IMPROVED QUALITY OF SFM-PROCEDURES BY SYSTEMATIZED OPERATIONAL PLANNING

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Introduction

The ability to create 3D-physical objects directly from 3D-CAD-data marks a new stage in the entire scientific technological development. The scientific spiral as a symbol for continuously higher developments of advanced production-technology demonstrates the new reached developmental level (see figure 1).

In the mid-fifties the amalgamation of 1) computer technology, 2) electronics (later microelectronics), and 3) machine tools led to the new quality in flexible manufacturing technology in kind of NC-technology. The resulting necessity for rational determination of tool movements, process sequences, and others with algorithmic approaches leads to many kinds of computer applications for geometrical and technological decision support. All practical applied CAP, CAM, CAD/CAM, CAE-systems are the evidence for algorithmic based solutions.

Now in the new developmental stage we have to consider some more and very difficult to determine influence factors from different aspects (see figure 2). The current amalgamation of 1) powerful NC-technology, 2) advanced computer technology in different kinds, 3) new physics principles like laser technology etc., and 4) the inclusion of new materials leads to new problem areas.

It can be emphasized that the traditional approach based on algorithmic solution for problem solving and decision support in connection with SFM for reliable process-determination and control seems restricted. Especially the exact determination of material properties and the material behavior under determined conditions are very difficult to solve in an algorithmic approach. The inclusion of specific object and process related knowledge seems necessary. Before these aspects will be discussed, a proposal for unified terminology will be briefly explained.

Justification of the Term "Solid Freeform Manufacturing"

Based on the interesting fact that scientists and researchers of different disciplines have developed the new technologies, and now the application ranges are also very many-sided, a lot of various terms are created. It is interesting to remark that this was not the case for example with NC-technology, laser technology, etc.

Only the main used terms are included in table 1. The comments on the right side are characterizing the restriction of most of the introduced terms. On the other hand, it seems clear that not only for international understanding, but also for conversation in every enterprise, a unified term is necessary. Normally such a term has to reflect kernel points on the determined content. This is given by 1) solidification as a typical feature of different procedures; 2) freeform as the feature for geometrical objects of any complexity; 3) manufacturing, because all kinds of procedures are prior manufacturing processes. The term fabrication was only justified during the first years, because it is also used for Invention. I do hope we all can find an agreement for the best suitable term: "Solid Freeform Manufacturing."

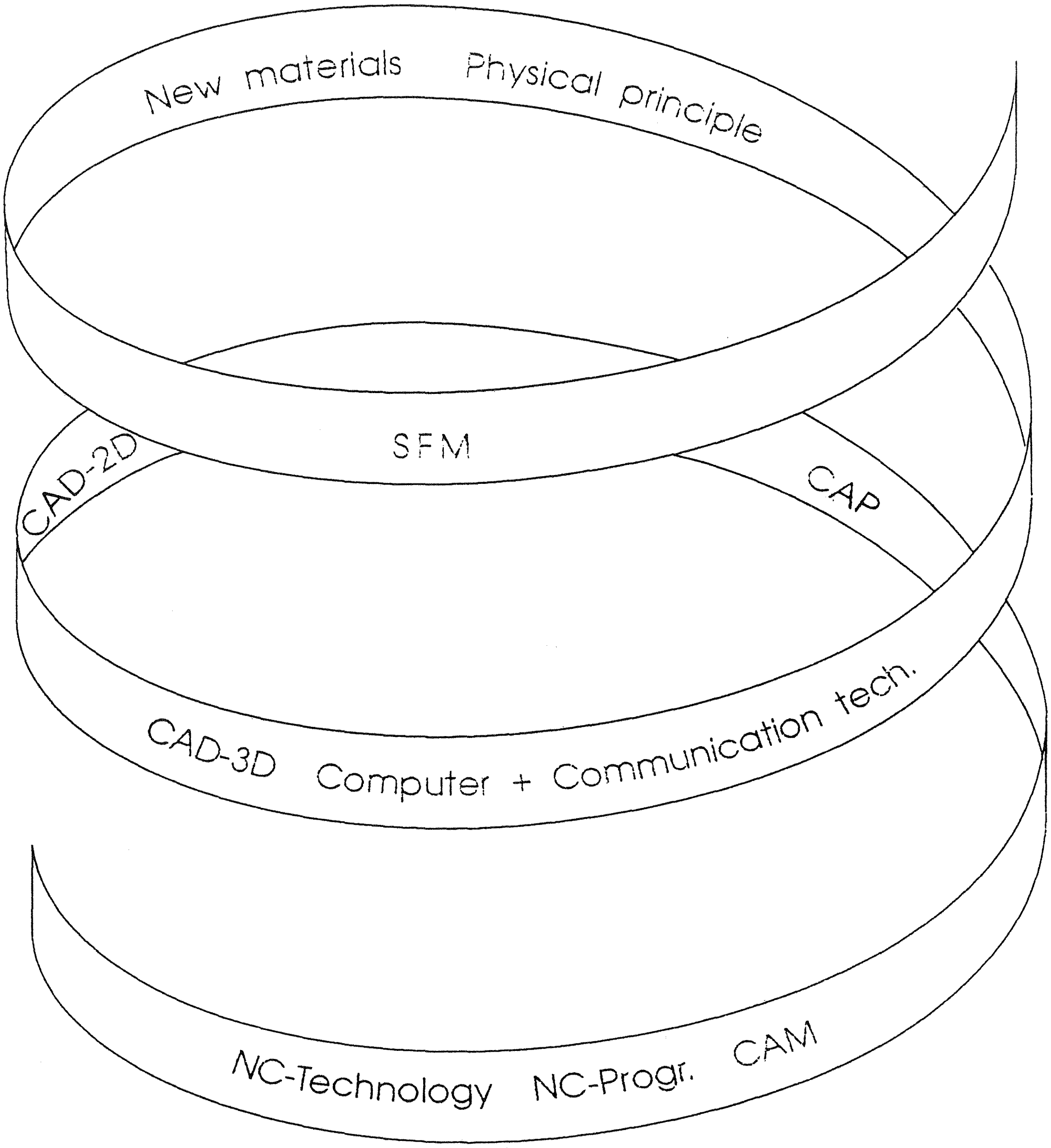

FIG.1: General developmental trends starting from NC-Technology

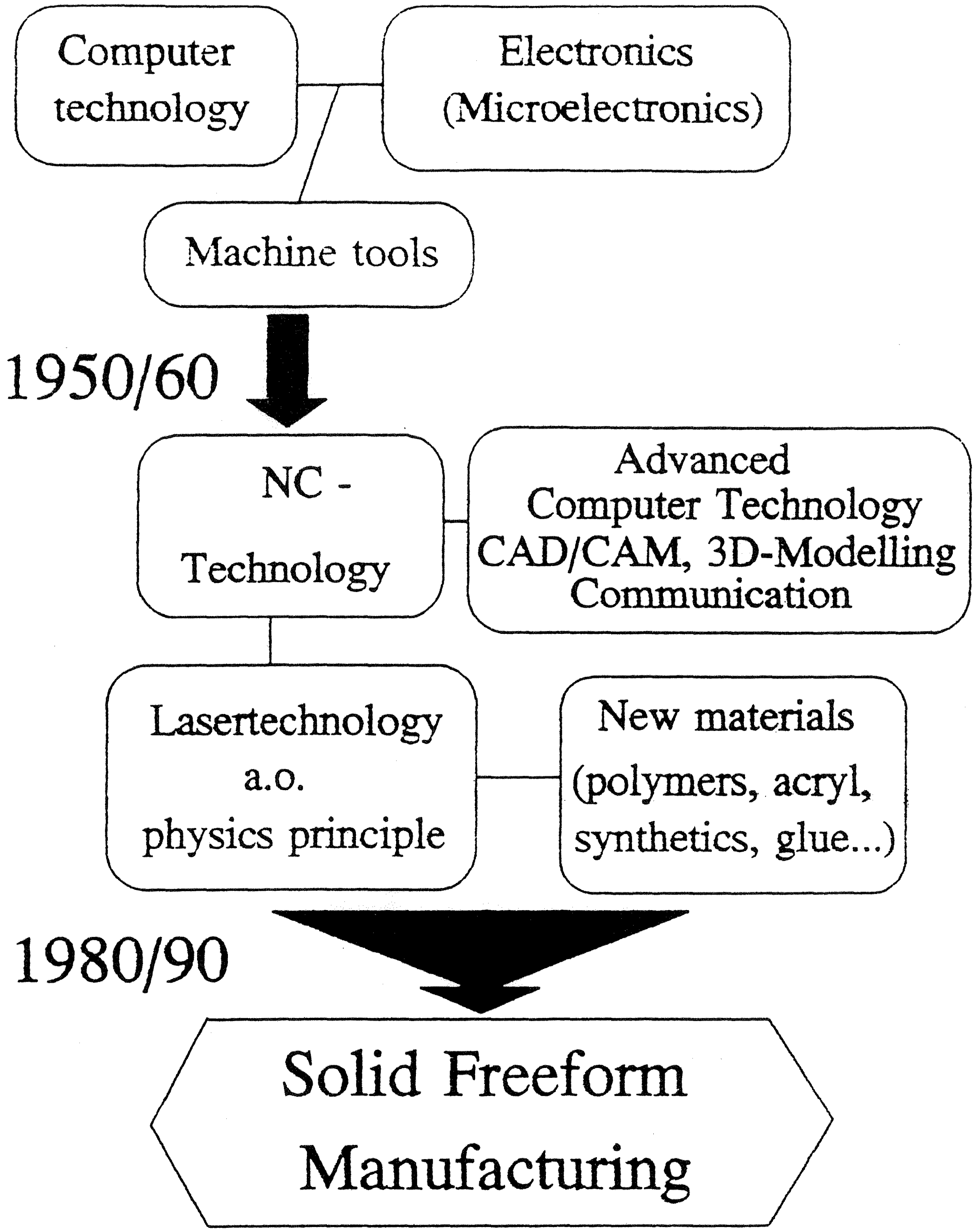

FIG 2: Developmental steps in advanced manufacturing technology

Term	Comments
CAD oriented Manufacturing	Not only CAD oriented (every manufacturing technology has to be customer oriented!)
Direct CAD Manufacturing	See above
Desktop Manufacturing	Not general to accept; the desk could be only a very small facility for manufacturing
Instant Manufacturing	In every manufacturing process will be produced "instant" parts
Layer Manufacturing	Characterized most, but not all of the new principles
Material Deposit Manufacturing	Includes the geometrical, not the physical aspects
Material Addition Manufacturing	see above (MDM)
Material Incress Manufacturing	Good explanation also from the geometrical aspect; difficult to translate
Solid Freeform Fabrication Solid Freeform Manufacturing	Both terms includes the aspect of solidification and the geometrical complexity of the manufacturing procedure
3D Printing	Printing is only one possibility
Rapid Prototyping	Widely used, but also in computer technology with other content

Table 1. Essential Terms for Solid Freeform Manufacturing.

General Requirements Concerning Systematized Operational Planning

The general task of operational planning consists of transforming of geometrical information into specific process information for building real objects in a reliable kind. The general SFM-process sequence of transferring 1) input data; 2) checking these data; 3) making evaluations concerning producibility; 4) preparing of building parameters for positioning and stepwise manufacturing under consideration of given possibilities (equipments) and specific restrictions required for process-accompanied documentation. The most customer deliver special recommendation for specific building parameters, shrinkage factors etc.

For making the entire process-chain transparent and reproducible, some additional information is necessary. In general the following aspects have to be considered:

1) In agreement with European and International (ISO) Quality-standards every element and requirement - especially also for process planning - have to be documented in a systematic and orderly manner in the form of written policies and procedures (ISO 9000).

2) The application engineer, who is responsible for the further input-data preparation (starting from 3D-data) has to oversee the entire process realization. Because of the many-sided influence-factors, he needs some systematic support.

3) Also the CAD-designer who intends to use SFM-techniques needs at least some basic principles which have to be considered in the design phase. This aspect is related to the requirements of Concurrent or Simultaneous Engineering in connection with necessary information feedback about producibility.

4) Every interested customer has to know what kind of processes for specific part requirements are suitable. It could be useful if suitable information is available for specific benchmark-tests for evaluation of different SFM-systems depending on part or factory specific requirements.

For all mentioned requirements, a suitable part classification seems to be a useful aid.

Part Classification for SFM Technology

The available classification methods and schemes for mechanical part manufacturing are not suitable for SFM-procedures, because the typical application ranges for this principle are restricted to a higher degree of complexity. Most simple part classes are not suitable for generation with SFM-procedures. A specific part classification was therefore proposed.

Main aspects for a suitable subdivision and classification scheme for SFM-procedures are:

1) similarities for specific rules for building procedures - dependent on the determined principle;

2) consideration of typical application ranges for different SFM-processes;

3) as a first approach, general classification independent of other essential influence factors like materials, measurements (sizes), accuracy, etc. (these have to be considered additionally).

It can be emphasized that the SFM-technologies have only a few restrictions concerning part classes. But based on the materials used (fluids, powder, solid), and the specifics of different building procedures, it seems very necessary to take into consideration specific requirements concerning the external and internal shapes, respectively, the general part structures. This request results from the different material behavior during and after the building processes, especially related to aspects of accuracy, stiffness, distortion, curling, etc. For this widely applied principle of Stereolithography, a lot of tests and measurements were made with specific test parts, but the results cannot be generalized because every part-structure leads to other behaviors (1, 2).

For solving this problem as a first approach the philosophy of Group Technology can be used in modified kind. That means a classification of typical part-structures with similar features could be possible and helpful. A proposal is shown in figure 3.

Application of Knowledge Based Methods

In the frame of the general part classification, a further detailed subdivision for every part class is possible depending on:

1) materials corresponding to different applications;

2) measurements (part sizes). The part sizes and part structures are mostly related to shrinkage, distortions, curling effects. Therefore specific experience has to be acquired and included into the necessary rule-system. Such rule-systems are necessary for every kind of material (resins, etc.) and every specific SFM-procedure.

3) accuracy, tolerances. These aspects are closely related to the same influence factors as mentioned above for measurements. Therefore the necessary rule-system has to consider these influence factors in complex kind.

4) surface quality, especially smoothness.

The surface quality of plans is standardized by ISO 1302, whereas for freeform shapes there does not exist any standard till now. Essential features are also: form deviations, position deviations, measurement deviations, and roughness and combinations. The surface quality depends on: material, building procedure (especially possible layer-thickness), necessity of support-structures. These influence factors have also to be considered in the specific rule-system.

It can be emphasized that all laser-lithography-procedures, which require support-structure, have to take into consideration specific requirements for the positioning and building procedure. Whereas the part classes 7 and 8 are extremely difficult from the points of accuracy, smoothness on both sides, and stability (respectively curling and distortion) for laser lithography principles; on the other side, these part classes are well suited for the LOM-principle.

With this example, it can be characterized that the different procedures have specific advantages and disadvantages related to the different part classes. A general differentiated rule base system can therefore be helpful for good work-division between different companies, service bureaus, and customers.

In general, it has to be emphasized that the highly sophisticated technology cannot be exactly determined like classical mechanical procedures. The many-sided influence factors request rule based methods for including specific experiences and knowledge. The acquisition of specific knowledge is mainly possible by careful application of suitable operational sheets.

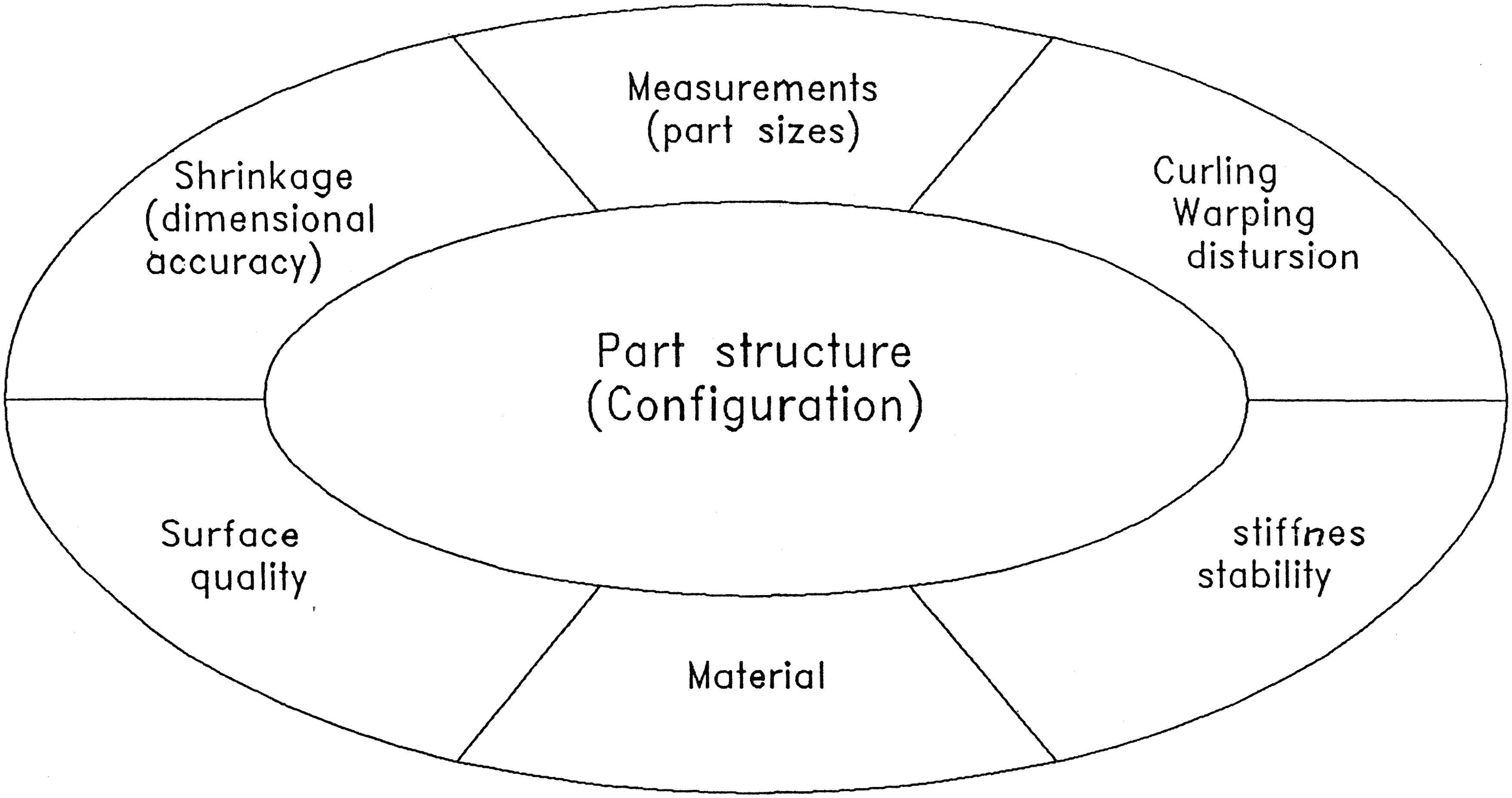

FIG 3 : Object related influence factors for quality justified SFM-procedures

Operational Planning Tasks and Methodical Aids by a Unified Operational Sheet

General Tasks

The SFM-operational planning tasks result by the logical sequence of the entire information flow and necessary decision steps. The main steps in the general process chain for the different SFM-procedures can be characterized as follows:

1) checking of the prepared 3D object input data
2) computer aided preparation of the building procedure (including positioning, slicing, preparation of support structures, if necessary) and if available, use of simulation techniques
3) controlling and supervising of the building procedure
4) postcuring (if necessary)
5) cleaning
6) finishing.

For evaluation of the results of manufactured parts under consideration of quality, costs, and time, all working steps have to be considered. Therefore, a suitable process accompanied documentation needs some more information as the detailed building parameters. In agreement with the experiences of traditional operational planning systems, the following aspects have to be considered:

1) identification of input data, media, responsible persons
2) determination of the geometrical objects, the building possibilities, spatial assortments, arrangements with other parts, necessary support structures, slice parameters
3) determination of technological parameters (cure depth, laser power, respectively other physics parameters).
4) software-handling, user-support, dialogue mode, graphical aids
5) recommendations for postcuring, cleaning, finishing

Unified Operational Sheet

It will be endeavored that the operational planning system can be used for all SFM-techniques. This request can be fulfilled if a general operational sheet will be completed by specific recommendation depending on determined requirements by the different procedures. Based on these general requirements, a unified operational plan is proposed which has to be prepared and used by the application engineer (SLA-user) for every part, also in case of repetition. For practical usage the following aspects and remarks have to be considered. The key point of the proposed operation sheet I is the relation to the aspects of FMEA (failure mode and effect analysis). That means that in addition to the necessary object-specific facts, which are included in the operational sheet, all essential comments and evaluation of results are most important. The operational sheet I covers the entire process chain. The operational sheet II is fully identical to the specific recommendation of a determined equipment and used specific materials and includes only the building process.

Utilization of Information Content of Operational Sheets

There are given different possibilities for utilization of the information content:

1) Basis for exact time and cost calculation for every object manufactured by the determined SFM-equipment.

2) Basis for time and cost estimation for carefully selected parts (based on the proposed part classification and part analysis at the determined company).

3) Using of these time and cost-elements as a realistic basis for qualified Benchmark tests.

4) Basis for knowledge and rule acquisition in the given part-class-related frame, including the opportunity for continuous qualification of the rule system ("knowledge source").

As was emphasized in the introduction, the material properties and the changing physical parameters (i.e., laser-power, laser-beam diameter, etc.) in relation to different part-structures do not allow any algorithmic determined approach. Therefore, such human oriented adaptive learning seems necessary.

Expected Results and Advantages

The proposed method for operational planning is based on the currently available experiences primarily suitable for laser-lithography procedures. But it depends on more detailed knowledge about other SFM-techniques like Cubital "Solid Ground Curing" or DTM "Selective Laser Sintering," or Helisys "Fused Deposition Materials," or any other commercially available systems, a modification seems very easy. It can be pointed out that with a permissible additional expenditure, some important results are possible:

1) Methodical support for a systematically guided operational planning by the responsible application engineer.

2) It allows a systematized acquisition of rules and knowledge, which can be collected to reuse.

3) The quality of the reached results can be improved. That leads to an increased success-rate and to reduction of waste.

4) The exact determination of process-data and times is the basis for exact economical calculations.

5) The learning phase for part preparation can be shortened.

By the proposed methodical approach, a first startpoint and general frame is given. The rule system especially concerning the shrinkage factors has to be completed depending on included different part classes. In this connection, it can be emphasized that depending on specific application requirements and frequency in a determined part class, a further subdivision is possible. But under consideration of user-friendly handling of the proposed method, the general subdivision in ten part classes seems most suitable.

Summary and Conclusion

First approaches were made on selected parts. In this connection the principle suitability of the proposed method was confirmed. A consequent broad application and further development is planned in cooperation with the German NC-Society.

Acknowledgment

This paper was prepared during my sabbatical time at NTH/SINTEF, Trondheim, Norway. I would like to thank very much Prof. Ø. Bjørke and his colleagues for providing worthwhile experiences and support. Practical tests were also supported by BIBA, Bremen (Prof. Hirsch and his colleagues) and 3D-Systems, Darmstadt. By the companies: Cubital/Germany; Dormier/Germany; CMET/Japan; EOS/Germany, some informative material was delivered and interesting discussion provided. Many thanks also for this useful cooperation.

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