Product Model Driven Direct Manufacturing

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Abstract

The input to the freeform fabrication process is essentially geometric data, raw material, material data and process parameters. Optimal process parameters depend upon current material and the part geometry.

This paper describes an research approach in which all necessary input including process parameters are obtained or derived from the product model. The part geometry with its process parameters is transferred as a STEP model to the SFF system. In the SFF system this model is converted to the internal format, coupled to the process parameters. The approach is exemplified with the SLS machine from DTM as SFF system.

Introduction

The product model as the base for different activities, from idea to final product, is the key to successful product realization. The product model as a knowledge base contains of course geometric and technical data but can also refer to company specific information, product background, history, synthesis & analysis results, reasons for decisions etc.

Freeform fabrication gives unique possibilities to really integrate product development, design, process planning and fabrication. In particular the SFF technology is conceptually capable of creating a very direct and fast physical version of the designers intent as given in the product model. This means that product realization with solid freeform fabrication gives new iterative possibilities, Fig. 1. These possibilities put new requirements on our models, our design support and the software for freeform fabrication.

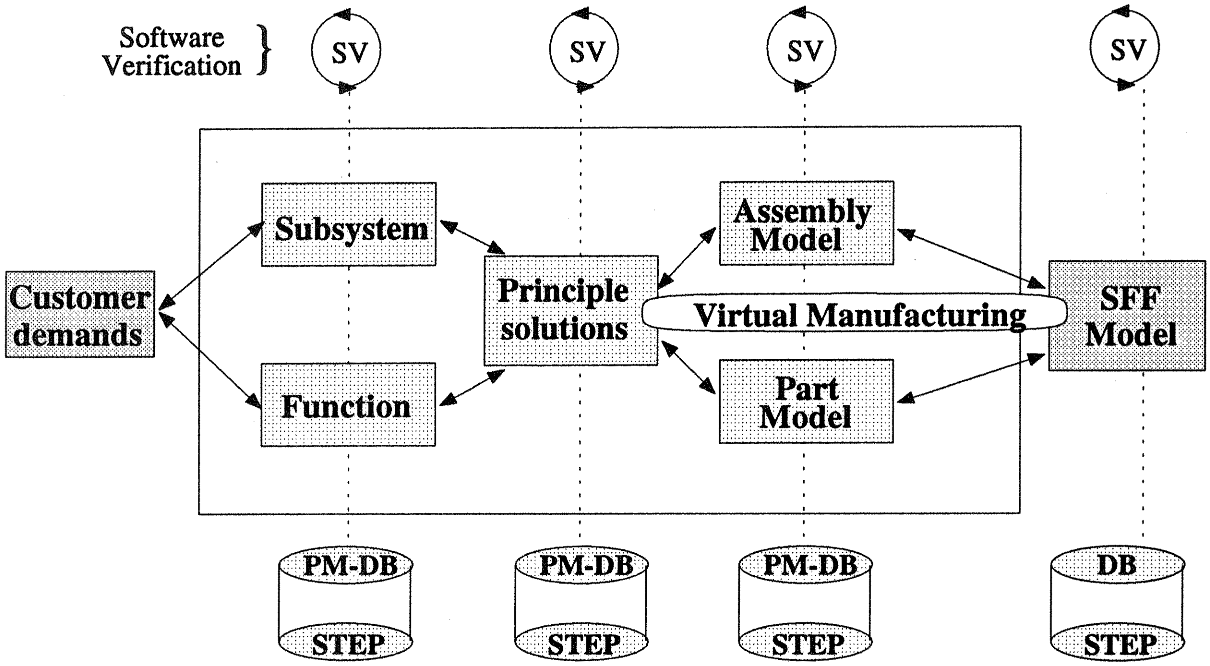


Figure 1 Product Models (PM) in Product Realization

Basis of Research

At the Department of Manufacturing Systems at KTH, research has over the years been conducted on geometric, product and feature modeling etc. In a new research project, Product Model Driven Direct Manufacturing [6], principles and methods for direct manufacturing driven by product model data is being developed, Fig. 2. The product model includes geometry, dimensions/tolerances, functional surfaces, technical data, etc. and the process model is utilized for the simulation and control of a machine tool such as the Selective Laser Sintering (SLS) machine.

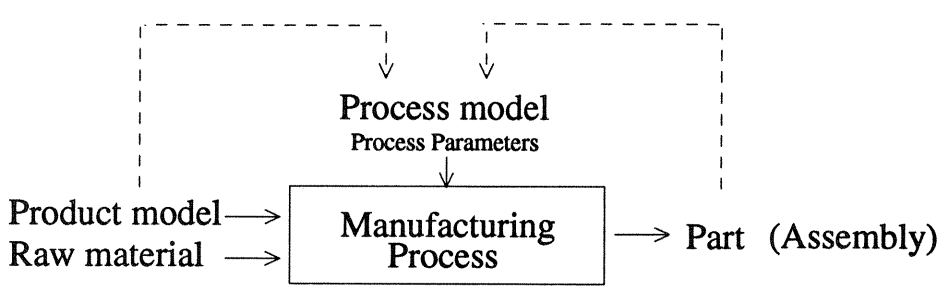


Figure 2 Product Model Driven Direct Manufacturing

In 1993 a SLS machine from DTM [11] was installed at IVF-KTH[1] to serve as a tool for long-term as well as applications research. During this first year we have gained considerable practical experience [5, 9] with the SLS machine. In research collaboration with Swedish manufacturing companies around 150 test parts of various kinds have been produced in the SLS machine. One example is an adjustable wrench, built in nylon with three components and in one operation, Fig. 3.

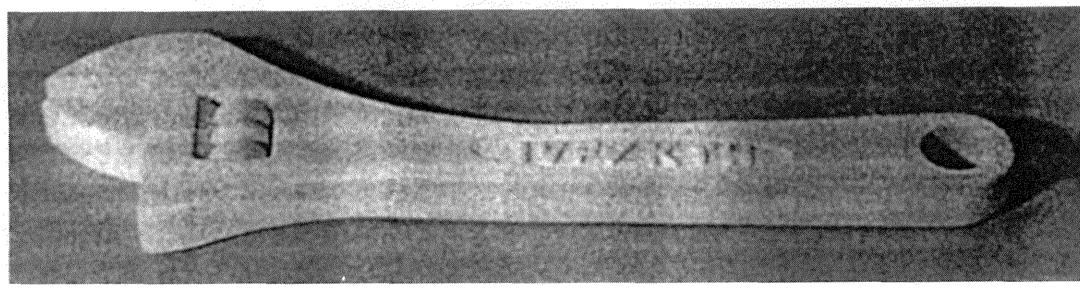


Figure 3 A wrench, built as one assembly in the SLS machine at IVF-KTH

Research approach

The external interface to the SLS software system consists today primarily of the STL-file and process parameters such as laser power and layer thickness. The STL-file is internally sliced into layers from which the scanning patterns are calculated. The process parameters can interactively be modified by the operator. For different materials, predefined material configuration files are used.

Although the present commercially available solution may yield very good results, it is far away from what is conceptually possible, given a product model and a predictable process. Our proposal and research approach is therefore to change the current external interface in order to make product model driven direct manufacturing feasible.

Intelligent scanning is certainly an improvement but in the SLS process we need to have software control of both the laser beam scanning paths and corresponding process parameters, intelligent sintering [3, 13]. This is not only because of the well-known drawbacks with the STL file format [4, 9, 10, 12, 13], like gaps in the faceted model or that the resolution in the STL-file is fixed (which means that for improved resolution the whole STL-file must be recalculated from the original geometric model). It is a combination of process dependent reasons and the STL format that makes the situation problematic. To underline the need for the proposed change, a number of examples of present weaknesses are given:

- In the SLS process we must compensate for *the shrinkage* but as the shrinkage is dependent upon part geometry (~0.3%) it is almost impossible to find *one* correct shrinkage scale factor for the whole part.

[1] The utilization of the equipment is shared by IVF (The Swedish Institute of Production Engineering Research) and KTH (The Royal Institute of Technology).

- The need for compensation for *the thickness of the laser beam* (~0.4 mm), presently done on the STL-file, is also dependent upon material and part geometry. Very thin sections can for example totally disappear or get unnecessary weak. A better solution would be to generate compensated laser beam scanning paths directly from the product model.
- There is also a need to compensate for *the applied energy*. As the build height increases, more and more heat is accumulated in the sintered part (due to the applied laser energy). It is therefore desirable to modify the applied laser power when the build height increases. As the amount of modification is material and part geometry dependent it should preferably be calculated by FEM-like simulation programs [2] and by calculation of applied laser energy to the powder surface [8].
- Another phenomena is that *the temperature distribution is non-uniform* (partly due to the location of the infrared heaters) in the circular build area.
  Although difficult one possible way to compensate for this is to have a likewise non-uniform scanning pattern.
- The *scanning direction* is uni-axial which gives different accuracy in x and y directions. With software controlled multi-axial scanning patterns this problem would disappear and the surface finish would be improved.

From these examples we can conclude that software control of laser beam scanning paths and process parameters is vital for the optimal generation of accurate and dimensionally stable parts. Although the given examples are specific to the SLS process, similar problems arise in most freeform fabrication processes.

Another problem is the present lack of possibility of having a direct feedback loop in the sintering process [13], today we have to draw our conclusions by examination the final part.

Our research approach now is to compute optimal scanning patterns and process parameters from the product and process model. In this approach the part geometry is connected to process parameters. The STL-file format is not appropriate because it contains no process parameters, no scanning contours and no connections to material data.

We propose the use of a STEP-based[1] format [1]. There is a need to develop an application protocol[2] (AP) for freeform fabrication, [10, 13]. As a first approach we

[1] PDES/STEP (ISO 10303) is an ongoing project and an international effort to specify a series of standards for the unambiguous representation and exchange of computer-interpretable product information throughout the life cycle of a product.

[2] From the user point of view, an implementation of STEP is usually done in the form of an Application Protocol (AP).

intend to utilize the already defined protocol AP204[1] and by extension of that protocol we can include

- process parameters
- scanning patterns and
- material data

and connect it to the part geometry. We call this model a *general SFF model*. In our first approach it consists of a number of strategic discs, Fig. 4. A proper location and thickness of each disc can be calculated by use of a process model and analysis & simulation programs that calculates heat transfer, shrinkage etc. according to simulated scanning patterns and process parameters. The idea is *not* to include all scanning patterns and contours, only *the scanning principle* used by the analysis and simulation programs. As the strategic slice is much thicker than the slices in the fabrication process this would not imply a huge amount of data.

As the STEP standardization efforts in the area of feature modeling [7] improves, we probably will utilize such an application protocol, i.e. how to utilize information about features such as holes etc. in the product model in the final fabrication process.

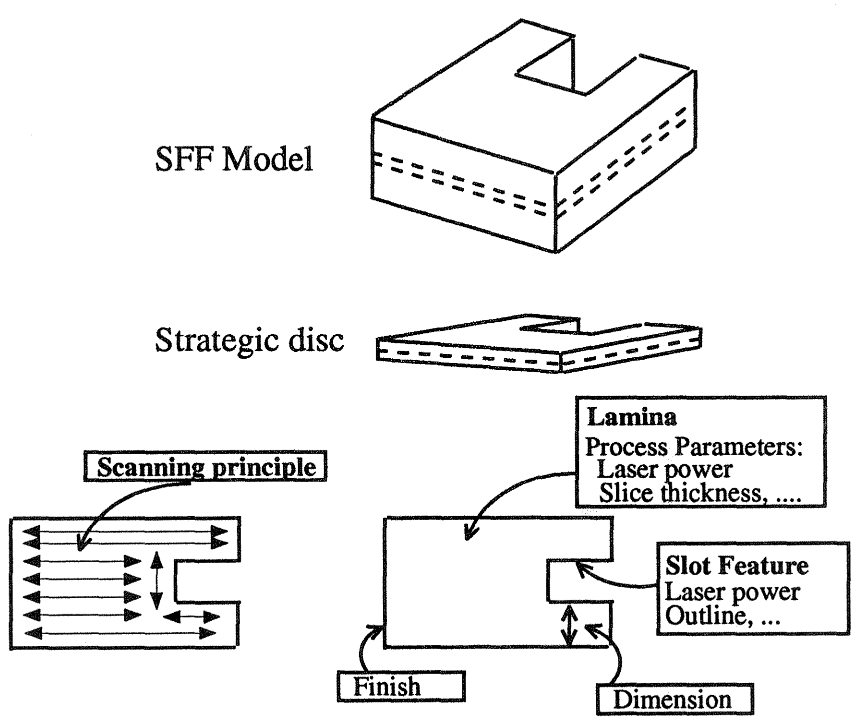
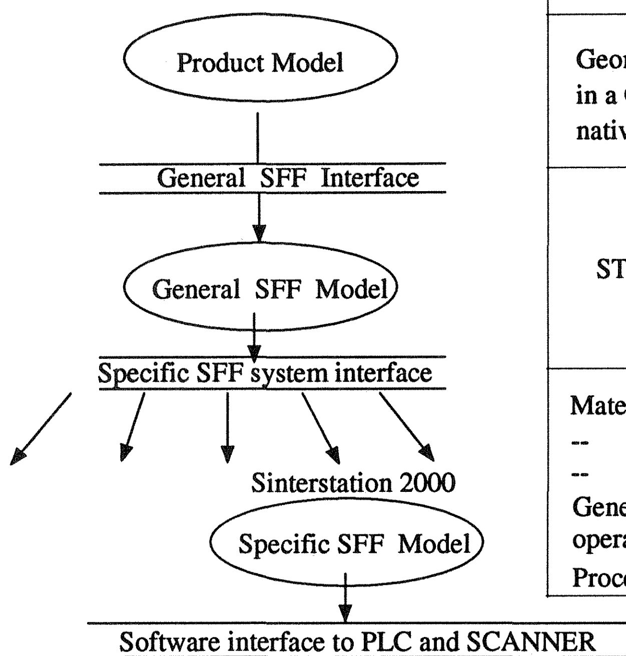


Figure 4 The general SFF model consists of strategic discs accompanied by process parameters and scanning principles.

[1] Application Protocol for Mechanical Design using Boundary Representation

A specific SFF system can now read this STEP based general SFF model and convert it to the systems internal format, a specific SFF model, Fig. 5. To able to convert the general model, the SFF system must be equipped with various software tools such as a STEP interpreter, a boundary geometric modeler, software for contour generation etc.

Our research intent is to investigate more precisely which software tools actually are needed and how they should operate together. The next step is to specify a research implementation.



Models in SFF	
Current	Future
Geometry Model in a CAD-systems native format	Product Model in a STEP format
STL file	SFF Model in STEP format
Material data -- -- Generated by operator: Process parameters	Material data Scanning contours Process model Generated automatically: Process parameters

Figure 5 From the product model to a specific SFF model

Summary

We have presented an research approach in which the process parameters and scanning patterns are derived from the product model and from the use of a process model. We have discussed some drawbacks with the STL format and some SLS process weaknesses. We conclude that software control of laser beam scanning paths and process parameters is vital for the optimal generation of accurate and dimensionally stable parts. We also propose the use of a STEP based format and outlines one idea how to create a general SFF model carrying part geometry, process parameters and scanning principles to be used by different SFF systems.

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