International Journal of Automotive Technology, Vol. 8, No. 3, pp. 327−335 (2007)

1229−9138/2007/034−09

KEY TECHNIQUES IN DEVELOPMENT OF VEHICLE GLASS DROP DESIGN SYSTEM

B. LIU[1], C.-N. JIN[1] and P. HU[2]*

[1]Institute of Auto-body and Die Engineering, Jilin University, Changchun 130025, China
[2]School of Automobile Engineering, Dalian University of Technology, Dalian 116024, China

(Received 31 July 2006; Revised 21 February 2007)

ABSTRACT−A new optimization scheme and some key techniques are proposed in the development of a vehicle glass drop design software system. The key issues of the design system are how to regenerate the glass surface and make the vehicle glass drop down along the glass channels. To resolve these issues, a parameterized model was created at first, in which the optimizing method and Knowledge Fusion techniques were adopted the optimized process was then written into the glass drop design system by coding with C language and UGS/Open Application Programme Interface functions etc. Therefore, the designer or engineer can simulate the process of glass dropping along the channels to assess the potential interference between glass and door accessory by using this software system. All of the testing results demonstrate the validity of the optimizing scheme, and the parametric design software effectively solves the key issues on development of the door accessory package.

KEY WORDS : Optimization scheme, Glass drop design system, Knowledge Fusion

NOMENCLATURE

KF	: knowledge fusion
UGS/Open API	: application programme interface
KBE	: knowledge based engineering
UGS/NX	: Software of Unigraphics Solutions Inc
UGS/UI	: user interface in UGS/NX software

1. INTRODUCTION

Many universities and research institutes abroad have done remarkable and advanced research on KBE. As an example of applying KBE theory to developing systems for auto-body parts and mechanisms Chrysler has developed a design tool based on the STONE rule to simulate the motion of window glass and to test for interference between the glass, the hinge, the lock and other door accessories while the glass rises and drops (Bates and Heikal, 2002; Calkins *et al.*, 2000; James *et al.*, 2004; Reinscmidt and Finn, 1992).

Some domestic colleges are also studying KBE. For example, (Zhang and Liu, 2002) conducted research on Door system development under CATIA V4 platform, which focuses on the design process and design rules for door accessories packaging, interference check and motion simulation.

However, the work mentioned above handles the glass surface as a plane or as a cylindrical face. This simplified scheme treats the glass drop track as being linear or revolving movement along the channels of the glass. In fact, the glass surfaces of a vehicle window are 3D, free-style surfaces. Thus the glass should be reconstructed as helicoids during door system design or in the developing of relative motion mechanics. Actually, the glass motion tracks should be two helix curves.

The present paper mainly proposes some key techniques for developing a glass drop system, including a glass barrel surface optimization scheme and motion analysis process based on UGS/Open API & KF, in which KBE theory and C language are applied. Compared with the above researches, a critical feature of the present system development is that the two helix curves and the helicoids (barrel surface) can be regenerated by an optimizing procedure through the defined points. From the iterative optimizing scheme, the deviation from the regenerated glass surface to the original styling surface can be controlled within a limited small value. This glass drop design system is very practical and effective since it resolves the core problem in developing door system.

2. PROTOTYPE PART

After studying all types of sheet metals used in manufacture of an auto body, a top-down design scheme was

---

Corresponding author. e-mail: pinghu@dlut.edu.cn

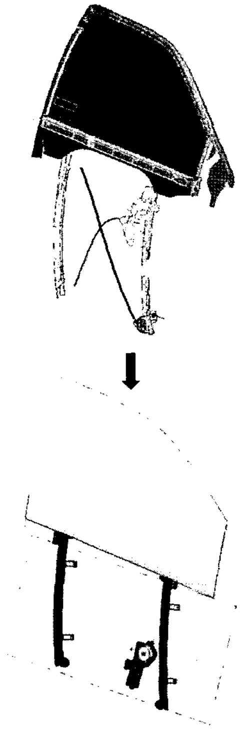


Figure 1. Detailed part and prototype part.

proposed and described (Bhise *et al.*, 2004).

The detailed parts could be simplified by neglecting or removing the minor features and then reconstructed corresponding to parameterized models with a common structure this approach is called the Prototype Part or Prototype Assembly, and is shown in Figure 1 (Kim *et al.*, 2002). As a new concept, the prototype part is the abstract of the detailed part in high level, which integrates special knowledge and expertise (Liu *et al.*, 2006). The glass drop design system is based on the Prototype Part concept.

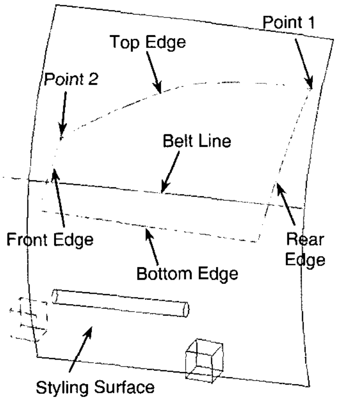
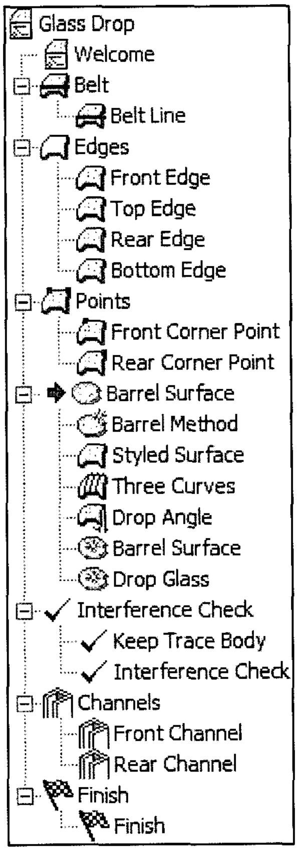


Figure 2. Input of glass drop system.



- Glass Drop
  - Welcome
  - Belt
    - Belt Line
  - Edges
    - Front Edge
    - Top Edge
    - Rear Edge
    - Bottom Edge
  - Points
    - Front Corner Point
    - Rear Corner Point
  - Barrel Surface
    - Barrel Method
    - Styled Surface
    - Three Curves
    - Drop Angle
    - Barrel Surface
    - Drop Glass
  - Interference Check
    - Keep Trace Body
    - Interference Check
  - Channels
    - Front Channel
    - Rear Channel
  - Finish
    - Finish

Figure 3. Design process.

3. KERNEL PROBLEM IN GLASS DROP DESIGN SYSTEM

Of all door accessories, the glass and the glass regulator are the most important sub-systems of the door system. They take up too much room in the door space.

According to the Requirement Specifications of the glass drop design system, the inputs of this design system are defined as the belt line, the glass edges, the original styling glass surface, the limited points of glass movement and the section parameters of glass channel. Figure 2 shows the input objects of the glass drop system. The interaction between user and the design system is communicated by UGS/UI, a type of interface supplied by UGS/NX software.

First, the glass drop design system optimizes and regenerates a thickened barrel surface (helicoids) from the original styling surface, glass edges and the limited points of glass movement. Second, two parameterized glass channels are created. The channels are guided by two helix curves having same pitch. Finally, the motion analysis is implemented in order to check whether the glass interferes with other door accessories during the movement.

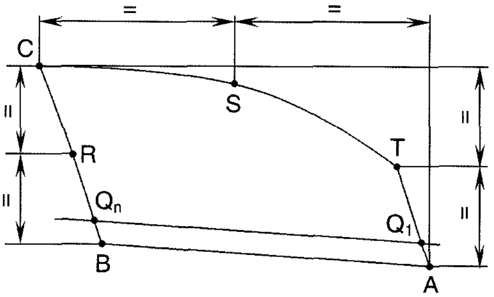


Figure 4. Relationships between glass points.

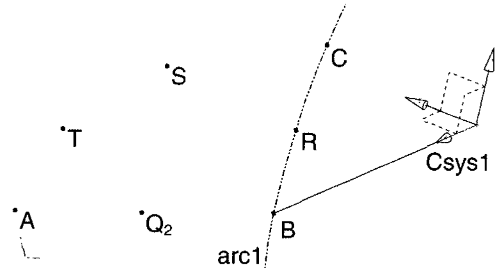


Figure 5. Step 1 of modeling.

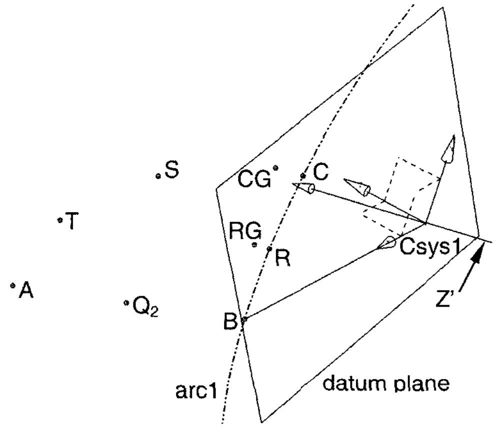


Figure 6. Step 2 and step 3 of modeling.

Figure 3 shows the detailed top down design process. Thus, the key element of this design system is to optimize and regenerate the glass surface. In other words, the primary problem is how to create the helicoids according to the input information, such as the belt line, original styling surface and glass edges. It should be mentioned that the helicoids must pass through the existing defined points A, B, C and any deviation from the regenerated surface to the styling surface should be controlled within the range of the limited tolerance of design specification. Figure 4 shows the definition of the limited points of glass movement and the relationship within them.

A: the lower end point of the front edge
B: the lower end point of the rear edge
C: the upper end point of the rear edge
R: the point on the rear edge with an intermediate Z coordinate between point B and point C
S: the point on the upper edge with an intermediate X coordinate between point A and point C
T: the point with an intermediate Z coordinate between point A and point C. It can be on the front edge or on the upper edge, depending on the Z coordinate.
Q_1: the point on the belt line, computed at minimum distance from the front edge
Q_n: the point on the belt line, computed at minimum distance from the rear edge

The detail of design requirements are summarized as following:

Points A/B/C are fixed points that the final glass surface must go through exactly. Points R/S/T are used to verify the deviations from the final glass surface. Points $Q_1/Q_2/Q_3 \ldots /Q_n$ are used to define the belt line. Q_1 and Q_n could be the same point as A and B.

4. OPTIMIZATION SCHEME

4.1. Parameterized Glass Surface Modeling

There are three steps to create the parameterized model in UGS/NX manually. First, create two helix curves having the same pitch, one of them passing through the Point B (named as RHC, rear helix curve), and another through the Point A (named FHC, front helix curve). Second, create the arc passing through the points A, Q, and C. Third, generate a parameterized surface by sweeping the arc or line along the two helix curves. The detailed process can be described as follows:

Step 1. Create the arc (called arc1) via points B, R and C. Then create a local coordinates system named as Csys1 whose origin point is located on the center of arc1 and whose axis X is chosen along the direction from the center of arc1 to point B. The axis Z is defined as perpendicular to the plane that arc1 lies in. Figure 5 illustrates the detailed information of this step.

Step 2. By revolving the axis Y of Csys1, the axis Z of the Csys1 is rotated by SP1 radians, and then by revolv-

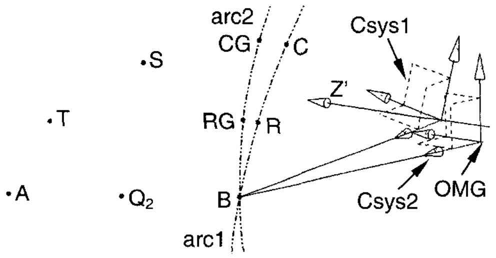


Figure 7. Step 4 of modeling.

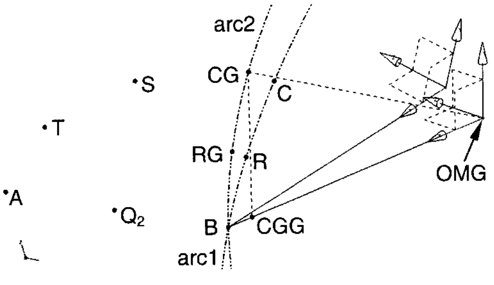
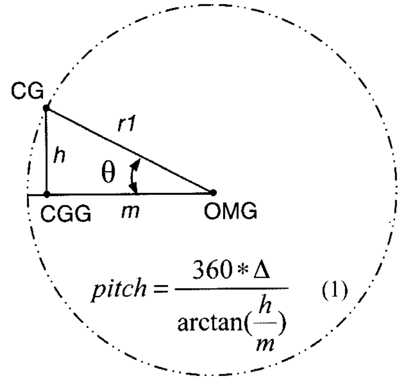


Figure 8. Step 5 of modeling.



$$pitch = \frac{360 * \Delta}{\arctan(\frac{h}{m})} \quad (1)$$

- Δ : Distance from C to CG
- h : Distance from CG to CGG.
- m : Distance from CGG to the arc center OMG.

Figure 9. Formula for the pitch of helix curve.

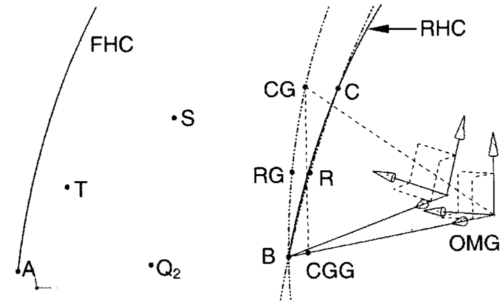


Figure 10. Step 6 of modeling.

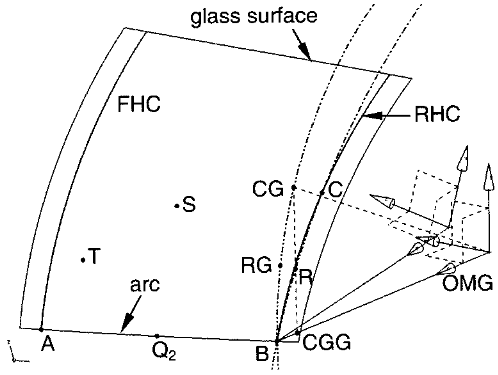


Figure 11. Parameterized glass surface model.

ing the axis X the resulting axis Z is rotated again by SP2 radians. As a result, the new axis Z' is obtained. (In other words, rotate plane YZ by SP1 radians revolving the axis Y, and then rotate the resulting plane XZ by SP2 radians revolving axis X SP1 and SP2 are design parameters).

Step 3. Create a datum plane through the point B and perpendicular to the axis Z', then project the point R and the point C onto the datum plane in order to obtain corresponding points RG and CG, respectively.

Step 4. Create the arc (arc2) through the points B, RG and CG, then create another local coordinates system named Csys2 which is located on the center (named OMG) of arc2. The axis X of Csys2 is along the direction from the center of the arc2 to the point B, and the axis Z is perpendicular to the plane that the arc2 lies in. This local coordinates system (Csys2) will be used to construct the helix curves.

Step 5. Calculate the pitch of the helix curves. In the plane that arc2 lies in, project the point CG onto the axis X of Csys2 to get a new point named CGG. The points OMG, CG and CGG comprise a triangle plane (shown in the following Figure 9). If considering point C as a point resulting from the movement of point B along the RHC, the swept angle from the point B to the point C along the RHC can be determined as θ measured on the triangle plane. Also, a Δ value is introduced, which is defined as the distance from the point CG to the point C along axis Z of csys2. Thus, the formula to calculate pitch can be obtained by

Step 6. According to the calculated pitch, create the rear helix curve (RHC) whose start point is point B under the coordinates system Csys2. This helix curve must pass though the points B and point C. Likewise, create front helix curve (FHC) with same pitch through the point A.

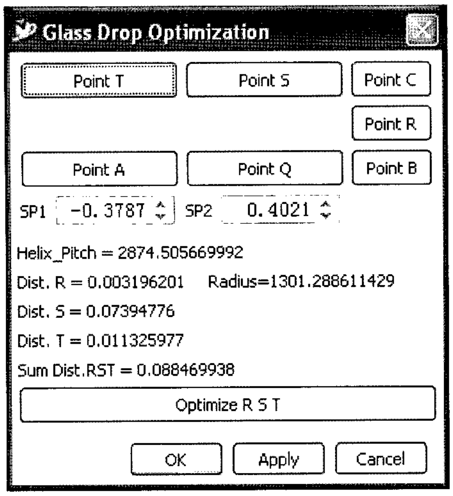
Step 7. Create the arc through points A, B and Q, then sweep the arc along FHC and RHC to obtain the parameterized glass surface. Obviously, this surface is helicoid and passes through the points A, B, C.

In general, the deviations of the helicoid relative to the three points R, S and T will be driven by the angles SP1 and SP2 which is to say that the deviation values change as SP1 or SP2 changes.

4.2. Construct Optimizing Model

The optimizing model is constructed by KF, which is a type of object-oriented language. The language is accepted widely as a kind of knowledge-driven program language based on engineering rules (Unigraphics Solutions Inc, 2002).

KF can take advantage of any experience, expertise and other information relevant to each phase of the engineering life cycle of an end user product. Users could



SP1 -0.3787 SP2 0.4021

Helix_Pitch = 2874.505669992
Dist. R = 0.003196201 Radius=1301.288611429
Dist. S = 0.07394776
Dist. T = 0.011325977
Sum Dist.RST = 0.088469938

Figure 12. Interface for optimization.

create rules that represent the relationship between the geometry parameters and engineering attributes (Ding, 2004).

KF could also utilize external knowledge sources, such as databases, excels etc as well as supply interfaces for some other modules, such as analysis and optimization.

Now, this powerful developing tool is used to optimize the parameterized model created in section 4.1. Of course, it is necessary to build an interface for the operation. Figure 12 shows the interface built by the UGS/UI Styler tool that is offered by the UGS/NX software it permits setting up a user-defined interface.

Next, by using KF language, all of the optimization processes are programmed and written into a file named "glass_drop_optimization.dfa". This file includes the creation of the parameterized model and its optimization process is implemented by an optimizing class.

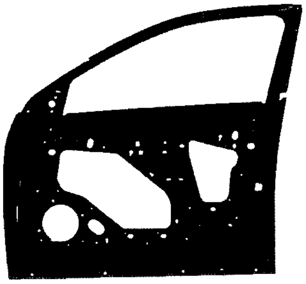
According to the discussion about glass surface modeling process in section 4.1, the final glass surface is driven by two non-user inputs SP1 (horizontal angle adjustment) and SP2 (vertical angle adjustment).

Therefore, it is necessary to identify the best angles to achieve minimum deviations between points R/S/T and the final glass surface.

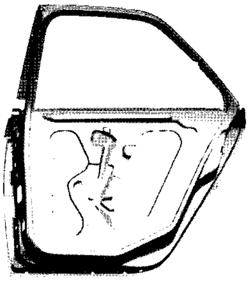
The optimization parameters and settings are as follows:

Design Variables: SP1 and SP2
Optimization Objective: Dist_R+Dist_S+Dist_T
Design Constraints: Helix_pitch
Relative Convergence: 0.025
Absolute Convergence: 0.001

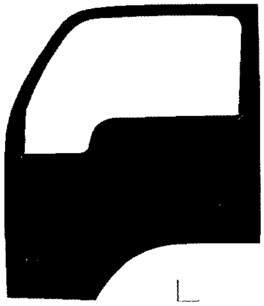
- SP1: horizontal angle adjustment
- SP2: vertical angle adjustment
- Dist_R: distance from point R to final glass surface



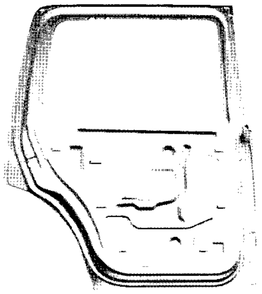
Part_843 (front door of one passenger car).



Part_199 (rear door of one passenger car)



Part_169 (front door of one truck)



Part_939 (rear door of one SUV)

Figure 13. Four testing parts.

- Dist_S: distance from point S to final glass surface
- Dist_T: distance from point S to final glass surface
- Helix_pitch: pitch of helix curve

In the end, the entire optimizing process was integrated into the glass drop system by using UGS/Open API and

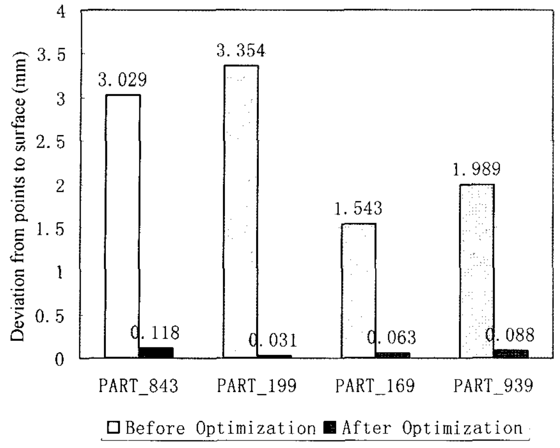


Figure 14. Comparison of optimization result.

C languages.

UGS/Open API is a product that encompasses the flexible integration of many different software applications with UGS/NX through an open architecture.

In the source code, the first stage is to create the parameterized glass surface model according to section 4.1.

The second stage is to define and obtain all optimization parameters.

Table 1. Testing result data.

Distance Part	Dist.R	Dist.S	Dist.T	Sum Dist. RST
Part_843				
Before optimization	0.003984	1.760316	1.264839	3.029139
After optimization	0.005344	0.058062	0.055592	0.118998
Part_199				
Before optimization	0.001237	2.145509	1.207716	3.354462
After optimization	0.002471	0.008907	0.020199	0.031577
Part_169				
Before optimization	0.007714	0.937127	0.603042	1.547883
After optimization	0.009947	0.038075	0.015959	0.063981
Part_939				
Before optimization	0.003709	1.250823	0.733982	1.988514
After optimization	0.003196	0.073948	0.011326	0.08847

The last stage is to carry out optimization scheme by optimizing function. This process was implemented by the third optimizer from Altair Engineering of Troy, Mich.

HyperOpt is a commercial design optimization application that performs optimization, parametric studies and system identification. Moreover, it has been integrated in UGS/NX platform. Thus, there is no need to develop new optimization arithmetic considering the cost and time.

4.3. Testing Optimization Scheme

Testing is very important to validate the optimization scheme and to improve the performance of vehicle glass drop design system (Shinji and Masaru I, 1990).

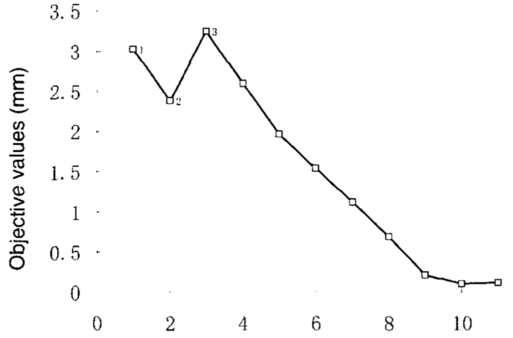


Figure 15. Part_843 iteration history.

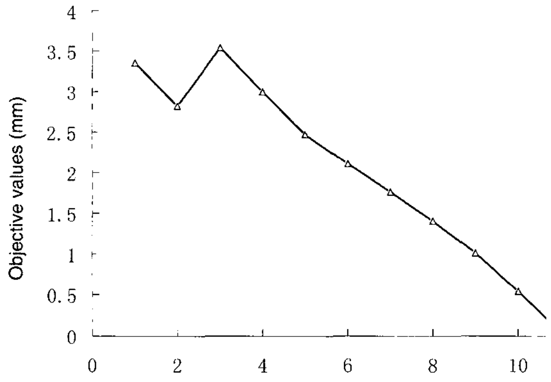


Figure 16. Part_199 iteration history.

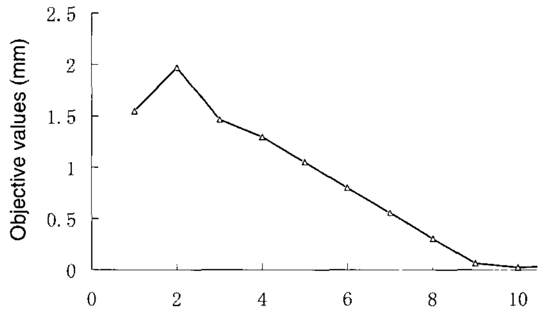


Figure 17. Part_169 iteration history.

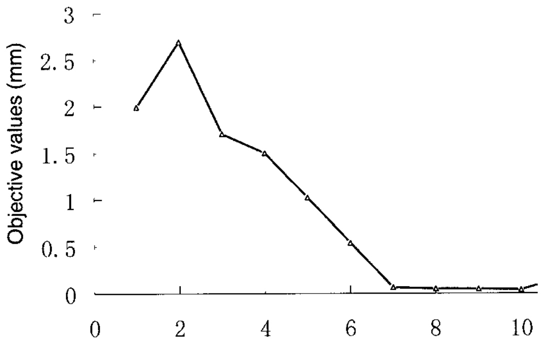


Figure 18. Part_939 iteration history.

Four testing parts come from variety of vehicle type and have different structures for universality.

Testing result data is shown in Table 1.

Figure 17-Figure 18 show the iteration history of the four parts in optimization process.

The testing results data demonstrate that the distance from any point (R/S/T) to the glass surface is smaller than 0.2 mm. These results could certainly satisfy the design specification which is to say the performance of the design system was improved greatly with the new optimization scheme.

5. MOTION ANALYSIS AND NTERFERENCE CHECK

The purpose of glass a drop design system is to ensure that the glass can be lowered into the door without interfering with the door accessories such as impact bar, glass regulator, door lock, door hinge and limited latch etc. Therefore, the motion of the glass along channels becomes very important to validate the design of door system.

To check interference of the glass surface with adjacent components in the door assembly, collisions are checked against all other door accessories that are visible at the time the check is performed.

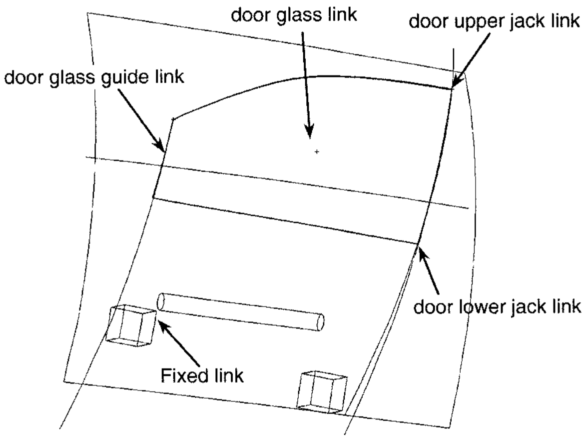


Figure 19. Links definition.

5.1. Motion Analysis Scheme

The Motion Simulation application is an integrated CAE tool that allows the user to transform a geometric model into a mechanism model and then graphically evaluate the analysis results. The Motion analysis mechanism was constructed by using existing geometry to create links and then constraining this geometry with joints and motion drivers.

A link is a mechanical feature that represents a rigid body. Five links were defined in the analysis scheme including door glass link, door glass guide link, door upper jack link, door lower jack link and fixed link. Figure 19 shows the detailed information of links.

Joints represent constrained motion in parts of a system. Joint constraints are defined by the type of physical connections made between the parts. All joints require a connection between two rigid bodies (represented by links). In addition, the ADAMS solver that was integrated in the UGS/NX platform assigns a set of coordinate systems, or markers (I and J), to each pair of joints.

Three type joints were used in the motion analysis

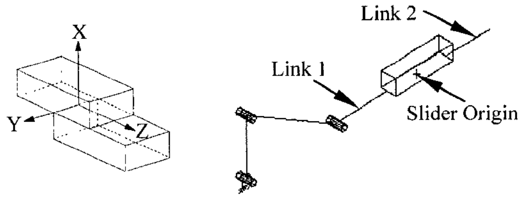


Figure 20. Slider joint.

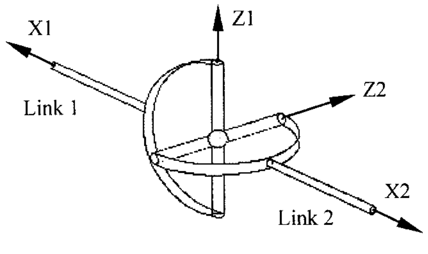


Figure 21. Universal joint.

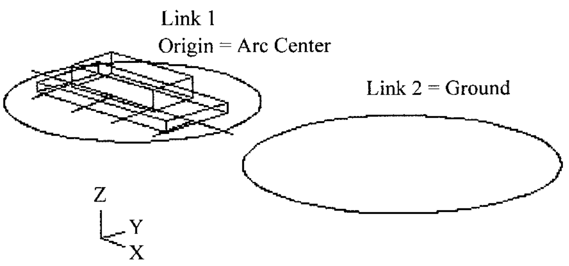


Figure 22. Planar joint.

scheme. The first one is the slider joint, shown in Figure 20.

A slider joint connects two links, allowing one translational degree of freedom between them. Slider joints do not allow rotational movement between the two links. The door glass link and door glass guide link were defined as slider joints.

The second type is a universal joint, which connects two revolving links that lie in a controlled angular misalignment.

Universal joints are typically used to create a flexible joint that allows two degrees of rotational freedom. The door glass link and door upper jack link were defined as universal joints in the scheme.

The third joint is planar joint that connects two links, allowing three degrees of freedom between them: two translational and one rotational. In a planar joint, the two links are free to slide and rotate relative to each other while remaining in planar contact. The door lower link and ground were defined as a fixed planar joint.

Additionally, the door glass link and front helix curve were defined as a point-on-curve joint.

5.2. Motion Analysis and Clearance Check

For the static analysis, the user can drag the slider in UI to move the glass along the defined path by the percentage indicated from 0% to 100% of the drop distance limit. The glass moves on the screen in concert with the slider. For the dynamic analysis, the user can set the range of motion that can control the lower or upper limits of glass movement. And the number of steps should be indicated to control the discrete locations that are used for clearance check. Next, choose the generate motion button the system will launch the ADAMS solver with the specified parameters to produce the motion path (see Figure 23).

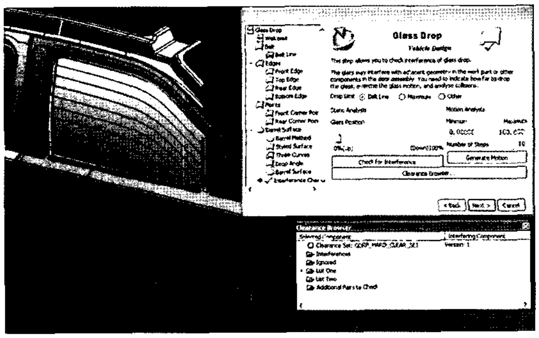
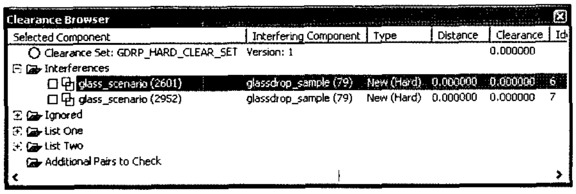


Figure 23. Dynamic analysis for glass drop.



Clearance Browser

Selected Component	Interfering Component	Type	Distance	Clearance	Id
○ Clearance Set: GDRP_HARD_CLEAR_SET	Version: 1			0.000000	
Interferences					
☐ glass_scenario (2601)	glassdrop_sample (79)	New (Hard)	0.000000	0.000000	6
☐ glass_scenario (2952)	glassdrop_sample (79)	New (Hard)	0.000000	0.000000	7
Ignored					
List One					
List Two					
Additional Pairs to Check					

Figure 24. Clearance check.

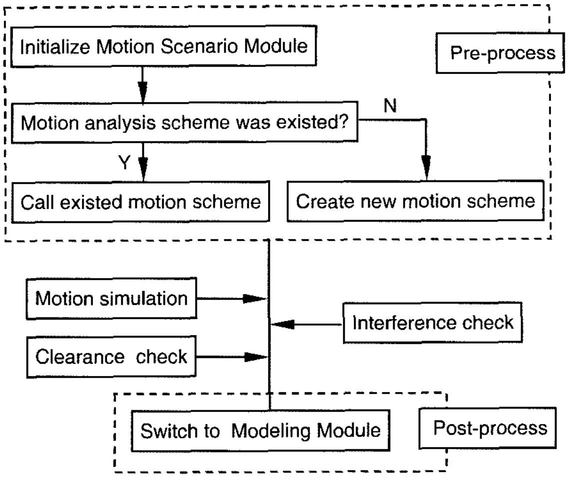


Figure 25. Flow chart of motion analysis and clearance check.

The information box will pop up to indicate whether or not hard collisions will occur after the user clicks the "check for interference" button in UI. The Clearance Browser tool will further examine the results of the analysis. Unlike the hard collisions for the check option, this analysis tool uses clearance zones and other advanced capabilities. Define the clearance value and press "Clearance Browser" button to get clearance browser as follows Figure 24.

The whole process is illustrated in Figure 25.

6. CONCLUSION

This paper proposes a new optimization scheme and some key techniques in the development of a glass drop system. With the various development tools such as KF, UGS/UI and UGS/Open API, these techniques have been successfully applied in the glass drop design system.

The glass drop design system not only creates a parameterized modeling of the glass drop and channels, in which users could modify and update the modeling by changing the input parameters or rules, but also optimizes the glass surface and simulates the virtual glass movement exactly.

The optimization scheme could be separated into three general steps, creating a parameterized model manually, setting up the optimization model by KF language, and carrying out the optimization by UGS/Open API.

The testing results show that this scheme efficiently solves the critical problem in developing glass drop design system. The optimization accuracy is obviously increased.

Therefore, the performance of the door accessory product was greatly improved.

ACKNOWLEDGEMENT–This work was funded by the National Outstanding Youth Foundation (No. 10125208) and the Key Project of the National Natural Science Foundation of China (No. 19832020) and this support is gratefully acknowledged.

REFERENCES

Bates, M. C. and Heikal, M. R. (2002). A knowledge-based model for multi-valve diesel engine inlet port design [C]. *SAE Paper No.* 2002-01-1747.

Bhise, V., Kridli, G. and Mamoola, H. (2004). Development of a parametric model for advanced vehicle design [C]. *SAE Paper No.* 2004-01-0381.

Calkins, D. E., Egging, N., Scholz, C. and Gomez-Levi, G. (2000). AutoDSS: A system level KBE tool for vehicle product definition [C]. *SAE Paper No.* 2000-01-1351.

Ding, Y. (2004). *Studies of Methodology for Conceptual Auto-Body Design Using KBE and DFM Techniques and Development of the Special-Purpose ICAD Software.* Ph. D. Dissertation. Jilin University. China. 46–49.

James, L., Ken, H. and Karim, N. (2004). Design and development of a cylindrical HVAC case [C]. *SAE Paper No.* 2004-01-0381.

Kim, H. S., Yim, H. J. and Kim, C. B. (2002). Computational durability prediction of body structures in prototype vehicles. *Int. J. Automotive Technology* **3, 4,** 129–135.

Liu, B., Jin, C.-N., Ding, Y., Wang, H.-Y., Shi, Y. and Hu, P. (2006). Study on the UGS/NX-based design and package system of vehicle body-side. *J. Jilin University, Engineering and Technology Edition*, **36**, **Suppl**. **1**, 33–38.

Reinscmidt and Finn, G. A. (1992). *Integration of Expert Systems Databases, and Computer-Aided Design.* Presented at Intelligent Design and Manufacturing, Edited by Andrew Kusiak. USA.

Shinji, N. and Masaru, I. (1990). Investigation of car body structural optimization method [J]. *Vechicle Design* **11**, **1**, 79–85.

Unigraphics Solutions Inc. (2002). *UGS KF Training Course.* Tsinghua University Press. China. 1–6.

Zhang, J.-Y. and Liu, Z. (2002). Research and development of automotive door accessory database system. *Automobile Technology*, **2**, 14–15(in Chinese).