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Improvement of Structural Stiffness of a Cell Separation Equipment using Finite Element Analysis

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Abstract

The goal of this research is to suggest the improved structural design of cell separation equipment for shortening the initial setting time and increasing its accuracy. To achieve this goal, first, the structural dynamic characteristics of current equipment is evaluated by performing the modal test to check modal frequencies. Input vibration of the current equipment is also investigated by analyzing the frequency component of the vibration generated from the motor part to make sure whether measured modal frequencies cause a problem or not. Second, a 3D CAD model and its finite element (FE) model are created by using commercial softwares, Pro/E and ABAQUS. By correlating modal test results and FE results each other, the updated FE model describing more precisely test results is obtained. Then, an improved structural design is proposed by reinforcing the stiffness to make measured modal frequencies outside the frequency range of the input vibration.

Keywords: structural characteristics of cell separation equipment, modal test, finite element method, FE model correlation.

INTRODUCTION

Several bio-techonology companies such as Cytogen have developed equipment for separation, detection and analysis of blood cancer cells. One of their difficulties is the improvement of structural characteristics is usually performed based on their experience since it is hard to evaluate and improve the dynamic stiffness of the equipment properly for small and medium sized companies. With current equipment, it is necessary to take a lot of time for adjusting the initial setting values due to the problems such as new installation by newly developed process, external vibration of the equipment and so on. This is also closely related to the process errors and performance of the equipment. Therefore, minimizing setting-value changes and process errors due to the external vibration can be a key for entering the global market and increasing their sales.

Numerous studies applying FE-analysis for adding stiffness have been performed [1-3]. In order to predict structural characteristics of a machine or equipment accurately, its FE model should be updated by using experiment results such as modal testing results [4-5].

In this research, the structural stiffness of the current equipment was evaluated and its corresponding FE model was correlated by using modal testing results. In addition, input vibration of the equipment was also investigated by analyzing the frequency component of the vibration generated from the motor part to make sure whether measured modal frequencies cause a problem or not. Lastly, an improved structural design was suggested by reinforcing the stiffness to make natural frequencies which deviates from the main input-vibration frequency range of the motor.

MEASUREMENT OF STRUCTURAL DYNAMICS OF EQUIPMENT

To evaluate the dynamic characteristics of the equipment, with the consent of Cytogen company, a SCADAS mobile data acquisition system (Siemens Inc.) was used as shown in Fig. 1. After exciting the equipment by using an impact hammer, acceleration signals were measured by using a 3-axis accelerometer. Although it could not be described in Fig. 1 perfectly due to the company confidentiality, there were moving parts operated by about 20 motors on the left side of the cantilever structure. After complicated movement by motors, the diluted blood is separated and analyzed. As shown in Fig. 2, the cell separation device was simplified and modeled as a flat plate and cantilever structure, and a modal test was performed [6].

The main measured modes are shown in Fig. 3-4. For company's security, the natural frequency for each mode is normalized by the sampling frequency. At first glance, the modes of Fig. 3 and Fig. 4 appear to be similar. However, the mode (f_n = 0.45) in Fig. 3 shows a rotational mode along the y-axis since the stiffness of the part supporting the cantilever is weak in rigidity. On the other hand, the mode described in Fig. 4 (f_n = 0.90) corresponds to the first bending mode, which is the elastic mode of the cantilever beam alone. In order to reproduce the modes shown in Fig. 3 and 4 in a finite element model, it is necessary to insert a spring element between the plate and the cantilever beam in the construction of the finite element model. In the next chapter, it will be discussed in detail.

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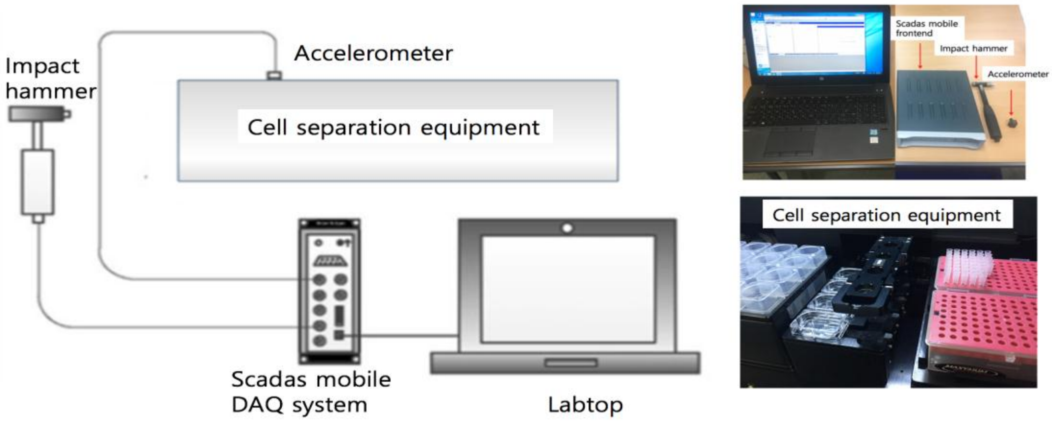

Figure 1: Test setup.

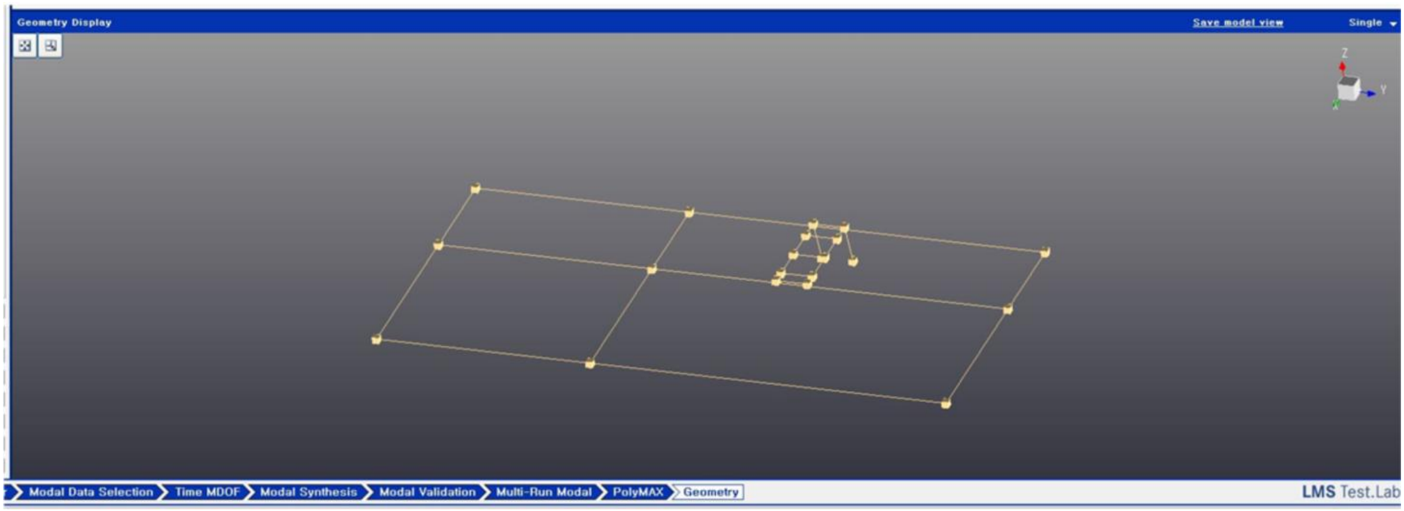

Figure 2: Modeling of the cell separation equipment for modal testing.

FINITE ELEMENT MODEL GENERATION AND CORRELATION BETWEEN MODELING AND MEASUREMENT

In order to reproduce the main modes (see Figs. 3 and 4) obtained by the modal test, a finite element model is generated as shown in Fig. 5 and a solid element acting as a spring is inserted between the plate and the beam for the purpose of reproducing the rotational mode in Fig. 3. For your information, when the plate and the beam are connected by using a 'tie' constraint in ABAQUS, the mode in Fig. 3 did not occur. Therefore, it can be assumed that the mode in Fig. 3 is caused by insufficient stiffness between the plate and the beam.

The correlated results are shown in Figs. 6 and 7. By controlling the Young's modulus of the inserted element between the cantilever and the plate, the finite element model is correlated. Table 1 shows that both results are well aligned and it is confirmed that a reliable finite element model is obtained.

Table 1: Experimental and correlated finite element model results

Normalized frequency	Rotational mode	Bending mode
Measured result	0.45	0.90
Finite element method	0.45	0.92

INPUT VIBRATION MEASUREMENT

For a linear mechanical system, there is no problem for the vibrational resonant modes if there is no vibration input corresponding to their resonant frequencies. Therefore, it is very important to analyze the frequency range of the vibration input. At first, measuring the vibration of the motor part was tried. However, unfortunately, the accelerometer was interfered with the motor part during its movement, and it was impossible to directly measure the vibration of the motor part. For this reason, during the operation, the vibration as close as possible to the motor was measured.

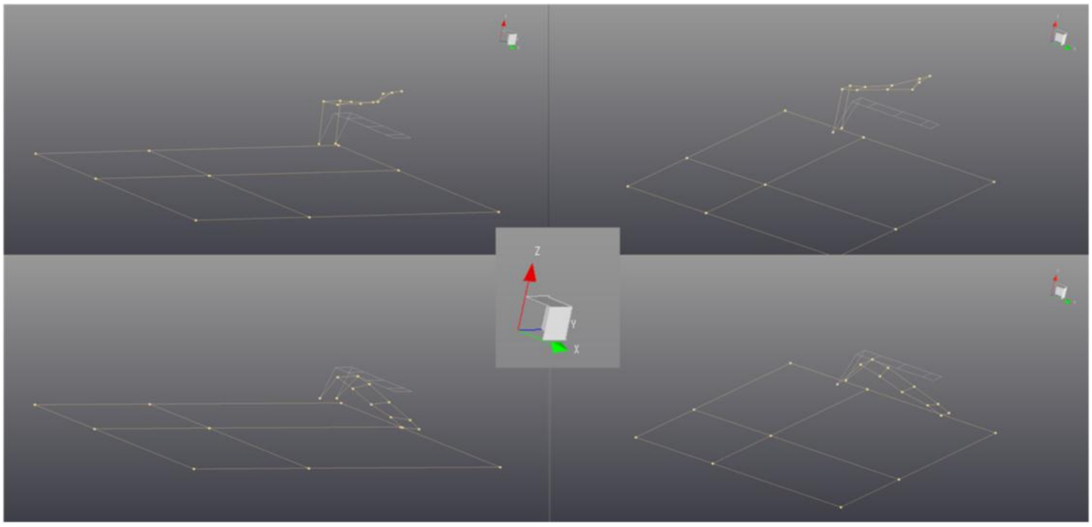

Figure 3: Measured mode that rotates around y-axis (f_n = 0.45).

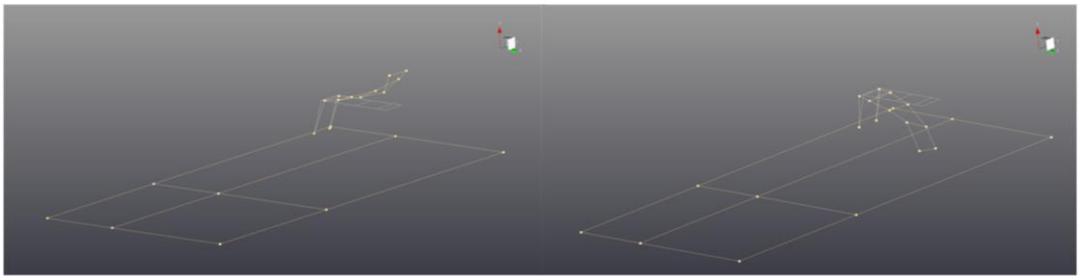

Figure 4: Measured first bending mode (f_n = 0.90).

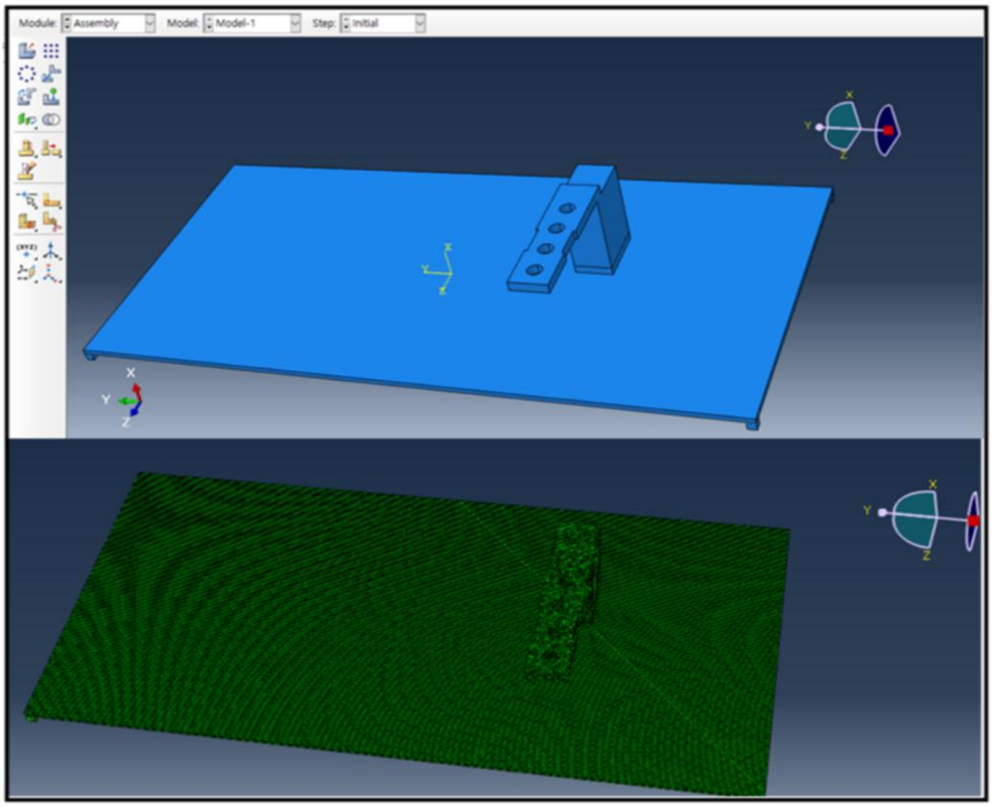

Figure 5: Finite element model of equipment.

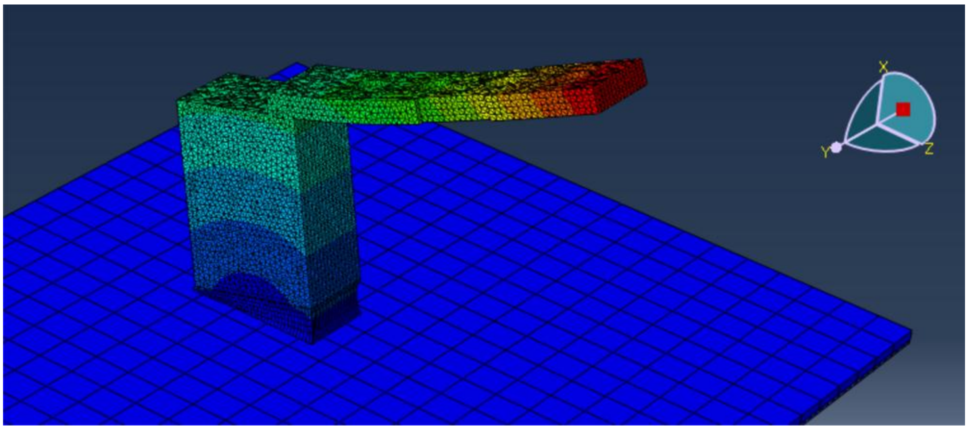

Figure 6: Correlated results (rotational mode, f_n = 0.45).

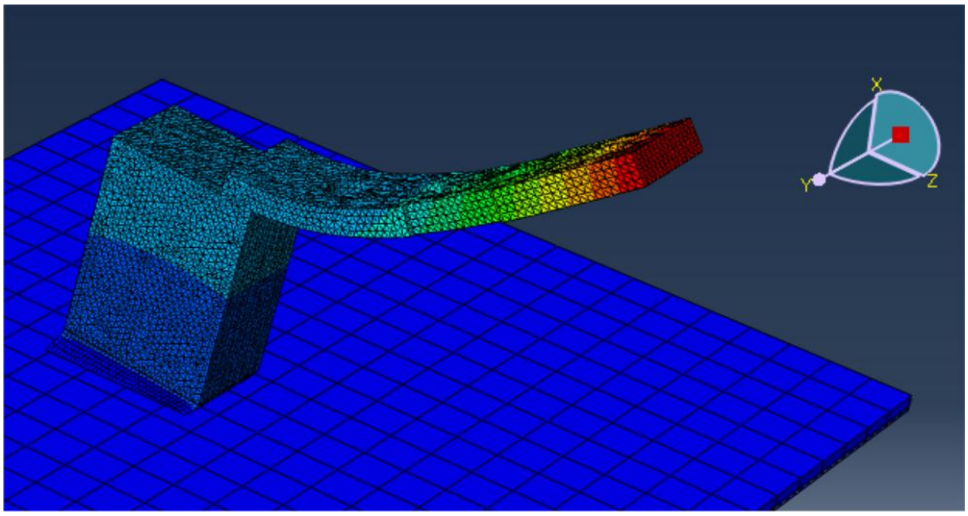

Figure 7: Correlated results (first bending mode, f_n = 0.92).

The measurement result in Fig. 8 shows that the input vibration is concentrated between the normalized frequency of 0.3 and 2.0. Therefore, it can be concluded that the measured two modes (i.e. the rotational mode (f_n = 0.45) and the first bending mode (f_n = 0.9)) may play an important role in the entire vibration level.

SUGGESTED STRUCTURAL DESIGN

Figure 9 shows a new design suggestion that can reduce the displacement corresponding to the two modes by making the normalized frequency exceed 2.0. The related frequencies are shifted to the normalized frequency of 2.0 or more as shown in Fig. 10 and 11. It is predicted that the two modal frequencies can be avoided from the main component of the input vibration in Fig. 7 and the vibration of this equipment will be greatly improved.

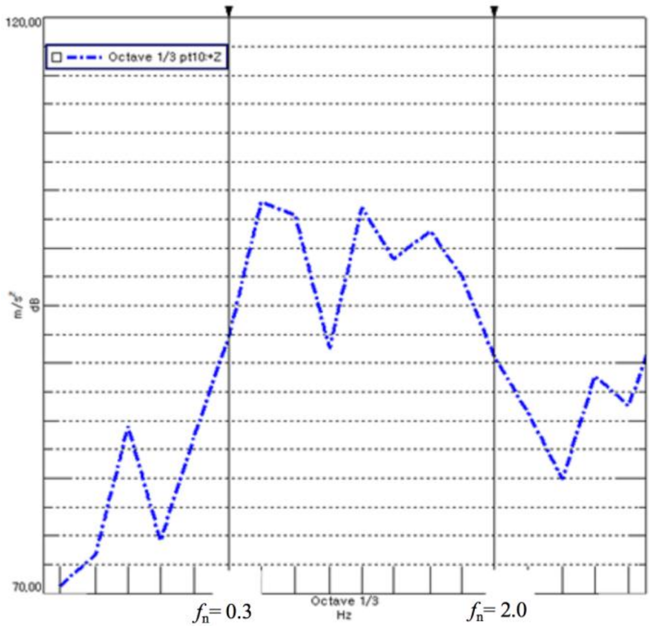

Figure 8: Input vibration close to the motor.

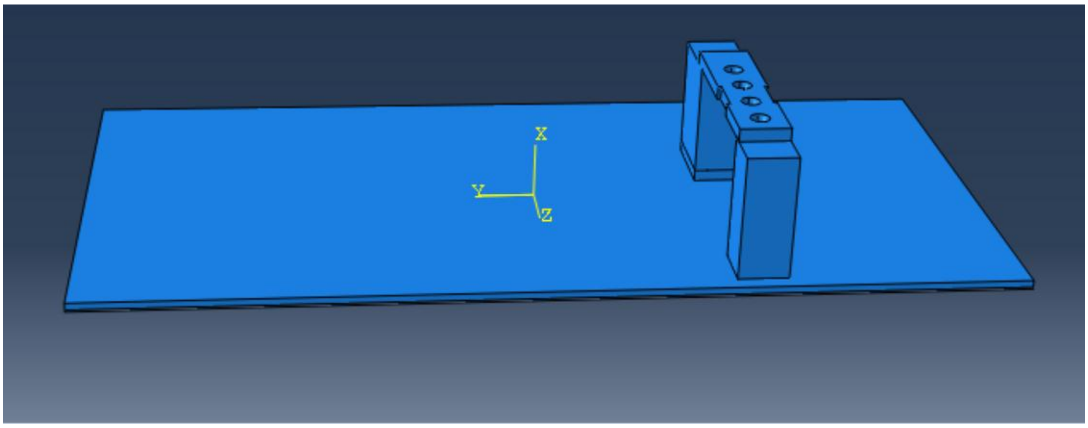

Figure 9: Suggested design.

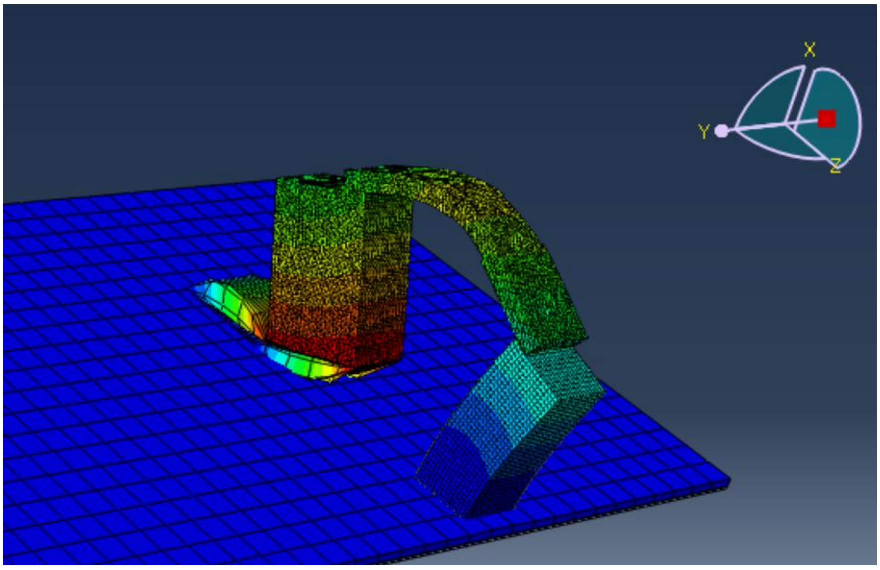

Figure 10: First elastic mode of suggested model (f_n = 2.18).

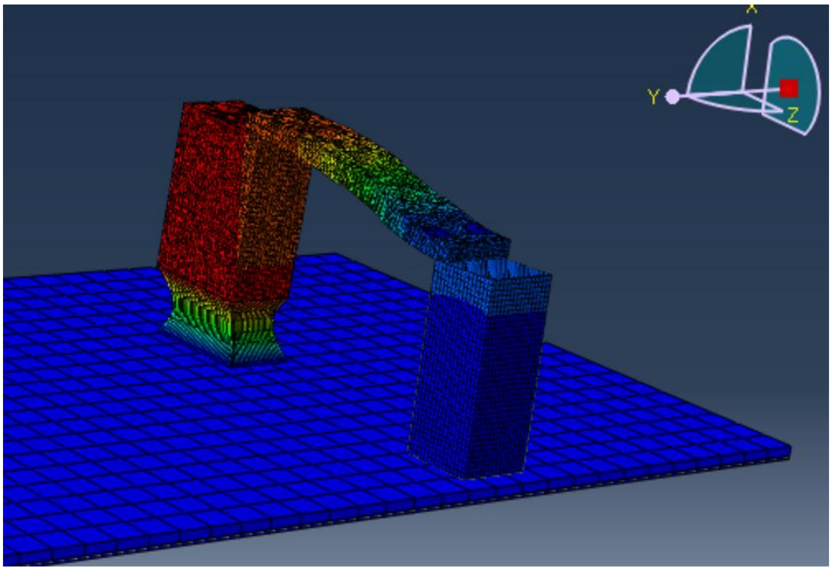

Figure 11: Second elastic mode of suggested model (f_n = 2.45).

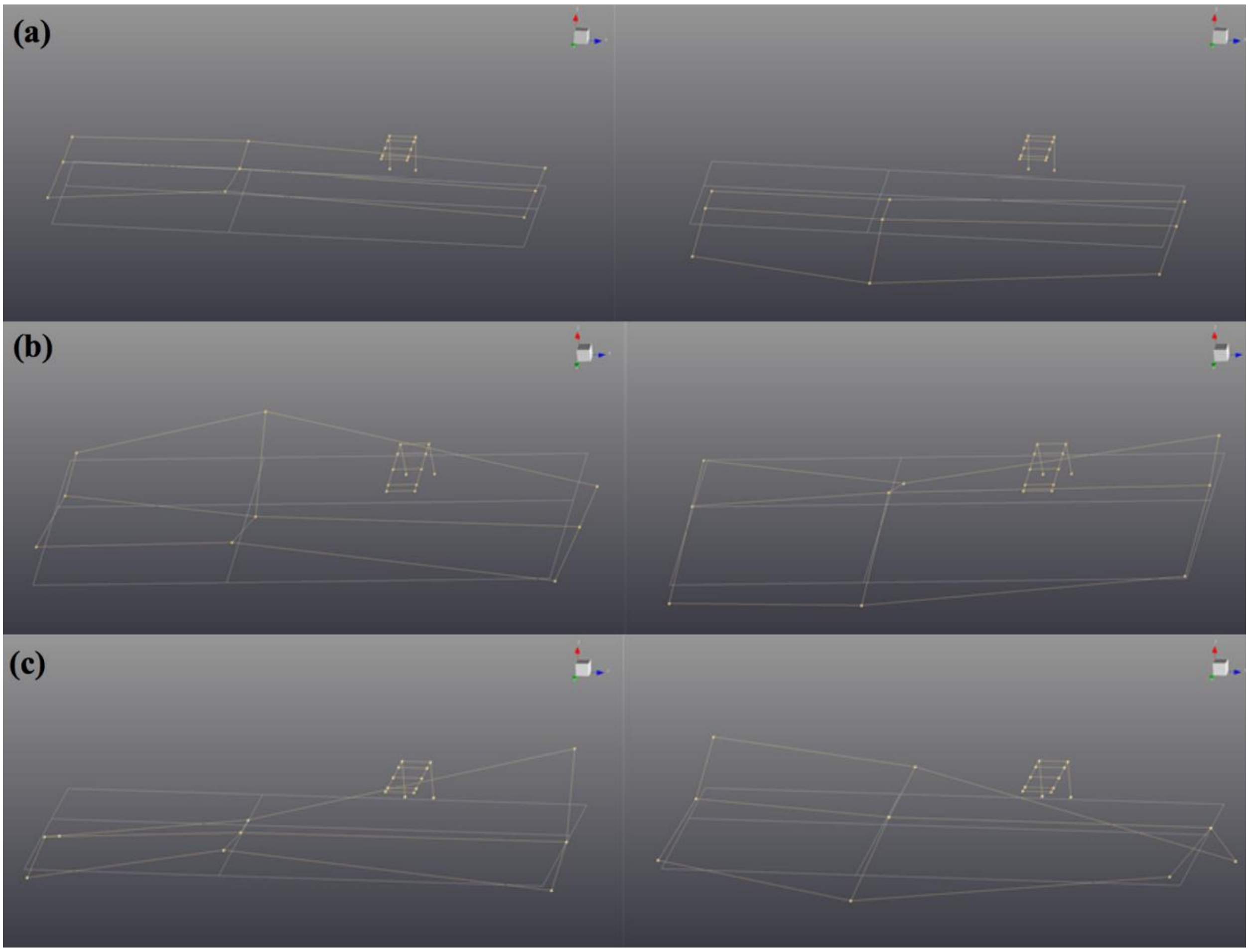

Figure 12: Experimental modes of plate, **(a)** rigid body mode $f_n = 0.78$, **(b)** bending mode $f_n = 1.2$, and **(c)** tortional mode $f_n = 2.7$.

In addition, the vibration modes of the plate are shown as Fig. 12. It can be observed that there are two main modes (i.e., a rigid body mode and a bending mode) whose normalized frequencies are less than 2.0 (i.e., $f_n < 2.0$). In order to improve the dynamic characteristics of this equipment, it is necessary to make the frequencies of these two modes greater than 2.0 by increasing the bolting points, installing an additional structure to hold the edges of the plate more rigidly, or adding stiffeners and ribs.

CONCLUSION

In this study, the structural characteristics of a cell separation equipment is evaluated by modifying the finite element model using the modal test results and building a reliable model. An improved structural design is suggested to let the normalized modal frequencies of the beam be 2.18 and 2.45. They exceed the main input vibration frequency range. In addition, some suggestions making the normalized modal frequencies greater than 2.0 are also presented. This includes increasing the bolting points and adding stiffeners and ribs. The suggested results would help to shorten the initial setting time which currently takes more than two weeks and maximize competitiveness as reliable medical equipment.

ACKNOWLEDGMENT

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