Investigation of an optimal magnetic attachment structure using three-dimensional finite element method
-An influence of different magnetic assembly and keeper structure on attractive force-

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Abstract

Magnetic attachments are designed to exert an attractive force at clinically useful levels. However, more improvement is necessary considering strict clinical conditions. The present study analyzed and investigated magnetic attachments from the point of magnetic circuit using a three-dimensional finite element method to enhance the performance of magnetic attachments.

An analysis model was constructed based on a dental magnetic attachment (GIGAUSS D 600, GC). Round shaped non-magnetic body was embedded in the shield disk of a magnetic assembly and center of the attractive surface of a keeper in the analysis model. Analysis was performed by changing the diameter of a non-magnetic material by 0.05 mm. Magnetic flux density distribution and attractive force were evaluated by the analysis.

An increase in magnetic flux density on the attractive surface was confirmed by embedding a non-magnetic body to a magnetic assembly and a keeper. However, magnetic flux density was oversaturated when it exceeded a certain value. A similar tendency was confirmed in attractive force.

Introduction

Magnetic attachments have been continuing to improve. Various magnetic circuits have been designed so that the minimal size of magnetic attachment can exert 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 bodies. Magnetic flux can penetrate a magnetic body, but cannot penetrate a non-magnetic body. Magnetic flux is the magnetic line of forces. It penetrates a magnetic body and forms the closed magnetic circuit that exerts attractive force when a magnetic assembly and a keeper come into contact[1)].

Attractive force is affected by attractive surface area of a magnetic assembly and a keeper, and magnetic flux density. Since the size of a magnetic attachment should be minimal, it is impossible to increase the attractive surface area of a magnetic assembly and a keeper[2)] . Attractive force of a magnetic attachment can be effectively increased by increasing magnetic flux density. A magnetic circuit changes by incorporating a non-magnetic body in the inner structure of a magnetic assembly and a keeper, and this may increase a magnetic flux density. In other words, clinically-feasible magnetic assemblies and keepers can be developed by introducing an optimal magnetic circuit. Finite element method is considered the most effective method to optimize the magnetic circuit as it can visualize the dynamic behavior of the magnetic circuit inside a magnet, and simulation can be performed by changing the conditions.

Objective

A non-magnetic body was embedded in the center of a magnetic assembly shield disk and center of the attractive surface of a keeper. Three-dimensional finite element method was performed to analyze the influence of a difference in the magnetic circuit on the attractive force, and to optimize the magnetic circuit.

Materials and Methods

1. *Analysis model*

The size of a magnetic assembly was 1.8 mm in radius and 1.3 mm in height, and a magnet inside the magnetic assembly was a round shape, and was 1.3 mm in radius and 0.5 mm in height. The size of a ring was 0.2 mm in width and 0.2 mm in height. A shield disk was 1.1 mm in radius and 0.2 mm in height. A keeper was a round sharp, and was 1.8 mm in radius and 0.7 mm in height. Considering the model was axial symmetry, 1/4 model was set as a basic model (Fig. 1).

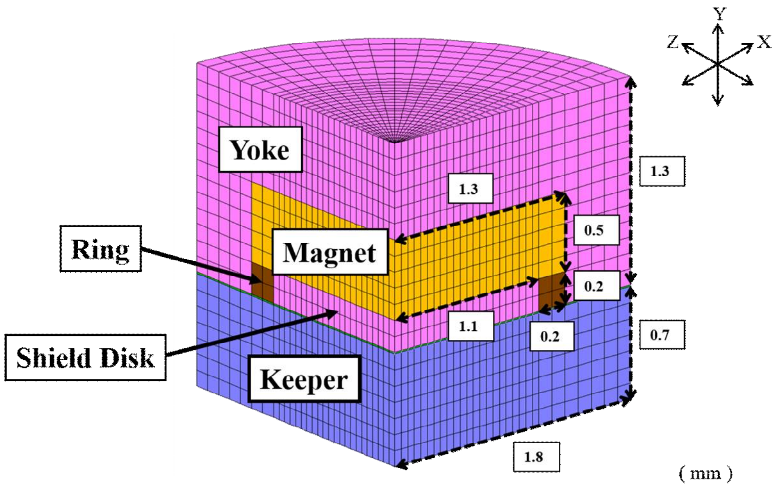


Fig .1 Basic model

Analysis range was 2 mm around a magnetic assembly and a keeper, and the analysis of the factor was performed. 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. Element type was three-dimensional pentahedron and hexahedron elements. The element count was 53,802, and nodal point count was 57,784.

The components of a 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 a yoke and a keeper was SUS447J1, and the B-H curve of the magnetic properties was calculated by the approximation formula (Table 1).

Table 1 Analysis conditions

Magnetic assembly		
	Nd-Fe-B	(BH) max = 46 MGOe
		Residual magnetic jnduction = 1.22 T
Keeper & Yoke		
	SUS447J1	Saturation magnetic induction = 1.35 T

B-H curve $B = Bs \{ 1 - \exp (-\mu_r \cdot \mu_0 \cdot H / Bs) \}$

2. *Analysis items*

A non-magnetic body was embedded in the center of the shield disk of a magnetic assembly and center of the attractive surface of a keeper. The radius of a non-magnetic body was changed by 0.05 mm increments from 0.05 mm to 0.5 mm in the center of a shield disk (10 patterns in total)(Fig. 2).

Magnetic assembly

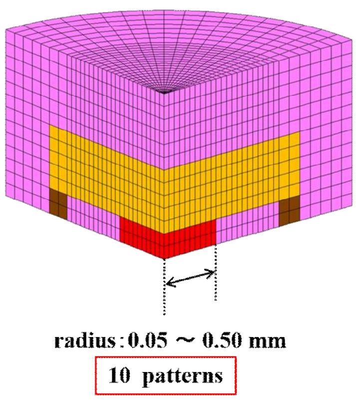


Fig.2 Analysis item of magnetic assembly

In the center of the attractive surface of a keeper, the radius of a magnetic body was changed by 0.05 mm increments from 0.05 mm to 1.0 mm, and the depth was changed by 0.1 mm from 0.1 mm to 0.6 mm (120 patterns in total)(Fig. 3).

Keeper

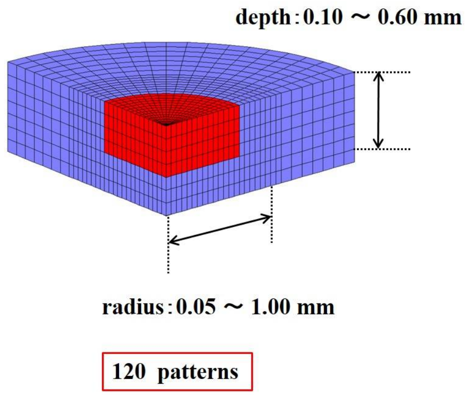


Fig.3 Analysis item of keeper

These patterns were combined, and a total of 1,200 patterns were analyzed (Fig. 2). Analysis result was evaluated as magnetic flux density and attractive force.

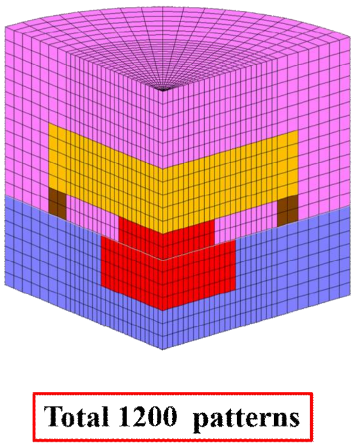
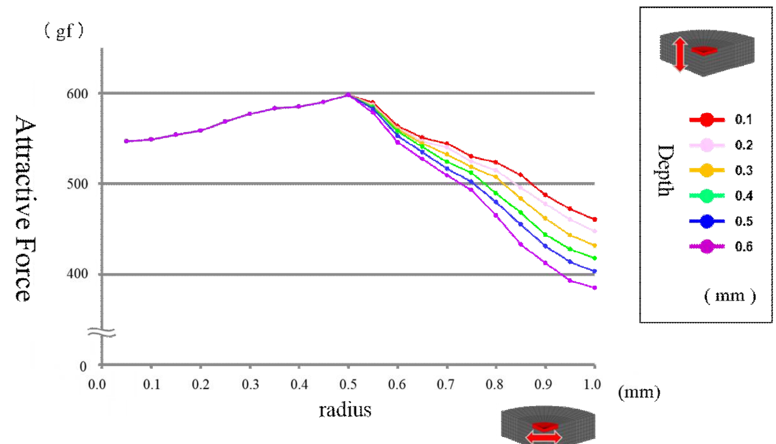


Fig.4 Total patterns

Results

1. *Attractive force*

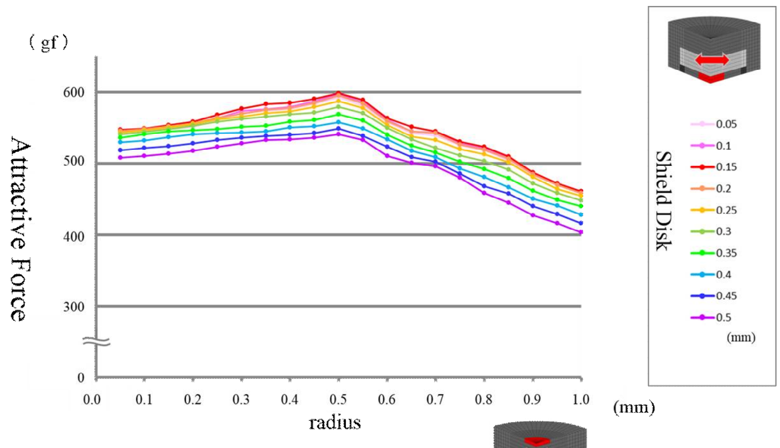
Fig. 3 shows the influence of the radius of a non-magnetic body embedded in the keeper attractive surface on the attractive force for the depth where the radius of a non-magnetic body in the center of a shield disk was 0.15 mm. There was no influence of depth until the radius of a non-magnetic body in the attractive surface of a keeper reached 0.5 mm. Attractive force was the highest at 0.5 mm in radius. When the radius exceeded 0.55 mm, attractive force started to decrease and was affected by the depth.



＊ radius of non-magnetic material in shield disk : 0.15 mm

Fig.5 Influence of the depth

Fig. 4 shows the influence of a change in radius of a non-magnetic body in the attractive surface of a keeper on attractive force for the radius of a non-magnetic body in the center of a shield disk. Since there was a little influence of the depth of a non-magnetic body until the radius of a non-magnetic body in the center of a keeper attractive surface reached 0.5 mm where attractive force continued to increase (Fig. 3), the depth of a non-magnetic body was set at 0.1 mm. Attractive force increased with an increase of a radius of the non-magnetic body in the center of a keeper attractive surface. The attractive force reached a maximum of 598 gf when a radius of a non-magnetic body in the center of a shield disk was 0.15 mm and that in the center of an attractive surface of a keeper was 0.5 mm, but decreased thereafter with an increase of a radius of a non-magnetic body on the attractive surface of a keeper. When attractive force of the basic model was defined as 100%, the attractive force was increased to approximately 110% at 0.15 mm radius of a non-magnetic body in the center of a shield disk and 0.5 mm radius of a non-magnetic body in the center of an attractive force of a keeper where attractive force reached the maximum.



＊depth of non-magnetic material in keeper : 0.1 mm

Fig.6 Influence of shield disk and keeper

2. *Magnetic flux density distribution*

Fig. 5 shows a typical magnetic flux density distribution of the analysis results. The radius of a non-magnetic body in the center of an attractive surface of a keeper was changed when the radius of a non-magnetic body in the center of a shield disk was 0.15 mm and the depth of a non-magnetic body in the center of an attractive surface of a keeper was 0.1 mm.

An increase in the magnetic density was confirmed in the magnetic assembly and attractive surface of a keeper. When the radius of a non-magnetic body in the center of an attractive surface of a keeper exceeded 0.75 mm, the magnetic flux density in the magnetic assembly and on the attractive surface of a keeper became oversaturated, and a decrease in the magnetic flux density in the magnetic assembly and inside a keeper was observed.

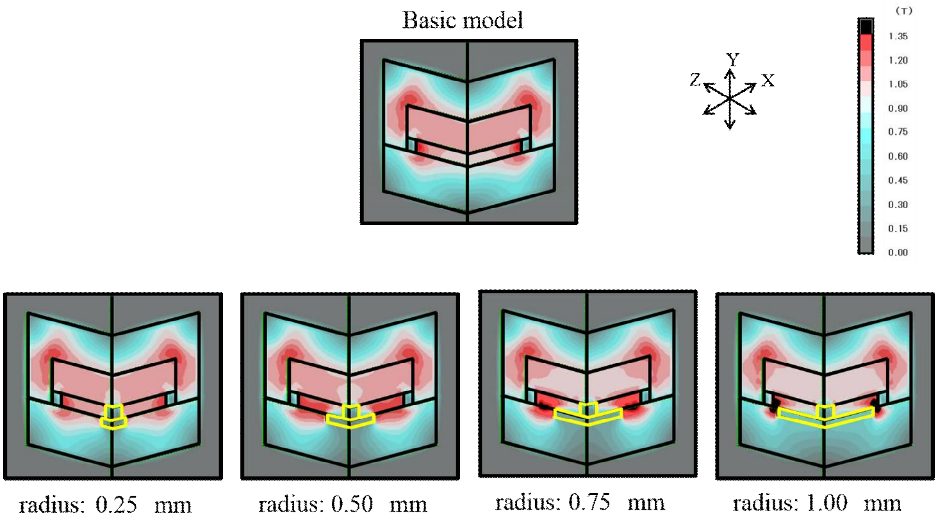


Fig.7 Magnetic flux density distribution

Discussion

1. *Efficiency of finite element method*

It is difficult to measure and observe the detail of behavior of attractive and repelling force created by a magnet. This is because the magnetic field has a gradient in all directions, and, therefore, simple calculation formula cannot be established. Although it is possible to measure magnetic force and magnetic field at specific location, it is difficult to design the magnetic circuit from the measurements that exerts the maximum attractive force and verify optimal magnetic circuit that minimizes magnetic field leakage. Finite element method is the only way to investigate the inner behavior of the magnetic circuit. Magnetic circuit compartments were considered as micro-compartment to solve the simultaneous equation. 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 optimal magnetic circuit using a finite element method.

2. Accurate of the analysis result of the present study

The magnetic field analysis was performed in the present study. Since there is a magnetic field distribution in the space, it is prerequisite that the paths of integration in the space around the analysis model and the interface between a magnetic assembly and a keeper are subdivided. Exploratory analysis was performed to calculate the value with the least effect. Therefore, the analysis result of the present study is considered highly accurate[4) .

3. The relationship between the attractive surface area 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 a non-magnetic body, resulting in an increase in the magnetic flux density on the attractive surface. The attractive force was affected more by an increase in the magnetic flux density than a decrease in the attractive surface area, resulting in an increase in the attractive force. However, there is a limit of magnetic flux density in the magnetic body called “saturated magnetic flux density”. When the magnetic body reaches that point, an increase in the magnetic flux density stops even with the continuous increase of the size of a non-magnetic body. As a result, the attractive force decreases due to an influence of the attractive surface area. The relationship between the attractive surface area and magnetic flux density is extremely important for the optimization of the magnetic circuit.

4. Inference of the depth

In the present study, a non-magnetic body was embedded in the center of a shield disk and attractive surface of a keeper. The magnetic circuit of a magnetic assembly and inside a keeper was changed by changing the radius of a non-magnetic body, resulting in an increase in the magnetic flux density distribution on the attractive surface. The attractive force is affected more by the magnetic flux density than a decrease in the attractive surface area, resulting in an increase in the attractive force. The attractive force reached its maximum at 0.15 mm radius of a non-magnetic body in the center of a shield disk and 0.5 mm radius of a non-magnetic body in the center of an attractive surface of a keeper. When the magnetic flux density on the attractive surface became oversaturated, attractive force decreased due to a decrease in the magnetic flux density and attractive surface area. When the radius of a non-magnetic body in the center of a shield disk is constant, the attractive force continued to increase until the radius of a non-magnetic body is increased to 0.5 mm. The attractive force is affected by an increase of the magnetic flux density on the attractive surface, and is rarely affected by the depth of a non-magnetic body. However, when the radius of a non-magnetic body in the center of an attractive surface of a keeper exceeds 0.5 mm, the magnetic flux density on the attractive surface becomes oversaturated. The magnetic flux that could not penetrate the attractive surface flows into the non-magnetic body. The magnetic flux is hard to penetrate a non-magnetic body, but a small amount of magnetic flux can flow. The deeper the non-magnetic body gets, the more difficult the magnetic flux can penetrate the non-magnetic body. It is considered that a decrease in the

attractive force is caused by the depth of a non-magnetic body.
Further analyses are necessary to optimize the magnetic circuit.

Conclusion

The influence of a non-magnetic body in the center of a shield disk and attractive surface of a keeper was analyzed and investigated using a three-dimensional finite element method, and the following results were obtained:

1. In the present analysis model, the optimal inner structure of a magnetic attachment was 0.15 mm radius of the non-magnetic body in the center of a shield disk and 0.5 mm radius of the non-magnetic body in the center of an attractive surface of a keeper.
2. The attractive force increased until the optimal inner structure value was reached, and decreased thereafter with an increase of the radius.
3. The influence of the depth of a non-magnetic body in the center of an attractive surface of a keeper was small until the radius reached the value where the maximum attractive force was achieved.
4. When the radius of a non-magnetic body in the center of a shield disk and attractive surface of a keeper exceeded the value where the maximum attractive force was achieved, the magnetic flux density on the attractive surface became oversaturated.

References

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