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THE APPLICATION OF CURVATURE AND CONTOUR LINES IN SCULPTURED SURFACES MACHINING ON NUMERICAL CONTROL MILLING MACHINES

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The exact sculptured surfaces machining time can be substantially reduced when one tool movement machined strips are properly distributed. Characteristic sculptured surface lines are suggested. Their picture provide sufficient information for correct trajectory design. Practical applications are discussed. Four examples are given.

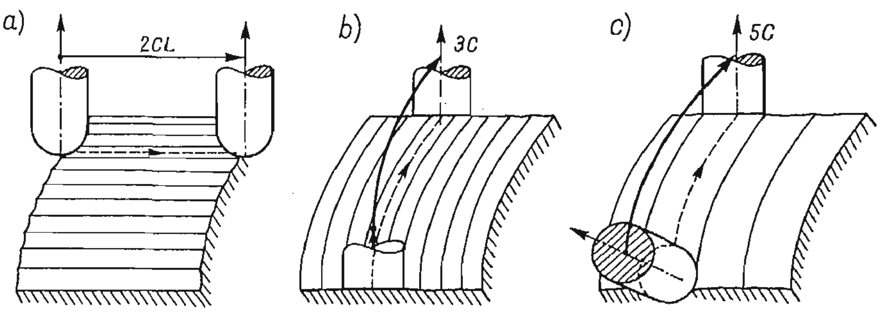

Fig. 1. Machining on milling machines type 2CL, 3C, 5C

1. Introduction

The surface regularity in the sense of slow curvature changes may be necessary because of aerodynamic and aesthetic expectations. In this paper some technology conditions leading to similar regularity demands will be described. They appear when precise sculptured surfaces face milling on numerical control milling machines is applied. In works [1] [2] fundamental connections between the local machined strip width, tool dimensions, position, and movement direction are presented. It was shown, that optimal (taking strip width as a criterion) machined strip positions are similar:

— to contour lines when 2CL milling machines are applied,
— to gradient lines when 3C milling machinnes are applied,
— to principal curvature lines when 5C milling machines are applied.

Interactive computer graphics methods make it possible to use the mentioned lines picture on the display as a basis for general trajectory design when programming NC milling machines. This approach allows to design a trajectory in such a way as to make the consecutive machined strips broad and not overlapping one another. The trajectory design method depends greatly on the milling machine type. In the next sections sculptured surfaces face milling on the milling machines type 2CL, 3C, and 5C will be described. The surface lines characteristic for particular machines type will be derived.

2. The face milling on 2CL machines

In this case miller moves round the surface in such a way as not to change the distance from the machine table (fig 1a). The machining accuracy depends mainly on tool shape and the difference between tool distances in two adjacent tool movements. It was shown in [1] that:

— the trajectory of the tool-surface contact point is similar to the surface contour line in practically all the cases,
— broadest machined strips are obtained when spherical end mills are applied,
— the machined strip width can be approximately described as

$$d \cong 2\sqrt{2h}$$

where h — machining tolerance;
— tool radius assumed equals 1,

— regions close to the surface ridges limit maximum tool distance difference.

3. The face milling on 3C machines

In this case the miller moves round the surface in such a way that the tool axis is constantly perpendicular to the fixed plane (usually table plane — fig. 1b). In [1] it was shown that:

— the broadest machined strips are obtained when cylindrical, flat end mill is applied, and tool-surface contact point moves approximately along gradient lines.
— the machined strip width d can be approximately described as:

$$d \cong 2\sqrt{\frac{2h}{\sin\alpha - \varkappa_y}}$$

where h — machining tolerance,
$\varkappa_y$ — surface normal curvature in plane tangent to tool edge at the contact point,
α — angle between the normal to surface at the tool-surface contact point and the tool axis,
— tool radius is 1.

— the surface point cannot be machined when the curvature of the contour line drawn through this point is smaller then $1/r$, where r is tool radius.

4. The face milling on 5C machines

In this case miller moves round the surface in such a way that the direction of the tool axis may be changed (fig. 1c). In [1] it was shown that:

— the broadest machined strips are obtained when toroidal end mill is applied and tool-surface contact point moves approximately along principal curvature line. The line characterizing smaller principal curvature should be chosen. (It has been assumed that in convex surface the curvatures are negative.)

— the maximum machined strip width d can be approximately described as

$$d \cong 2\sqrt{4\sqrt{\frac{2h}{\Delta\varkappa}}-\frac{8h}{\Delta\varkappa}}$$

where $\Delta\varkappa$ — principal curvatures difference in the contact point;
h — machining tolearnce;
— tool radius is 1.

It should be stressed that in this case the maximum strip width is a decreasing function of principal curvatures difference.

5. Examples of trajectory design

To illustrate the use of characteristic lines, four surfaces are presented in the figures 2, 3, 4 and 5. In figures marked a the surfaces are presented. They are displayed by constant parameter lines. All the four pictures look like one another. In figures marked **b** Bezier characteristic points for analyzed surfaces are displayed. It is easy to observe that there are substantial differences between the shapes, however, Bezier points do not make it possible to analyze how great the influence on milling process is. Let us analyze the machining process on NC milling machines of type 2CL, 3C and 5C.

5.1. 5C face milling. In this case constant smaller principal curvature lines and constant principal curvatures difference lines are of at most importance. Constant smaller principal curvature lines (figures marked c) present the approximate tool movement directions when maximal machined strip width is to be obtained. Constant principal curvatures difference lines (according to point 4) make it possible to decide how the machined strip will change along surface-tool contact point trajectory (figures marked d). It is easy to observe in figures 2c and 3c that in case of surfaces 1 and 2 the optimal tool movements direction are clearly defined. In case of surface 1 machined strips width will be approximately constant due to the parallelism between trajectory lines in fig. 2c and constant strip width lines in fig. 2d. In figure 3d the principal curvatures difference extremum can be observed (marked with +) so in case of surface 2 machined strips width is likely to vary along the strip and reaches its extremum value in the + area. In some cases of that kind interactive machined strip arrangement should be made. A much more complex situation can be observed in cases of surfaces 3 and 4. Principal curvature lines in figures 4c and 5c are less regular and umbilic points marked with + can be observed (one in fig. 4c and two in fig. 5c). If machining time is very important due to trajectory design

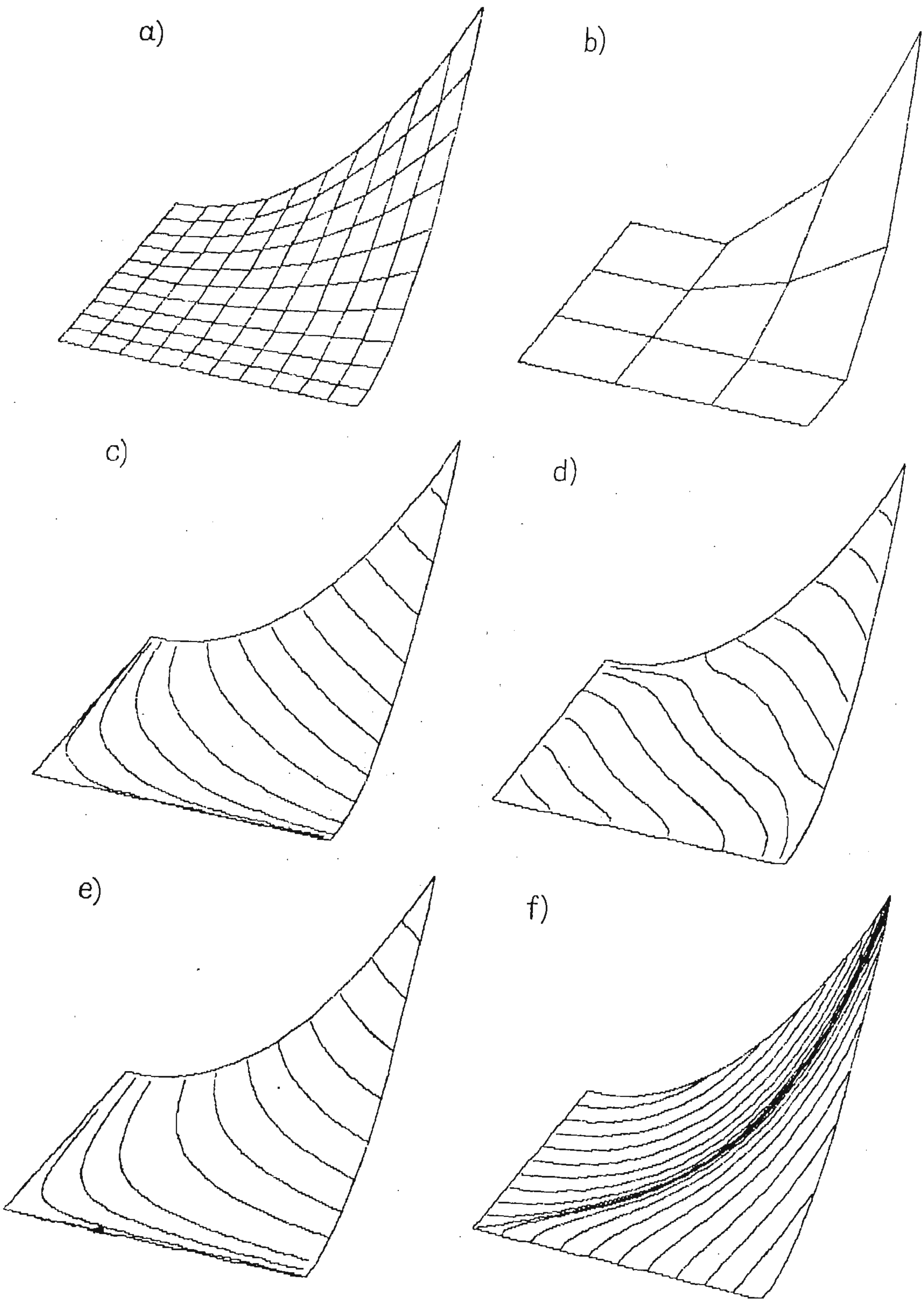

Fig. 2. Surface 1 characteristic lines

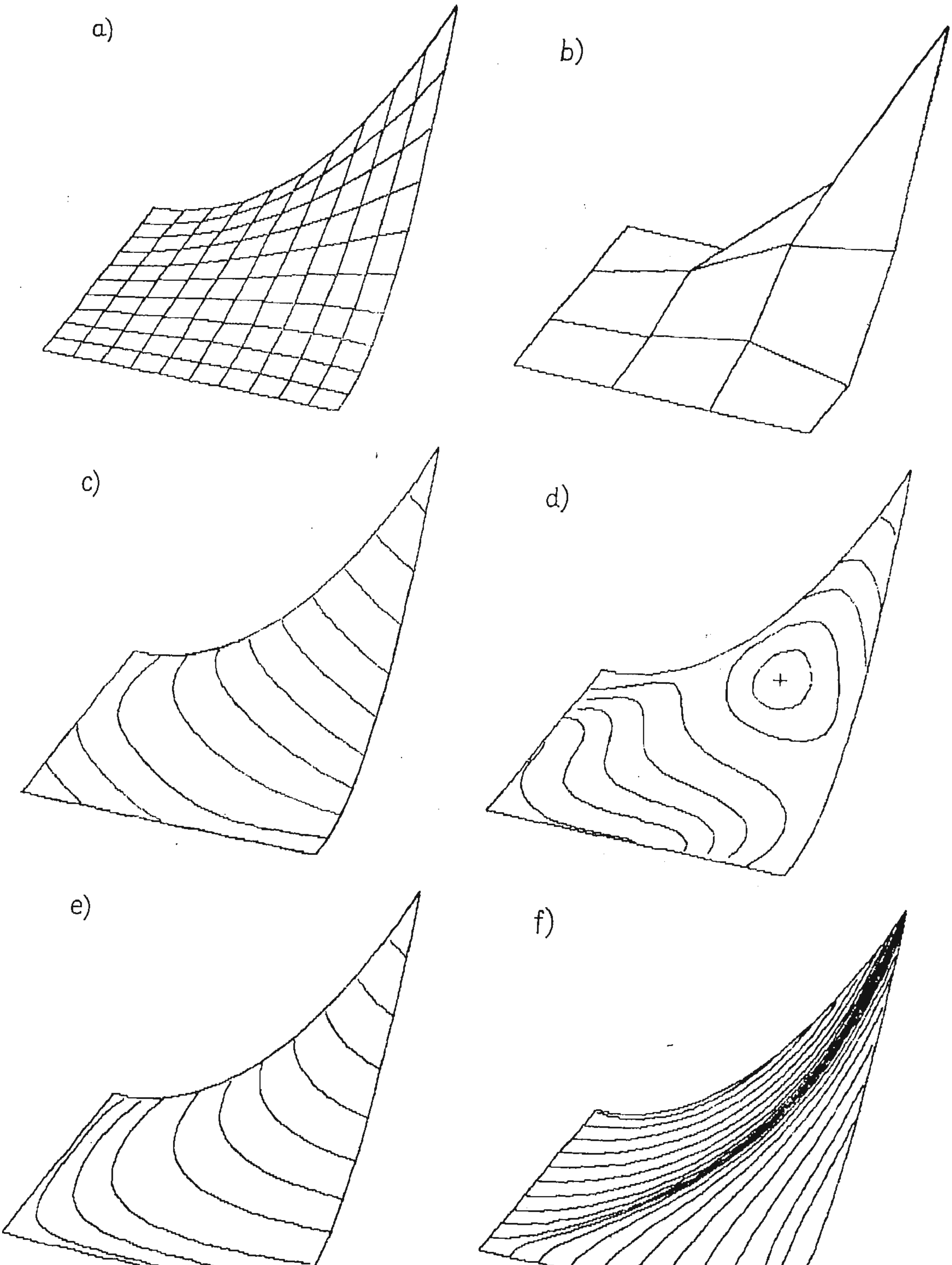

Fig. 3. Surface 2 characteristic lines

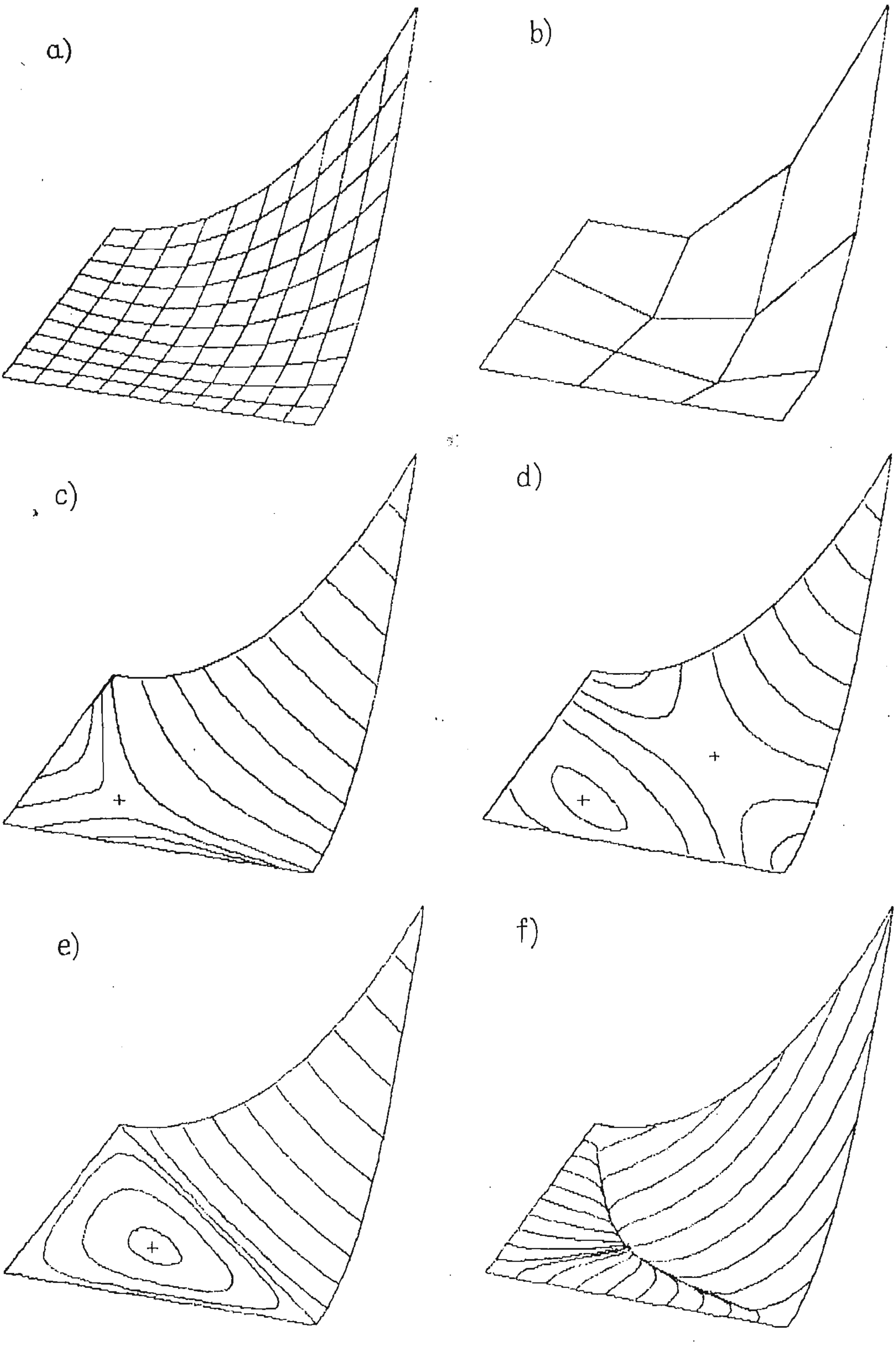

Fig. 4. Surface 3 characteristic lines

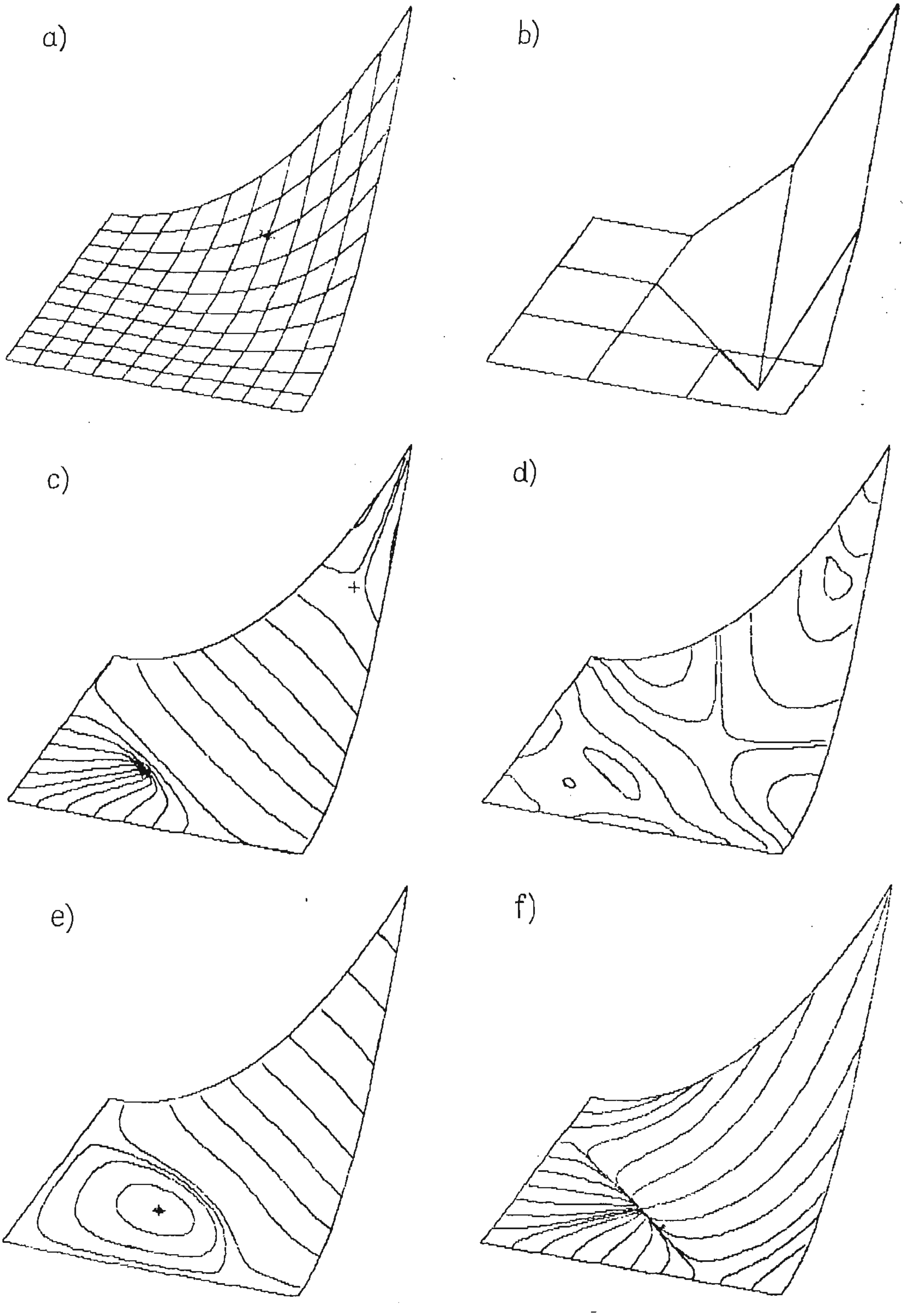

Fig. 5. Surface 4 characteristic lines

process, both surfaces should be divided into parts with similar optima lmachined strip directions. When observing constant principal curvatures difference lines in figures 4d and 5d machined strips width can be expected to vary substantially from point to point so, that in surface 4 case maximum strip width machining method may turn out to be quite useless. However, if applied after all interactive machined strips arrangement should be used.

5.2. 3C face milling. In this case the contour lines (figures marked e) and gradient lines (figures marked f) give most information about machining process. As it has been discussed in point 3 the maximum strip width trajectories are approximately parallel to gradient lines. In figures 2f and 3f can be observed that the programming process in case of surfaces 1 and 2 should be clear. A more complicated arrangement can be observed in case of surfaces 3 and 4. The contour lines shown in figures 4e and 5e present local surface minimum (marked with +). At that point it should be stressed that the shape and position of contour lines depend on miller axis direction. The contour lines planes are perpendicular to the tool axis direction. In both cases in the lower part of surfaces ridges originating from the minimum can be observed and trajectory design in their surroundings can be a somewhat more complicated as in the rest of the surface. Moreover the surroundings of the minimum points are unmachinable when cylindrical flat end mill is applied this being due to the undercutting conditions discussed in point 3.

All the problems with 3C machining of surfaces 3 and 4 have their origin in improper surface position relatively to the tool axis direction. If there is a possibility to place machined part on the milling machine tool in such a way as to make the minimums disappear, surfaces 3 and 4 machining will be as simple as in cases 1 and 2.

5.3. 2CL face milling. In this case contour lines (figures marked e) give most information about machining process. Gradient lines (figures marked f) can also be helpful in surface ridges regions finding. As mentioned in point 2 the tool trajectories are in this case parallel to the contour lines. In case of surfaces 1 and 2 the trajectory design process is a simple one. If machining accuracy has to be preserved (see p. 2) the ridges, regions easy to observe in figures 2f and 3f, (high density of gradient lines), should be taken into account.

In case of surfaces 3 and 4, in the surrounding of minimum, the trajectories will assume the shape of closed curves. This need some extra programming effort at the beginning and the end of cutting tool movement. The minimum point will probably be badly machined because of zero cutting speed in the lowest point of the spherical end miller. These two last disadvantages can be easily done away with, if it is possible to reposition the surface as to make the minimum point disappear.

6. Summary

Proposed methods of surface shape displaying make it possible to obtain sufficient information to program the NC milling machines. Machining process planning consist of two stages: global movements planning and local adjacent machined strip positioning. Proposed characteristic lines are particularly useful when global problems are being solved. The local problems (machined strips overlapping) can be solved automatically by computer system itself or in more complicated cases by interactive computer graphics tools.

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Р е з ю м е

ИСПОЛЬЗОВАНИЕ ЛИНИЙ КРИВИЗНЫ И УРОВНЕЙ ДЛЯ ОБРАБОТКИ КРИВОЛИНЕЙНЫХ ПОВЕРХНОСТЕЙ НА ФРЕЗЕРНЫХ СТАНКАХ, УПРАВЛЯЕМЫХ ПРИ ПОМОЩИ ЭЛЕКТРОННО-ВЫЧИСЛИТЕЛЬНЫХ УСТРОЙСТВ

Правильное размещение поясов обработки при отделочной фрезерной обработке криволинейных поверхностей может значительно сократить время обработки. В работе предлагаются характерные линии криволинейных поверхностей, образ которых является источником необходимого числа данных для правильного проектирования траектории инструмента. Обсуждается практическая пригодность данного типа образов поверхностей, а также приводятся практические примеры.

S t r e s z c z e n i e

ZASTOSOWANIE LINII KRZYWIZNOWYCH I KONTUROWYCH PRZY OBRÓBCE FREZOWANIEM POWIERZCHNI KRZYWOLINIOWYCH DLA OBRABIAREK STEROWANYCH NUMERYCZNIE

Dokładną obróbkę frezowaniem dużych powierzchni krzywoliniowych można znacznie skrócić przez właściwe rozplanowanie pasów obrobionych jednym ruchem narzędzia. Sposób obróbki zależy od typu obrabiarki (2CL, 3C, 5C). Dla każdego z typów wyróżniono najkorzystniejszy kierunek ruchu narzędzia. W każdym z przypadków zaproponowano również linie charakterystyczne powierzchni, których rysunek daje wystarczającą ilość informacji do zaprojektowania trajektorii narzędzia. W przypadku obrabiarek typu 2CL i 3C są to poziomice i linie gradientowe, zaś w przypadku typu 5C linie krzywiznowe i linie stałe różnicy krzywizn głównych. Praktyczną przydatność linii charakterystycznych przedstawiono na czterech przykładach.

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