Design for Microassembly – Capturing Process Characteristics

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Abstract

Micro systems technology (MST) is considered to be an enormously strong economic driver in the 21st century. Market estimations predict a large volume of products in MST within the next decade. Within MST, microassembly shows vast potential in a wide range of industrial applications. Currently this potential has only been shown by the development of demonstrator products within research environments and with limited transfer to industrial practice. Microassembly is in particular necessary to produce multi-material devices with complex and true three-dimensional geometries. Although there are various DFA methods in use since the seventies to guide the designer to producing efficient and economic design, there is a lack of well defined solutions tailored to the microworld and its specific challenges. In fact, most DFA methods focus on assembly of products with part dimensions ranging from a few millimetres up to several decimetres. For the design of microproducts it is essential to consider key assembly process features in the early design stages. Furthermore it is important to provide support in the selection of suitable assembly processes by considering process related requirements as well as offering quantitative cost analysis to support the decision making to assure best producability and by this means enable an increased transfer of microproducts from the research laboratory to industrial production.

Keywords: Microassembly, Design, Process selection

1. Introduction

Microassembly is a fast moving and complex domain which is characterised by part dimensions from sub millimetres to a few millimetres with functional part features in the range of micrometers, small tolerances and high positioning accuracy, typically 0.1-10 micrometers [1]. Due to increasing miniaturisation of parts and products, novel challenges arise [2,3,4]. The production of multi-material devices with complex and true three-dimensional geometries is considered to be extremely difficult and at present can only be achieved through means of microassembly. Essential problems are identified with regard to the determination of assembly processes for automatic microassembly, in particular joining, feeding and handling. The transfer from the product development stage in the research laboratory to the production stage on industrial scale is delayed most of the time because of the difficulty in developing cost-effective manufacturing processes [5,6].

Accurate consideration of microassembly processes already in the design stage does not only increase the transfer to market but also dramatically reduces the costs of assembly of miniaturised or hybrid systems in the microdomain, which are estimated to run up to 80% of the production cost [7]. That is why this paper describes a DF\textsubscript{µ}A methodology that facilitates both, design improvements early in the design phase by capturing available microassembly process characteristics and product-process analysis which provides a way to select and determine appropriate assembly processes.

The paper is structured as follows: After the introduction in Section 1, relevant prior work regarding DFA in the microworld is described in Section 2, whereas Section 3 describes the conceptual layout and the implemented product-process analysis of the developed DF\textsubscript{µ}A methodology. Finally the paper closes with the conclusion and a brief outline of future work in Section 4.

2. State of DFA in the Microdomain

There are various DFA methods in use since the seventies to guide the designer to producing efficient and economic design. The Hitachi Assemblability Evaluation Method, the Lucas DFA Evaluation Method and the Boothroyd-Dewhurst DFA Method have to be named as the most common conventional DFA methodologies. However, most DFA methods focus on assembly of products with part dimensions from a few millimetres up to several decimetres [8].

Pahl and Beitz have developed a systematic design approach aiming at evaluating the conceptual design [9]. The product design is broken down into designs for separate functional modules which are then considered independently, minimising their interactions. The main benefit of this approach is the simplification of the design process for the individual modules. However, this approach is disadvantageous with regard to fostering function integration and hence can increase the overall complexity of the product by resulting in a higher part count and additional manufacturing problems, especially in the micro domain.

The conclusion that there is a lack of well defined methodologies for the microdomain is underlined by findings of major international studies, carried out by renowned institutions: [6,10,11,12]. Nevertheless, efforts towards DFA in the microdomain can be found in the literature and will be analysed subsequently. The design rules’ validity for the microassembly area of an existing DFA-tool is discussed in [8]. It is stressed that it is not possible to examine all existing design rules. However, one conclusion is that “the majority of the design rules in macro DFA are valid also for micro DFA” [8]. On the other hand it is also pointed out that “some of the most critical parts of the assembly
process, i.e. handling, feeding, gripping etc.” require updating or new design rules for the microdomain. Furthermore, it is stated that the integration of the product design, the process and the production equipment becomes even more important in the microworld. The product design has implications on the possible handling technologies and vice versa. This clarifies that a DFµA methodology needs to incorporate a method for making the match between required processes and existing processes. Function, technology, material, stress, principles, guidelines, microspecific effects are multidisciplinary boundary conditions that not only influence microcompatible design [13], but also need to be considered for accurate process selection. Reference [14] describes a design for microassembly approach which is based on only proven interconnect and packaging technology that targets design for cost effectiveness and not optimisation of functionality. The Finnish company Deltatron tries to initially integrate microworld specific design rules into their DFA-Tool. Conventor offers design packages for MEMS applications which focus mainly on silicon. At the moment they do not support the selection of microassembly processes.

Finally, it can be summarised that efforts are spent on deriving design rules for specific areas of the microdomain. But it becomes clear that design guidelines in the conventional sense are not sufficient in the microdomain. Due to constantly ongoing research and an enormous variety of assembly processes the designer needs to be made aware of what is possible, to realise a producible and cost effective design. The methodology presented in the next section attempts to address the above explained DFµA knowledge gap.

3. DFµA Methodology

Although there are no common DFA methodologies for the microdomain, there are still some properties which all methodologies should comply with to be useful for the designer. A number of characteristics that should be addressed by any DFA methodology can be found in [15,16]. It can be summarized that DFA methods need to be complete, systematic, measurable and user-friendly. In addition they should provide support of cross-functional teams, transfer of knowledge, cost analysis, quality assurance, geometric product evaluation and design suggestions. As these requirements are general and only related to the design of the methodology they are also valid for a methodology which is used in the microdomain.

The conceptual structure of the DFµA methodology, considering most of described requirements, is presented in the following section. Because of the critical importance of assembly processes in the microworld and since the intention of the method is to enable and support the assembly of complex multi-material micropackets, the focus is laid on different aspects than the one’s of traditional methodologies.

3.1. Conceptual Layout

The DFµA methodology facilitates improvements early in the design process through:
- Application of design rules and guidelines which are focused on the microworld to cope with its specific challenges.

![Fig. 1. Conceptual DFµA Layout](image)

- Consideration of key assembly process features in early design stages.

Moreover, the determination of appropriate assembly processes through capturing of process related requirements is another major objective. Figure 1 illustrates the conceptual layout of the DFµA methodology and its underlying models which assure a sound product design that can be produced cost-efficiently because suitable assembly processes are selected. The first design specifications will be based on the product requirements which influence the design the most, mainly functional requirements. Only conceptual drawings are needed. But, like in other DFA methods, the more comprehensive the initial information the more effective the result. That initial product design will be analysed and evaluated by applying the DFµA guidelines.

After feeding the input from the DFµA guideline model into the design the next step is the process-product-analysis which is the key development within the methodology. The aim is to feed process related design aspects into the product design and to indicate the most appropriate assembly processes. The processes are selected based on the (in previous steps) improved design. Offering qualitative cost analysis supports the decision making for the assembly system design.

3.2. Process-Product Analysis

Optimum process selection is an extremely
Handling

Checking

Part B

Joining

Moreover, it is process not only avoids difficulties, but directly affects attributes and requirements. Selecting the optimum objective is to find the best match between process certain materials, product sizes and shapes. The thus reducing overall costs. Some are restricted to further processing, like checking or closed loop control, produce high precision components requiring little or no orders. Some processes require expensive tooling, but processes have different advantages and limitations. important aspect of production. Different assembly processes have different advantages and limitations. Some are ideal for mass production, others for small orders. Some processes require expensive tooling, but produce high precision components requiring little or no further processing, like checking or closed loop control, thus reducing overall costs. Some are restricted to certain materials, product sizes and shapes. The objective is to find the best match between process attributes and requirements. Selecting the optimum process not only avoids difficulties, but directly affects the product cost and marketability [17]. Moreover, it is important to choose the right process-route at an early stage in the design before the cost-penalty of making changes becomes large [18].

Rarely can any product be made by a single process. Several processes are usually available and appear competitive. As a result, it is necessary to store the capabilities in a model to enable the optimum process selection. Furthermore materials, tolerances, basic configurations, method of joining parts, etc. need to be specified to choose appropriate processes, which meet the design specifications. Limitations of the available equipment need to be considered within the evaluation of processes; this is especially true for assembly of MST products. By establishing rules the capability model provides answers to the following questions:

- What is particularly useful for a certain process?
- Which techniques (e.g. certain joining techniques) should be avoided under which circumstances?
- Which techniques have what advantages?

Because each process is characterised by different attributes the use of a process capability model in the DFµA methodology is of such importance.

It assures the systematic and complete consideration of all available processes in an iterative procedure. A strategy for selecting processes which is utilised for the DFµA methodology is shown in Figure 2. It starts by considering all processes as possible candidates until shown to be otherwise. In a step by step approach processes are excluded until a final process is chosen. However, the final choice is based on a comparison of process-cost.

Figure 3 gives an illustrative example of how the process-product analysis is structured. Based on the (in previous steps) improved design, the assembly processes are chosen, namely feeding, handling, joining and inspection processes. In the displayed instance the selection of feeding processes is explanatory described.

First all parts to be fed are selected. The process related product requirements and part properties (like dimensions, shape, fragility, sensitivity to contamination etc.) are retrieved. Using this information results in:

- A list of suitable feeding processes,
- A list of processes, which can be considered if minor changes in the design will carried out (including indications for design improvement),
- The exclusion of a number of feeding processes, because of major design problems...
and contradiction to the process related product requirements.

To enable the most appropriate choice from several suitable processes a qualitative cost analysis can be conducted to support the decision making. The described and on the basis of feeding illustrated way of selecting processes determines step by step all necessary processes. The allowance for suggestion of design changes guarantees that the optimal feeding processes are selected, especially under consideration of the extreme dependency of the requirements for microassembly on the products to be assembled.

4. Conclusions

This paper elaborates on the need for a DFµA theory and has shown that there is a lack of well defined DFµA methodologies at present. To deal with the complexity of the microassembly environment a DFµA methodology has been presented. Its overall intention is to help overcome the barriers between prototype developments in research laboratories and production on an industrial scale by enabling the efficient assembly of complex miniaturised devices with cost-effective processes.

The conceptual layout of the overall methodology has been outlined. It is mainly based on the application of microworld specific guidelines, the utilisation of information about microspecific process characteristics, in about particular joining, feeding and handling processes, and the use of a cost model for decision support.

Special focus was laid on the describing the process-product analysis in which the process characteristics are captured for the product design stage. It is shown that the selection of appropriate microassembly processes is enabled. The general process selection strategy has been illustrated and the actual procedure of choosing the most appropriate process has been shown exemplary based on the feeding process.

Future development needs to be focused on further expansion of the DFµA methodology’s underlying models. This means in particular that the process capability and cost model need to be enhanced and a decision making method has to be implemented to enable cooperation of the models.

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References


