Influence of inclination angle of attractive surface on the attractive force of magnetic attachment with optimal structural design.

H Kumano. [1], H Nagai.[1], R Kanbara. [1], T Masuda.[1], Y Nakamura.[1], K Shoji.[1],Y Takada.[2],Y Tanaka[3] and J Takebe.[1]

[1]Department of Removable Prosthodontics, School of Dentistry, Aichi Gakuin University
[2]Division of Dental Biomaterials, Tohoku University Graduate School of Dentistry
[3] Aichi Gakuin University

Abstract

We analyzed and investigated the influence of the inclination angle of attractive surfaces on the attractive force in the magnetic attachment with the optimal structure design by using the three-dimensional finite element method. Two types of analysis models were constructed: basic model and optimal model with optimal structure design. In the analysis items, the attractive force when the magnetic assembly and the keeper were in contact with each other, and the inclination and the detachment with the one end of the keeper as a fulcrum were considered. There were 21 different inclination angles of the attractive surface ranging from 0 to 20 in 1 degree increments. The keeper was observed with regards to an increase in the inclination angle of the attractive surface and the related decrease in the magnetic flux density inside the magnet assembly using both the basic model and the optimal models were. The attractive force in both the basic model and the optimal model decreased in inverse proportion to the inclination angle of attractive surface. The results of this analysis suggest that the magnetic attachment with the optimal structural design is strongly influenced by the inclination angle of attractive surface.

Introduction

Recently magnetic attachments have continued to improve. Various magnetic circuits have been designed so that a minimal size of magnetic attachment can exert a high attractive force. A magnetic attachment consists of a magnet assembly and a keeper. A magnet in the magnetic assembly is encapsulated by magnetic and non-magnetic materials. Magnetic flux can penetrate a magnetic body, but cannot penetrate non-magnetic material. Magnetic flux is the magnetic line of forces. It penetrates magnetic materials and forms the closed magnetic circuit that exerts attractive force when a magnetic assembly and a keeper come into contact.

Up to now, for the purpose of further improving the attractive force of magnetic attachment, the following methods have been carried out: 1) Change of the magnetic circuit of magnetic attachment structure, 2) Analysis on the attractive force, and 3) Using a three-dimensional finite element method[1)]. As a result of these methods, the central portion of the keeper and magnet set of non-magnetic material is applied to the optimal structure, it was confirmed that there was an improvement in the attractive force of magnetic attachment[2)].

Objective

Three-dimensional finite element method was performed to analyze influence of attractive surface inclination on the attractive force of magnetic attachment with optimal structural design.

Materials and Methods

1. *Analysis model*

The size of the magnetic assembly was 3.6 mm in diameter and 1.3 mm in height, and a magnet inside the magnetic assembly was a round shape, and was 2.6 mm in diameter and 0.5 mm in height. The size of the ring was 0.2 mm in width and 0.2 mm in height. The disk yoke was 2.2 mm in diameter and 0.2 mm in height. The keeper was round and sharp, and was 3.6 mm in diameter and 0.7 mm in height.

Considering the models were line-symmetry, half of the model is shown as the basic model (Fig. 1) and the other half is shown as the optimal model (Fig.2). The optimal model structural design is the same as the basic model but also has non-magnetic material inserted into the magnetic attachment.

Analysis range was 3.0 mm around a magnetic assembly and a keeper. Marc mentat 2010 (Multi-Purpose Finite Element Pre and Post Processor, MSC) was used for model construction, and μ-MF (electromagnetical field analysis system, μ-TEC) analysis software was used. The element type was a three-dimensional pentahedron and hexahedron elements. The element count was 107,604, and nodal point count was 112,468.

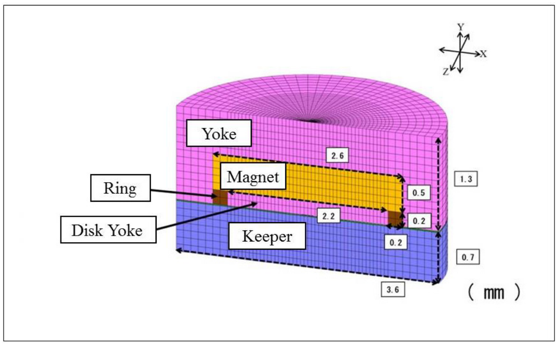

Fig.1 Basic model

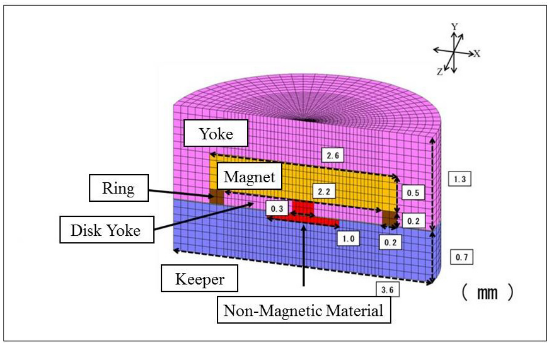

Fig.2 Optimal model

2. *Analysis condition*

The components of the magnet were Ne-Fe-B (Neodymium, ferrum, boron), and its magnetic properties were calculated based on the thermal property of GIGAUSS D 600 and values provided by a manufacturer[3)] . The component of the disk yoke and the keeper was measurement of magnetic properties of SUSXM27, and the B-H curve of the magnetic properties was calculated by the approximation formula (Table 1)[4)].

Table 1 Analysis conditions

Magnet		
	Nd-Fe-B	(BH) max = 46 MGOe Residual magnetic jnduction = 1. 22 T
Keeper & Yoke		
	SUS XM27	Saturation magnetic induction = 1. 35 T
	B-H curve	$B = Bs \{ 1 - \exp (-\mu_r \cdot \mu_0 \cdot H / Bs) \}$

3. *Analysis items*

From the condition where the magnet assembly and the keeper were in contact with each other in the optimal model, the attractive force when inclined and detached from one end of the keeper as a fulcrum was analyzed. There were 21 different inclination angles of the attractive surface ranging from 0 to 20 in 1 degree increments. In addition, the same analysis item was used in the basic model (Fig. 3).

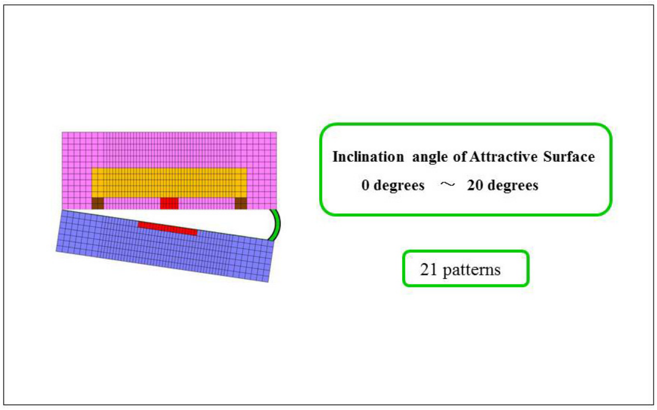

Fig. 3 Analysis items

Analysis result was evaluated as magnetic flux density **vs.** attractive force.

Results

1. *Magnetic flux density distribution*

Representative magnetic flux density distribution (Fig. 4, 5).

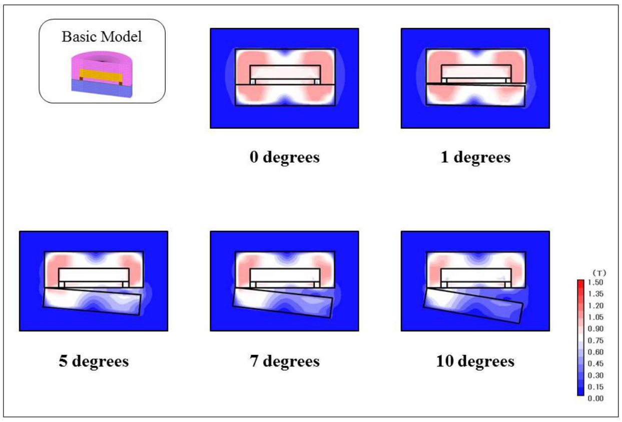

Fig. 4 Magnetic flux density distribution (Basic Model)

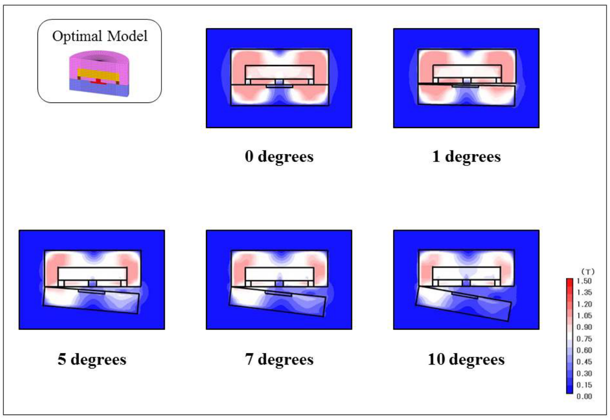

Fig. 5 Magnetic flux density distribution (Optimal Model)

In both the basic model and optimal models, concurrent with an increase in the inclination angle of the attractive surface, a decrease in the magnetic flux density inside the magnet assembly, the keeper, and the in the magnetic flux density in the disk yoke on the right side of the magnet assembly was observed. In addition, an increase of magnetic field leakage at the top of the keeper of attractive surface was observed with the increase of the inclination angle of the attractive surface in both the basic model and the optimal model. Inclination angles of 0,1, and 5 degrees of the attractive surface when comparing the basic and optimal model showed an increase of the magnetic flux density at the shield disk of the magnet assembly was observed in the optimal model. However, at 7 and 10 degrees, this increase in magnetic flux density was not observed.

2. Attractive force

A graph of the analysis of the attractive force results is shown (Fig. 6). Attractive force in both the basic and optimal models decreased in inverse proportion to the inclination angle of attractive surface. The inclination angles of attractive surface up to 5 degrees was more optimal in the model than in the basic model, it was thus confirmed that the attractive force is large.

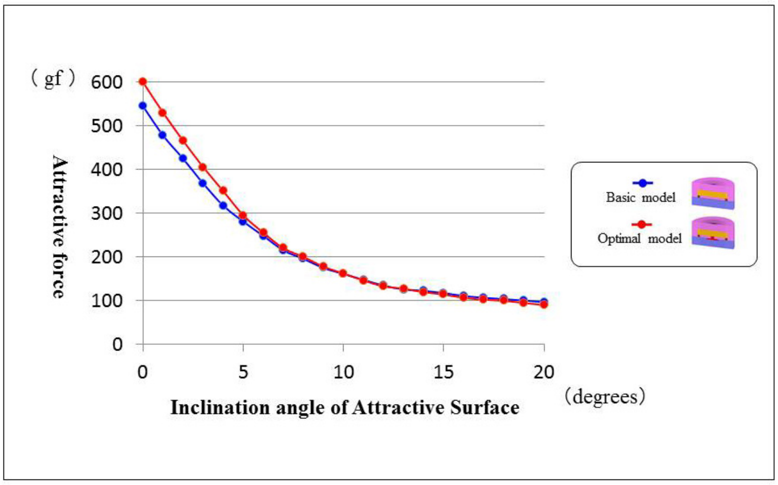

Fig.6 Attractive force

When the inclination angle of attractive surface was 6 degrees or more, it was confirmed that the attractive force was almost the same for both the basic and optimal models.
The reduction rate of the attractive force in the inclination angle of attractive surface of 6 degrees was about 44% in the basic model and about 58% in the optimal.

Discussion

1. Efficiency of finite element method

It is difficult to measure and observe the details of the behavior of attractive and repelling forces created by a magnet. This is because the magnetic field has a gradient in all directions, and, therefore, a simple calculation formula cannot be established. The finite element method allows visualization and simulation of the inner behavior of the magnetic circuit by adding various conditions. It is considered time-efficient and cost-effective to search for optimal magnetic circuits using the finite element method.

2. Efficiency of analysis model

Magnets have a magnetic field distribution in space defined as a "leaky magnetic field." In other words, it has a magnetic field around the magnetic attachment. Therefore, the accuracy of the analysis results will be increased if the analysis range of the magnetic structure of the magnetic attachment and the circumference of the keeper are analyzed. In this study, we confirmed the range of magnetic field leakage, and analyzed the elements of the magnet assembly and the keeper around 3mm in the construction model. In the final analysis, the accuracy of the analysis in this model is high.

3. The relationship between the attractive force and magnetic flux density

The attractive force of a magnet can be expressed as $F = (1/2\mu_0) \cdot S \cdot B^2$ {μ_0: space permeability, S:attractive surface area, B: magnetic flux density}[5]. The attractive force of a magnetic attachment is affected more by magnetic flux density than attractive surface area. Therefore, attractive force can be increased efficiently by increasing the magnetic flux density. The magnetic circuit changes by replacing part of a keeper of a magnetic attachment with non-magnetic material, resulting in an increase in the magnetic flux density on the attractive surface. The attractive force was affected more by an increase in magnetic flux density than by a decrease in the attractive surface area, resulting in an increase in the attractive force.

However, from the results of this analysis, the reduction rate of the attractive force was larger in the optimal model than in the basic model. The reason is that the optimal model sets the non-magnetic material in the center of the magnet assembly and keeper, so as to increase as much as possible the magnetic flux density. Therefore, in the optimal model, since the attractive surface of the keeper is inclined and detached, the magnetic flux density distribution inside the magnetic assembly and the keeper are strongly influenced, so that the reduction rate of the attractive force becomes larger than the basic model considered.

Conclusion

The results of this analysis using the three-dimensional finite element method for determining the effect of the inclination angle of attractive Surface on the magnetic flux density distribution and the attractive force in the magnet attachment which gave optimal structural design obtained the following conclusions:

1. The influence on the magnetic flux density distribution by the inclination angle of attractive surface was larger in the optimal model than in the basic model.
2. The reduction rate of the attractive force by the inclination angle of the attractive surface was larger in the optimal model than in the basic model.
3. The results of this analysis suggested that the magnetic attachment with the optimal structural design is strongly influenced by the inclination angle of attractive surface.

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