ERGONOMIC DESIGN OF LASER SINTERING SYSTEMS - RESULTS OF AN EMPIRICAL STUDY

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Abstract
Additive manufacturing processes such as laser sintering are characterized by a high rate of innovation, are a standard procedure in rapid prototyping and are becoming increasingly important in small-series production.
Despite the growing importance of additive manufacturing processes, there are no comprehensive ergonomic studies about work using additive manufacturing systems. This study therefore investigates the working processes of laser sintering systems. The method is guided by the DIN EN ISO 9241-210:2011 standard and helps to record the context of use, to accomplish usability tests and to develop design recommendations.
The outcome of the study shows that the efficiency of the laser sintering operating process can be significantly increased by implementing ergonomic recommendations and consequently further improve the employees' working conditions.

Keywords:
ergonomic design, additive manufacturing, laser sintering, usability.

1 ERGONOMICS IN ADDITIVE MANUFACTURING

Additive manufacturing processes, such as laser sintering, are characterized by being highly innovative, are seen as the standard prototype production process and are increasingly important in small batch production [1]. As a result of this, the global market for industrial additive manufacturing systems achieved 19,3% growth in 2012 [2]. Despite the increasing importance of additive manufacturing in the industry, there are as yet no comprehensive ergonomic studies related to operating processes with these systems. Furthermore, discussions among experts in the field have shown that the subject of human-centered system design has not, as yet been a priority for this very new and dynamically growing industry.

2 OBJECTIVES AND PROCEDURES

The objectives of the study are to show where there is potential for improving ergonomics in additive manufacturing, as exemplified by EOS FORMIGA P100 und P110 laser sintering systems, and to derive

recommendations for action which lead to improved usability for the operators and raise productivity.
The chosen method is based on DIN EN ISO 9241-210:2011 requirements (Fig.1) and is comprised of three steps.

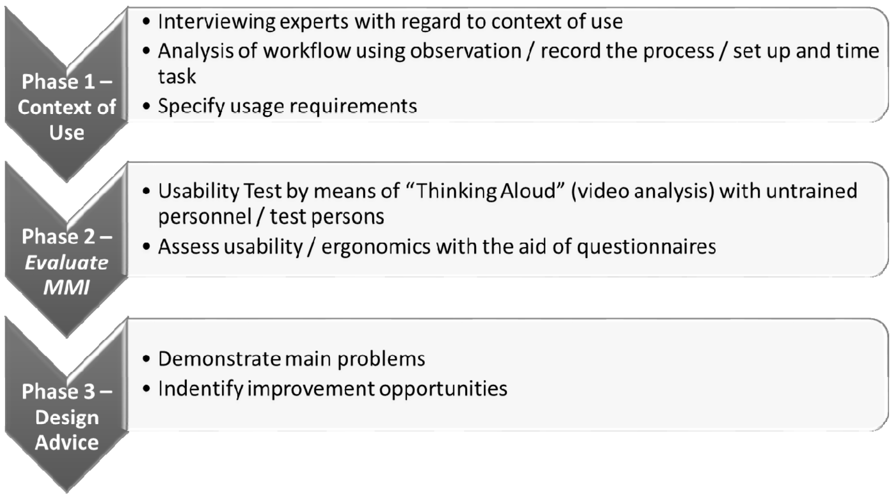


Figure 1: Project Method, Based on DIN EN ISO 9241:210:2011.

The first step is comprised of identifying and specifying the context of use. In order to establish the context of use, interviews were conducted with experienced users of laser sintering systems and processes were recorded at a large manufacturer of electrical connection technology. Furthermore, the operational processes using EOS FORMIGA P110 at this manufacturer were analyzed and the actual times for completion of an individual task were taken. The individual tasks were collated into a matrix, which shows the elements that the manufacturer can influence (controllability matrix), in order to assist the subsequent formulation of design recommendations (Fig. 2).

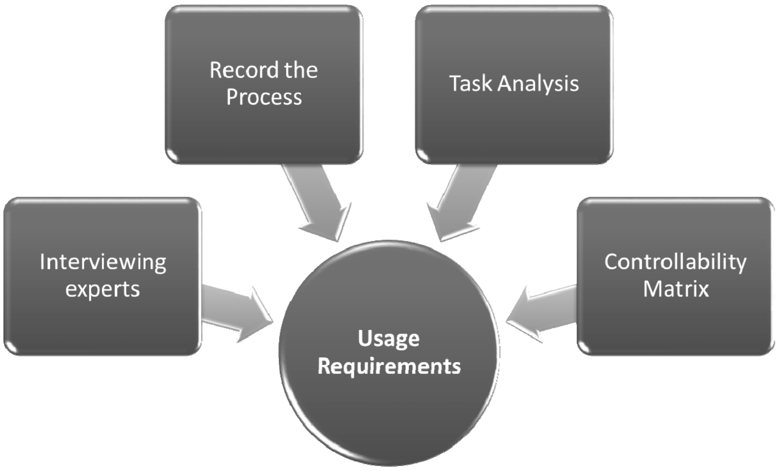


Figure 2: Methods to Establish Usage Requirements.

The second step involved conducting usability tests with EOS FORMIGA P100 in the design and development laboratory at the Ostwestfalen-Lippe University for Applied Sciences. In the third and final step, design recommendations are derived from the analytical results.

3 PROJECT PHASES AND RESULTS

3.1 Establishing the Context of Use

In order to establish the context of use, four semi-structured interviews were conducted, based upon an interview guide with 23 questions. This followed the content of DIN 9241-110:2008 context of use [4] and included information about user characteristics, aims and tasks as well as the system environment, amongst other things. The results showed that an employee’s tasks could be loosely subdivided into five subcategories:

1. Prepare customer quotes and accept orders.
2. Create works order.
3. Set up and complete order on the machine.
4. Clean machine and prepare for the next order.
5. Component finishing.

The first two sub processes are performed at a computer desk, only sub processes 3 and 4 are performed at the machine. It should also be noted that the first sub process is generally performed several times a day, since works orders for the machine usually comprise of a collection of customer orders.

Aside from the information about the user, tasks and system environment, the results of expert interviews also delivered the first indications of potential improvements. Employee statements indicated that the dust extraction from neighboring systems was insufficient, this resulted in the dust which results from unpacking components not being fully extracted, but distributed into the room. This dust generation can cause certain flooring to become slippery and can, therefore, pose a danger to employee safety. Furthermore, the space available was not large enough to allow placement of machines and materials for optimal workflow.
The objective of the Task Analysis was the analysis and evaluation of the completion of the five sub processes by one employee. The operational time of the person, not the usage time of the machine, was examined since the actual production process usually takes many hours without the supervision of an employee. The results of the study show that the first two sub processes, which are performed at the computer desk, take approximately two thirds of the total operational time examined (one hour and twenty four minutes) (Table 1).

Table 1: Task Analysis.

Sub Process	*Classification*	*Time Taken (Min.)*	Percentage of Total Time
(1)	Prepare customer quotes and accept orders	11:01	13%
(2)	Create works order	41:23	49%
(3)	Set up and complete order on the machine	04:49	6%
(4)	Clean machine and prepare for the next order	09:39	12%
(5)	Component finishing	16:58	20%

A lack of compliance with Dialogue Principles DIN 9241-110:2008, could be observed, as various software programs were used to prepare and convert CAD data. In “Magics” software, for example, when placing components, a wait time, which was not consciously noticed by the operator (Tacit Knowledge), could be observed and the software therefore did not conform to user expectations. It could also be shown that the software lacked intuitivity and learnability.
After collecting information and identification of improvement potential in the individual sub processes, these were represented in a Controllability Matrix showing factors that the company can control (Fig. 3). This figure shows that, in sub processes 1, 2 and 5, a medium to high controllability is

possible, whereas sub process 3 and 4 can only be marginally controlled, or are unable to be controlled by the manufacturing company, as it has no influence over the system design. The duration of the processes shows potential for ergonomic and efficiency improvement.

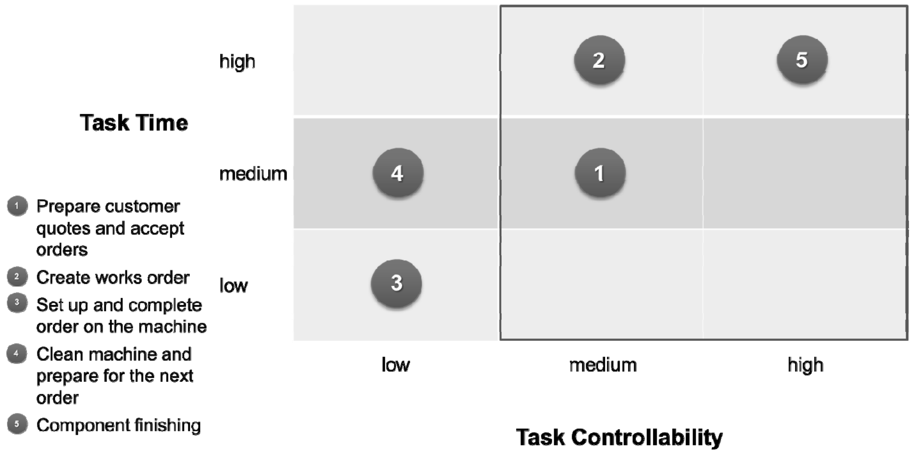


Figure 3: *Controllability Matrix (factors the company can control).*

3.2 Usability-Tests and Questionnaires

The usability test was performed on the EOS FORMIGA P100 laser-sintering system, with eleven participants, studying sub processes 3 and 4. The participants had no experience with the systems and, therefore, received an introduction to the manufacturing process before the tests began. The test took approximately 45 minutes and contained seven different tasks, which the participants performed on the system. The task execution was videoed and the participants were then required to assess each step of the task with the help of a questionnaire designed according to The Compendium of Ergonomics, by The Federal Institute for Occupational Safety and Health [5].

The single tasks “Raise Platform”, “Pre-Heat”, “Switch On / Off Nitrogen Supply” and “Begin Works Order” could all be completed by the participants within a short time period, as it appears that the system controls in this regard were self-explanatory and intuitive. Difficulties were incurred when switching the systems on (6 out of 11 participants), loading the works order (7 out of 11 participants) and shutting the system down (6 out of 11 participants). Above all, the works order loading symbol (7 out of 11 participants) and the shutting down symbols (6 out of 11 participants) were criticized as neither were considered to be self-explanatory in the context of this task (Fig. 4).

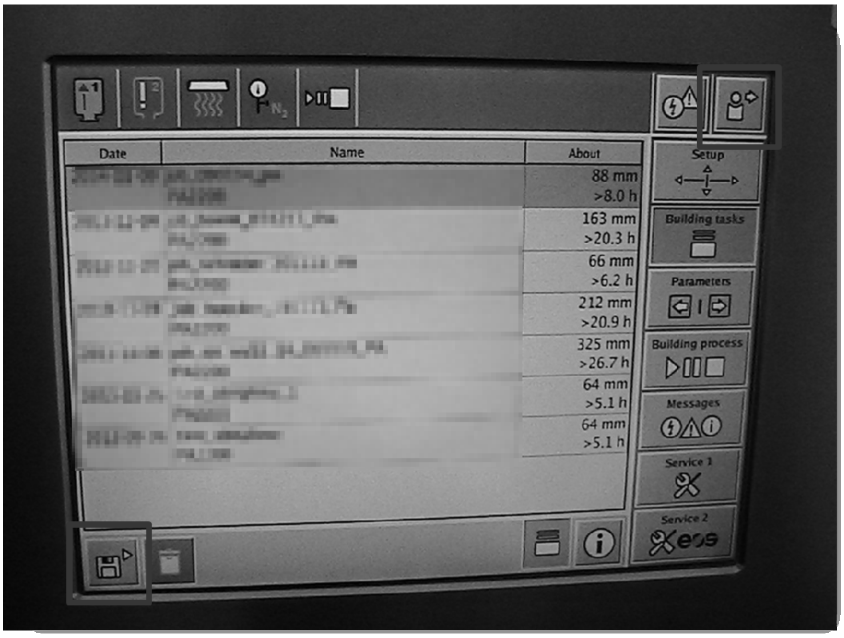
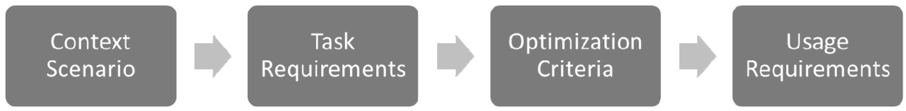


Figure 4: EOS FORMIGA P100 Laser Sintering System Control Panel.

Further ergonomic optimization potential could be identified in the ease of use of the powder container, during powder container changeover on the machine, as well as plugging in the heater plug, due to the participants often having to stoop or twist whilst performing these tasks. Furthermore, physical problems for the employees occurred during change over of the powder container, depending on the fill-up quantity, these can weigh up to 18 kilograms. It was noted that participants had problems with unscrewing the powder container lid because it was difficult to loosen and correct re-position when replacing was also problematic. Moreover, dust distribution was generally considered to be disturbing due to deposits on working clothes and the working environment, as well as the increased danger of slipping.

3.3 Design Recommendations

Based on the context of use analysis and the usability study, design recommendations were formulated for each of the sub processes. A context scenario was described as the basis for the design recommendations, out of which task requirements, optimization criteria and, finally, usage requirements were derived and defined. Figure 5 shows an example of this process. A selection of design recommendations will be explained in each sub process.



Example:

Context Scenario	Task Requirements	Optimization Criteria	Usage Requirements
Employee places newly mixed powder on the mixing station. In doing so the employee has to stoop, as the mixing station is on the floor	The employee should have be able to place the powder container more easily	Work station ergonomics	Place the mixing station at an ergonomic height

Figure 5: Model and Example for the generation of Usage Requirements.

Sub Process 1: Prepare Customer Quotes and Accept Orders

It was noted that the quotation process involved enquiries from various sources, using differing file formats and containing differing information. Standardization of the quotation process, using a standard form as well as limiting the CAD formats accepted could dramatically reduce the operational time and therefore increase order processing efficiency.

Sub Process 2: Create Works Order

The manufacturer should adapt the software to conform with user expectations, improvements of intuitivity and learnability should also be made.
Due to the long component layout processing times, the use of an additional program “3D Nester” is to be recommended, this program produces an automatic layout, which dramatically reduces processing times. The yearly License costs of 3,150.00 € will pay for itself in a very short time.

Sub Process 3: Set Up and Complete Order on Machine

Due to the problems with unscrewing the lid and the lifting problems highlighted by the usability test, handling of the powder container can be greatly improved by the construction of an area / shelf to place the container on and a transport trolley. Single, non self-explanatory symbols in the control system should be replaced and learnability can be improved to conform to ISO DIN 9241-110:2008.

Sub Process 4: Clean Machine and Prepare for Next Order
Changing the location of the heating unit and simplifying the plug construction can improve heating unit handling. The heating unit plug is to be constructed in such a way that sharp parts are avoided and the risk of injury thus reduced.

Sub Process 5: Component Finishing
The finishing station, mixing station and blast cabinet should be height adjustable to accommodate the user's individual body size whilst finishing the components.

4. CRITICAL APPRAISAL

The results of the study show clear ergonomic improvements to be made to the additive manufacturing system appraised. Implementation of the design recommendations would provide improvement for both the employees working conditions and the efficiency of the operating systems. However, as yet only two systems have been examined. Further studies in this sector must be carried before representative statements can be made regarding ergonomics in additive manufacturing. The development of industry standards with regards to regulations and guidelines could also help to establish ergonomic standards industry wide.

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