RESEARCH ON THE SURFACE QUALITY EVALUATION OF RACING CAR DEFLECTOR WITH HIGHLIGHT LINE ANALYSIS IN ASSEMBLY ENVIRONMENT

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Abstract. In view of the present situation of quality analysis methods regarding automobile surface, this paper has introduced the theoretical basis and definition of class A surface. Four highlight line configuration types have been studied in the 3D assembly environment for evaluation of the curved surface quality; they are reflection, projection, isocline, and reflection contours. In the assembly environment, a comparative analysis of racing car deflector surfaces has been given by the four types, and it provides theoretical evidence for other technical analysis as well.

Keywords: assembly environment; racing car deflector; curved surface quality; highlight line analysis.

References

[1] Gao Bin. Quality Detection and Modification of Curves and Surfaces [D]. Zhejiang: Zhejiang University, 2005.

[2] Nicholas Patrikalakis, Takashi Maekawa. Shape Interrogation for Computer Aided Design and Manufacturing [M]. Germany, Springer-Verlag Berlin Heidelberg, 2002.

[3] Yu Nishiyama, Yoh Nishimura, Takayuki Sasaki, et al. Surface Faring Using Circular Highlight Lines[J]. Computer-Aided Design & Applications, 2007, 04, 01:405–414.

[4] Zhang Wang-shan. The Surface Reconstruction and Forming Analysis of Auto-Body Panels [D]. Wuhan: Wuhan University of Technology, 2012.

[5] David Salomon. Curves and surfaces for computer graphics[M]. New York: Springer New York Inc., 2005.

[6] Wu Zheng-feng, Yuan Xuan-cheng, Ma Ning-bo. Design the Exterior Surface of Car Rear Bumper and its Quality Analysis Based on CATIA [J]. Automobile Technology, 2012, (09):57–60.

Problem statement. Since the internal combustion started to be used in automobiles, the pursuit of speed has never ceased. With the continuous development of science and technology, people's pursuit of speed and safety of cars are also a process of using scientific and technological means to gradually study and explain the unknown areas. Speed and safety have always been a relevant topic for racing cars. For driving fast cars, the design of the external deflector surface affects not only the operational wind resistance, but also the vehicle air pressure in the running process of distribution, thus affecting the speed and safety performance. Therefore, the surface quality of automobile outer panel deflector has been an important research topic in the field of automobile development.

In the past, the inspection of automobile body surface quality often depended on the experience of professional cable makers. With the elaboration of research on the surface quality inspection, the tool for surface quality analysis of the illumination model shows good physical meaning and is intuitive observationally [1]. It has been taken as a basis for the formation of many analysis methods and theories, and gradually became the main means of current surface quality evaluation [2]. Highlight line quality analysis is one of the preferred methods for evaluating the surface quality in the automobile industry [3]. In the three-dimensional (3D) digital design stage of the car deflector development, the use of high line analysis tools directly in the product assembly environment in order to analyze the surface quality can greatly improve the design efficiency of the car products and check the coordination between the surfaces of the deflector with other parts, so as to improve the design quality.

Basic material

1. Theoretical foundations of surface construction and evaluation

1.1. Theoretical foundations of surface construction

The surface modeling requirements for modern automotive product design are increasing constantly, and the traditional geometric drawings have failed to render these free surfaces. Therefore, since the French engineer Pierre Bezier proposed the Bezier curved surface in 1962, many scholars have studied the method of surface configuration. The most important are Bezier surface, B spline surface and non-uniform rational B spline (NURBS) surface [4].

The Bezier surface can construct complex surfaces by control points, but the number of these points determines the polynomial times. The more there are control points, the greater is the calculation. Besides, the Bezier curve surface does not have localization, that is, when any control point changes, the overall shape of the surface will be changed [5], which makes it difficult for the engineer to introduce partial modifications.

B spline curves can inherit the good properties of Bezier curves. At the same time, they also solve the difficulty of adjusting Bezier curves; it is the most popular method of spline construction. The parametric equations of B spline curves are as follows [6]:

$$P(u)=\sum_{k=0}^{n} P_k B_{k,d}(u). \qquad (1)$$

$$u_k \le u \le u_{n+1}$$

In equation (1), P_k is the k^{th} control point of the curve, $B_{k,d}(u)$ is the base function, and d is the number of B spline curves.

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

$$B_{k,d}(u) = \begin{cases} 1, & if\ u_d \le u \le u_{d+1} \\ 0, & other \end{cases} \qquad (2)$$

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

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

$$P(u\ ,\ v) = \sum_{i=0}^{m}\sum_{j=0}^{n} P_{i,j} B_{i,k}(u) B_{j,h}(v) \qquad (3)$$

$$u_k \le u \le u_{m+1},\ \ v_l \le v \le v_{n+1}$$

In formula (3), $B_{i,k}(u)$, $B_{j,h}(v)$ are the basis functions of the k-order and h-order B spline curves of the node vectors u, v. It can control the distribution of nodes so that the B spline curves can be controlled flexibly [7]. But the B spline surface cannot accurately represent the two quadric surfaces outside the paraboloid, and only an approximate expression can be given.

NURBS surfaces are the generalization of Bezier surfaces and B spline surfaces. It is a mathematical method not only to describe the free surface and to unify the B spline surface construction method, but also to describe the two surfaces. It provides a common mathematical form for the construction of free surfaces. In the NURBS curve and surface structure, the curve control points will be empowered according to their different importance. To further realize the adjustment of the surface, the control points will be arranged by weight evenly or unevenly in the space. The mathematical equations of [8] are as follows:

$$P(u\ ,\ v) = \frac{\sum_{i=0}^{m}\sum_{j=0}^{n} \omega_{i,j} P_{i,j} B_{i,k}(u) B_{j,h}(v)}{\sum_{i=0}^{m}\sum_{j=0}^{n} \omega_{i,j} B_{i,k}(u) B_{j,h}(v)}. \qquad (4)$$

In formula (4), $P_{i,j}$ is the control point of the surface, and $\omega_{i,j}$ is the weighting factor associated with the control point of $P_{i,j}$, are the basis functions of the k-order and h-order B-spline curves of the node vectors of u and v, respectively.

NURBS can achieve better surface modeling than ever before. The International Organization for Standardization (ISO) also defines NURBS as the unique mathematical method of industrial product geometry. The Bezier and B-spline construction methods have been unified into the NURBS. At present, most of the 3D computer-aided free-form surface of the spline is NURBS.

1.2. Definition of Class A Surfaces

The term “A-level surface” starts from the automotive industry and is the highest expression for the quality evaluation of automobile body surface. At present, there is no specific mathematical expression, 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} [9].

As the definition of A-level surface lacks the specialized mathematical expression, different designers with different evaluation techniques to different design products will give different evaluation results of the A-level surface. In practical engineering applications, 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.

The development of computer-aided design technology provides a new idea for objective evaluation of engineering surface quality. The use of computer technology can realize objective evaluation of the surface shape, position gap, curvature changes, curvature continuity and so on. The quality evaluation and analysis of the highlight curve surface is a commonly used analysis method for surface quality evaluation by means of computer-aided technology.

2. Analysis of surface quality highlighting method in assembly environment

2.1. Highlight line analysis form

At present, the main methods for 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. There are four main forms of highlight line analysis: reflection line, projection line, isocline and reflection contours, as shown in Fig. 1.

In a reflection line, as shown in Fig. 1, *a*, the light is placed in a fixed position to reproduce the reflected surface of the light, and when the model is rotated, moved or modified, the reflected highlight line is updated. Reflection lines are most commonly used to evaluate the final model.

In a projection line, as shown in Fig. 1, *b*, the geometrical quality of the surface is evaluated using the surface of the direct projection model (without reflection) to analyze whether there is a consistent shape on the surface or a discontinuity between the faces.

Isocline, as shown in Figure 1, *c*, can help to analyze variations in the slope of the product surface. The curve is created according to the points on the surface which have the same tilt angle on the specified reference vector.

Reflection contours, as shown in Fig. 1, *d*, can visually simulate the line of reflection of the light of the fluorescent tube on the surface.

2.2. Layout of the assembly environment

When performing the highlight line analysis, we can choose three forms of layout: create it by the specified point, select the uniform interval in the selected analysis surface, or select the interval between the two points specified in the analysis of the surface.

Through these three forms of layout, the design analyst can directly select the local area to be analyzed in the assembly environment of the product 3D model (not necessarily the whole surface) and analyze the change of the surface curvature. The analysis method has greatly raised the efficiency of the engineers. In addition, the analyst can select the highlight line, analyze the object node in the component navigator, and select the appropriate option to remove or hide the highlight line. The designer can select the required analysis form according to the surface quality analysis requirements. By setting the corresponding parameters and proper operation, such as rotating and translating the assembly parts, the system will update the inspection results according to the input in order to find a curve surface that does not conform to quality, and optimize it.

2.3. Surface quality analysis for the racing car deflector

Racing deflector cover is one of the most important parts of the car design. At a high speed that the vehicle develops, the deflector surface modeling will determine the level of air resistance and air pressure distribution, and also have a great influence on the car's energy consumption, controllability, stability and safety. Therefore, the deflector surface quality evaluation is an important part of the overall car surface design. The advanced computer-aided design technology can directly perform the detection analysis on specific surface quality of the model in the three-dimensional assembly environment.

Taking the application of the bright line surface quality analysis in a concept car as an example, let us analyze

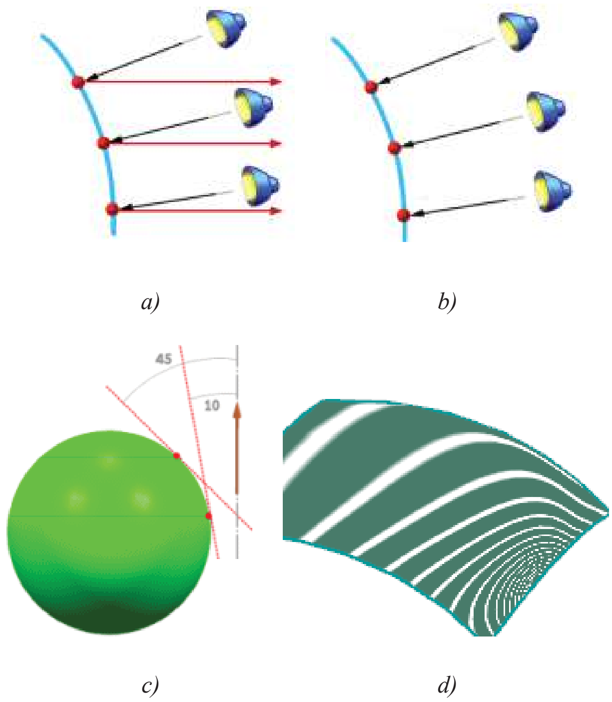

Fig. 1. Four highlight line configuration types in assembly environment:
a — reflection line; *b* — projection line; *c* — isocline; *d* — reflection contours

the surface quality of some deflectors in the vehicle assembly environment.

First of all, the car design assembly model is opened in the product three-dimensional digital design system, or a new analysis of assembly components is created, as shown in Fig. 2.

Subsequently, the surface quality highlight line analysis tool is started, and the relevant parameters are set, and the surface analysis form is selected (reflection line, projection line, isocline, reflection profile) according to the surface inspection requirements, as shown in Fig. 3.

In the case of a reflective highlight line, this mode sets the light source at a certain position, simulates a set of reflected lights and displays them in bright lines on the curved surface of the deflector. In addition, we can also set the light source layout, the number of lights, light distance and location parameters, observe the surface quality, lock the reflection and rotate the components to observe the surface, as shown in Fig. 4.

The surface quality can be analyzed by resetting the highlight line, analyzing the parameters, and comparing the shapes and distributions of the highlighted lines under each reflection. If the distribution of the line group is uniform and there is no copy reflection, it indicates that the design surface has a high continuity, smoothness, and quality.

In order to verify the evaluation results, we can also use the projection line, isocline and reflection contour lines to inspect the surface, and compare the results of inspection of all forms. By comparison, the bright lines are not radially reproduced, the connection surface normal vector has an equivalent point of the same direction, and the bright line distribution changes evenly. These results verified the above surface inspection, as shown in Fig. 5–7.

The use of computer-aided technology to analyze the quality of the racing car deflector surface is an important technical support towards intelligent, fast and personalized vehicle design. Highlight line surface quality analysis can also be applied to other passenger cars, aircrafts, motor vehicles, mobile phones, and other fields of product design. Therefore, the study of the curved surface modeling and quality analysis in 3D assembly environment can not only greatly reduce the difficulty of the analysis for the designers and improve the efficiency, but also reduce the costs. The research has broad market prospects and realistic needs.

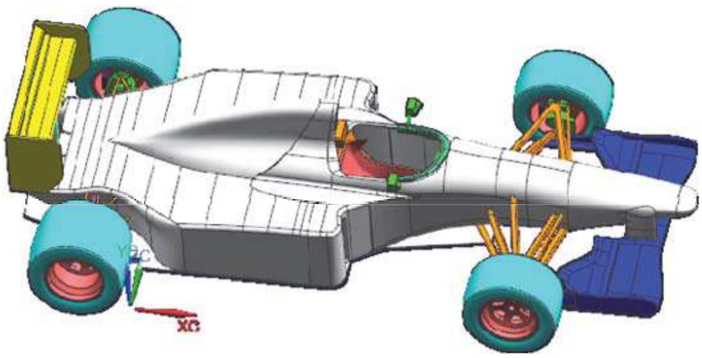

Fig. 2. Assembly Model for Racing Car Concept Design

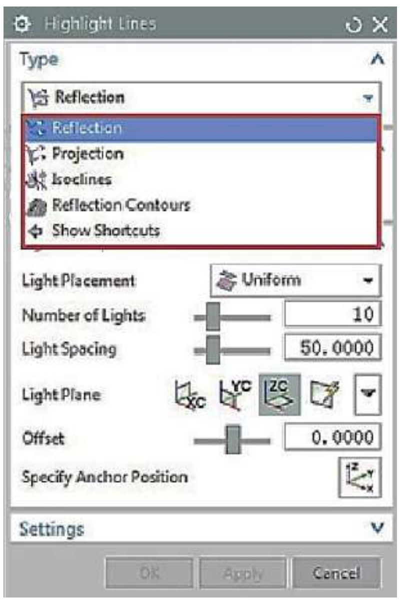

Fig. 3. Highlight Line Analysis Dialog

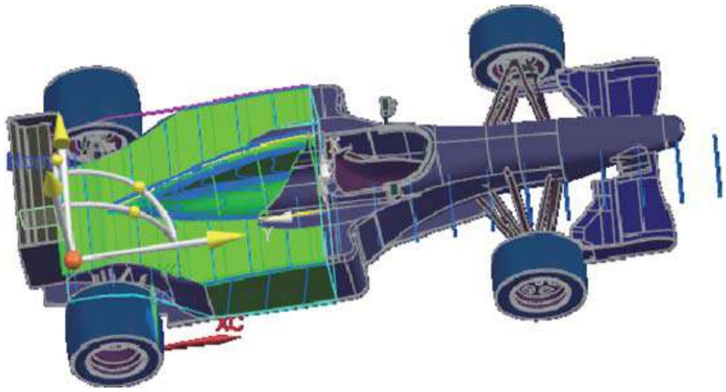

Fig. 4. Deflector Surface Inspection for Reflection Type

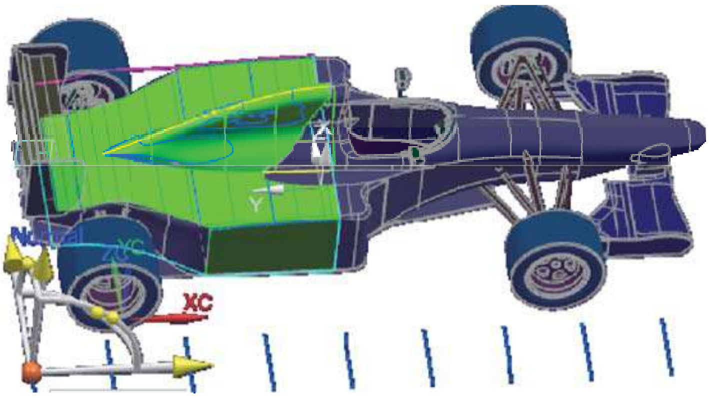

Fig. 5. Deflector Surface Inspection for Projection Type

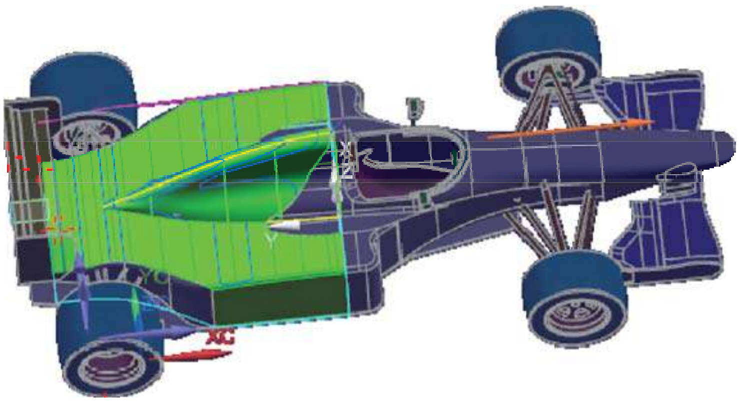

Fig. 6. Deflector Surface Inspection for Isocline Type

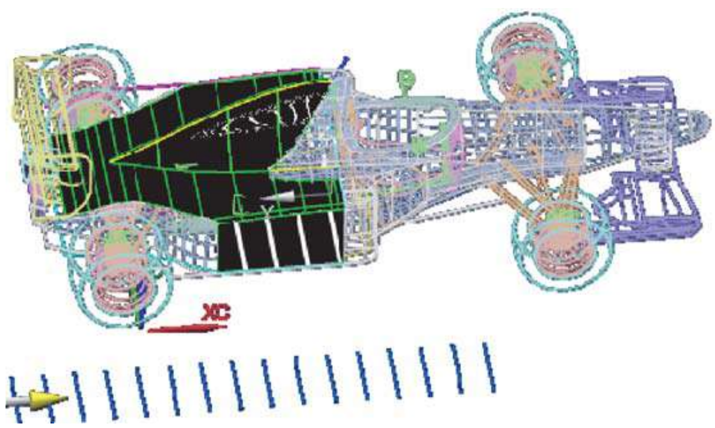

Fig. 7. Deflector Surface Inspection for Reflection Contours Type

CONCLUSION. This paper has studied the method of highlighting the surface quality of the racing car deflector in the 3D assembly environment. This method has a high visibility, high efficiency and high accuracy. It can also check the consistency of design for the specific area surface and the whole surface. The technology provides the basis for other process analysis during product development in the sphere of professional racing. In addition, combining the three types of coordinate surface measurement, we can perform the surface quality analysis during the process of product design or application and quickly find defects in order to improve the curve surface quality.

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