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THE RESEARCH AND APPLICATION ON HIGHLIGHT LINE OF CURVED SURFACE QUALITY EVALUATION BASED ON 3D ASSEMBLY ENVIRONMENT

Abstract. *In view of the present situation of quality analysis methods of curves and curved surfaces, the paper introduced the theoretical basis and mathematical expression of curves and curved surfaces. Four highlight line configuration types, such as reflection, projection, isocline, reflection contours, for evaluate the curves and curved surface quality had been studied in the 3D assembly environment. Finally, a comparativeanalysisofimpellerbasesurfacehasbeengivenbythefourtypesin a 3D impeller assembly.*

Keywords: Assembly Environment; Curved surface quality; Highlight line analysis

Problem statement

With the improvement of living standards, people's demand for life products is no longer limited to the quality of products. The aesthetic and humanized embodiment of the design of industrial products will not only help the product to spread quickly and widely, but also bring more added values to the product. Therefore, the shape design of industrial products, especially the design quality of curves and surfaces, is attracting more and more attention from product designers. Curve and surface quality analysis is widely used in automobile, ship, aircraft, clothing design and other fields. However, traditional curve and surface quality inspection is often time-consuming, and the reliability of inspection results is not high. For example, in the design phase of car body, the model is often used to repair the curve repeatedly. The approximate smooth curve is achieved, and the contour curve is often drawn in the inspection stage, and the curve quality is observed through the experience of the professional discharge operator [1].

The continuous development of computer technology provides a new and more efficient detection method for curve and surface design, such as detection based on curvature and detection based on illumination model. These methods reveal the curvature changes of product parts and curves by computer simulation. Highlight line analysis is one of the illumination model methods. It can express the quality of curves and surfaces more visually and intuitively [2]. The quality inspection of curve and surface is no longer carried out by the model of paper and mud. In the product design stage, the quality of curve and surface can be detected in the product assembly environment by digital modeling [3]. The product designer can constantly adjust the curve and surface design according to the software test results, so as to achieve beautiful sculpt and harmonious aesthetic feeling.

Theoretical basis of curve and surface

Most of the curves and surfaces examined by highlight line analysis are from the designer's experience or by detecting the point cloud of the sample surface to fitting the surface at the later stage. No matter how the source of the curved surface is to be inspected and processed, it is necessary to first understand the theoretical development and construction method of curves and surfaces.

Bezier curve and surface

Bezier, as a parameter curve first appeared in computer curve construction, was put forward by French engineer Pierre Bezier in 1962. In a given space, the location vector P_k (k=0,1,2,…,n) of n+1 points, then the parameter equation of the Bezier curve is as follows [4].

$$P(u) = \sum_{k=0}^{n} P_k B_{k,d}(u), \quad u \in [0,1] \tag{1}$$

Among them, P_k (k=0,1,2,…,n) is the characteristic polygon that forms the Bezier curve. $B_{k,n}(u)$ is then Bernstein basis function.

$$B_{k,n}(u) = \frac{n!}{(n-1)!\,k!} u^k (1-u)^{n-k} \quad (k=0,1,2,\ldots,n) \tag{2}$$

By defining the Bezier curve above, we can give the definition of Bezier surface in the form of tensor product, and set $P_{i,j}$ (i=0,1,2,... n; j=0, 1, 2, ... m) is a $(n+1)\times(m+1)$ spatial point sequence, and the parametric equation of Bezier surface is as follows.

$$\begin{aligned} P(u,w) &= \sum_{i=0}^{m}\sum_{j=0}^{n} P_{i,j} B_{m,i}(u) B_{n,j}(w) \\ &= (B_0^m(u), B_1^m(u), \ldots, B_m^m(u)) \bullet \mathrm{P} \\ &\bullet (B_0^n(w), B_1^n(w), \ldots, B_n^n(w)) \end{aligned} \tag{3}$$

$$\mathrm{P} = \begin{bmatrix} P_{0,0} & P_{0,1} & \cdots & P_{0,n} \\ P_{1,0} & P_{1,1} & \cdots & P_{1,n} \\ \vdots & \vdots & \ddots & \vdots \\ P_{m,0} & P_{m,1} & \cdots & P_{m,n} \end{bmatrix}$$

According to the properties of (1), (2) and (3), we can see that as long as the position point of the direction of the curve is given, that is, the control point of the curve, the complex curve can be drawn through the Bezier curve, but the number of the control points determines the number of polynomial, the more the control points are, the more the computation is, and the Bezier curve and surface are not local. That is to say, changing one of the control points will change the overall shape of the curve and surface [5], which will make it difficult for engineers to modify locally. The Bezier surface is derived from the Bezier curve, which has most of the same properties.

B-splines curve and surface

B-splines curves and surfaces can inherit the good properties of Bezier curves and surfaces, and solve the problem that Bezier curves and surfaces are difficult to be partially adjusted. The parameter equation of the B-splines curve is as follows [6]:

$$P(u) = \sum_{k=0}^{n} P_k B_{k,d}(u)$$
$$u_{min} \le u \le u_{max}, 2 \le d \le n+1 \tag{4}$$

In formula (4), it is the number K control point of the curve. $B_{k,d}(u)$ is the function; d is the number of B-splines curves.

According to the Boolean Cox recursive definition commonly accepted by B-splines curves, its basis functions $B_{k,d}(u)$ can be generalized as:

$$B_{k,d}(u) = \begin{cases} 1, & u_d \le u \le u_{d+1} \\ 0, & \text{other} \end{cases} \tag{5}$$

$$B_{k,d}(u) = \frac{u - u_k}{u_{k+d-1} - u_k} B_{k,d-1}(u) + \frac{u_{k+d} - u}{u_{k+d} - u_{i+1}} B_{k+1,d-1}(u) \tag{6}$$

Therefore, the parametric equation of the B-splines surface with $k \times h (k \le m, h \le n)$ order may be:

$$P(u,v) = \sum_{i=0}^{m}\sum_{j=0}^{n} P_{i,j} B_{i,k}(u) B_{j,h}(v) \tag{7}$$

In the formula (7), $B_{i,k}(u), B_{j,h}(v)$ is the basis functions of the k-order and h-order B-spline curves of the node vectors U,V, and $u_k \le u \le u_{m+1}$, $v_l \le v \le v_{n+1}$, u_k is node value. If node value is equidistant, then formula (4) corresponds to uniform B-splines curve, otherwise, it corresponds to non-uniform B-splines curve. The distribution of insertion nodes can be controlled so that B-splines curves and surfaces can be flexibly controlled. The conic curve cannot be constructed by B-splines, because the parametric equation of the curve is a rational polynomial, so the non-uniform rational B-splines is introduced [7].

Non-Uniform Rational B-Splines curves and surfaces

Non-Uniform Rational B-Splines, NURBS, is an excellent modeling method for curve and surface. NURBS surface is a generalization of B-splines surface. Its parametric equation is as follows [8].

$$P(u,v) = \frac{\sum_{i=0}^{m}\sum_{j=0}^{n} \omega_{i,j} P_{i,j} B_{i,k}(u) B_{j,h}(v)}{\sum_{i=0}^{m}\sum_{j=0}^{n} \omega_{i,j} B_{i,k}(u) B_{j,h}(v)} \tag{8}$$
$$u, v \in [0,1]$$

In the formula (8), $P_{i,j}$ is the control point of the surface, and$\omega_{i,j}$ is the weighting factors associated with the control point of $P_{i,j}$, $B_{i,k}(u), B_{j,h}(v)$ are the basis functions of the k-order and h-order B-spline curves of the respectively node vectors of U and V [9].

Definition of Class A Surfaces

The term “A-level surface” starts from the automotive industry and first proposed by Dassault in France. At present, the specific indicators are: the position between the adjacent surface gap below 0.005 mm, cut rate change below 0.005°, curvature change within 0.5 mm^{-1} [10]. As the definition of A-level surface lacks the specialized mathematical expression, it is generally required that the surface splice should satisfy the ideal G2 continuous (the second order geometric continuity) or above, the control points have fixed distribution rule in a large convex surface, and the surface point cloud deviation does not exceed ±0.5 mm in practical engineering applications [11].

In the construction of NURBS curve and surface, the control points of the curve and surface are empowered according to the different importance, so that the control points are arranged in a uniform or non-uniform layout with weight in space so as to achieve the idealized control of the adjustment surface. NURBS can achieve better surface modeling than before, and the international organization for Standardization (ISO) also defines NURBS as the only mathematical method of the geometric shape of industrial products, and Bezier and B-splines construction are also integrated into NURBS. At present, the splines created in the mainstream 3D computer aided design are all NURBS.

Analysis of surface quality highlighting method in assembly environment

Most of the existing computer-aided design systems have implemented the quality analysis of the curved surface of a single part, however, single surface quality analysis often fails to fully reflect the design quality of the entire product surface, and the efficiency is not high. By directly analyzing the quality of product curved surface in 3D assembly environment, It can not only grasp the relationship of the surface design as a whole, but also can help the designer to directly and quickly check the quality of curves and surfaces, thereby improving the quality and level of design [12].

Form of curved surface quality analysis

Through the study of many current curve and surface quality analysis tools, at present, the main methods of analyzing the surface quality directly in the 3D assembly are: high line analysis, curvature comb continuity analysis, local radius analysis, and gap and altitude difference analysis of the nearest point. The surface quality analysis tool based on illumination model has good physical meaning and intuitive observation. It is a very important way of surface quality analysis. On the basis of it, many analytical methods and theories have been formed. Among them, highlight line analysis is a very important analysis method in illumination model analysis. There are four main forms of highlight line analysis: reflection line, projection line, isocline and reflection contours, as shown in Fig. 1.

Reflection line, as shown in Fig. 1 (a), It is similar to evaluating the surface shape of a product in a showroom. When the light is placed in a fixed position, it can reproduce the reflection surface of the light, and when the model is rotated, moved or modified, the highlight lines will also be updated. Reflection lines are most commonly used to evaluate the final model.

Projection line, as shown in Fig. 1 (b), the projection line uses light directly to the surface of the model to evaluate the geometric quality of the surface, analyzing whether there is a uniform shape on the surface or discontinuity between the surface and the surface. The system simulates a set of lights that illuminate the selected surface but do not produce reflected light. The method can assess the degree of dishing of discontinuities between two faces as well as the consistency of multiple face shapes or the geometric quality of a simple positioning surface.

Isocline, as shown in Fig. 1 (c), the use of equal slant curves is to help analyze the changes along the slope of the product surface. When creating the curve, it should be based on the points on the surface and the points with the same inclination angle on the specified reference vectors. The analytical form of Isocline depends on the number of equal slant and the angle at which they start and end.

The reflection contours, as shown in Fig. 1 (d), it is close to reality showing the reflection line of fluorescent tube light on the surface.

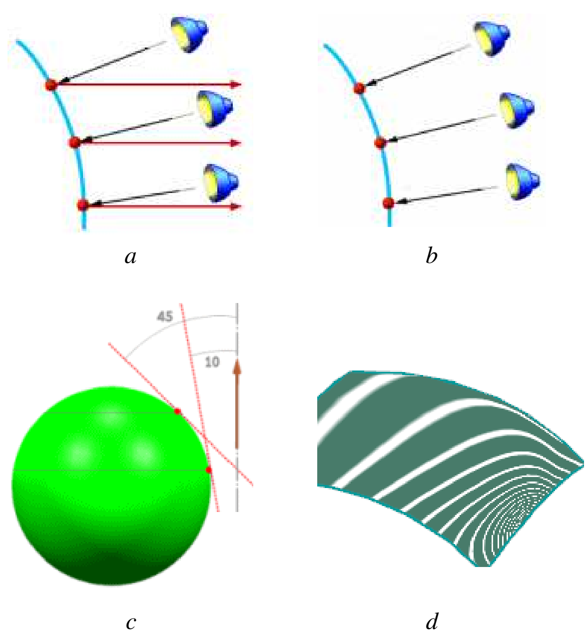

Figure 1 – Four highlight line configuration types in assembly environment: a – Reflection line; b – Projection line; c – Isocline; d – Reflection Contours

Layout of the assembly environment

When we conduct highlighting analysis, we can choose three forms of layout: (1) create by the specified point; (2) select uniform intervals on the selected analysis surface; (3) select a uniform interval between two specified points on the analysis surface. With these three forms of choice, design analysts can directly select the local area that they want to analyze, not necessarily the entire surface. This is more efficient and faster, and can better analyze the curvature change of curves and surfaces. And the analyst can also select the highlight line analysis object node in the component navigator and select the desired option to remove the highlight line, or delete or hide them. Fig. 2 shows the three different effects of selecting the reflection, projection and reflection contours, under the same conditions. The design analyst can select the required analysis form according to the quality analysis requirements. And by rotating and translating parts, the system responds in real time and updates real-world results based on the input. Design analysts set appropriate parameters through appropriate operations, and then can easily find out the curve and surface that do not meet the quality, so that it can be improved and optimized [13].

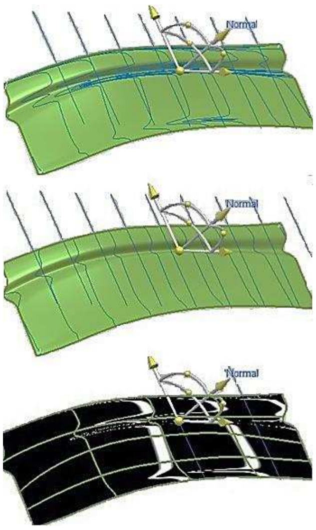

Figure 2– Highlight line contrast with reflection, project and reflection contours types

Analysis examples

Usually, the 3D design phase of product design will be assembled and designed after the completion of component design. at this time, it is generally difficult for designers to find the correctness of the assembly model through visual inspection. Therefore, a computer-aided inspection tool is needed to check the model from various angles. Using advanced computer-aided design techniques, the detection and analysis of the specific curve and surface quality of the model can be performed directly in the 3D assembly environment. The following example is a part assembly model of a product impeller, through a variety of analytical forms of highlight line analysis tools, analyzing the curved surface of the impeller base.

Open the assembly part to be analyzed in the 3D system, or create a new analysis assembly component and assemble the components in the assembly environment, as shown in Fig. 3.

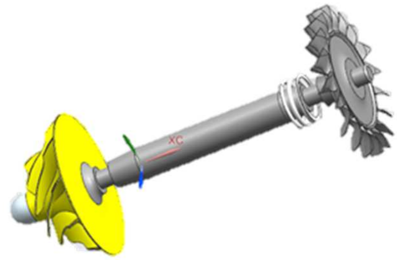

Figure 3 – Assembly components of impeller in a product

BY the surface quality analysis highlight line analysis special tool and set the parameters, selecting the surface analysis form according to the surface inspection requirements (reflection line, projection line, isocline, reflection contours), as shown in Fig. 4.

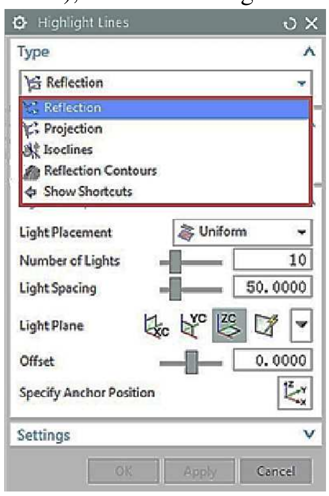

Figure 4 – Highlight line analysis dialog

In the example of reflection highlight line, the light source is fixed to a certain position, simulating a set of reflected lights and displaying them on the curved surface of the impeller base in highlight lines. In addition, you can also set the parameters such as light source layout, number of lights, distance and location of light to observe the quality of the surface. You can also lock the reflection and rotate the component to observe the curved surface, as shown in Fig. 5.

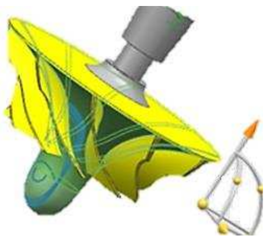

Figure 5 – Impeller base surface inspection under reflection type

By observing the reflective highlight line of the curved surface of the impeller base shown in Fig. 5, the distribution of the line group is uniform and there is no duplicated reflection, which indicates that the design surface has good quality. In the same way, you can also use the three forms of projection line, isocline and reflection contours highlight line to check the surface, and the inspection results can be compared. By the comparison, it can be seen that the highlight line in each form are uniformly changed, and the above-described surface inspection results are verified, as shown in Fig. 6.

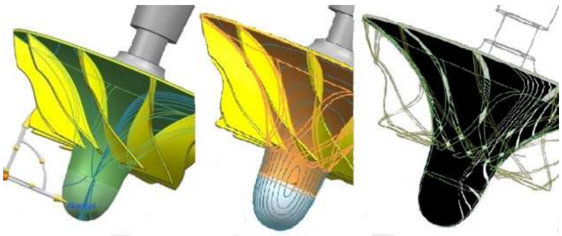

Figure 6 – Impeller base surface inspection contrast with project, isocline and reflection contours types

Conclusions

This paper studied the method of Highlight Line of Curved Surface quality evaluation based on 3D Assembly Environment, analysis on the quality of the impeller base surface of the impeller assembly part through 4 forms of analysis, the results show that the distribution of bright lines is uniform, this part of the design surface has good continuity and smoothness.

In addition, the analysis of the method of Highlight Line of Curved Surface quality evaluation based on 3D Assembly Environment is intuitive, efficient and accurate; it can also control the light source configuration and highlight line display by setting relevant parameters. Through the appropriate secondary development by the user, a complex or special surface can be quickly modeled; Combined with the three-coordinate surface measurement, the surface quality of product design or application process can be analyzed, quickly find the defects, so as to improve the quality of curves and surfaces.

Thanks to the in-depth study of surface configuration theory algorithms and the wide application of computer-aided design. At present, almost all product designs in various fields such as automobiles, airplanes, motor vehicles, and mobile phones are inseparable from computer-aided surface design and quality analysis. The improvement of people's living standard also makes product modeling more complicated and personalized. Therefore, we study the curve and surface modeling and quality analysis in 3D assembly environment. It can greatly reduce the difficulty of designers' analysis, improve efficiency, reduce costs, and has broad market prospects and practical needs.

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ДОСЛІДЖЕННЯ ТА ЗАСТОСУВАННЯ НА ВИСВІТЛЕННІ ЛІНІЙКИ ВИРІВНЮВАННЯ ЯКОСТІ ПОВЕРХНІ НА ОСНОВІ 3D-СЕРЕДОВИЩА СКЛАДАННЯ

Анотація. *З огляду на сучасну ситуацію методів якісного аналізу кривих та криволінійних поверхонь, в роботі було введено теоретичну основу та математичне вираження кривих та викривлених поверхонь. Чотири типи конфігурації ліній висвітлення, такі як віддзеркалення, проекція, ізоклін, контури відбиття, для оцінки кривих та викривленої якості поверхні вивчено в середовищі 3D-складання. Нарешті, порівняльний аналіз поверхні робочого колеса був заданий чотирма типами у складі 3D робочого колеса.*

Ключові слова: середовище складання; вигнута якість поверхні; лінійний аналіз

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