한국기계가공학회지, 제20권, 제7호, pp. 66～71(2021.07) ISSN 1598-6721(Print)
Journal of the Korean Society of Manufacturing Process Engineers, Vol. 20, No. 7, pp. 66~71(2021.07) ISSN 2288-0771(Online)

https://doi.org/10.14775/ksmpe.2021.20.07.066

Shape Design of Hinge Stopper to Improve Refrigerator Door Opening Force

Ji-Hwan Seo*, Sanghoon Lee**,#

*Department of Mechanical Engineering, Keimyung University
**Department of Mechanical and Automotive Engineering, Keimyung University

냉장고 도어 개방력 개선을 위한 힌지 스토퍼의 형상설계

서지환*, 이상훈**,#
*계명대학교 기계공학과, **계명대학교 기계자동차공학과
(Received 17 June 2021; received in revised form 23 June 2021; accepted 24 June 2021)

ABSTRACT

In this study, the shape design optimization of a refrigerator door hinge stopper was performed to reduce the discrepancy in the opening forces of the left and right doors of a double-door refrigerator. A finite element model was constructed and analyzed by quasi-static analyses to evaluate the structural performance of the door hinge stopper. The reaction moment calculated at the hinge axis was used as a measure of the door opening and closing forces. The design objective is to increase the door opening force by 50% while maintaining the door closing force and the maximum stress calculated in the body of the hinge stopper at the current level. A new design concept with a contacting slot was proposed to decouple the door closing and opening forces. Shape optimization was performed to determine the dimensions of the new design of the hinge stopper, and the rib pattern was determined by topological optimization to further increase the door opening force. It was observed that the new design met all design requirements.

Keywords : Door Opening Force(도어개방력), Door Closing Force(도어닫힘력), Shape Optimization(형상최적화), Quasi-static Analysis(준정적해석), Topology Optimization(위상최적화)

1. Introduction

A stopper made of injection-molded plastic is installed in the door hinge of a double-door refrigerator, which has been widely sold recently. Thus, the door opens and automatically closes at a specific angle when an opening force of a certain magnitude or more is applied. Certain models use the same stoppers for the left and right doors, and certain models use an injection-molded stopper on one side and an automatic hinge with automatic closing function on the other side. In the latter case, there may be a difference in the opening force of the left and right doors, and because of this, there are reports of customer misunderstandings and related claims. If

Corresponding Author : shlee122@kmu.ac.kr
Tel: +82-53-580-5264

Copyright © The Korean Society of Manufacturing Process Engineers. This is an Open-Access article distributed under the terms of the Creative Commons Attribution-Noncommercial 3.0 License (CC BY-NC 3.0 http://creativecommons.org/licenses/by-nc/3.0) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

the structural stiffness of the injection stopper is increased, the opening force can be increased, but the closing force also increases simultaneously. This causes the door to bounce more, and the stress generated in the stopper increases, thereby increasing the risk of breakage.

This study aims to reduce the difference in the opening force between the left and right doors by improving the shape of the existing injection-molded stopper. In this process, the increase in the closing force owing to the change in the shape of the stopper is minimized, and the stress generated in the stopper body is maintained at the same level as that of the existing product. Therefore, a quasi-static analysis that simulates the behavior of the injection-molded stopper when the door is opened and closed was performed using a commercial finite element analysis program. After proposing a new shape, a detailed design that satisfied the design requirements was derived using the shape optimization and topology optimization methods.

Section 2 describes the finite element analysis of an injection-molded stopper. Section 3 deals with the new shape concept and the process of design optimization, and Section 4 provides the discussion and conclusions of this study.

2. Finite Element Analyses of Stopper

2.1 Description of product

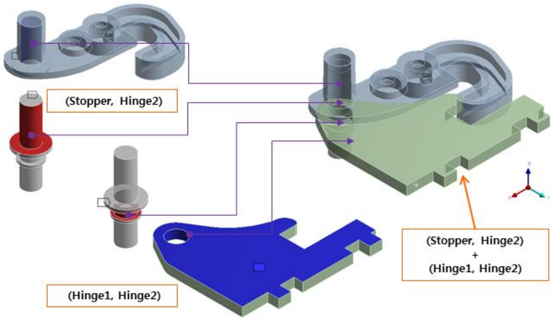


Fig. 1 Door hinge stopper module

The subject of this study was a hinge stopper module comprising sheet metal parts and a stopper made of polyoxymethylene (POM) material, as depicted in Fig. 1. The stopper was attached to the refrigerator door, and the sheet metal part was attached to the refrigerator cabinet to generate an opening and closing force using the interference between the two parts while the door was opened and closed.

2.2 Analyses of hinge stopper

2.2.1 Finite element model

To evaluate the behavior of the injection-molded stopper when opening and closing the door by quasi-static analyses, sheet metal parts, hinges, and injection stoppers were modeled with linear hexahedral elements, as demonstrated in Fig. 2. The overall model included 125,226 nodes and 103,194 elements. The amount of interference between the sheet metal part and the stopper when opening and closing the door followed the specifications suggested by the manufacturer, and the amount of interference was naturally reflected in the process of assembling the three modeled parts.

2.2.2 Quasi-static analyses of hinge stopper

Table 1 summarizes the mechanical properties of the POM material of the injection-molded stopper used in the analysis and SCP-1 , the material of the sheet metal parts and hinges. SCP-1, which has a relatively high stiffness, was modeled as a linear elastic material,

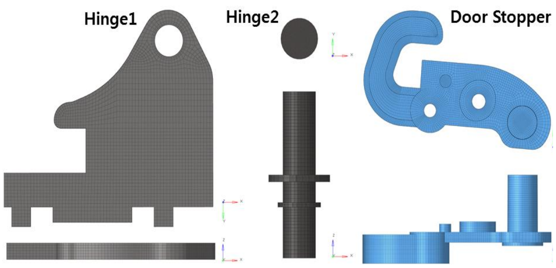


Fig 2. Finite element model of stopper module

Table 1 Material properties of door hinge stopper hinge

Material		SCP1	POM
Density	(kg/m^3)	7850	168000
Young's modulus	(MPa)	1410	2748
Poisson's ratio		0.3	0.37
Yield strength	(MPa)	171.5	28.5
Ultimate strength	(MPa)	309.9	57.5
Tensile elongation	(%)	42.5	41.4

and POM was modeled as an elastoplastic material following the piecewise linear plasticity model . The injection-molded stopper and the sheet metal part (Hinge 1) were constrained to Hinge 2, as illustrated in Fig. 2, and all the degrees of freedom of Hinge 2 and bolted parts of the injection-molded stopper were constrained. The opening and closing operations of the door were simulated by applying a forced displacement such that Hinge 1 rotated with respect to the axis of Hinge 2. The forced displacement was applied in a quasi-static manner, which is different from the real situation. However, it was believed that the door opening and closing speeds were not high enough to cause a significant dynamic effect on the behavior of the stopper. A frictionless contact condition was applied between the stopper and the sheet metal part, together with the interfaces with Hinge 2. When the rotation angle of the sheet metal part was increased, the stress generated in the injection-molded stopper and the reaction moment measured on the rotation axis of the sheet metal part were calculated. This reaction moment was a measure of the opening and closing forces generated by the stopper when opening and closing the refrigerator door.

Table 2 summarizes the reaction moment calculated from the rotational axis of the sheet metal part according to the rotation angle of the sheet metal part. Fig. 3 schematically illustrates this phenomenon. Notably, the maximum reaction moment was

Table 2 Opening force, Closing force of initial model

Time [s]	Moment [N×mm]	
	Opening Force	Closing Force
0.2	978.3	254.8
0.4	2527.9	876.8
0.6	3958.4	1431.1
0.8	4974.1	1956.4
1.0	5595.8	2437.1

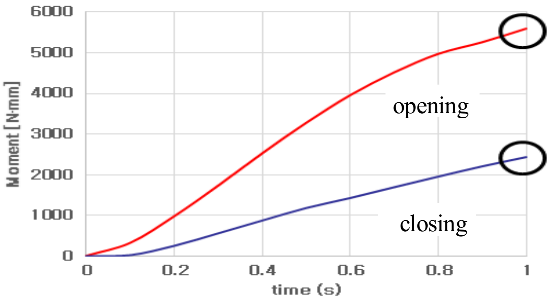


Fig. 3 Reaction moments as function of angle

approximately 5600 N·mm when the door was opened and approximately 2440 N·mm when the door was closed. Fig. 4 illustrates the equivalent stress diagram calculated from the injection-molded stopper when the door was opened. The maximum equivalent stress generated in the body, excluding the part in direct contact with the sheet metal part, was calculated to be approximately 33 MPa.

3. Shape Design of Stopper

3.1 Design requirements and concept

To reduce the difference in the opening force of the left and right doors, the following design goals were set. The reaction moment when opening, which is a measure of the opening force, should be increased by at least 1.5 times compared to the current design, and the reaction moment when closing should not increase by more than 10% compared to the current design. In addition, the stress generated in the stopper body must be maintained at a level similar to that in the current design.

If there is no requirement that the closing force should be maintained at the current level, the goal may be met by simply increasing the stiffness of the existing stopper. However, because the closing force also increases if the stiffness of the stopper body is increased, a new shape of stopper is proposed, in which the closing force and the opening force can be individually adjusted.

A groove was added to the body of the existing stopper, as depicted in Fig. 5, and a circular hole was added to the end of the groove. The groove made in the stopper body contributed to the bending stiffness of the stopper as both sides of the groove came into contact when the door was opened, but when closing, it simply opened and did not contribute to the bending stiffness. Therefore, it is possible to adjust the closing force by precisely adjusting the length and position of the groove. The hole made at the end of the groove was made to relieve the stress concentration caused by the groove, and the stress generated around the groove could be controlled by adjusting the size of the hole.

3.2 Detailed design of new stopper

3.2.1 Optimal Shape design of stopper body

The CAD program SPACECLAIM and ANSYS[1] DesignXplorer were used for the optimal shape design of the stopper. As shown in Fig. 6, three parameters that determine the increment of width of the stopper body (Y) from the initial design, the length of the groove (D), and the radius of the hole (R) were selected as design variables. The initial value of the variable (Y, D, R) is $(0, 6, 1)$(mm). The upper and lower limits of the design variables were determined considering the possible model generation range.

$$0 \le Y \le 3.5;\ 6 \le D \le 9;\ 1 \le R \le 3 \tag{1}$$

An optimal design problem is formulated as follows from the design requirements:

$$\begin{aligned} &Maximize\ T_O \\ &Subject\ to\ T_C \le T_{C,0} \times 1.1 = 2681\,N \bullet mm \\ &\qquad \sigma_O \le \sigma_{O,0} = 35\,MPa \\ &\qquad \sigma_C \le \sigma_{C,0} = 32\,MPa \end{aligned} \tag{2}$$

where,

T_o : Reaction moment when door opens

T_c : Reaction moment when door closes

σ_o : Maximum equivalent stress (opening)

σ_c : Maximum equivalent stress (closing)

Values with subscript 0 indicate the values in the initial model. The optimization was performed using the nonlinear programming method using the Kriging metamodel[2] built into DesignXplorer, and the results are shown in Fig. 7. The optimized values of the design variables were $(0.5, 8.0, 2.1)$ (mm). In the optimized model, the opening moment was 8485 N·mm, which was 34% higher than the initial value of 5596 N·mm, and the closing moment was 2549 N·mm, which was 4.4% higher than the initial value of 2437 N·mm, which satisfied

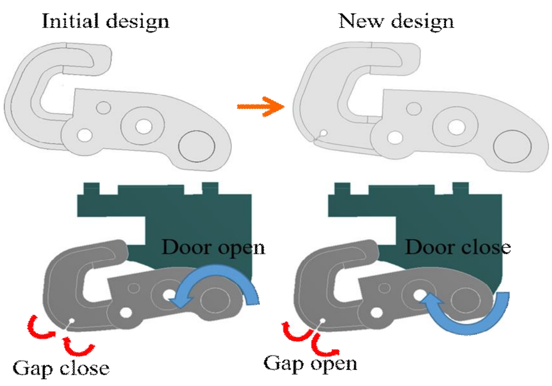


Fig. 5 New design concept of stopper

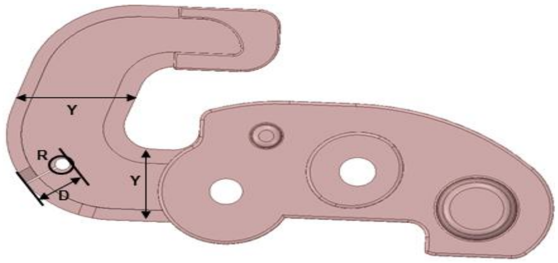


Fig. 6 Design variables of shape design

the requirements. The maximum stress generated during opening and closing was 33 MPa when opened and 31 MPa when closed. Thus, the shape optimization of the stopper body was successfully performed, but the value of the opening moment did not meet the requirement of 1.5 times the initial value requested by the manufacturer; therefore, additional reinforcement using topology optimization was followed to meet that requirement.

3.2.2 Reinforcement design for stopper body

To further increase the opening moment, a rib design was performed using topology optimization. If the width of the stopper was increased, the overall stiffness increased, and the opening moment increased. However, the stress at the sides of the stopper body simultaneously increased, which implied that the improvement in the opening moment by only adjusting the width of the stopper body was limited.

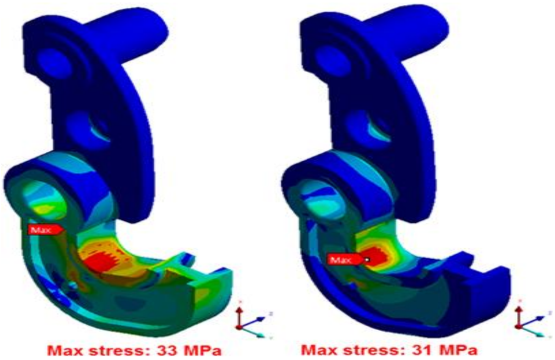


Fig. 7 Stress distribution in optimized stopper

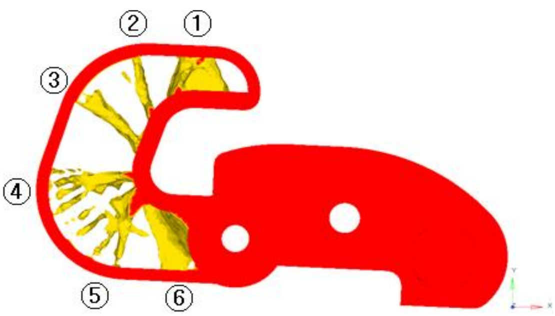


Fig. 8 Results of topology optimization of stopper

Topology optimization was performed using the density method[3] provided by Altair OptiStruct[4], and the optimization problem was formulated as follows:

$$\begin{aligned}&Minimize\ Compliance\\&subject\ to\ V \leq 0.3V_0\end{aligned} \tag{3}$$

where V is the volume of the design domain, and V_0 is the volume of the design domain in the model before topology optimization. To appropriately allocate the reinforcement rib, the design and non-design areas were carefully divided. The rib shape of the stopper obtained by topology optimization is demonstrated in Fig. 9. As shown in the figure, the connection part

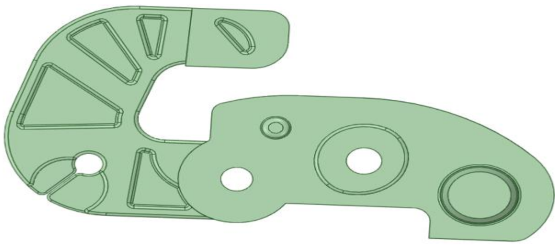
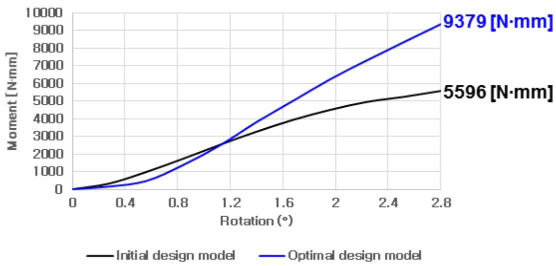
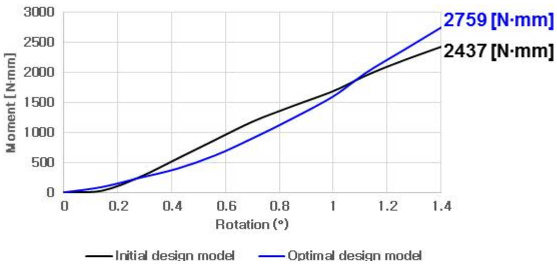


Fig. 9 Final design of hinge stopper



(a) Opening moment of optimal design model



(b) Closing moment of optimal design model

Fig. 10 Opening/closing moment comparison

marked with numbers (1 - 6) was an important part of supporting the load when the door was opened and closed. The final model was designed using the reinforcement pattern thus determined, as illustrated in Fig. 10.

In the process of designing the final model, corner rounding was appropriately reflected in the stopper considering manufacturability. The compliance of the final optimal model with the design requirements was checked using ANSYS. Fig. 10 presents the reaction moment values according to the door opening and closing angles. The opening moment of the optimum model was 9379 N·mm, which met the target with a value almost similar to 9422 N·mm, which was 1.5 times the target value of the initial opening moment. Notably, the closing moment of the optimal design model was 2759 N·mm, which was an increase of approximately 11% compared to 2437 N·mm of the existing model. Thus, it was confirmed that the design goal of increasing the opening moment by more than 1.5 times compared to the initial model while maintaining the remaining performance measures at/below the existing values were achieved. The stress generated in the stopper body was 33 MPa when opened and 31 MPa when closed, confirming that it was maintained below the design limits.

5. Conclusions

To reduce the difference in the opening force of the left and right doors of a double-door refrigerator, an optimal design of the shape of the door stopper was performed. To individually control the opening and closing forces, a new concept of different stiffnesses during door opening and closing by machining a groove in the stopper was proposed. Through reinforcement using additional shape optimization and topology optimization, we succeeded in realizing an opening force 1.5 times higher than the initial opening force without significant increases in the stress and closing force.

However, there is a problem in that wear may be accelerated owing to the increased contact stress during opening, and a solution to this problem will be provided by additional research.

References

1. ANSYS Workbench User’s Guide, ANSYS Inc. 2015.
2. Jin, R., Chen, W., Simpson T., “Comparative Studies of Metamodeling Techniques Under Multiple Modeling Criteria,” Structural and Multidisciplinary Optimization, Vol. 23, pp. 1-13, 2001.
3. OPTISTRUCT User`s Guide, ALTAIR Inc. 2018.
4. Bendsøe M., Sigmund O., Topology optimization - theory, methods and applications, Springer, 2003.