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Numerical analysis and optimal design for new automotive door sealing with variable cross-section

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ABSTRACT

Automotive door sealing system isolates passenger compartment from water, dust and wind noise. It has the most direct influences on door-closing performance, which is determined by cross-section design in terms of its appropriate Compression Load Deflection (CLD) property. Traditional sealing structure has uniform geometrical cross-section. It has the shortcomings of bad fitting in corner parts with large curvatures, causing inaccurate door-closing effort design. Regarding the door panel's complex 3D profile, numerical analysis and optimal design for new sealing with variable cross-section are developed in this paper. Firstly, the whole sealing is partitioned into several parts. For four nearly straight segments, conventional 2D numerical analysis can still be used to obtain desired geometrical configuration. For other four curved corner parts with large curvatures, 3D numerical analysis of door closing is applied. Secondly, 2D geometrical cross-section optimization is proposed. Instead of three variables in previous research, five variables are selected for featuring cross-section geometry and used for next CAD reconstruction with more precision. After comparison between Back Propagation (BP) neural network and the Kriging surrogate model, BP neural network which performs better and efficient in this automotive design optimization field is applied for extracting nonlinear mapping between five cross-section parameters and compression load, which were parallely optimized by Genetic Algorithm (GA) and its efficiency and accuracy are compared with another evolutionary algorithm of Particle Swarm Optimization (PSO). Thirdly, 3D numerical modeling of four curved corner parts' closing process is realized, of which twisting and bending effects during seal assembly are taken into account, thus minimizing theoretical error and producing more realistic solution. Consequently, the desired geometrical configurations for both straight parts and corner parts satisfying designated CLD property can be obtained and the whole sealing can be achieved with variable cross-section, resulting in an ideal door closing effort. Finally, a Matlab-based platform has been developed to assist the design and optimization process. Experiment and case study indicates that it provides an effective method for new door sealing design with variable cross-section.

1. Introduction

Automotive door seals are installed in narrow gaps between door and body frame along the perimeters of the opening panels, as shown in Fig. 1. They prevent water and dust from entering passenger compartment and accommodate metal manufacturing variations [1]. Door-closing effort is determined by six factors of seal rubber's compression load, cabin volume, door weight, latch, etc. It was revealed that door sealing consumes 35–50% energy during the door closing process [2], thus making it become the dominant role for door closing effort design [3–5].

As a component intimately associated with human sensibility, automotive door sealing design includes suitable cross-section's geometrical parameters, as well as appropriate rubber material property, which result in the desired Compression Load Deflection (CLD) and the final door-closing efforts. Better sealing performance requires both higher reaction force and a wider contact area. However, better door-closing performance requires the opposite conditions [6]. A good door sealing design needs to satisfy both the sealing quality and the door-closing performance. Consequently, door seal design is defined as the compromise between these two reciprocal design targets, which have several features of nonlinearity, such as hyper-elastic rubber material, rubber's large deformation and rubber–metal contact behavior.

Conventionally, door-closing effort design and measurement have mostly relied on experimental methods. Ordieres-Meré

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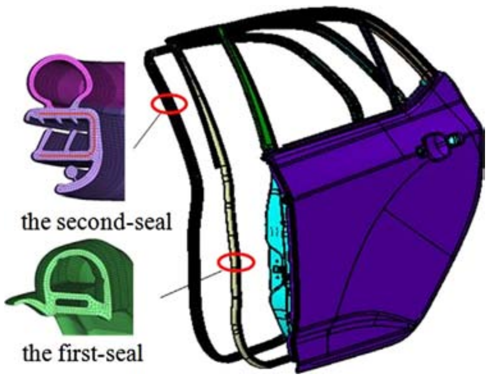

Fig. 1. Illustration of door sealing.

tested quasi-static driven door forces [7]. Egashira et al. measured door-seal reaction force and calculated the changes in the inner cabin's atmospheric pressure by air flow [8]. However, the narrow and limited closed space between door seal and door panel makes it difficult to monitor the deformation process and hard to obtain the necessary data of compression load by the traditional measurement methods. Experimental methods have disadvantages in determining the many factors related to door closing effort design and are not particularly feasible for new development of optimized seal design regarding to cost and time.

Nowadays, computational efforts have been implemented for door seal design. For instance, 2D cross-section of the door seal is modeled and analyzed, making extraction of the reaction force and contact area conveniently [9]. Kim et al. developed a numerical process to predict minimum door-closing velocity and virtual reaction force versus closing time data [10]. 3D door-closing analysis, using explicit code, was introduced to produce a more realistic solution. Nonlinear finite element analysis is applied to investigate seal performance, permitting numerous design iterations to be evaluated quickly prior to manufacturing and testing the first prototype parts.

Although numerical analysis makes great contributions to the door seal design, there still exists some problems for this high non-linear behavior. Door seal is generally in the form of dual extrusion bulbs of metalloid sponge and dense rubber. Its mechanical properties vary with the amount of deformation, previous load history, temperature, frequency and amplitude of the motion [11–13]. In order to predict the accurate door closing performance, seal material properties must be investigated carefully, which is a challenging task in computational mechanics due to large deformations and the nearly incompressible nature of rubber [14–17].

Moreover, traditional sealing system has uniform geometrical cross-section. Very few parameters of height and wall thickness are selected for geometrical description. It is simple for design, but would cause inaccurate reconstruction of geometrical configuration. Because the cross-section remains unchangeable, it is easy for manufacturing, but has the shortcoming of bad fitting in large curvature corners and cannot satisfy the varied CLD requirements from different locations of door like the roof part, A-pillar part, B-pillar part and sill part.

Recently, variable cross-section extrusion technologies have been invented. With the computer control of extrusion die, rubber can be manufactured with changed cross-section. With regard to automotive door's complex 3D profile, new sealing with variable cross-section is desired and can be achieved with the help of new extrusion technology. Consequently, more cross-section geometrical parameters are required. Optimal design of new sealing system could benefit greatly from numerical analysis in term of efficiency and research cost. Regarding to material nonlinear, contact nonlinear and geometrical nonlinear of door sealing, this paper provides a practical numerical approach for new automotive door sealing with variable cross-section.

It firstly presented the door sealing partition process based on closing efforts design. A typical door sealing is geometrically divided into eight segments, considering the curvature change of true profile. Secondly, combination of experiment and numerical analysis is used to identify the hyper-elastic material model of door seal rubber. Thirdly, it solved the problem of cross-section's geometrical configuration and optimal variable selection. By using BP neural network, the nonlinear mapping mechanism between five cross-section parameters and the desired CLD is established. Based on Genetic Algorithm, cross-section parameters are parallely optimized. Fourthly, numerical modeling of 3D door closing is constructed for corner parts, taking into account the influence of twisting and bending during door seal assembly. By using 2D cross-section optimization for nearly straight segments of door seal and 3D numerical analysis for the rest of the corner parts, the whole sealing can be designed with variable cross section. Finally, a Matlab-based re-exploration platform has been developed, assisting this new sealing system design and demonstration.

2. Door sealing partition based on closing efforts design

Door sealing accounts for a substantial portion of door closing effort. Geometrical and topological parameters of seal cross-section, as well as the appropriate rubber material property, would result in a desired Compression Load Deflection (CLD) and door-closing performance in the end. Traditional sealing structure has uniform geometrical cross-section. However, because of door metal panel manufacturing deviation on which seal rubber was mounted and the 3D true corners parts with large curvature, this type of structure has the shortcoming of bad fitting, causing inaccurate door-closing effort design. New door sealing needs variable cross-section so that it can bring about change in the CLD curve at different locations, thus satisfying the desired different compression loads and seal qualities.

Considering the non-planar profile of practical sealing in engineering, a typical door sealing is partitioned into eight segments, of which four are nearly straight segments and four are corner parts with large curvatures, as shown in Fig. 2. The whole sealing compression load required by good door seal performance is then distributed into each part. Since different compression loads could be raised from different cross-sectional designs of sealing structure, each of the eight segments' cross-section parameters needs to be optimally designed based on the distributed compression load, so that sum of them could fulfill the desired total door closing effort.

For four nearly straightly segments, conventional 2D numerical analysis of compression process can still be used because of the unchanged compression direction of the door sheet metal.

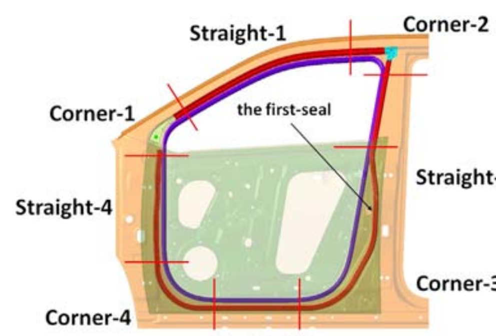

Fig. 2. Partition of door sealing system.