FREEFORM SURFACE MEASUREMENT FOR TOOL CORRECTION

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Abstract: Forming tools are often used to manufacture freeform surfaces. In free forming, the geometry of the workpiece is fully or partially determined by that of the tool (e.g. forming die). Therefore the quality of the finished product largely depends on the geometry of the tools. Tool geometry, though, is changed in the course of the manufacturing process. Reasons are wear e.g. caused by friction and optimisations carried out manually during tryout. When it is time for repair or manufacture of new tools, there is no record of these geometrical modifications applied to the tools. A model in the form of a closed quality control loop to feed back geometrical modifications to CAD and CAM systems, is presented in this contribution. A means of creating the individual components of the quality control loop is described. Particular care has been taken to ensure that both, the measurement and the feedback are limited to selected areas, in order to minimize the required cost and time.
Keywords: Coordinate Metrology, Evaluation.

1   INTRODUCTION

Freeform surfaces of many products in our daily lives are important to us for both functional and aesthetic reasons. Their uses range from that of a soap dish, formed so as to be aesthetically pleasing to the shell of an aircraft, designed from an aerodynamic point of view. As a result of technical advances in the techniques used to manufacture such surfaces and ever higher customer expectations in terms of product design, such parts will become increasingly important. Requirements relating to the quality of the surfaces, in particular, will become more exacting.

The quality of parts with freeform surfaces that are produced with forming tools depends largely on process control and on the quality of the tools used. Research conducted in this field concentrates on these two areas. In this context, digitisation and geometric reconstruction (reverse engineering) are among the subject areas relevant to metrology. In contrast, the techniques applied in the quality assurance and implementation of quality control loops assume a subordinate role. However, this is the area in which improvements stand to be made, particularly in view of the rising expectations in terms of the quality of parts with freeform surfaces. The concept and the technical tools presented here, illustrate how a quality control loop for the production of these parts can be developed, taking in account the changes of tool geometry during the use of the tools.

2   CHANGES OF TOOL GEOMETRY DURING USE

Steel forming tools with freeform surfaces for use in metal forming operations, are currently manufactured in milling or eroding operations. The development of new technologies such as HSC, has made it possible to mill even materials which are notoriously difficult to cut and which were previously always eroded [1]. Indeed, the levels of form accuracy and surface quality achieved in milling operations, are particularly high [2]. The specifications regarding tool accuracy for a metal forming operation, are thus usually met with ease.

Before using the tool in a manufacturing environment, there is often an extensive tryout phase, despite the use of computer-assisted simulation. At this stage, the tool geometry is modified in order to optimise the forming process. Material is frequently removed manually, with the aid of grinding tools. Deposition welding is used to add material to selected areas which are then ground until they fit into the surrounding geometry. The geometrical alterations are very rarely documented or fed back to the design department.

In addition to these deliberate geometrical modifications, unintentional changes to the geometry also occur as a result of wear when the tool is in use. These effects are particularly noticeable when the tool is subjected to high levels of mechanical and tribological load [3].

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As a result of these mechanisms, the tool geometry used in the manufacturing process is not the same as the geometry designed using the CAD system. This is verified by the chromatic diagram showing deviations between measured data and CAD data relating to a forging die in Figure 1.
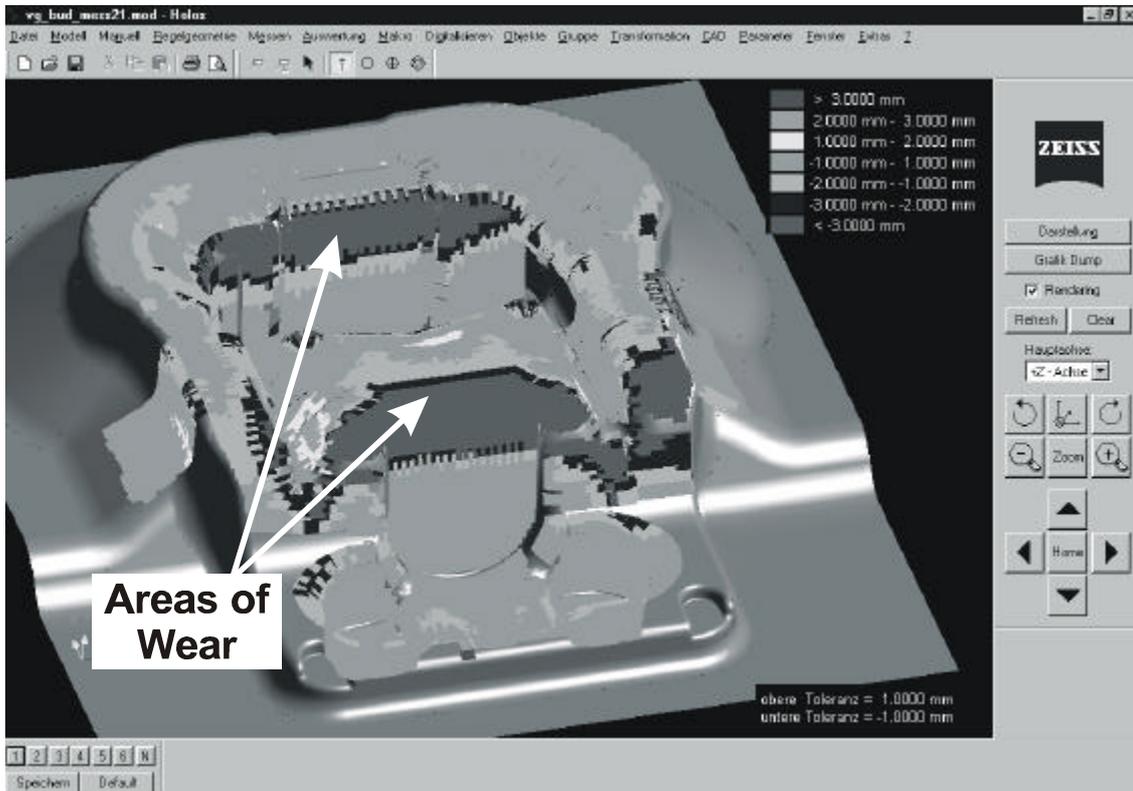

Figure 1. Deviation areas due to wear.

3   MANUFACTURING AND QUALITY TESTING OF FORMING TOOLS

At present, forming tools are designed in a CAD system based on the CAD data of the part to be manufactured. The CAD data of the tool is used as input information for the CAM system in which the NC programs for the milling operation are generated. The required geometry is filed in geometrical terms, in the CAD data and in the NC programs.

The demands imposed on quality testing of forming tools are wide-ranging. Material characteristics and geometry almost always have to be tested. Gauges or special test equipment, such as multipoint measuring instruments, are generally used. Despite their high level of flexibility, coordinate measuring machines are rarely used, mainly because they are regarded as slow and because they are often physically separated from the manufacturing facility. However, with machines suitable for use within a manufacturing environment and the development of techniques capable of recording measuring points rapidly, like optical measuring methods or scanning techniques for touch probe systems, all this could change [4].

Nowadays, geometric tests conducted using the described measuring methods on the forming tools which have been milled, usually confirm the high quality and efficiency of the manufacturing techniques. Since virtually no measuring is carried out after optimisation or after use, there is a complete lack of information relating to the geometrical modifications which is needed, when the time comes to manufacture a new tool. On the other hand, it is virtually impossible to restrict repair only to the worn areas of forming tools. So there is a lack of feedback of the geometrical modifications carried out which is required in order to optimise and enhance the quality of tool manufacture.

4   LINKING MAINTENANCE AND USE BY A CONTROL LOOP

To identify geometrical changes to the tools, the tools must be measured after use and the results have to be fed back to the tool manufacturing department. Here, two different aims are being pursued: On one hand, it is vital that information about geometrical changes required in order to optimise the tool, is fed back to the design department thus permitting to adapt the CAD data accordingly. If this is

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done, there will be no need for any tool optimisation when a new tool is manufactured subsequently. On the other hand, information about localised areas of wear can be used to aid CAM-assisted tool repair operations. In both cases, the approach is almost identical. The only difference is the type of information passed on after the measuring results have been processed. For the adaptation of CAD data, information about the extent of the deviation at each point is required. To determine the area of wear, it is sufficient to pass on information defining the boundaries of areas at which the deviations exceed a specified tolerance.

The basis for the measurement of the tools, is the required geometry as defined by the CAD design data. The tolerances are also specified by the design engineers. General information about areas of deviation may be available after tool use. This can be used to determine which surface areas should be measured. In addition to the measuring instruments, suitable software will be required to process the data received. The results obtained in the measuring operation, provide information about the actual geometry of the tool. The feedback of this information closes the control loop which links tool manufacture with tool use (Figure 2).
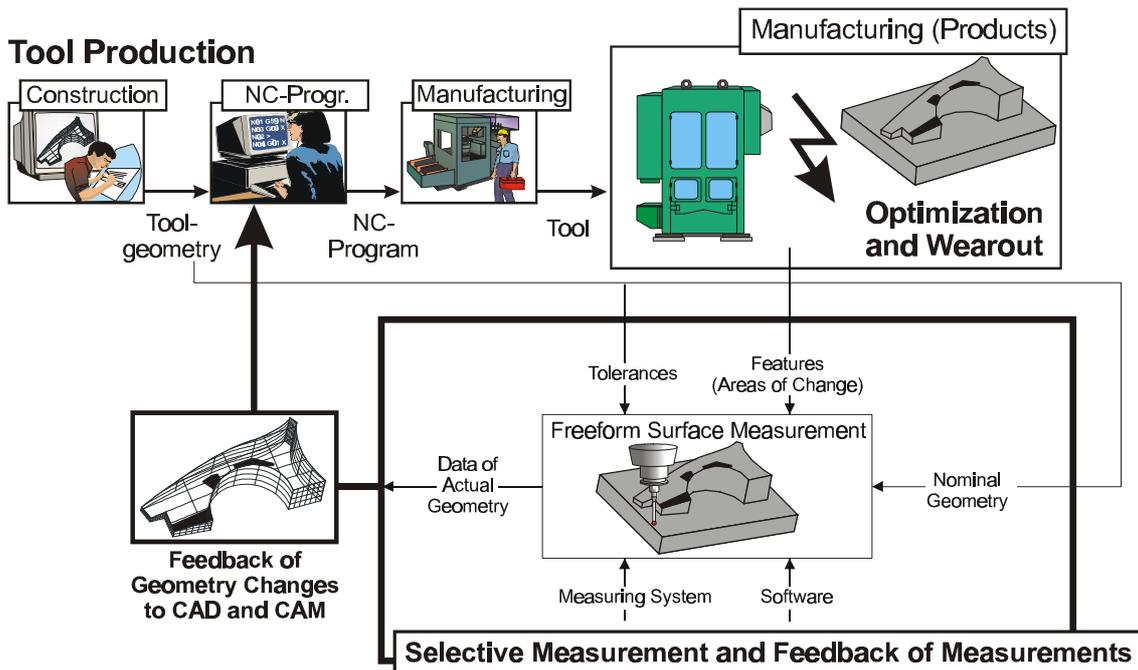

Figure 2. Control Loop.

5   COMPONENTS FOR THE CONTROL LOOP

Coordinate measuring machines are particularly suitable for measuring tools with freeform surfaces. A coordinate measuring machine usually consists of several positioning axes, equipped with an optical or tactile probe. After a probing operation, the measuring systems on the positioning axes are read, thus giving the spatial position of the point probed. When a coordinate measuring machine is used to measure freeform surfaces, it is essential to specify the individual travel motions and the probing operations. After a data processing operation which varies depending on the measuring technique used (e.g. probe radius compensation in tactile measurements), the measured points recorded, are passed on for a further processing operation which varies depending on the use to which the measuring results are to be put [5]. Measuring machines which use optical techniques to record several points at the same time and file these in a generally unsystematic manner, are not included at this point.

The entire operation of selective freeform measuring technology was presented using an SADT (Structured Analysis and Design Technique) model, in order to systematise the individual steps in the process. This top-down modelling method starts with an activity box which represents the entire process under examination. The process is described in greater detail by dividing it up into individual activities. Individual activity boxes can be further subdivided on other sides. Each box represents a process which transforms input data into output data. An arrow pointing towards the box signifies input

data and one pointing away from the box signifies output data. The control mechanisms are shown by arrows pointing down towards the box and tools are shown by arrows pointing up to the box [6].

The activity box, which represents the entire process of selective freeform measurement in the context of tool manufacture and use, is shown in Figure 2. The breakdown of the process is shown in Figure 3.

The principle components of selective freeform measurement in the quality control loop for forming tools, are the generation of the measuring sequence and the subsequent data processing operation. Measurement and data preparation are functions which can be carried out by the measuring machine and its control software.

There are already products on the market, which are capable of generating measuring sequences for freeform surfaces based on CAD data. Some of these are extensions for CAD and CAM systems (e.g. IBM's Inspection Planning Assistant for CATIA and the Pro/CMM for Pro/Engineer from Parametric Technology Corporation). Others, are stand-alone systems (e.g. PC-DMIS from Brown & Sharp, CAMIO from LK, SILMA from Adept Technology). All of these systems permit measurement points to be created on freeform surfaces, regardless of the way in which the surface has been segmented. However, the degree of automation in the creation of measuring points varies very considerably. The measuring sequences can be transferred to the measuring machine either via manufacturer-specific formats or via the non-manufacturer-specific DMIS format [7]. To date, DMIS has been the only non-manufacturer-specific format suitable for transferring measuring sequences for coordinate measuring machines, to have established itself successfully on the market. However, since the degree to which this standard has been implemented by individual manufacturers of measuring machines varies enormously, problems continue to arise when it is used for transfer to machines made by different manufacturers.
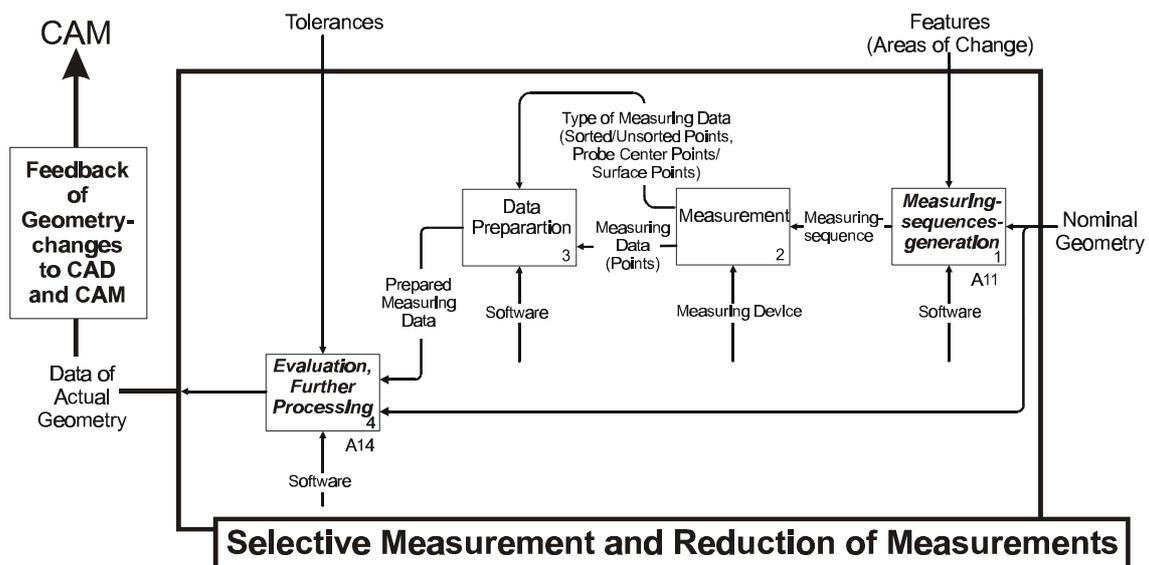

Figure 3. SADT-model of the components.

When the data recorded by the coordinate measuring machine is fed back in an operation which is also specified in the DMIS standard, there is frequently a lack of implementation. Consequently, it is often necessary to fall back on the manufacturer-specific measuring protocol. In the case of freeform surfaces, it is practically only individual points which are transferred. When an optical measuring head is used, the points measured lie directly on the surface of the object. However, when tactile systems are used, the points measured are the mid-points of the probe tip, which must be shifted in normal direction using the amount of the probe radius. In such cases the data must be prepared.

When the geometrical modifications undertaken in the course of tool optimisation are fed back into a CAD system, the surface points are transferred directly. Many CAD systems have interfaces for this purpose and there are a variety of techniques of adapting the surfaces to correspond with the measured points [8]. Due to the measuring strategy used, the points are usually arranged linearly. This facilitates the adaptation.

When the measurement data is to be used to guide finishing work to be carried out on areas of deviation which have arisen as a result of wear, the boundaries of these areas must be defined. First, it

is necessary to determine the degree to which the measured points deviate from the required geometry. To do this, the surface of the CAD-representation which has the smallest distance to the measured point must be identified. When this has been done, the distance can be calculated between the measured point and the area concerned. When no probe radius compensation was carried out during the data preparation operation, the probe radius must be subtracted from the deviation calculated. Since the surface of the forming tools can usually be represented clearly over one plane, all measured points with two coordinates on this plane are likewise described unambiguously. The deviations at each measured point are stored together with the two coordinates from this plane. In this data structure, the boundaries of the areas of deviation can be determined with the aid of contour tracking algorithms used in image processing operations [9] (Figure 4).
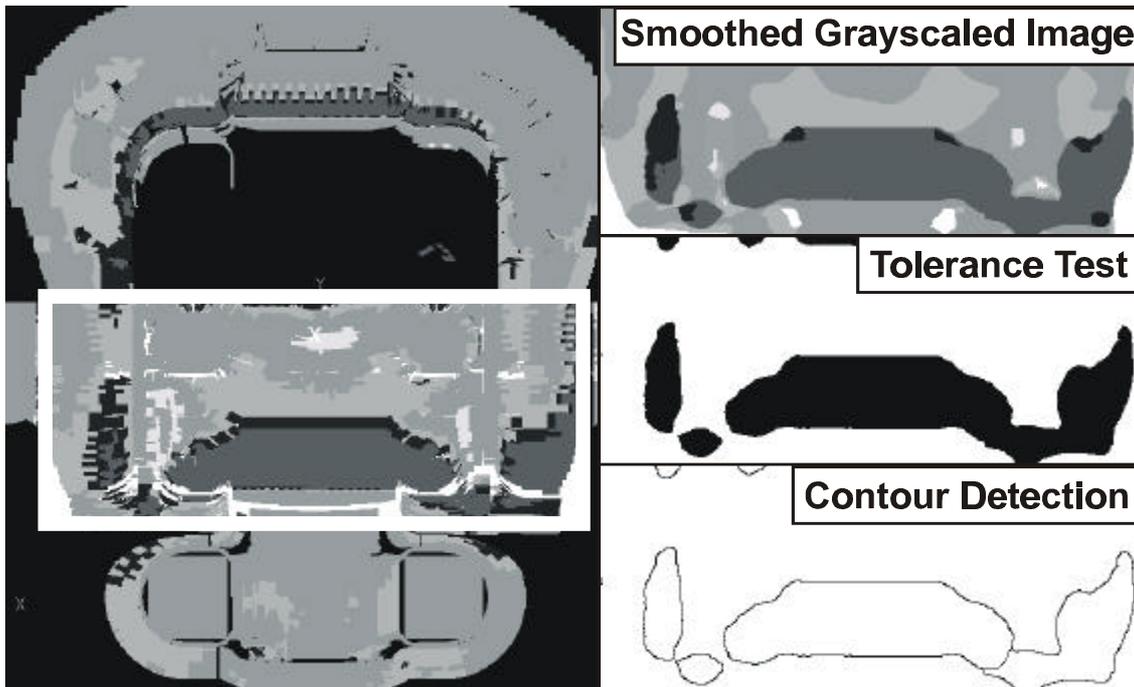

Figure 4. determination of the borders of the deviation areas.

The boundary is described by a succession of points. The addition of the third coordinates creates a three-dimensional polyline which can be transferred using standard transfer formats for CAD data (e.g. IGES) along with the required geometry, to a CAM system. When the polyline is projected onto the required geometry, the area to be machined in the course of the selective machining of freeform surfaces, can be defined (Figure 5).

A software prototype to perform these functions is currently being developed as an extension of a CAD system, by the Chair of Manufacturing Metrology and Quality Management at the University of Aachen. This will permit measuring sequences to be generated for coordinate measuring machines, deviations to be identified and the boundaries of the areas of deviation to be defined.

6   Conclusion

Due to geometrical changes to forming tools during the period of tool deployment, the actual tool geometry does not correspond to the geometry specified in the tool design. These geometrical changes can be measured rationally using modern measuring methods such as coordinate measuring technology. It is vital that the measurement data is processed in a suitable manner, if the results of the measurement operations are to be used effectively in CAD and CAM systems. There are special extensions for CAD systems, which adapt CAD data to the measurement data. In those cases in which the CAD data does not need to be adapted but the tool geometry should be reconstructed in accordance with the target data, the boundaries of the areas of deviation should be defined. These boundaries, in the form of polylines, can be used in CAM systems for selective machining of areas of deviation which have occurred as a result of wear, for example. This approach is suitable not only for forming tools as described here, but also for cutting tools which are very prone to localised wear on areas of the cutting edge.
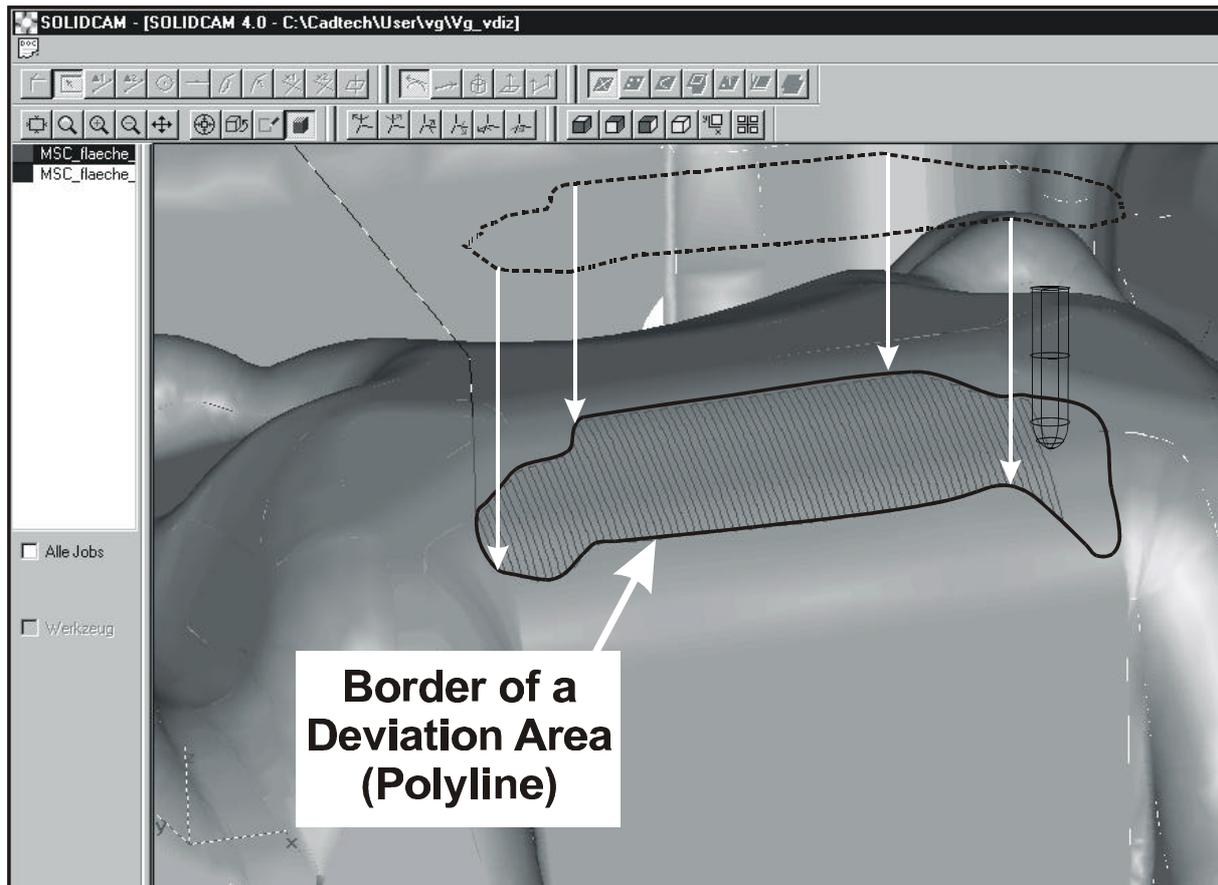
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Figure 5. manufacturing sequences for the correction of the deviation areas.

REFERENCES

[1] Weinert, K., Guntermann, G., Bearbeiten von Freiformflächen. Werkstatt und Betrieb, 131 (1998) Nr. 9 pp. 828-835.

[2] Klocke, F., et. al., Competitive manufacturing processes - solutions for the machine tool industry, Eversheim, W., Klocke, F., Pfeifer, T., Weck, M., Manufacturing Excellence in Global Markets; Chapman & Hall, London 1997 pp. 419-466.

[3] Lange, K., Cser, L., Geiger, G., Kals, J. A.. G., 1992, Tool Life and Tool Quality in Bulk Metal Forming, Annals of the CIRP, Vol. 41/2/1992, pp. 667-673.

[4] Pfeifer, T., Imkamp, D.: Optimization Potential in Manufacturing Metrology (Topic 14, Volume VIII), proceedings of IMEKO World Congress June 1-6 / 1997, Finland, Tampere.

[5] Bosch, J. A., Coordinate Measuring Machines and Systems, Marcel Dekker Inc., New York 1995.

[6] Ross, D. T.: Applications and Extensions of SADT, IEEE Computer Magazine 18 (1985), Nr. 4 pp. 25-34.

[7] Dimensional Measuring Interface Specification, Revision 3.0, ANSI/CAM-I 101, Consortium for Advanced Manufacturing - International, Inc., Arlington (Texas), USA 1996.

[8] Roth-Koch, S., Merkmalbasierte Definition von Freiformgeometrien auf Basis räumlicher Punktwolken, PhD Thesis, University Stuttgart, 1995.

[9] Russ, J. C., The Image Processing Handbook, CRC Press, Springer, Berlin 1999

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