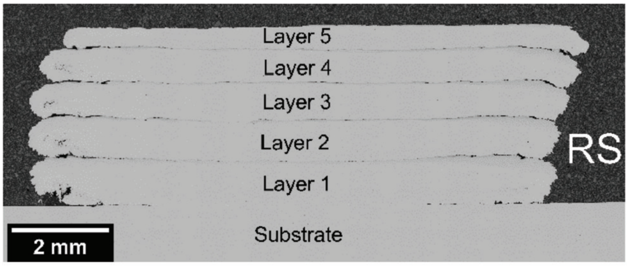


Figure 3: Cross-sectional view of multilayer depositions of 304L stainless steel onto 304L by friction surfacing

The (Z) forces for multi-layer depositions are plotted in Figure 4. With increasing friction surfacing passes for 304L the onset of a steady-state region of the deposition (during traverse) is delayed. The plunge force is around 6500 N and a steady state force around 3400 N. As a result of the high surface-roughness on aluminum deposits and a change of the deposition height within the 1st layer, the 2nd and the 3rd layers do not have higher plunge forces. For aluminum, the plunge force is around 3700 N and the steady state force 1568 N, which is half of stainless steel. Just like with stainless steel the steady state force increases 400 N after the first layer. [4, 5]

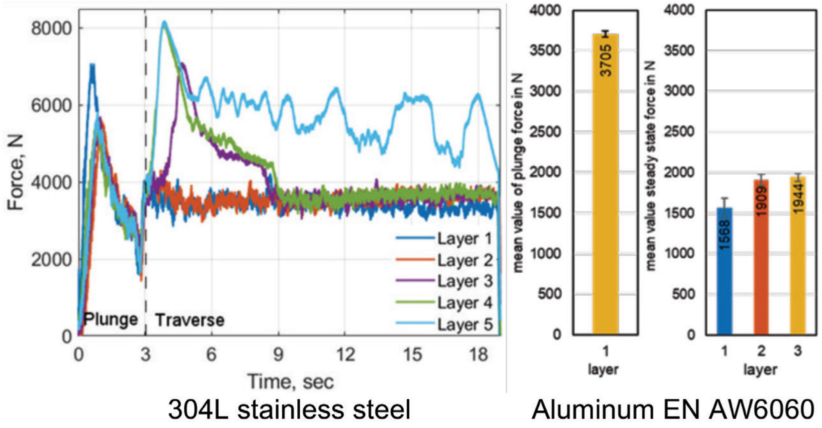


Figure 4: Z-forces for deposition of 304L and EN AW6060 - T66

4 Conclusions

Friction surfacing process forces are substantial, should be monitored, but can be borne by common CNC machine tools, making them additive-subtractive machines. Multiple layers can be deposited with process control.

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