HSC-Appropriate NC Programming in Die and Mould Manufacturing

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Abstract: In the last years, demands on sculptured surfaces in dies and moulds have increased because of improvement of software and machining technology. First, it only was important to perform NC programs to ensure secure processes when manufacturing sculptured surfaces. Today, especially in the HSC process chain, CAM strategies are necessary to reduce flow time by supporting the capabilities of the HSC technology with suitable NC programs. Substance will be the lack of information at the transition from roughing to finishing and the localisation and elimination of critical 3-axis machining situations.

1. MOTIVATION

Reducing the overall product development time from the idea to production maturity has for quite some time been a central topic especially in die and mould manufacturing. The reasons for tightening the product development process are decreasing product cycle times, increasing component variety and constantly growing international competitive pressure. A way out is provided only by steady organisational and technological development in all areas of the production chain.

High-speed milling, for instance, offers a most appropriate opportunity for reduction of run times, since the high cutting speeds and feed rates involved permit reducing production times and minimising rework due to the achievable closer line widths [1, 2]. Application of high-speed machining is focused on the areas of rapid tooling, electrode manufacturing, and direct milling of moulds out of steel or cast iron. The latter item undoubtedly is the one which offers by far the greatest potential.

However, there are difficulties in converting the technological results into actual application. The existing CAD-CAM systems are inadequately prepared for HSC-proper programming since with the data structures available today in CAD-CAM systems this cannot be done at all or with a high input of time only [3]. The objective will be to make all milling operations HSC-proper by the introduction of machining objects into the CAD-CAM systems used in die and mould manufacturing.

2. DEGREE OF INNOVATION

The Institute for Production Engineering and Machine Tools (PTW) of the Darmstadt University of Technology has been doing research in the field of high-speed machining for almost twenty years. Focal items in the field of die and mould manufacturing are the determination of HSC-appropriate milling strategies for HSC machining of sculptured surfaces as well as the generation of technological application data for different groups of materials [4]. These results are included among others in a CAD-CAM system to support the CAM programmer.

As to the CAD-CAM systems used in die and mould manufacturing applications, these mostly are free-form surface modellers. They permit mathematical description of extremely complex surface configurations in a model, making them accessible for production purposes.

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Since in most cases the desired geometry is described by a surface modeller while the row geometry is defined by a volume modeller, frequently there are two different data models to be considered for complete machining of a component. From this results a break or incision in program generation between roughing and finishing operations. In particular at the transition from roughing to finishing, the CAM programmer can only rely on his imagination as to the intermediate geometrical results as well as on his experience how to proceed. Today's CAD-CAM systems do not support this process [5].

In addition, the sculptured surface programming modules are based on purely mathematical definition potential. This leaves all technological points of view completely out of consideration in generating NC programs. Apart from a lack of flexibility in the choice of cutting strategies, this results in NC programs being determined by the possibilities of the system and optimised strategy and technology parameters as well as the geometrical description of the component not being taken into account. Until this date, no approaches of this kind have become known in CAD-CAM systems.

Whenever programming errors or system-related errors occur in the NC program within the control system, these can be corrected with considerable effort only. However, the objective should be not to have such errors occur in the control system. This is ensured by an optimised free-form geometry description in the CAD-CAM system which stores individual machining steps as machining objects in order to improve the overall machining process. The machining objects include the information relating to the geometry to be machined as well as to technology and strategy [6]. The advantage of a modular machining description is to be found in the fact that individual machining objects can be exchanged. This allows a geometry B to be machined equally well as a geometry A since the complete machining description of A is copied while only the geometry is exchanged.

3. OPTIMISED SEMI-FINISHING STRATEGY

As a basic requirement for optimum HSC finishing, a near-constant offset must be present so as to keep the cutting conditions as constant as possible. In order to achieve high quality as to surface roughness, dimensional accuracy and trueness of shape, cutting strategies must be used which depend on the surface geometry [5].

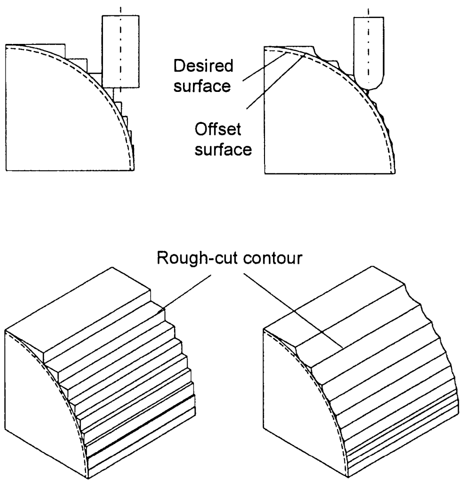

Figure 1. Terraced forms depending on tool geometry

Based on a 2.5 axis roughing operation, semi-finishing is made by conducting the tool parallel to the final contour using various infeeds until a uniform offset is achieved. During this process, the tool makes up to one third of air-cutting, especially during the first infeed steps. Besides this air-cutting, the absence of geometrical support during semi-finishing constitutes the central problem. Prior to both roughing and finishing, the NC programmer can make use of a known component geometry available as a computer-integrated representation, i.e. prior to roughing by means of the defined blank, prior to finishing by means of the final contour and the known offset. Prior to semi-finishing, however, he is compelled to form his own mental model of the intermediate geometry. Collisions, if any, occur between tool and semi-machined geometry, but rarely between tool and final contour or clamping devices. Reasons for this can include the terraced shape depending on the tool geometry (Fig. 1).

As is shown in Fig. 2, at first the actual maximum offset after roughing is calculated. In comparison with what is technologically possible, the permissible offset is determined along the tool motion paths of the maximum offset.

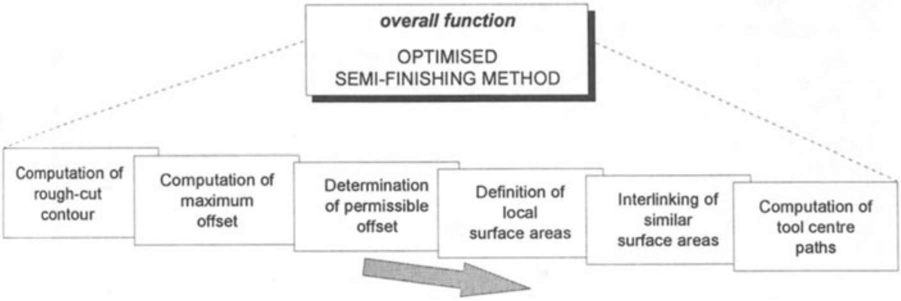

Figure 2. Optimised semi-finishing method

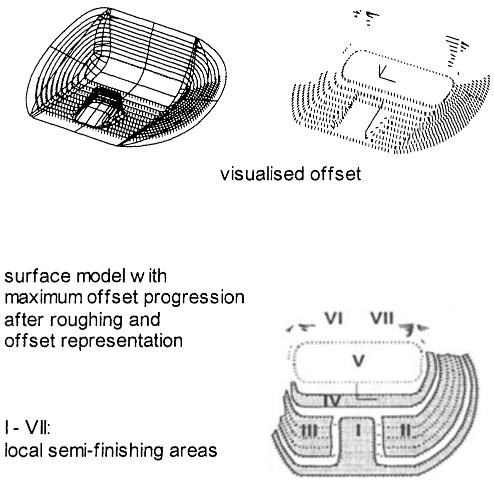

Figure 3 .Limits of local semi-finishing areas

Also, the computed intermediate geometry is divided into areas of identical semi-finishing zones (Fig. 3). Since different offset conditions are obtained depending on the contour of the rough-cut component, machining areas presenting similarity of contours are combined by decomposing the component into surface sections having identical geometry configurations and by storing similarity areas in an array. By marking the area to be machined, optimised semi-finishing motion paths are derived which can be used for computing the tool envelope volume.

4. DESCRIPTION OF MACHINING OPERATIONS BY MEANS OF MACHINING OBJECTS

In order to establish machining objects, it is required to have the nominal geometry, the machining method and the material being machined available as input parameters. The nominal geometry is a topological sculptured surface, i.e. it is described completely by patches joined together without any gaps. A patch is the smallest form feature unit described unmistakably by u, v vectors through their origin, direction and amount. The machining methods are constituted by roughing, pre-finishing and finishing operations; as to the workpiece material, the choice includes heat-treatment steel, hardened cold-working steel, cast iron, electrode copper, aluminium and graphite. After making these inputs, the resulting outputs are technology parameters, information as to the tool, as well as a strategy recommendation. These are provided as „information windows" by a CAD-CAM system with an application procedural interface (API) in order to give the NC programmer the required support in technology and milling strategy which normally he can only compensate by know-how or trial.

4.1 Identification of Form Feature Areas

The nominal surfaces subdivided into areas of equal contact conditions are composed of form features. These are convex and concave curvatures, chamfers, grooves, bores etc. and can be identified over the entire component surface as coherent areas having equal characteristic configuration.

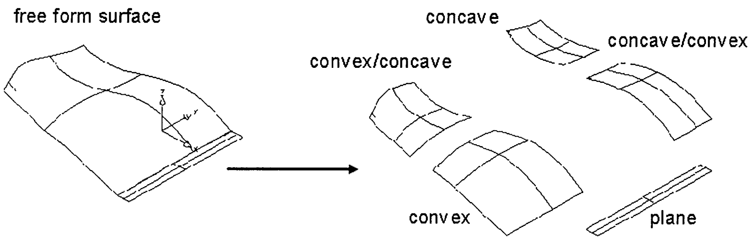

Figure 4 . Automatic identification of form feature areas

How to classify the sculptured surfaces according to surface configuration? A sculptured surface or partial areas of such a surface are at first automatically subdivided into the respective patches. Each patch is sorted by size and is appropriately examined in a definite amount of points for its curvatures in u and v direction. For this purpose, a field of u and v vectors is placed over the patch in a constant width of steps so as to form a network. The nodes mark the points where the patch has been examined for the amounts of its curvatures and the mesh size represents the distance between nodes. If there is a change of signs in the respective direction of curvature at adjacent nodes, a surface point of the patch is stored in this location. This converts the original patch into m*n smaller patches according to the number of m surface points generated in u direction and the number of n surface points generated in v direction. These smaller patches are subsequently classified by concave or convex feature areas through calculating the curvatures in u and v direction at the surface points (u = 0.5, v = 0.5) of the respective smaller patches. An example illustrates the principle (see Fig. 4).

4.2 Linkage of Identified Form Features into Machining Objects

Having achieved the possibility of describing the machining operation by means of machining objects and additionally of subdividing sculptured surfaces into areas of identical contact conditions, these modules are in the following processed together. Thus, either surface areas with mainly concave curvature or such with mainly convex curvature are automatically identified and subsequently are linked with information about geometry, technology and strategy to form machining objects.

The machining strategy presented as the result of this is divided into the areas of geometry, technology and milling strategy as illustrated by an example in Fig. 5. The information about the milling strategy includes machining proposals taken from the technological know-how existing at PTW. These machining proposals can in the following steps be further specified for production planning.

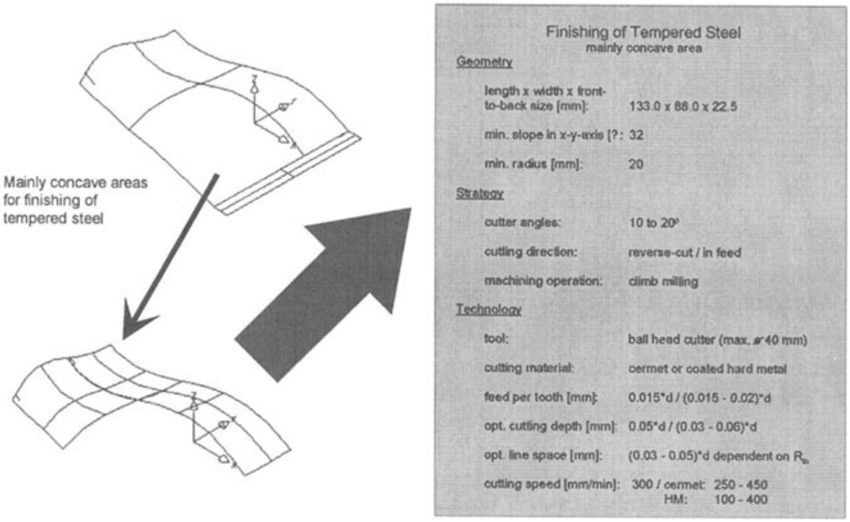

Figure 5 Linking of form features to machining objects

The geometry information includes the form feature dimensions (length, width and height), the maximum angle of inclination related to the x-y plane and the minimum surface radius. When using a ball end cutter for the pre-finishing or finishing operation, a measure is immediately furnished for the maximum possible cutter diameter. Taking the maximum angle of inclination into account, any tool collision is prevented as this information defines the maximum possible advance in the feed direction. The form feature dimensions give indications as to the adequate choice of machine tool (working range) and a rough choice of correct tool dimensions.

The technology information furnishes binding proposals as to the shape of the tool and the cutting material to be chosen, related to the type of machining and of the work-piece material. In addition, the machining information includes data on optimum cutting speed, feed per tooth, infeed depth and width completed respectively by range information. Finally, a strategy recommendation is made including information on the direction of movement, on the machining process and the ideal angle of incidence.

5. PRODUCTION OPTIMISATION PRIOR TO MACHINING

Today, NC programs are frequently used which are not primarily concentrated on the philosophy of technologically optimised and thus also economically efficient machining, but in which solely the possibilities offered by the CAM system are determining for the tool motion. For once, the times for NC path generation are partially too long, so that for reasons of time alone no variations of NC programs are made for finding optimised solutions. Also, frequently there are not so many possibilities or alternatives in NC program generation within CAM systems which would allow variations to be made.

For this reason, critical machining situations must be localised and eliminated prior to machining, such as

- limits of infeed in machining steel or cast iron,
- cutting curve correction in choosing the tool diameter,
- relief cutting control,
- support by visualised offset conditions,
- analysis and elimination of critical tilting angles,
- automatic identification of filigrane features and optimised HSC machining of these by means of long tool overhangs,
- analysis of the flute as a critical machining feature.

As an example, automated identification of filigrane features such as pockets or bores and optimised HSC machining of these with long tool overhangs are explained below.

In a first step, information is derived about automatic identification of pockets and bores by means of studying the angles of inclination on the component surface, since especially for filigrane features there is a danger that the smallest tool diameter required for geometry reasons will result in an inadequate length/diameter ratio for the tool. In conjunction with the large tool wrap conditions as they occur in such machining applications, this can lead to increased wear and even tool failure.

Procedure: A network of points is distributed over a sculptured surface. By comparing the z-co-ordinate (corresponding to the tool axis) of neighbouring points, wide variations in the z-direction can be identified. The cutting curves of the sculptured surface with planes in the y-z- and x-z-direction then provide the paths for the network of points. Due to the great differences between z-co-ordinates, it is possible to distinguish pockets and bores from strongly curved concave surfaces. The following condition is established:

$$\frac{\Delta x}{\Delta z} \geq \tan\left(\frac{\pi}{6}\right) \quad \text{or} \quad \frac{\Delta y}{\Delta z} \geq \tan\left(\frac{\pi}{6}\right)$$

Subsequently, an examination is made as to whether the pocket can be machined with the tool chosen, by comparing the surface within the set of lines describing the rim of the pocket or bore with the face of the cutter. If the surface of the pocket or bore is smaller than double the face of the cutter, HSC-appropriate machining can no longer be ensured. Furthermore, the curvature of the set of lines is compared with the curvature of the tool. This way, a check can be made as to HSC-appropriate machining with the tool chosen.

If the pocket can be machined with the tool chosen, HSC-appropriate approach and retract strategies for long tool overhangs are proposed in order to obtain HSC-appropriate roughing strategies for machining pockets and bores. These are subsequently offered as applications in a CAD-CAM system.

The basic requirement for the approach is „gentle plunging" into the material. A very adequate path of approach resulting from this is a helical line which due to both a circular and a ramp movement of starting will subject the tool to a minimum of load. The tool plunges into the material on a helical line after approximately one revolution and penetrates to the desired infeed depth during one further revolution. A relief cut of e.g. 0.1 mm can be added to the helical line in order to facilitate the combined roughing operation. The diameter of the helical line is chosen so as to generate an overlap in the centre of the helix during each revolution.

The combined roughing operation is composed of the starting strategy and clearing of a plane, spirally if possible, from inside out before the next plane is machined. Since a new starting procedure is required for each plane, it is an obvious choice to combine the two strategies.

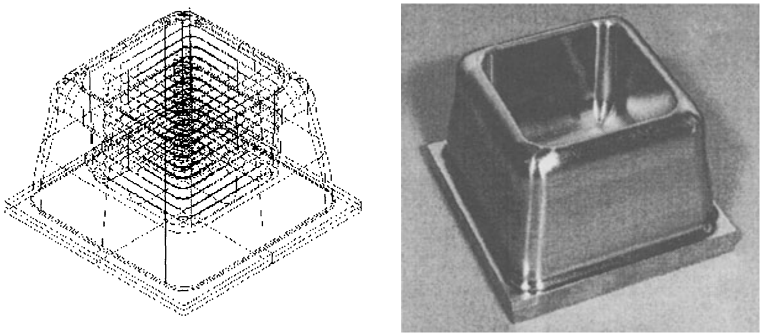

Figure 6. Example of HSC-appropriate pocket machining and mould produced by milling

An example is shown in Fig. 6. What can be seen is a deep pocket (l/d >5) which in each of the roughing planes has been machined in a way appropriate for HSC. The following conditions must be fulfilled:

- The strategy of approach must be adaptable to the process.
- Down-milling must be possible within the pocket.
- It must be possible to machine the pocket with „soft" motions, i.e. small wrap angles in the directional changes of the roughing spiral.

Evaluation of the semi-finishing operation can be made after finishing only. It is the quality of the finished surface that permits the efficiency of the semi-finishing operation to be measured. The goal of achieving, prior to finishing, an offset which is as constant as possible is mandatory with a view to an optimum result of finishing. Offset variations due to step heights above a tolerable limit will cause waviness of the finished surface. Investing into a more thorough and thus more prolonged semi-finishing operation will as a rule pay off. The higher the requirements made of the final contour, the more attention must be paid to the semi-finishing operation. By means of the known actual offset after each machining operation, it will be possible to perform thorough semi-finishing at machining times which are still acceptable.

Due to the shape of the component having high side walls, a high proportion of flutes as related to flat wall areas, and the roughing or semi-finishing operation in z-constant planes with the resulting terraced steps, the best results as to surface quality are furnished in this case by plane-wise machining parallel to the contour. The results of pulling or boring cuts are less favourable as these bring about wide variations of infeed depth in the feed direction, primarily due to inadequate semi-finishing. Other advantages to be mentioned are shorter machining time and the more harmonious path motion of the tool in this case and with this strategy.

6. CONCLUSION

Today, „stable process runs" are particularly important. In this connection, highly aggravating problems such as safe machining of critical areas, application of long tool overhangs, and safe approach strategies have been studied for possible action to reduce instabilities. The machining strategies found were subsequently implemented in a CAD-CAM system. Also, identification of critical machining situations and their elimination are already included in an advanced CAD-CAM system.

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