Supporting the Set-up Processes by Cyber Elements based on the Example of Tube Bending

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Abstract: The increasing demand for individual and customized products constrains industrial companies to produce lower quantities which caused higher set-up times of the machines and therefore higher costs per piece compared to their traditional mass production. Especially within small and medium enterprises, the set-up processes often take place manually. However, the result is a critical factor for production success itself. During the set-up process, the worker is confronted with an information overload caused by the complex production system such as those like a tube bending process. Within this paper we outline a project called 'Cyberrüsten 4.0' that aims to provide a cyber element which is able to display needed information and adapted feedback for the set-up process. For this purpose, there are several steps of a practice-based research necessary. These steps were framed by the Design Case Study.

Keywords: Cyber Elements, Design Case Study, Mental Models, Usability, Set-up process, Information Overload, Feedback, Tube bending process, Additive Manufacturing

1 Introduction

Globalization and the resulting larger markets as well as the cheaper production possibilities offer a lot of potential to industrial companies. However, globalization is often accompanied by a number of challenges, too, because global markets imply global competitors. Industrial companies need to adapt their products to market trends at even shorter intervals. In addition, market positions must be expanded with new more advanced products offering higher quality at competitive prices. It is a constant tension

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area between customer-driven cost pressure, quality demands and features expected of the products that customers request.

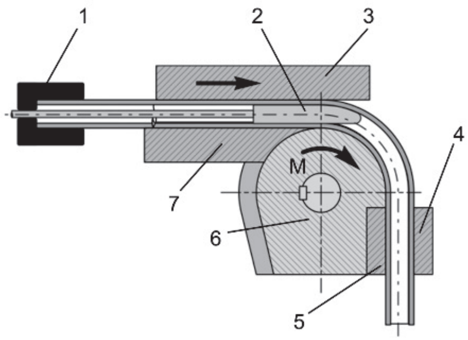
The satisfaction of customer requests and their steadily increasing demand for individual and customized manufacturing products led to an increased number of product variations. An early attempt trying to tackle this challenge was the process-centered concept of ‘lean production’ that aims at meeting the requirements of the flexibility with which companies must react to global market changes. One characteristic of lean production is that production planning does not primarily optimize machine capacity, but is geared towards customer demands [WJR90]. Lean production and cyber-physical systems offer new options for the physical process design [Bi07]. The changes brought about by lean production were so far-reaching that they signify a paradigm shift – especially in European and Northern American industrial companies. More recently, the concept of lean production has been expanded towards a socio-technical system that integrates the entire company, customers, suppliers, maintenance and process control as well as appropriate feedback loops [SW07]. But following the concept of lean production, the increasing demand for individual and customized products constrains industrial companies to produce lower quantities that caused higher set-up times of the machines and therefore higher costs per piece compared to their traditional mass production. Especially the effort of a machine set-up rises dramatically related to its switch-on time. According to individual products, the workers are not able to develop appropriate routine with reference to set-up processes.

Based on the background of increasing complexity, individualization and industrialization the additive manufacturing plays an important role [LKP15]. As a flexible manufacturing technology it contributes to reduce the production time of high quality products in small batches. In the framework of this technique the operator can be assisted by cyber-physical elements respectively digital models. Due to fast operating and set-up concepts, the additive manufacturing is used economically and efficiently. The social-technical field of application can be transferred into additive manufacturing process properties.

Therefore, we want to outline an approach that will tackle the high set-up times machine workers are challenged with during the manufacturing processes. For example, the rotary draw bending process requires six to eight tools which have to be adjusted within the set-up process. Set-up times are in the range of 60 to 90 minutes under laboratory conditions. In contrast, the set-up of a basic injection molding process only includes one tool and takes place in a time interval of about five to fifteen minutes. The question we try to answer is how to support the worker during the set-up processes based on modern information and communications technology (ICT) tools composed of a software managed physical tool. In section 2 we outline the process of rotary draw bending and the challenges workers are confronted with. Section 3 introduces the methodological framework, whereby section 4 constitutes our empirical-based approach for gathering information about the actual and informal practices of workers during set-up processes. Based on this method, we will take a look at future work.

2 Rotary Draw Bending of Profiles and the Information Overload for the Manufacturing Workers

The rotary draw bending is a manufacturing process with a complex tool setting (see fig. 1) [EM13], [VDI3430]. The complexity is caused by a trial period in which the different independent machine axes are adjusted. The semi-finished product is fixed between the outer and inner clamp die. After that, it is bended around the tool center point of the bend die. The pressure die is a tool for fixing the straight part of the tube in front of the forming area. With the collet's help, the tube can be fed and pushed in the forming direction.



No.	Tool
1	collet
2	mandrel
3	pressure die
4	outer clamp die
5	inner clamp die
6	bend die
7	wiper die

Fig. 1: Tool setting of a rotary draw bending process [VDI3430]

Depending on the geometrical factors – in this context the bending factor B (bending radius to tube diameter) and wall-thickness factor W (tube diameter to wall-thickness of the tube) are worth mentioning – the number of required forming tools increases immediately with the raise of forming complexity (see fig. 2) [En14]. A mandrel, for instance, has to be used to fill up the gap in the middle of the tube. Out of these circumstances, the machine operator has to decide which tool has to be adjusted in which position and which force has to be tuned in. Furthermore, different paths of trying out the production process lead to the goal of producing an accurate tube.

The current state of the art reveals to adjust the process on the staff's knowledge base comparable to the principle of trial and error [He15], [Ko13]. The cause lies in the minimal standardization of bending processes. Therefore, the expert's know-how leads to an island of information. These information will not be regular in other bending operation. Due to this, the result of a good bending operation getting an accurate bent part and even the time to try out the manufacturing process depends on the machine operator. If an employee with an extensive experience adjusts the machine, she/he will reach the goal faster than an employee with less experience in job.

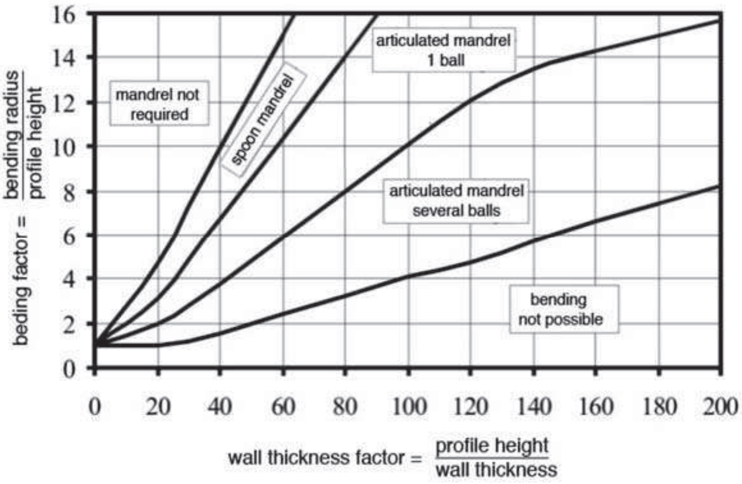


Fig. 2: Bending diagram for mandrel selection [VDI3430]

Next to the problems of saved and badly communicated information about the adjustment steps, different material characteristics of the semi-finished products (straight tubes) lead to more complex situations. For example, a well operating bending process can change into a bad one if the delivery charge of the semi-finished product is changed.

At the end of the bending operation the manufacturer gains a lot of specific knowledge regarding the bent part. These characteristics have to be measured and evaluated to the technical usability of the bent part as shown in [Ku16] to sell the product to the costumer. To the operator this induces a situation of a highly complex task, because there are a lot of dependent characteristics of the machinery and the material, which cannot be anticipated in advance and may be influenced in a dynamic procedure [BJ95]. Observing this procedure therefore makes it necessary to consider the different personalities for the operators. That leads to different levels of perceived complexity [Ca88] and different levels of information are processed without an overload [EJ04], [Wi01].

3 Design Case Study as Methodological Framework

As methodological framework, the project focuses on Design Case Studies. The main goal of new developments in an industrial surrounding aims to reinforce the economic efficiency of companies. In addition to that, formal organizational structures will decline and informal aspect as well as the differentiation of work practices will increase. ICT tools help to reach this goal by combining technological, organizational and social perspectives. However, to integrate such a tool, it is necessary to follow up a practical oriented approach of designing this tool. Typically, three main steps are necessary in the context of a Design Case Study. The first step is the empirical pre study with a focus on social practices. It even consists of micro level descriptions of social practices. In the following step a context-oriented design process of the ICT tool takes place. Next to the social aspects, the tool's description from a product and a process perspective should not be neglected. Finally, the Design Case Study records the introduction, appropriation and potential re-design of the ICT tool [Wu09], [Wu11].

In this case the main task of the ICT tool or other cyber elements will be to provide information and feedback. The evaluated data defines which information is needed and mental models contribute to prepare feedback appropriate to the user.

The whole design work will be attended by the usability idea. This means a participatory work progress between the development sector and the subsequent users [Wu15]. Nevertheless, the ICT tool will be used in an industrial surrounding. As a result of this, the tool must exhibit a robust construction and an ergonomic shape, that is adapted to the workday.

After certain design and construction phases, there will be different appropriations with the users of the tool. The guiding principle is to go through several iteration loops. In the course of the iteration loops, the ICT tool is continuatively adjusted by the users' needs. However, we expect to explore some opportunities to improve the tool. Empirical methods will help us to detect the changed user behavior and even to recognize improvements while the set-up process takes place.

4 Empirical Pre-Study

In order to get insights into the worker's specific knowledge and informal practices, we will conduct an empirical study. This empirical pre-study will take place in the context of a Design Case Study and fulfills the task of providing a knowledge base consisting of a large technical and social understanding. Building on the knowledge base the ICT tool will be developed. Furthermore, a common project language for communication with the practitioners will be established. The result of the pre-study is gaining a common understanding of problems and aspects which offer potentials to be improved [Ro16].

4.1 Empirical Access in the Production Environment

The testing field for the investigation of the empirical data will be an initial set-up process. Later on, it is still possible to expand the testing field on further set-up actions.

The common empirical pre-study includes several well-known methods as described in [PD15]. In this case, the challenge consists of the complex production environment in combination with a manually embossed set-up process. To face the given challenge, we need several perspectives to create an empirical data base [Wu15]. In a first step, we will concentrate on the technological background. Next to the machine-equipment, several other influences have to be taken into consideration, for example the bending devices or the semi-finished products. The analysis of documents (set-up plan, work instructions and user manuals) will be extended by intensive observations and expert discussions.

In a second step, the organizational structures will be determined. The empirical study tries to answer the question of how the set-up process is integrated in the entire manufacturing process. The set-up process is a manual process. As a result, the social perspective plays an important role. The human resource as well as the work flow has therefore to be examined. In this context, ethnographical methods such as interviews and expert discussions will take place. We expect to reveal both formal and informal organizational structures.

4.2 Possibilities for Using Mental Models

As a logical consequence of personalized internal cognitions, mental models represent a reduced image of the reality respectively of an original system [Jo83]. This is also known as tacit knowledge that controls action- and object-related human behavior on a hierarchical basis [FZ94], [Ha86], [Ha96]. Thus, every human being constitutes different homomorphic models to avoid an information overload through the reduction of cognitive effort and complexity [Ha96], [Si76]. To enable an effective transfer of tacit and formal knowledge, studies have shown that the variation of instruction and feedback is context-sensitive [LSZ12]. Concretization and contextualization of linguistical, metaphorical or sensual expressions take place via using analogies by falling back on known issues or experiences [GG83], [La87], [Sc94].

To support the machine operator within the set-up process by means of cyber-physical elements, initially mental models have to be derived. These models help to interpret work plans correctly and to control decision-making efficiently. Building on this, information of prevailing-processes as well as the cyber-physical adjustment instructions should be deduced, linked with the machine sensors and returned via user-friendly visualization. The adjustment implies a complex task. Therefore, it is to be expected that the operators use different heuristics to prevent an information overload. According to this, the development of various mental models is foreseeable, whereby a wide variety of features can influence the model design. At first, personal characteristics, e.g. perceived complexity [Wo87], [Ca88], motivation and attractiveness [LL90], [LL02] as well as risk perception and risk behavior [WBB02] or risk-reducing strategies [CL06] and specific knowledge [Ce08] have to be tested on their effects. Furthermore, context attributes that influence the operator's decision have to be used [JL09], [HNM07]. Therefore, his hierarchical embedding and his strains through the workplace should be considered, too.

Regarding the system to be developed as a feedback system, it leads to the approach of mental and conceptual mental models to get an accurate, consistent and complete system's representation [No83]. For an application the feedback-intervention-theory has to be considered. Following the theory feedback mediates positive and negative effects on performance both [KD96]. This finding is partly supported by Illies and Judges [IJ05] who show diminishing effects of positive feedback. The adaption of mental models to further set-up processes and also to further sectors gains a crucial importance to generate synergies, especially with reference to the transfer of tacit knowledge. Based on essential influencing factors, categories or cluster should be constituted to map different learning effects depending on time and quality.

5 Conclusion and Outlook

The project's main target is to support the operator using a cyber-physical element within the set-up based on the example of a tube bending process. The reduction of the set-up process' complexity should be generated by the creation of decision-makings. The connection of setting procedures and 'best practice' provides the basis for IT-supported assistance through visualization tools. Those tools should explicate the tacit knowledge in a simple manner and initiate an optimized feedback and learning process to reduce the recorded cognitive challenges. Essentially, the approach aims at the generation of low-waste production. At a later point of time, the initial limitation on the tube bending process will be abrogated and other set-up processes will be taken into account.

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